BUILDING MATERIALS

BY

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NINTH EDITION

WITH A FOREWORD BY

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FOREWORD TO THE THIRD EDITION

I have read through the book on Building Materials by Mr. S. Rajaraman, Lecturer in the Engineering College Trivandrum, Travancore University. He has in its small compass condensed a world of information and of a type most useful to the freshman and the mature alike. It is a good refresher course and a vade-mecum of information put in the fewest possible words to convey the knowledge required; and the information is neither old nor obsolete. It is all fresh and up to date. It is a very useful book and can be usefully added to any technical Library. It does not pretend to be an encyclopaedia, having been got up as a text book. It is just what it claims, a good young Engineer's guide to the materials used in Engineering construction.

L. VENKATAKRISHNAN.
PREFACE TO THE THIRD EDITION

The need of a comprehensive and up to date handbook on Building Materials for the use of students of Engineering has prompted the compilation of this book.

The previous edition has been completely revised and the subject matter enlarged and rewritten at many places. The author’s thanks are due to Dewan Bahadur L. Venkatakrishnan B. A., B.E., I.S.E., (Retd. Chief Engineer, Madras P. W. D.), Chief Engineer, Travancore Government, for his Foreword.

No claim to originality is made for the contents.

Trivandrum, 1945. 

S. R.

PREFACE TO THE SEVENTH EDITION

The sixth edition has been thoroughly revised. In Ch. V, portions on ‘Heat Treatment,’ ‘Welding,’ ‘Solders,’ ‘Alloys,’ and ‘Methods of Protection of Metals from Corrosion’ have been enlarged and rewritten, and descriptions of ‘Vitreous Enamel’, ‘Ceramics’ and ‘Adhesives’ have been added. It is hoped that this edition will cover the properties of all materials used in the ‘Building Industry’.

Trivandrum, 1953. 

S. R.

PREFACE TO THE NINTH EDITION

The eighth edition has been revised and enlarged incorporating the latest developments and the particulars available from the Indian Standard Specifications issued up to this date.

Trivandrum, 1957. 

S. R.
### Important Conversion Factors:

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Note: All temperatures given in the text are in °C.

* μ = 1 micron = 1 × 10⁻⁶ mm.
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BUILDING MATERIALS

CHAPTER I

STONES

Introduction: The expression "Building Materials" is used in a comprehensive sense and embraces those required for all constructions of structures. Every structure consists of: i Solids: e.g., stone, brick, timber, metal, etc.; ii Cementing materials: e.g., lime and cement, mortars made with them, and clay or mud; and iii Protective materials: e.g., plaster, paints, and varnishes.

The materials used in building construction are obtained from nature either in their natural condition or after conversion by manufacturing processes. It will be obvious that, before engineers construct buildings or other engineering structures, they should become conversant with the properties and characteristics of the materials they propose to use in the construction so as to be able to select the suitable materials. They should also be conversant with the methods of carrying out sound construction. Necessarily, they should be conversant with the various technical terms used by the trade and the profession.

General: Stone is extensively used: i As blocks in foundation, basement, and superstructure of walls; in lintels; in arches, abutments, and piers of bridges; in dams; etc., where strength and durability are essential; ii As thin slabs or flags for pavements in buildings, roads, etc.; iii As blocks and slabs for facework of structures requiring architectural treatment; iv As slates for roofing purposes; v As broken stone for cement concrete required for foundations, flooring, artificial stones, hollow and solid blocks, and reinforced concrete; railway ballast; road aggregate; substitute in place of sand; and vi As limestone in manufacture of lime, cement, blast furnace flux, and various other processes.

Stone is gradually losing its universal application as a building material for the following reasons: i Sources of supply are gradually diminishing; ii Suitable and durable alternative materials are now available; iii Important buildings, which would have consumed large quantities of stone, are constructed of steel or reinforced concrete (R. C.) frame with some form of panel dressing; iv Nowadays a careful study of the properties of stones has brought to light the defects which are responsible for the collapse of many ancient structures. Hence its
application is restricted to the use of only the best varieties; and \( v \) Sand-faced and rusticated bricks, faience ware, cast stone, etc., lend themselves to easier architectural treatment and have therefore overshadowed the use of stones.

**Geological Classification of Rocks:** 1. **Eruptive, Igneous or Unstratified rocks:** The earth was originally a molten mass composed of various substances and it cooled from the surface and solidified into igneous rock. \( Lava \), flowing in volcanic eruptions, when cooled before or after reaching the surface, also constitute igneous rocks e.g., granite, trap, etc. The uneveness of the earth's surface is due to: i contraction while cooling, ii upheavals caused by earthquakes, and volcanic eruptions, and iii denudation.

These are subdivided into three main classes based on the mode of solidification: i **Plutonic or major intrusive rocks:** which cooled slowly under a considerable thickness of already solid crust and which are coarsely crystalline viz., granite, gabbro; ii **Hypabyssal or minor intrusive rocks:** which have cooled under a relatively thin cover and therefore have crystallised more rapidly than the true plutonics, and which are fine-grained or crystalline viz., granophyre, dolerite; and iii **Volcanic or extrusive rocks:** which have been poured out on the earth's surface and have cooled more quickly than either of the other types, and which are extremely fine-grained or dense viz., obsidian, basalt. The majority of igneous rocks used in building construction are plutonic rocks.

Another method of classification is based on the relative proportion of silica: i **Acid rocks:** with over 66% silica viz., granite, rhyolite, pitchstone, etc.; ii **Intermediate rocks:** with 55 to 66% silica viz., syenite, diorite, trachyte, etc.; iii **Basic rocks:** with a silica % below 55 viz., gabbro, peridotites, serpentine, etc.; and iv **Ultrabasic rocks:** which contain mostly olivine.

2. **Aqueous, Sedimentary or Stratified rocks:** After the hardening of the earth's surface by cooling, other destructive agencies work on it such as wind, frost, rain, chemical acids from the air or dissolved in water, etc. The rocks are then subjected to weathering and breaking up. Glaciers play a large part in breaking up rocks. Rains and resulting torrents move the broken pieces, roll them along breaking and wearing them further. They carry the broken pieces from the higher to the lower reaches and, as the velocity of the water gradually diminishes in the lower reaches of the earth's surface, the debris carried by the rivers is deposited, the larger and heavier pieces first, the smaller and lighter pieces next, and
the fine powdered material last in their courses. This has been going on
for millions of years. Due to seasonal variations (wet and dry), the ma-
terials are deposited in layers and compressed by the weight of ever ac-
cumulating deposit above and the pressure of water and mixed and jointed
together with natural cementing materials. These form sedimentary or
aqueous rocks. From the very process of their formation, they will be
laminated or stratified.

These rocks are subdivided into three great sections: i) Mechani-
cally formed: Rocks which are derived by weathering of pre-existing
rocks, transported and deposited by moving waters and subsequently
consolidated e.g., cliff debris, breccia, gravel, conglomerate, sand, etc.;
ii) Chemically precipitated: Rocks formed chiefly by concentration through
evaporation of aqueous solutions, changes of temperature, loss of CO₂,
etc., and in some cases by the action of organic life and resulting in the
precipitation of insoluble salts e.g., limestone, dolomite, gypsum, etc.; and
iii) Organically derived: Rocks which have been directly built up by the
action of animals and plants, or formed out of their detrital remains e.g.,
limestones, peat, lignite, etc.

3. Metamorphic, Schistose or Altered rocks: These are either
bedded, schistose, foliated, or crystalline in structure and form a
group which embraces either igneous or sedimentary or even meta-
orphic rocks, which have been changed either in mineral composition or in
texture or in both (metamorphosed) by geological agents such as heat,
pressure, and hydrothermal solutions e.g., granite changes to gneiss,
basalt to schist and laterite, limestone to marble, sandstone to quartzite,
shale by degrees to slate, phyllite, and mica-schist, etc.

Physical Classification of Rocks: Based on general struc-
ture: (vide: 'Characteristics of good building stones') i Stratified: e.g.,
slates; ii Unstratified or granular: crystalline e.g., granite and amorphous
or dense e.g., obsidian; and iii Foliated: e.g., gneiss.

Chemical Classification of Rocks: Based on chief constituent mineral: i Siliceous: where the principal constituent is silica e.g.,
granite, quartzite, etc.; ii Argillaceous: where the principal constituent is
clay e.g., slate, laterite, etc.; and iii Calcareous: where the principal con-
stituent is CaCO₃ e.g., limestone, marble, etc.

Rock-forming Minerals: The minerals of importance are:

Quartz: Comp.—SiO₂, Syst.—Hexagonal. Sp. Gr. (G) = 2.65.
Hardness (H) = 7. Fr.—Conchoidal. Cl.—Indistinct. It is a crystalline
form of silica, usually colourless or white, but sometimes coloured brown
yellow, pink or amethyst due to the presence of small impurities generally metallic oxides. It is extremely resistant to both mechanical and chemical attack. The absence of cleavage, decomposition, or twinning distinguishes it from felspar under the microscope. It occurs in different varieties viz., coarsely crystalline e.g., rock-crystal, amethyst, smoky quartz, milky quartz, etc.; cryptocrystalline—fibrous e.g., chalcedony, agate, etc.; and granular e.g., flint, jasper, chert, etc.

✓ **Felspar** occurs commonly as orthoclase, microcline, and one or other of the members of the plagioclase series.

**Orthoclase** : Comp.—KAlSiO₃. Syst.—Monoclinic. G = 2-56 to 2-58. H = 6. Fr.—Conchoidal. Cl.—Two perfect at 90°. It has a white, grey, or pink colour and shows development of tabular crystals.

**Microcline** : Comp.—KAlSiO₃. Syst.—Triclinic. G = 2-57 to 2-6. H = 6. Fr.—Uneven. Cl.—Two perfect nearly at 90°. It is flesh-red, yellow, or deep green in colour and is associated with orthoclase.

**Plagioclases**: Comp.—Mixtures of sodium aluminium silicate (albite) and calcium aluminium silicate (anorthite) in all proportions. Syst.—Triclinic. G = 2-6 to 5-8. H = 6. Fr.—Uneven. Cl.—Two perfect never at 90°. Multiple twinning is characteristic of the plagioclases.

**Felspathoids**: resemble felspars chemically, but are deficient in silica. They are found only in certain kinds of igneous rocks.

✓ **Micas** are specially distinguished by their ready basal cleavage into thin, parallel, transparent, elastic laminae. They are highly lustrous, vitreous, and tough. The two forms in which they occur in igneous rocks are muscovite (white mica) and biotite (black mica).

**Muscovite** : Comp.—KAl₂Si₃O₁₀ (O H)₂. (White mica). Syst.—Monoclinic. G = 2-76 to 3-1. H = 2 to 2-5. Fr.—Nil. Cl.—Highly perfect basal. It is strongly resistant to the ordinary agents of weathering.

**Biotite** : Comp.—K (Mg, Fe)₂AlSi₂O₁₀ (OH)₂. (Black mica). Syst.—Monoclinic. G = 2-7 to 3-1. Fr.—Nil. Cl.—Highly perfect basal. On account of its iron contents, biotite, on exposure to weather, loses its elasticity and commonly alters to soft green chlorite.

**Amphiboles**: are a family of minerals crystallising in orthorhombic, monoclinic, and triclinic systems. They are similar to pyroxenes in chemical composition and physical properties and are distinguished by cleavage. The important mineral is hornblende.

**Hornblende** : Comp.—(Ca Mg Fe Na Al)₃ (Al Si)O₁₁ (OH).
Syst.—Monoclinic. G = 3·2. H = 5. Cl.—Perfect prismatic. It is dark green to black in colour and alters to chlorite on exposure to weather.

**Pyroxenes**: crystallise in monoclinic and orthorhombic systems. The important mineral is augite.

**Augite**: Comp.—Ca (Mg Fe Al), (Al Si) O 10. Syst.—Monoclinic. G = 3·2 to 3·4. H = 5. Fr.—Uneven. Cl.—Two imperfect. It is dark green to black in colour and alters to chlorite by hydration.

**Chlorite**: Comp.—(Mg Fe) 2 (Si Al) O 10 (OH) 2, variable. Syst.—Monoclinic. G = 2·6 to 3. H = 2·5. Cl.—One perfect basal. It is an alteration product, green in colour, derived from the decomposition of biotite, hornblende, or augite.

**Serpentine**: Comp.—Mg, Si, O 10 (OH) 2. Syst.—Monoclinic. G = 2·5 to 2·7. H = 3·5. Cl.—Sometimes distinct. It is an alteration product of olivine, pyroxene or amphibole showing variegated colours.

**Olivine**: Comp.—Mg Fe, Si O 10. Syst.—Orthorhombic. G = 3·2 to 3·5. H = 7. Fr.—Conchoidal. Cl.—Imperfect. It is green in colour and alters to serpentine and iron oxide.

**Calcite**: Comp.—CaCO 3. Syst.—Hexagonal. G = 2·6 to 2·8. H = 3. Fr.—Difficult. Cl.—Three highly perfect rhombohedral. It is an important constituent of many sedimentary rocks. It is usually colourless, but may be white, yellow, brown or red if impurities are present. It is used in the manufacture of limes and cement.

**Dolomite**: Comp.—Ca Mg (CO 3) 2. Syst.—Hexagonal. G = 2·85. H = 3·5. Cl.—Three perfect rhombohedral. It occurs in various shades and is isomorphous with calcite.

**Characteristics of Good Building Stones**: The qualities essential in good building stones are:

1. **General Structure**: This denotes the manner in which the constituent minerals are arranged. There are three types of structure in rocks: **stratified, unstratified (granular)**, and **foliated**. Stratification is generally found in sedimentary rocks and is due to the manner in which such rocks are formed in nature, viz., by successive deposits of the materials of which they are composed e.g., sandstone. Stratification in good rocks should not be visible to the naked eye except by the difference in colour. The grains should also be uniform in size. Stratified rocks can be easily split along the planes of stratification or ‘planes of cleavage’ and are therefore suitable for pavings, floorings, roofings, etc.; e.g., slates. The **granular structure (crystalline as in granite, and amorphous or dense as**
in obsidian) is found in rocks that have been formed by volcanic agency, or in sedimentary rocks whose structure has been altered by oscillation of the earth's surface (by earthquakes or tremors) and the action of fire or hot water e.g., quartzite. The foliated structure (a parallel arrangement of minerals showing a tendency to split in definite directions) is found in metamorphic rocks which are formed by the action of heat, pressure, or both e.g., gneisses and schists.

2a. Texture: denotes the arrangement of the constituent minerals of the rock. The typical crystalline textures are: i Granitic: where the crystals are compact and fused together and microgranitic where they are of microscopic size; ii Granular: where the crystals are of similar size, partially rounded in outline and cemented together by some binding material; iii Graphic or pegmatitic: where two constituents have developed simultaneously in large crystals, mutually grown. When the structure is on a microscopic scale, it is called micrographic or micropegmatitic; and iv Porphyritic: where the crystals of one or more of the constituents are developed on a larger scale than the rest. The other important textures are: i Glassy or vitreous: with no crystals, like glass; ii Vesicular or cellular: where there are spherical or irregularly shaped cavities; iii Schistose or foliated: where the minerals are arranged in parallel layers; and iv Oolitic: where the rocks are made up of spherical grains which are built up of concentric layers, and sometimes also show a radiating structure, with an interstitial cement of calcareous material. When the grains are as large as peas, it is called pisolitic. Uniformity of texture is essential in a good building stone.

\[b.\] Fracture: denotes the kind of surface obtained by breaking the rock in a direction other than that of cleavage, if such exists, and enables us to determine the texture. It is called conchoidal when the surface presents a curved, shell-like appearance (glassy texture), even when it is flat (crystalline texture), and uneven when it is rough and irregular (granular texture).

3. Specific gravity: indicates the weight of a stone. Dense and compact stones have greater specific gravities and fewer pores than porous or open-textured ones.

ISI tests for: i Specific gravity: For true sp. gr. \(G_i\) the specimen shall be crushed and passed through 15 Sieve 15. The material passed through this sieve shall be used. The sp. gr. bottle method is used. 6. For apparent sp. gr., 5 cm cubes are used. The specimen shall be dried at 105 to 110° for 72 hours, weighed \(w_i\), and placed in a vacuum desic-
cator. The pressure shall be reduced to 74 cm of vacuum. Pre-boiled
and cooled distilled water shall be admitted into the desiccator through
the top funnel until the specimen is completely covered. The specimen
shall be left overnight in this state. It shall then be weighed in water
\( w_1 \), wiped with a damp cloth and then weighed in air \( w_2 \). The apparen-
t-\( w_3 \), g. \( G_2 = w_1 / (w_2 - w_3) \). ii Porosity: From the data collected in i
above, the porosity can be obtained as 100 \( \frac{(G_1 - G_2)}{G_1} \)\%. The values of
\( G_1 \), for some common building stones are: Granite 2.67 to 2.7; Syenite 2.7;
Diorite 2.85; Gabbro 3.0; Sandstone 2.65 to 2.95; Limestone 2.75; Gneiss
2.69; Slate 2.89; Crystalline Limestone 2.64. The porosity of sandstone
varies from 1 to 15\% and shale from 3 to 5 \%.

4. Weight: Stones differ in their weight per c. ft. Whether a
heavier or a lighter variety is to be used for a structure depends on the
nature of the structure and the stresses it has to withstand. For marine
engineering works like breakwaters, wharf walls, dykes, etc., retaining
walls and dams, the heavy variety should be used. For vaulting and
other similar works, a light variety should be used.

5. Strength: depends upon specific gravity. Stones of igneous
origin are stronger than sedimentary, and crystalline ones are superior to
non-crystalline (the finer the crystalline texture, the stronger the stone).
Stones are generally strong enough for ordinary building purposes. But
in structures like large arches, lofty trusses, masonry dams etc., the
stones should be tested for compressive resistance, and in beams, lintels,
corbes, etc., they should be tested for bending stresses and suitable
stones selected.

ISS for tests on natural building stones:

1. Compressive strength test: The specimen shall be cube, square
prism or cylinder, cut from the sample with saws or core drills. The
diameter or lateral dimension shall be \(< 5 \text{ cm} \) and the ratio of height to
diameter or lateral dimensions shall be \( < 1 \). The load-bearing surfaces
shall be finished to as nearly true and parallel planes as possible by using
grinding wheels and abrasion powder or rubbing plates. The load-bearing
surfaces and the direction of the bedding planes or rift shall be carefully
marked on the specimens. At least three specimens, kept in water (20 to
30\°) for 24 hours prior to test, shall be used. The load-bearing surfaces
shall be covered with 0.5 cm thick plywood and the load applied axially
at a uniform rate of 140 kg/sq cm/min. The usual values of comp.
strength in kg/sq cm are: Igneous: Granite 773 to 1,308; Syenite 872 to
1,526; Diorite 872 to 1,533; Basalt 1,528 to 1,891; and Trap 3,269 to
ii **Transverse strength test**: The specimens shall be 10 cm × 5 cm × 5 cm. At least three specimens kept under water as in i shall be used. The direction of bedding planes or rift shall be marked on the specimens. They shall be evenly supported upon two self-aligning steel bearers 4 cm in diameter and 15 cm c/c (Fig. 1). The load shall be applied centrally at a uniform rate of 200 kg/min through a third bearer 4 cm in diameter placed midway between the supports upon the upper surface of the block and parallel to the supports.

iii. **Shear strength test**: Specimens are: Bars 5 cm × 5 cm × ≤18 cm for use with Johnson shear tool; and Slabs 3 cm (thick) × 10 cm (wide) × ≤10 cm (long), for use with Dutton punching shear device. They are
tested either oven dried at 110 to 120° for 24 hours or wet immersed in water for at least two weeks.

For the former, the specimen is centred in the tool (Fig. 2). The tool is then centred in any testing machine with the centre of the spherical block in contact with the centre of the top portion of the plunger of the shear tool. The rate of loading shall be such that the speed of the moving head is > 0.1 cm/min. The shear strength equals max. load divided by twice the area of centre section of the specimen.

For the latter, use a spherical block of sufficient size to cover the upper end of the plunger of the punching device. The specimen shall be centred between the upper and lower plates of the punching device (Fig. 3). The upper plate shall be carefully lowered to contact with the specimen. The punching device shall then be centred in the testing machine with the centre of the spherical block in contact with the centre of the top portion of the plunger of the shear device. The shear strength equals (Total max. load - Initial load required to bring the plunger in contact with the surface of the specimen) ÷ (Diameter of plunger × Thickness of specimen).

6. **Hardness and toughness**: Hardness is the resistance of a stone to abrasion and depends upon the hardness of the constituent minerals. It is of importance where the stone is to be used in structures subject to much wear and friction as floors, pavements, and aprons of structures, such as bridges, weirs across streams and rivers. Stones used in structures subjected to vibrations of machinery and moving loads should be tough. Hardness is determined by comparing with Moh's scale, which, arranged from the softest to the hardest, is as follows:

- 1. Talc
- 2. Gypsum
- 3. Calcite
- 4. Fluorspar
- 5. Apatite
- 6. Felspar
- 7. Quartz
- 8. Topaz
- 9. Corundum
- 10. Diamond

Ordinarily minerals scratched by a thumb nail have a hardness no. of less than 2.5 and minerals scratched by a pen-knife less than 5.5.
The abrasion test is performed on the Dorry's machine to determine the resistance to wear, the attrition test on the Deval's machine to determine the degree to which the stone will resist combined impact and abrasion, and the Page impact test to evaluate the toughness. For a description of these tests refer to 'Road Aggregates' by B. H. Knight.

7. Facility for working: means that it will be easy to work on the stone, such as dressing, moulding, carving, etc. This quality is generally opposed to durability, hardness, and strength. Soft stones like limestone, sandstone, and soapstone are easier to work into mouldings and carvings, than granite, trap or basalt.

8. Fineness of grain: Fine grained stones will be required for carved or moulded work. Their durability depends upon the extent of the crystallisation of the particles and the quality of the cementing material. Amorphous particles with earthy appearance are bad and will be readily disintegrated by any of the destructive agents.

9. Compactness: Stones also depend for durability to a large extent on the compactness of the particles or density of the stone. For this reason, the best building stones are those of the older formations found at great depths. They are often found near the surface, having either been thrown up by volcanic eruption or earthquake disturbances, or having been exposed by denudation due to wind, running water, glaciers, etc.

10. Porosity and absorption: Porosity depends upon the voids and absorption upon the characteristics of the constituent minerals. For a given void space in a stone, the permeability or tendency of outside moisture to travel inside depends upon the sizes of the voids; the smaller the size, the smaller the permeability. The less porous a stone is, the less moisture it can absorb and the more useful it will be for building purposes. Porous stones are destroyed by disintegration and decomposition. The alternate wetting of stones in exposed faces by rain water, and subsequent drying in sunshine, causes disintegration. In winter, in cold countries, the water absorbed by the stone freezes, expands, and disintegrates the stone. Rain water carries with it \( \text{O}_2, \text{N}_2, \text{CO}_2, \text{H}_2\text{S}, \text{HCl}, \text{H}_2\text{SO}_4, \text{H}_2\text{SO}_4, \) etc. The solution of these gases and acids are absorbed by the stones being driven in by the wind and they act upon the constituents of the stones, dissolve them, and cause them to crumble to powder.

ISI test for water absorption: The test shall be performed on 6, 3 cm cubes. The specimen shall be dried to constant weight (48 hours from the time it reaches 110°) in a ventilated oven at 110 to 115°, cooled
to atmospheric temperature and weighed \((w_1)\). It shall be completely immersed in clean water at 20 - 30° for 24 hours, removed, surface water wiped off with a damp cloth, and weighed \((w_2)\).

**Moisture absorption by weight after 24 hours total immersion**

\[
100\frac{(w_2 - w_1)}{w_1} \%
\]

The specimen shall again be so placed in water that water can circulate freely on all sides of it. The water shall be heated to boiling in one hour, boiled continuously for 5 hours and then allowed to cool to 20 to 30° by natural loss of heat for < 16 or > 19 hours. It is then freely suspended in water at 20 to 30° so that it is completely immersed and then weighed \((w_3)\). It shall then be removed, surface water wiped off, and weighed \((w_4)\).

**Moisture absorption by volume after 24 hours total immersion**

\[
100\frac{(w_3 - w_1)}{(w_4 - w_1)}\%
\]

**Absorption by weight after 5 hours immersion in boiling water**

\[
100\frac{(w_2 - w_1)}{w_1} \%
\]

**Absorption by volume after 5 hours immersion in boiling water**

\[
100\frac{(w_3 - w_1)}{(w_4 - w_1)}\%
\]

The percentages of water absorption by volume for some common building stones are: Trap 0-1 to 6; Sandstone 2 to 10; Laterite 5 to 20; Shale 5 to 10; Limestone & Gneiss 0·15 to 1·11.

The saturation coefficient which is defined as the ratio of the water absorption to the total porosity \((w_3 - w_1)/(w_4 - w_1)\). A stone with a saturation coefficient of <0·8 has a relatively high proportion of pore space unfilled with water and so is immune from disruption by frost. A frost resistant stone should also show a low porosity.

11. **Weathering**: is the disintegration produced by physical changes and the decomposition produced by chemical changes at or near the surface of the stone by atmospheric agents. Variations of temperature, mechanical abrasion chiefly due to wind, crystallization of soluble salts contained in water, and growth of organisms are the physical agents while hydration, oxidation, carbonation, and solution are the chemical agents. The variety of stone which is not affected by any of these agents has weathered well. The best method of ascertaining whether a particular variety has good weathering quality or not is to inspect ancient structures built with that stone, particularly those faces which are exposed to the prevailing winds and on which sunlight does not play and to observe if the sharp edges and corners are preserved without being
rounded off or flaked off, whether chisel marks are distinctly visible and the surface shows a compact structure. If these are found satisfactory, that variety has good weathering quality. The unused face of the quarries may also be inspected.

A dense massive rock stands weathering better than one traversed by fractures. Weathering depends upon the quantity of resistant materials contained by the rock e.g., quartz unaffected, micas variable—changing to clay minerals, hornblende and augite to hydrous silicates and olivine to serpentine and iron oxide. Igneous rocks suffer most, in the early stages of weathering, from disintegration. In the advanced stages, chemical action becomes dominant. Sedimentary rocks, such as sandstones, shales, etc., except purely calcareous rocks, weather through purely mechanical processes. Limestones and dolomites weather by solution effect.

Microscopic test: Microscopic examination of thin rock sections reveals the nature of the mineral constituents, the average grain size, the nature of the cementing material and bonding of the particles in sandstones or limestones, the presence or otherwise of harmful decomposition products, and the existence of fissures, veins, and shakes. Such a test enables to match good stones with known weathering properties with samples, proposed for use and whose properties are less well understood.

ISI test for weathering: The test shall be performed on at least three specimens 6 cm diameter and 7.5 cm high or 6 cm cubes. The specimen shall be dried in a well-ventilated oven for 24 hours at 105 ± 2°, cooled in a desiccator, and weighed \( w_i \). It shall then be submerged in water at 20 to 30° for 24 hours and weighed \( w_s \) at the end of the period whilst totally immersed. It shall then be removed, surface water wiped off with a damp cloth and weighed \( w_i \). It shall be placed in a flat dish of glass, porcelain or glazed stoneware (about 7.5 cm diameter and 2 cm deep), and 2 g of powdered gypsum and 25 ml of water added. The unit shall then be placed in a well-ventilated oven and maintained at 105 ± 2° for at least 5 hours or until the water has evaporated and the powder is dry. It is then removed from the oven and cooled to 25 ± 5°. This completes the first cycle. The process is repeated 29 times except that only 25 ml of water shall be added each time. At the end of the 30 cycles, the specimen shall be cleaned with a stiff fibre brush to remove particles of gypsum clinging to the surface. The specimen shall be immersed in water for 24 hours, surface dried, and weighed \( w_s \). The weight \( w_s \) under water is also recorded.
Original absorption $a_i$ of specimen at the end of 24 hours immersion in water = $100\left(\frac{w_i - w_1}{w_1}\right)$, %.

Original volume $v_i$ of specimen after 24 hours immersion in water = $\left(\frac{w_i - w_1}{d}\right)$ where $d$ = density of water at temperature of observation.

Final absorption $a_i$ at end of 30 cycles = $100\left(\frac{w_i - w_1}{w_1}\right)$, %.

Final volume $v_i$ after 30 cycles = $\left(\frac{w_i - w_1}{d}\right)$.

Increase in absorption = $100\left(\frac{a_i - a_1}{a_1}\right)$, %.

Increase in volume = $100\left(\frac{v_i - v_1}{v_1}\right)$, %.

12. Durability: or the power of resisting atmospheric and other external influences is the most important, as it is through decay, rather than want of strength, that failures occur. A stone with good weathering quality is generally durable. Durability depends on the chemical composition, physical structure, resistance to weathering and the positions in the building or places where the stone is used. Hardness and compactness of structure are generally indications for durability in a stone. A good building stone should be homogeneous in structure. Stones with silicates as the cementing material are better than those with calcareous or ferruginous material. Crystalline stones are hard and compact and are superior to non-crystalline. A durable stone will retain for a long time the tool marks made during dressing and preserve its edges and corners sharp and true. City atmosphere, especially industrial ones charged with smoke, corrosive gases and acids, may affect stones in structures. A stone lasting well in the interior district may decay rapidly under the action of the sea air. In cold countries, frost often disintegrates rocks and stones, unless their exposed faces are protected by some coating. Iron pyrites tend to disintegrate the stone; iron oxide or carbonate in excess develops rust in the presence of water, particularly if the stone is porous; clay tends to decrease the efficiency of the cementing materials; chlorite has a disintegrating effect, particularly if the stone is igneous; CaCO$_3$ as calcite is liable to break up the homogeneity of the stone; soda and potash also have a disintegrating effect; and mica in excess decomposes and disintegrates the felspar.

Tests: Acid test: is done to test the stability of the cementing material in sandstones. A sample (50 to 100 g in weight) is immersed in a 1% solution of HCl for 7 days, the solution being agitated at intervals. If effervescence occurs at first, the presence of CaCO$_3$ is indicated. Such a sample will have poor weathering qualities. A good specimen should show sharp edges, and the surface should be free from powder.
Smith's test: is carried out to determine earthy matter or soluble mineral matter in stone. The sample is broken into small pieces and put into a test tube containing clean water. After an hour, the test tube is vigorously shaken. Clear water indicates a sample free from any soluble or argillaceous matter.

1. S. I. test (Crystallisation test): The test shall be performed on at least four 4 cm cubes. The specimens shall be dried for 72 hours and weighed. They shall then be suspended in a 14% solution of Na₂SO₄, decahydrate (density 1.055) for 4 hours at 29 ± 1°. They shall then be air-dried for 30 min and then dried overnight in an oven at 105°. Next morning these shall be cooled to room temperature in 3 hours, the operations repeated for five cycles, the specimens weighed, and the change in weight noted. The test shall be continued to 30 cycles, the gross change in weight found, and expressed as a percentage of the original weight. As the decay of stones is due to the crystallisation of CaSO₄, in the pores of stones, the weight of salt deposited in the pores each time will be an indication of the weathering qualities of the sample selected. Though the most troublesome salt in buildings is CaSO₄, yet it is not used in the test because of its low solubility in water.

Freezing and thawing test: The stone is kept immersed in water for 24 hours. Then it is kept for 24 hours in a freezing mixture at -12°. It is then thawed at atmospheric temperature in shade. The process is repeated a number of times. A durable stone should not show any appreciable change in weight or surface appearance.

13. Appearance: This quality of stone is of importance for face work of structures where the face work is intended to be pleasing to the eye and to be architectural and aesthetic. In the choice of a stone for a building, the colour of the stone is a good guide as to its durability. Highly coloured stones are often preferred for their architectural effect but they are frequently at the expense of durability. The red and the brown shades of colour in all sedimentary rocks are due to oxide of iron which, if present in large quantities, is apt to disfigure the face of the stone with rust and stains and also leads to rapid disintegration of the stone. Therefore lighter shades should be preferred to darker ones. There should be no clay holes, bands or spots of colour whatever, but the stone should be uniform in colour and structure.

14. Seasoning: All stones, when freshly quarried, contain a certain quantity of moisture known as quarry sap which renders the stones soft and therefore easier to cut. So, all work, such as dressing, carving, moulding, etc., should be done as soon as convenient after quarrying and
the stone then allowed to season, so that all the sap is expelled. Stones gain considerably in hardness by seasoning. Only well seasoned stones should be used in constructing a structure; otherwise the stones cannot dry out so quickly, the sap will remain in it and atmospheric gases as well as frost will act on the sap and disintegrate the stone.

Seasoning consists in leaving the quarried and dressed stones in the open air, preferably in open sheds to protect them from rain. The air will play around the stones and dry out the sap. The test for finding out whether a stone has seasoned well is to chisel it and note whether the chisel cuts easily and whether much dry stone dust is produced in the operation. The former shows that the seasoning is not sufficient and the latter that it is sufficient.

Dressing stones after setting, for removal of stains, should be avoided. Cover the stones after setting with a wash of plaster of Paris and lime in equal proportions. This wash can be washed and cleaned and with it the stains on the work will go.

15. **Natural bed**: The natural bed of a stone is that surface on which the material was originally deposited in the formation of the rock. The natural bed need not necessarily be horizontal as the stone rests in the quarry. It may be inclined and even vertical owing to the original beds at the time of deposition having become “folded” and disturbed by upheaval and other agencies.

The purpose for which a stone is to be used determines the position of its natural bed with reference to its position in the building. Such determination of the natural bed has an important bearing on the durability and strength of the stone. The stone should be so set in the structure that the natural beds of the stones are as far as possible at right angles to the force of pressure they are to resist and not in the same direction as the latter. In walls, such as ashlar work, the stones are placed with their natural bed horizontal since the pressure due to weight of the superincumbent wall acts vertically down. In stone arches, the stone voussoirs should be so placed that the laminae or natural beds of the stones are perpendicular to the line of the pressure in the arch. This means that the beds should be at right angles to the plane of the face of the arch. In string courses, cornices, etc., in which the stone is partially unsupported, the natural bed should be vertical. The bedding planes can be detected either by pouring water and finding the direction in which it flows or by examining for flakes of mica or by a magnifying glass. An experienced mason finds it by the feel and the resistance offered to the
chisel, as a laminated stone is easily worked along the bedding plane.

16. Resistance to fire: Fire brings about the destruction of stones due to: i Different coefficients of linear expansion of the constituent minerals; ii Poor conductivity of stone; iii Rapid rise in temperature of exposed faces due to fire; and iv Sudden cooling of surfaces of stone by cold water. In igneous rocks, like granite, free quartz undergoes a sudden expansion at 575° which leads to disruption of the rock. Limestones split into free lime and CO₂ at 800°. Also a considerable amount of heat is used up in the chemical dissociation of CaCO₂. Sandstones, with silicates as binders, resist fire very well. Argillaceous stones resist fire even better, but lack in strength and durability.

COMMON BUILDING STONES OF INDIA

A. Siliceous Stones: Granite: is an unstratified rock, of crystalline granular structure consisting of crystals of quartz, felspar, and mica with or without hornblende. The quartz appears as clear crystals, colourless or grey; the felspar as opaque crystals, white, yellow or red; mica as glistening scales; and the hornblende as black or dark green crystals. The colour of the stone depends upon that of the felspar and the durability upon the quantity of quartz and the nature of the felspar. If the granite contains a large quantity of quartz, it will be hard to work but unless the felspar is of bad quality, it will weather well. Granite containing decomposed felspar should be avoided for use as aggregate as this may set up expansive reaction in concrete. As mica is easily decomposed, a large proportion of it is a source of weakness. The quality of granite depends upon its durability and the size of the grains. The smaller the grains, the better can granite be worked, and the more evenly will it wear. Granite of good quality is a hard and very durable building stone suitable for works of importance, such as bridge abutments, piers, locks, etc., where weight and durability are essential. It is also used for ordinary buildings. The stone is not suited for carving, and its surface is destroyed by fire. Granite is quarried by wedging or blasting. Large blocks are obtained by the former process and smaller pieces, such as rubble, are obtained by the latter process. It occurs widely throughout India, the notable varieties being the charnockites of Madras, the khondalites of Orissa, and the granites of Mysore.

Syenite: contains felspar with usually hornblende, mica or pyroxene. It differs from granite in containing no quartz. It occurs in dark green, grey, and bluish grey colours with jointing, sheet and platy structures. It is used as road-metal and concrete aggregate. Some
varieties take a high polish and are used for external decorative purposes.

**Serpentine**: is found intermixed with carbonate of lime and steatite. It is found in all shades of green and red with mottled streaks and patches. It is compact, not brittle, easily worked, and takes a fine polish. It is used for indoor decorative work. The red varieties weather better than the green. It is found in Burma and Baluchistan.

**Rhyolite**: is an acid, coarse grained to glassy, volcanic rock. It occurs in white to light grey, pink and greyish black colours. It is black when extremely glassy (obsidian and pitchstone). It is a fine grained equivalent of granite showing fluidal, spherulitic, nodular and lithophysal structures.

**Diorite**: is an intermediate, coarse to medium crystalline, plutonic rock composed of plagioclase felspar and hornblende or biotite or both. It is dark in colour, and has sheet and platy structure. It has a high compressive strength and is used for road metal kerbs and setts and for rubble walling.

**Trachyte**: similar to syenite, is a greyish white coloured volcanic rock with a flow structure and porphyritic texture.

**Andesite**: is similar to diorite with a flow structure and porphyritic texture.

**Gabbro**: is a basic, coarse crystalline, plutonic rock occurring like granite, with a dark colour and banded structure. It possesses high compressive strength, and low absorptiveness and takes a high polish. It is used as road metal and for ornamental work. On weathering, it alters to deep red ferruginous clay soils.

**Dolerite**: is a basic, even grained, porphyritic, hypabyssal rock, dark in colour. It binds well with tar and hence used as road metal. It is not satisfactory as concrete aggregate since some types contain the readily oxidizable ferrous mineral chlorophaeite which causes expansion and disruption of the hardened concrete.

**Gneiss**: is any banded metamorphic rock, the bands of which are mineralogically unlike and consist of interlocking mineral particles, most of which are visible to the naked eye. It is composed of the same constituents as granite. There are different varieties: a. based on structural differences: banded gneiss, foliated gneiss; b. based on prevailing accessory mineral: biotite gneiss, hornblende gneiss; and c. based on composition and origin: granite gneiss, diorite gneiss. It shows a great variety of colours and on account of the banded structure is not so hard or
durable as granite and cannot be worked so uniformly. The reddish variety containing garnet or iron oxide is not likely to last well. But being capable of being split along the layers with facility, coming out in slabs of a few inches to a foot in thickness, gneiss is used largely as a building material and for paving. It is found in Kerala, Madras, Andhra, Mysore, Cutch, and Bihar.

**Basalt:** is an unstratified rock composed of fine-grained crystals of hornblende and felspar. It is dark in colour and is a very hard, compact, and durable stone, with a crushing strength of 6 to 8 tons. It cannot generally be obtained in large blocks but is well suited for ordinary buildings, unpaved highways, aggregates in concrete, and road metalling. It is hard to work but the red and yellow varieties, which are soft, are used for ornamental work. Basalt occurs in dykes or sheets penetrating or lying between the older rocks or upon the surface. It is sometimes stratified and sometimes columnar. As badly decomposed basalt becomes earthy, weathered rock should not be used for concrete aggregates.

**Trap:** is an old name applied to igneous rocks which were neither coarsely crystalline nor cellular or obviously volcanic. The rocks so designated included basalts, dolerites, andesites and porphyrites (types often grouped as whinstones); altered varieties of some of these such as epidiorites and diabase (types grouped as green stones) and finally the mica traps or lamprophyres. In India, trap is widely distributed in Bombay, Deccan, and Central India. (Rock-cut temples of Ajanta, Ellora, and Elephanta are in trap).

**Quartzite:** is a stratified crystalline rock composed of nearly pure silica. In colour it is of a more or less opaque white, and is very strong and durable, but is so hard that it cannot usually be worked for masonry. The Kutub Minar at Delhi is of this stone. It is found in the Salem and Coimbatore districts of Madras, Bundelkhand, Dhar, Gwalior, and Karnatak. It is usually broken for use as road metal. **Gunister:** is a variety of quartzite.

**Flint:** is a massive compact form of silica, generally dark in colour. It is found in nodules in chalk strata and breaks with sharp cutting edges. It is found in the Trichinopoly district of Madras and makes serviceable concrete.

**Sandstone:** As already stated, this is an aqueous or sedimentary rock, but it is styled as a siliceous rock, since it consists generally of grains of quartz i.e., sand cemented together by siliceous cement, carbonate of
lime, carbonate of magnesia or alumina, oxide of iron which gives it its
colour, or by mixtures of these substances. In addition to grains of quartz,
there are often flakes of mica, fragments of limestone, etc., mixed through-
out the mass. The durability of sandstone depends entirely on the
materials forming it; those with lime, alumina, and iron oxide will decay.
Sandstone is a porous stone, white, yellow, or red in colour. It is avail-
able in the South Aroostook district of Madras, Nellore, Cuddapah, and
Kurnool districts of Andhra, Mysore, Nagpur, and Jubbulpore. There
are many varieties of sandstones: Flagstone: easily splits into thin
slabs and is used for paving. Tilestone: splits into thinner slabs and is
used for roofing. Freestone: can be easily cut to any shape. Grit:,
obtained in large blocks, is used for heavy engineering works. The fret-
work found in the Taj Mahal at Agra is on thin slabs of sandstone.

Tests: A fracture should be bright, clean, and sharp, the grains
well cemented together and of uniform size. Colour is no guide to
quality. Good sandstone should weigh < 130 lb/c. ft., absorb > 5%
of its own weight of water, and only slightly effervesce when moistened
with a dilute solution of HCl.

B. Argillaceous Stones: Shale: is compact clay, marl, or silt
possessing a finely laminated structure and capable of being split into
very thin leaves. It displays a great variety of colours and is not as
strong as sandstones or hard limestones.

Slate: is a compact, fine grained, argillaceous rock that has
been subjected to enormous pressure and also to a shearing action which
has caused "planes of slaty cleavage", independent of the original
bedding planes, formed when it was first formed into a sedimentary rock.
The planes of cleavage often cross the original bedding planes at a great
angle. The planes of slaty cleavage enable the slates to be split into thin
laminae or slabs or sheets. The surfaces of these slabs are smooth.
Slates are composed chiefly of silica and alumina. In England, they vary
in colour from purple to green and are used for roofing purposes, as rect-
angular overlapping plates up to 2 sq. in area and 1" thick. In India,
coarser and softer varieties are found, which are well suited for floor
pavings, walls, sunshades, cornices, etc. The blue slates of Cuddapah and
Kurnool, known as Cuddapah slabs, are the best. Good slates are also
found in Simla, Gurgaon, Chanda, Monghyr, Singhbum, etc. The rock
is worked in tunnels one above the other, the blocks are blasted, broken
into required widths, split into 3" thicknesses, sawn into proper lengths,
split into thinner slabs and then squared. A good slate is hard, tough,
uniform in texture, of even colour, non-absorbent, and free from blemishes. It gives a sharp metallic sound when struck.

**Laterite:** (Latin Later = Brick, Tile) so called from its resemblance in colour to brick, is a sandy clay stone and is ferruginous, i.e., containing iron as oxide of iron. It is generally of cellular structure and of a deep brown red colour. It is widely distributed throughout India, especially near the coasts. It is generally found a few feet below the ground surface, though it occurs also on the surface due to denudation. When it is freshly uncovered, it is sufficiently soft to be cut out of its bed and to be dressed to proper shapes. But after a few month's exposure to the air, it becomes covered with a hard hydrated iron oxide which protects the stone from decay. It is employed as a building stone in the Trichinopoly, Tanjore, and South Arcot districts of Madras, the West Coast, Bihar, Orissa, and M. P. It is also used for pitching tank bunds, lining or stonning of wells, etc. The better qualities are very durable. Nodular laterite and the gravel resulting from it form a good road material and are also used for concrete. In Kerala, it is described as 'scraped and sifted gravel to distinguish it from 'cut gravel' which is obtained by excavating laterite gravelly soil and sifting and removing the earth from it. The scraped, sifted, siliceous gravel is harder than the cut gravel and is to be preferred for roadwork.

C. **Calcareous Stones:** **Limestones:** show great variation in origin and texture. They consist chiefly of CaCO₃ with small portions of silica, iron oxide, clay, and carbonaceous matter. They are spread all over India, the compact varieties being found at Porbander, Shahabad, Katni, Cuddapah, and Kurnool. The harder and denser varieties are used for concrete, but the softer and more porous types should be avoided. Any of the following varieties may be found in granular, oolitic, shelly or fossil form with the tendency to develop a crystalline form under subterranean pressure: i **Clayey limestone or bankar:** is hard, compact, and smooth. It occurs either as nodules 3 to 4 ins. diameter or is quarried as blocks. It contains about 70% CaCO₃ and 30% clay and sand. It does not weather well and is most suited for the manufacture of hydraulic limes and cement. It is used as road metal and in blocks for buildings. ii **Siliceous limestone:** is hard and compact, weathers well, and is used in buildings. iii **Ferruginous limestone:** is good, if the iron content is not excessive or loosely composed but forms a chemical amalgamation, probably as a cementing agent. iv **Calcareous limestone:** is not good, though certain siliceous limestones with 80% CaCO₃ are excellent because the silica acts as a protective coating to the main rock mineral. v **Magnesian**
limestone or dolomite: is heavy, compact, fire and weather resistant, but is attacked by the sulphuric acid fumes of manufacturing towns.

vi Chalk: is pure limestone. It is too soft for building purposes and is mainly used in the manufacture of lime, cement, and glazier’s putty.

vii Coral stone: is limestone dug out with crow bars in chest-deep water near the sea shore in low tides as at Rameswaram and Tuticorin. When freshly dug, it is soft; but it hardens on exposure.

viii Marble: When limestone (is metamorphosed) has become dense and crystalline through the action of heat and pressure during past geological periods, it is called marble. It occurs in various colours, is hard, compact, and durable, and takes a fine polish. The coarse grained varieties are used for architectural works and monuments, and the fine grained pure white varieties for statues. The ‘Moti Masjid’ and ‘Taj Mahal’ are of marble. It is corroded by the atmosphere, especially where the rain water carries sulphuric acid. It occurs in Jodhpur, Jaipur, Jubbulpore, Baroda, Ajmer, Alwar, and Rajputana.

Gravel: is a mixture of rounded water-worn pebbles of any stone with sand. It is found in the beds of rivers in alluvial tracts of country. It is used for road surfacing and in concrete.

Shingle: denotes large water-worn pebbles near the sea-shore.

Conglomerate: is the name given to gravel and shingle when they have been consolidated into stone, the pebbles being bound together by some kind of cementing material, which may be fine hardened sand, clay, or some calcareous, siliceous, or ferruginous cement. It is used on revetments and aprons.

STONE QUARRYING

Quarrying is the art of extracting stones for building and other purposes from natural rocks.

![Fig. 4 to 7](image-url)
Site for Quarry: Having selected the rock from which stone is to be quarried, we should start operations on that portion of the rock which has a good ‘face,’ that is to say, where the rock is exposed. It will then be easier and economical to quarry. Fig. 4 to 7 show rocks with one, two, and three clear faces with the location of bore holes. Rocks on slopes of hillocks or rocks which project above the ground surface in level plains are the best. Where such are not available and the rock lies buried in the earth, it will be necessary first to remove the overlying soil, which is a laborious process, and will add to the cost. Generally, the surface of the rock would, on account of the disintegrating action of the atmosphere, be disintegrated and therefore soft for a smaller or larger depth depending on the weathering qualities of the rock. This top crust is unsuitable for construction and has to be rejected, the denser rock below it only being accepted. There is a limit to the quantity of overburden that can be profitably dealt with beyond which it will be necessary to resort to methods of mining.

Principles of Quarrying: Facilities as regards communications, labour, water, supply of cheap power, site for dumping refuse, etc., must be considered. Perhaps the most favourable site is a steep slope or a perpendicular cliff.

Most hard rocks have three divisional planes which are usually at right angles to each other. Usually one of the divisional planes, either the bedding plane or a joint plane is found in an inclined position; when this occurs, the blocks or slabs slide forward when freed from the main mass. If the beds dip into a hill, it is better to work by underground chambers. Moderately tilted beds can be worked along the strike as long shallow quarries, and with very steep dip it is often possible to work the quarry as a steep-walled cut e.g., marble, natural cement rock, and clay deposits. Rocks in faulted stones are decayed and hence useless for dimension stones.

Granite: is quarried from hillsides or sloping ground. The beds, though horizontal occasionally, are very deep. When vertical fissures, of the same sort are seen, large blocks are got by wedging. Otherwise, and most frequently, blasting is resorted to. In the case of sandstone or similar quarries with well separated tilted bedding planes, distinct strike joints and less developed dip joints, the rock is first freed by a deep cutting parallel to the dip joints, while the working face has been cleared on the dip side parallel to the joint planes. By wedging (and blasting and undercutting, if necessary) the separate blocks are easily removed. Limestone: where it occurs as homogeneous in thin horizontal beds having good
natural beds, is levered out with crowbars and lifted to the surface, the quarry being worked in floors rather than in faces. Where it occurs in deep beds, without out-cropping, they are reached by long inclined shafts sunk in the hill side. Pillars of hard rock, of no value, occur at intervals and are left to support a natural roof of hard rock, while the bed of freestone is mined and removed. Marble: is quarried usually by levering, but more often wedging and blasting will have to be resorted to. Steeply dipping beds with irregular but distinct joints are quarried by wedging, undercutting, and finally sliding the blocks forward. In slate or similar quarries with the joint planes intersecting at angles other than right angles (perfect cleavage and one indistinct joint plane) narrow side cuts are made into the rock along the indistinct joint planes and the slate is prized off along the cleavage planes. In loose incoherent gravel, the quarry face is kept steeper than the angle of repose of the material. In shattered rock, which occasionally stands vertical, it may be necessary to undercut or blast it to enable the material to collapse into the quarry.

**Methods of Quarrying**: There are three methods in general use depending upon: 1) the purpose for which the stone is required, and 2) the texture or quality of the rock. These methods are: 1) Digging; 2) Splitting by: (a) wedges, and (b) burning; and 3) Blasting with explosives.

**Digging**: This method is adopted to quarry coral stones with crowbars. In the West Coast, laterite stone blocks for building construction are quarried by digging, not with crowbars, but with special tools suited to the purpose.

**Splitting**: This method is adopted in the case of granites of hard and tough texture for purposes of obtaining more or less regular rectangular shaped large blocks to be dressed as ashlar or cut stones. Where the texture of the rock is such that it will split easily, quarrying is done by:

**Wedging**: (Fig. 8 to 11.) When the surface soil and the top soft disintegrated stuff is removed, it will generally be found that the rock is broken up into natural rectangular blocks by fissures or cracks along which there is little or no cohesion. An approximately vertical fissure

Fig. 8 to 11.
being selected, the stone on one side of it must be broken or cut away in
order that a nearly vertical face is presented and successive blocks can
then be got out by driving steel wedges into the fissures with sledge
hammers and levering with the help of steel crow bars. If the stone lies in
beds without vertical fissures, it may be necessary to chisel a trench in it to procure a vertical
face. Each block, after being shifted, is got out of the quarry on a trolley or on rollers. When
natural fissures do not occur at suitable intervals from the vertical face, cleavage or splitting can
be effected artificially by chiselling a line of holes, 3 to 5" in depth and 4" apart, in the re-
quired direction, setting a row of steel wedges or conical pieces in the holes, and striking them
simultaneously from end to end of the line with heavy hammers. If the
rock is one that splits easily, hard wood pegs can be inserted in the holes
and made to swell by banking them up with moist clay. The expansion
of the wood splits the stone. Small blocks are obtained by plug and
feathers wedging (Fig. 12). Feathers are thin strips curved on one side to
fit the drill hole and flat on the other. Two feathers are placed in a drill
hole and a 'plug' or iron wedge is hammered between them.

Heating or Burning: It is generally found from experience
that this method is particularly suitable for splitting large exposed
boulders or where such boulders could be exposed by digging out the
surrounding soil in which they may be partly embedded. This method is
also adopted where only smaller blocks are required and more or less of
regular shape, and where the formation of the rock is suitable for it (as
for instance where the rock is bedded in horizontal layers of not too great
a thickness). A pile of wood is heaped on the surface of the rock, set fire
to and made to burn steadily for a few hours. The unequal expansion of
the rock causes separation of the upper layer, indicated by a dull bursting
sound. The area thus separated can be ascertained by sounding on the
surface gently with a crowbar or, hand hammer, and noting the hollow
sound. The loosened portion is then broken into smaller blocks as required
and taken out. Men experienced in the process can turn out fairly rectan-
gular blocks of required sizes suitable for coursed rubble masonry. This
method is largely used in Madura and Coimbatore districts of Madras, and
in the Mysore State for quarrying in granite and gneiss.

Blasting with Explosives: General: Blasting consists in boring
deep holes in the rock, loading them with blasting powder, dynamite or
other explosive, and firing. The explosion detaches a mass of stone which can afterwards be broken up, if necessary, to the sizes required. This method of quarrying stones for building construction shakes the soundness of the stone blocks, causes a good amount of waste, and makes it difficult to ascertain the natural bed of the stones. But it is well suited for making excavation, tunnelling through rocks, and for quarrying large quantities of stones of sizes down to road aggregate. It should be borne in mind that, whatever be the method of quarrying adopted, the stone should satisfy the specification of the particular work for which it is intended.

**Blasts**: are of two kinds viz., small blasts and large blasts. The latter are employed only in tunnelling and mining. **Small blasts**: (Fig. 13 to 16) are employed for obtaining stones for building purposes. The operations which constitute blasting are boring holes, loading, and charging. Holes are driven either with a jumper or with a boring bar and a hammer. The jumper is an iron bar 5 to 12' long, and 1 to 3" in diameter having steel chisel edges at each end. The boring bar has one end flat and the other chisel. Two men are required to work the jumper, one man sitting down guides it, while another forces it down the rock, turning the jumper now and then, thus gradually cutting a hole. A little water is poured in from time to time and the moistened rock dust in the hole scraped out with a scraping spoon. The jumper can only be used when the hole to be driven is vertical or nearly so. If the hole is inclined, it is driven with a boring bar, one man holding and turning it, while two others strike its flat end with heavy hammers. The rate of progress in these methods depends on the diameter of the hole and the nature of the rock, but 60' per day in gneiss rock may be regarded as an average for a party of 2 or 3 men.

The method for driving holes in common use in Kerala for shallow holes not exceeding 3 to 4' in depth is for a man to drive it with a boring bar 1/2 to 2' diameter and an ordinary (not particularly heavy) hammer. He can drive vertical or inclined holes with equal ease. The holes do not ordinarily exceed 1' in diameter and the rate of progress is about 5' per man in hard rock.

**Machine Drilling**: Though ordinarily and usually hand drilling, as explained above, is in common use for the purpose of blasting stones
for building, machine drilling is adopted when large quantities of stones are required in a limited time or where heavy and large excavations in hard rock have to be made rapidly as also in driving tunnels in rock. They are usually worked by *compressed air* as the motive force, the drills being known as *pneumatic drills*. They are also worked by direct steam or electric power. Pneumatic drills are best for tunnels and shafts. The drills in use are: i) *percussion drill*, also called *jack hammer* or *jumper drill*, consists of a cylinder in which a piston carrying a long piston rod works. The drill tipped with tungsten carbide at the end alternately strikes and is withdrawn from the rock as the piston moves to and fro in the cylinder. The piston rod and drill turn slightly on their axis after each blow and the drill is fed forward as the depth of the hole increases. The number of blows will be 20 to 30 per minute, the rate of progress being 5 to 10' per hour for a hole of 2 to 2 ½" diameter. This is used for continuous heavy duty in rock with a *feedleg* support or for deephole and quarry work with a 'drifter'. ii) *rotary drill*, also called *diamond drill*, consists of a hollow cylindrical bit having a cutting edge of diamonds. The drill rotates at 0 to 1,500 R.P.M. When the drill rod with the bit is rotated and fed forward, an annular hole is cut in the rock. The drillings are removed by forcing a stream of water through the hollow drill rod, when the water emerges, carrying the debris with it, up through the annular space between the outside of the bit and the walls of the hole. This is used for coring and blast hole work and also in chalk, shale, asbestos and chrome formations.

**Blasting**: The next operation is to charge the hole with the blasting material or explosive. The explosives may be: A. *Low explosives*: e.g., Blasting powder, ammonal, etc. These have a low rate of burning, a pushing, propelling, and lifting effect and a tendency to move towards open. B. *High explosives*: e.g., Dynamite, liquid oxygen, etc. These change from solid to gaseous state instantaneously, produce a violent shattering, tearing and cutting action and try to move towards harder surfaces.

The strength of an explosive is its power to exert energy and the speed is the time it takes to act. While high speed tends to shatter the rock, low speed gives a slow pushing or heaving effect. In order to break a boulder and at the same time to turn it out of the ground, the explosive should produce a comparatively sharp shattering blow, which will break the stone and at the same time blow it out of the ground.

**A. Low Explosives**: For obtaining stones for building structures with explosives, it is generally best to use blasting powder. The high
explosives shatter the rock badly and are chiefly used for excavating purposes, particularly under water. Blasting powder (gun powder) is a mixture of 75 parts by weight of saltpetre or KNO₃, 15 parts of charcoal, and 10 parts of S, made by grinding the ingredients with enough water to moisten the mass. It is then compressed to a cake and broken into grains (which are sometimes glazed by revolving with graphite) and sorted into sizes by sieves. The larger grains are used for rock blasting under the name blasting powder. The smaller grains are used for small armaments under the name gunpowder. It is undesirable for use in mines because of the flame produced on explosion and the ability of this flame to ignite gas and coal-dust mixtures. Evolution of CO is also a disadvantage. Blasting powder is sometimes made with Chile saltpetre or NaNO₃, as being cheaper. This is more powerful than the one made with KNO₃. The proportion is 70 parts NaNO₃, 16 parts charcoal and 14 parts S. The defect with this powder is that, as NaNO₃ absorbs moisture, the powder cannot be kept long. Ammonal: a mechanical mixture of NH₄NO₃, powdered Al, and charcoal, is also used.

**Line of Least Resistance:** (L. L. R.) (Fig. 17) is the line from the charge of explosive to the air along which the gases generated by the explosion will find the least resistance to bursting a path of escape for themselves. This line will naturally be along the line of the bore-hole itself unless precautions are taken to prevent such escape, to stop up or tamp the hole so that the L. L. R. may be through the solid rock. Otherwise, it is obvious that the blast will be absolutely ineffective. The length of the L. L. R. depends on the texture of the rock, and 'face'. The greater the toughness, the shorter the L. L. R. Good results will be obtained by making the depth occupied by the tamping material < 1 ½ times the length of the L. L. R. The L. L. R. need not be the shortest line from the charge to the surface of the rock.

The charge of blasting powder is obtained from the formula, Powder in lb. = (L. L. R. in ft.)² ÷ 32. This depends upon the power of the explosive, the toughness of the rock, the L. L. R., the depth of the hole, and the number of exposed faces of the rock (Fig. 4 to 7). As 1 lb. of blasting powder occupies about 30 c. in., we have data for determining the depth of the bore-hole in relation to its diameter. The depth of the hole required for the powder having been found this way, this depth is added to the depth of tamping as defined already (< 1 ½ times the least
distance through the stone from the powder charge to face of the rock),
thus obtaining the total depth of bore-hole required.

The charge of blasting powder having been poured in, a priming
needle of copper or bronze (Fig. 13 to 16) is inserted in it, the other end of
the rod projecting from the bore-hole. The needle is greased well. The
tamping material, consisting of ant-hill earth (which is an excellent
material for the purpose), burnt or dried clay powder (which is also a very
good material) is then put in, a little at a time, and rammed down with a
brass tamping bar of a diameter a little less than that of the hole and
eightly tapering, the priming needle being turned round from time to
time so as to loosen it. The needle and the tamping bar should never be
of iron as this metal strikes sparks, which ignite the powder and cause
accidents.

When the tamping is finished, the needle is withdrawn and the
hole left by it is filled to \( \frac{3}{4} \) of its depth with fine-grained powder in
connection with which is placed a piece of Bickford’s fuse (Fig. 18.) This,
if available, is the best for firing. This is a water-proof fuse, consisting
of a small rope of cotton, coated with tar, having for its core, a small
continuous thread of fine gunpowder. It burns at the rate of 2 to 2\( \frac{1}{4} \)
per min. This is called a ‘Slow Match’ and this rate of its burning enables the persons firing it to retreat
before the explosion takes place. Firing is effected
by applying a match to the exposed end of the fuse.
Where Bickford’s fuse is not easily or readily obtain-
able, the quarrymen in South India make their own
fuses by making tubes with paper or certain dry
leaves and filling them with the fine-grained powder.
If the hole is wet and the blasting has to be done
with powder, the charge may be placed in a water-
proof bag and the fuse tied closely in its mouth. For blasting rocks in
wet situations, dynamite or gelignite is usually used.

A good blast produces a dull or smothered sound or report, and
the mass of the rock should be first displaced without being blown into
fragments. A blast is most efficient when the L. L. R. is perpendicular to
the axis of the bore-hole and least efficient when it is the axis of the
hole itself.

When the explosion takes place, a mass of rock is loosened whose
volume is roughly twice the cube of the L. L. R. The weight of the rock
loosened is roughly 10,000 times the weight of the powder used. In small
blasts 1 lb. of powder will loosen about 4 T. or \(4 \times 2,240 \div (2.7 \times 62.4)\) = 53 c. ft. of rock mass; in large blasts about 3 T. or 40 c. ft.

**Failure to explode:** It occasionally happens that a charge fails to explode. It is called a miss-fire. In such cases, the safest method is to **jump** a new hole near the first (but not near than 6") and put in a fresh charge and fire it in the ordinary way. The explosion of the charge in the new hole will almost always explode the first charge which missed fire.

Blasting operations require the greatest care, including the storing of the powder. Definite working rules are invariably laid down at all works where blasting is done. **They should strictly be observed.**

B. **High Explosives:** **Blasting with dynamite:** Bore-holes are driven as in the previous case. The depths of the holes need not however exceed the L. L. R. and the diameter up to 5' depth may be 1". When several charges are to be fired simultaneously by an electric current, the intervals between the holes may be 1½ to 2 times the L. L. R.

Dynamite, manufactured by Nobel's Explosive Co., consists of nitro-glycerine rendered plastic by the addition of a powdered earth. The earth is called 'infusorial earth,' which is a deposit of fine, usually white, siliceous material composed mainly of the shells of the microscopic plants (called diatoms), or similar porous material which is known as 'dope.' Such dopes are inactive and take no part in the explosion. In hard rock and submarine blasting, dynamite containing 70% nitro-glycerine is used, for tunnelling 40 to 50%, for blasting soft rocks, trees, piles, etc., 30%.

Nitro-glycerine is made by the cautious addition of glycerine to a well-stirred and cooled mixture of the strongest HNO₃ and H₂SO₄. The oily product is washed to remove all traces of acids that might cause spontaneous explosion. Under the most favourable conditions, nitroglycerine is not safe to handle. Being a liquid and therefore liable to leakage from its container, it increases the danger of transport and storage. For this reason, it is commonly mixed with some absorbent as infusorial earth, or transformed into a gelatinous mass.

Dynamite is sold in cartridges, \(\frac{7}{16}\) and 1" diameter weighing 2 oz. and 2½ oz., respectively. Its efficiency is much greater than that of blasting powder. Ignited by ordinary means, dynamite merely flares; to be exploded, it must be fired by a **detonating agent** such as fulminate of mercury. The **detonator** is a small copper cylinder about \(\frac{1}{4}\)" diameter and 1" long with one end closed and containing about 5 to 20 grains of the fulminate. This may be fired by a Bickford's fuse or by electricity. Unlike powder,
dynamite will shatter rock when merely placed on its surface; but for economical use bore holes must be employed. Dynamite can be used in damp situations and under water.

*Splitting boulders by blasting:* For this the bore-hole should be made two-thirds the depth of the boulder, and one oz. of dynamite allowed for every 4 sq. ft. of least vertical cross section of the stone.

The bore-hole having been made, one end (cut square) of Bickford's *gutta-percha tape fuse* is pushed into a detonating cap until it touches the white fulminate within the cap. The cap is then compressed with nippers near the open end to connect it with the fuse. Care must be taken to see that the pressure is not too great. In damp or wet places the junction inside is made watertight with grease, white lead or tar smeared over the outside of the junction. The fuse and cap being ready a primer is opened at one end of the cartridge and the cap gently pushed in the dynamite, so that a part of it remains visible. The paper of the primer is then closed up and bound securely with wire or twine to prevent displacement of the cap.

One cartridge is first placed in the bore-hole and pressed, or squeezed down with a *wooden* rod, in such a way that it forms a good contact with the side of the rock in the bore-hole; the process is repeated with the second and remaining cartridges. Finally the primer furnished with the cap and the fuse is lowered or pushed gently, *but not rammed*, into the bore-hole until it rests on the charge. The space for about 8' above the charge is then gently filled with dry clay, *pressed, not rammed*, home and the rest of the tamping is formed of any material conveniently available at hand, *being gently packed with the wooden rammer*. After this is done, the fuse may be lighted.

Clay is on the whole the best material for tamping; but in using dynamite, tamping is not nearly of so great importance as it is when powder is used. Water tamping should only be used in wet places or when the charges are fired by electricity. When a miss-fire occurs with water tamping, it is only necessary to remove the fuse and the primer from the hole and put in a fresh one; but do not attempt to remove anything when stiff tamping has been employed.

*Other high explosives:* 1. **Blasting Gelatine**: is obtained by mixing nitro-cotton with nitro-glycerine until enough of the former has been dissolved to convert the latter into a jelly like mass. It is a tough, slightly elastic, semi-transparent substance containing 93% nitro-glycerine,
and 7\% nitro-cotton. It is 50\% stronger than dynamite and more insensible to shocks.

2. **Gun Cotton**: is made by the action of a cool mixture of HNO₃ and H₂SO₄ on clean cotton waste and while still moist, compressed into blocks or sticks. These are usually stored and transported in a moist condition. In the open it burns with extreme rapidity. It is unaffected by water and does not burn if containing about 10\% moisture. When wet, this can only be detonated by a primer of dry gun-cotton. It is as strong as dynamite, but less shattering in its effect.

3. **Gelatine-Dynamite**: contains 80\% blasting gelatine with nitrate of potash and wood pulp. It is used for blasting rock which is required to be removed in as large pieces as possible, as its action is a heaving and rending one rather than a disruptive one.

4. **Gelignite**: contains 65\% blasting gelatine with 35\% absorbing powder. This is plastic, water-proof and more powerful and convenient than ordinary dynamites. This should be stored in a place of cool, even temperature.

5. **Rock-a-rock**: contains 79\% of KCIO₃ (which is a solid) with 21\% of nitro-benzol, which is a liquid. Both are non-explosive during manufacture, storage, and transport. Explosion takes place only after mixing, which is done just before charging. Though this does not explode as easily as dynamite, its action under water is more effective. The bore-hole is filled with these cartridges in the top of which an exploder consisting of a tube of dynamite with a detonator is inserted (a portion of the exploder projecting outside the hole).

Electric firing with patent electric fuses and portable firing batteries is adopted in the case of hard rocks. The advantages are: i a large number of shots can be fired simultaneously; ii safety to workmen because of the remote control; iii greater efficiency of the explosives due to simultaneous firing; iv no miss-fire; and v adaptability for underwater work. The rack-bar exploder is one type of electrical appliance which is safe, quick, and can be used for blasting under water. It has a rack-bar, which, when pulled up and pushed down, rotates a coil by means of a gear wheel in a magnetic field. The potential difference thus set up causes a spark which ignites a fuse leading to the detonators connected in series to the exploder, by means of a twin-short firing cable. The exploder is kept at a distance, not exceeding one furlong, from blast holes. When a miss-fire occurs, the lead wires are disconnected and a check to see that the current is passing from the exploder, and that there is no fault in the
wiring, is made. If this is in order, either the tamping is removed carefully and a new priming cartridge inserted or the bore hole is discarded and a new one drilled.

**Blasting with liquid oxygen**: This explosive will be very useful: i where a large amount of blasting has to be done either for excavation or for obtaining building stones; ii in mining; and iii in wet situations. It is, comparatively, a cheap method of blasting. The cartridge, called Weber Cartridge, and containing aluminium as a fine powder, saw dust, and naphtha in a cylinder of brown paper is soaked in liquid oxygen before being charged into the hole. The cartridge is absolutely inert unless soaked in liquid oxygen, when it explodes with very great violence. Liquid oxygen manufactured by Linde's process is sent out in special containers (made on the principle of the Thermos flask) with a $\frac{1}{4}$" diameter mouth (always left open) to allow for the escape of the gas as it evaporates. Liquid oxygen is poured into cylindrical vessels called soakers at the quarry site, and the cartridge soaked. No detonator is required, but the charge must be exploded within 5 min. of charging, as otherwise the explosion loses its strength gradually as the oxygen leaves the cartridge and at the end of 20 min. there will not be any explosion at all. This explosive was used to a very large extent in the construction of the Mettur Dam.

**Quarrying with Machines**: This is adopted in large scale operations. Channelling machine or channeller is used to cut, with the aid of reciprocating saws or drills, grooves of any desired depth in the rock to free the sides of large blocks of stone. Such blocks are lifted with the aid of Weston's pulley blocks, portable hand cranes, derrick cranes, locomotive steam cranes, electric cranes, overhead travelling cranes (in workshops), gantry cranes (in quarries), floating cranes (in harbours), etc. For hoisting and transport of stones, in large quarries, cableways, aerial ropeways, and blondins are extensively employed. Large stones are broken to smaller sizes with the aid of i jaw crushers where one or more swinging jaws operate a fixed jaw; ii roll crushers where the crushing is effected by means of toothed, serrated, or corrugated surfaces of the roll, which feeds the material and fractures it against a fixed jaw or anvil; iii hammer or impact crushers: with hammers either mounted on spindles or loose or pivoted; iv gyratory crushers: where a crushing head is rocked by an eccentric on the inclined revolving shaft which carries it; and v cone or diac or gyrosphere crushers: Where the crushing faces are a pair of saucer-shaped discs, one stationary and the other revolving in such a way that the opening through which the material passes opens and closes, thus
crushing the material. The broken stone is screened into sizes by i rotary screens: inclined on their longitudinal axes, screens of various sized holes being disposed successively throughout their length forming the screen barrel. The material as received is fed into the fine screen end. Through the openings in this screen very fine stuff passes off and as the stone progresses down the screen barrel, the several sizes fall into bins arranged below them. ii inclined vibratory screens which consist of one or more meshes supported by adjustable springs in a frame across which runs a vibrating shaft, there being as many desks as the number of sizes which are required minus the oversize which flows over the end. The eccentric action of the vibrating unit produces a circular motion in the vertical plane in each screen cloth, instantly stratifying the material. The finer passing through the mesh and the coarser being conveyed forward and rejected. iii by horizontal vibratory screens where the screens oscillate backwards and forwards in the direction of their length, at the same time being imparted with a small rotary motion. There are many machines for making stone paving sets by machinery. Frame saw, diamond saw, and jointer saw are used to cut stones to different shapes and sizes. Planing and moulding machines are used for making mouldings, strings and cornices and turning lathes for turning bases, columns, caps, and balusters. Machines for polishing stones and cutting and facing tools, worked by compressed air, for fine-axing stone have been patented.

DRESSING OF STONES

Objects of dressing: are: i to secure as thin mortar joints between individual stones as possible, consistent with the kind of masonry to be built; ii to secure a pleasing appearance, with neat horizontal and vertical joints in the exposed faces of high class stone masonry; iii to secure proper bedding in high class stone masonry; and iv to secure special shapes for the stones as in the case of voussoirs and skewbacks for arches, copings to masonry pillars or walls, etc.
Kinds of stone masonry: i Riprap: denotes masonry of uncut stones piled together without any adhesive mortar between them. ii Uncoursed ordinary fieldstone wall (Fig. 19): of rock-faced stones of various sizes and shapes; iii Polygonal or random rubble wall (Fig. 20): where the stones are built in the wall to any shape or pitched to fit adjacent stones; iv Coursed rubble wall (Fig. 21): where the stones are roughly squared to suit the height of the courses required. Fig. 22 shows a wall with stratified squared stones with quarry face. This is between rubble and ashlar; v Ashlar: is the term applied to finely dressed stone worked to fit in the general face of the wall and is generally described according to the finish of the face of the stone. By some authorities the term ashlar is used only for cut-stone masonry where the joints are not more than 1/4 in. thick. The types are: coursed (Fig. 23), broken (Fig. 24), interrupted coursed (Fig. 25), and coursed (Fig. 26); and vi Cut or finished stone: denotes an expensive stone used in high class work where each stone is dressed accurately to shape on all faces in accordance with drawings prepared by the architects.

Varieties of dressing: Hammer-faced, quarry-faced, quarry-pitched, rustic faced, or pitch-faced: denotes a freshly fractured surface (Fig. 27).

This consists merely in knocking off the sharp and irregular corners of stones obtained by blasting, so that the thin knife-like edges and pointed angles are removed and such that the stones could bond well with one another in the masonry. This method of dressing is generally done for
random rubble masonry. Sometimes the beds and joints are either fully dressed one line or dressed only for a width of 3 to 4" from the edges of the exposed face or faces, so as to obtain reasonably uniform joints. Such stones are used in coursed rubble work. Chisel-drafted (Fig. 27): This is the same as above, except that in addition, margins 1 to 2" wide depending on the size of the block are worked around the face of the stone. The centre is either 'rough', 'punched', or 'picked'. Bush hammered (Fig. 30 and 31): gives a rough finish which has the effect of removing the outer skin of the stone. Boasted (Fig. 32): denotes a surface finished with a mason's 2" boaster in fairly even tool marks. Rusticated: The stone-work projects from the wall and is finished in several ways e.g., chamfer, chamfer fillet, rebated, etc. Broached or punched (Fig. 35 & 36): Lines of punch marks are made vertically, horizontally, or diagonally across the face, usually between chisel drafted margins. Rubbed finish is obtained by means of a rotating steel disc using water and sand or carborundum. Polished: See 'Polishing of stones.' Pitched faced (Fig. 37): The beds and joints are worked true and the lines for the face of the wall marked on the beds and joints. The lines are then 'pitched' with a hammer and pitching tool. The rough surface of the stone should extend over the surface, no punch or chisel marks being shown. Reticulated (Fig. 38): The surface is
worked true with a series of sinkings cut into the stone about 3/8" deep, the sinkings being separated by bands of regular width. *Vermiculated* (Fig. 39): The bands separating the sinkings of the reticulated are irregular in width and form, giving a worm-eaten appearance. *Sand blasting*: is used to get quickly the effect of carving upon stones. The polished surface is covered with a molten glue-like compound which hardens to a tough elastic consistency. The designs are imprinted on this covering, and the coating is removed from all the parts that are to be cut below the surface. A stream of powdered carborundum is blown against the design (the stone being kept in an illuminated closed chamber with the polished surface vertical) by compressed air when the exposed hard stone is cut, leaving the surface coating unaffected. The coating is then removed and the polished stone with sunk carving is obtained.

**One line dressed or rough tooled or boasted or droved finish**:
Where the masonry has to be built cheaply with fairly regular shaped stones with more or less plane faces, this finish shall be used. The stone received from the quarry shall be hammer dressed. Then the surface of the stone shall be dressed by removing the top layer of 0.3 cm thickness by a plane chisel or a boaster with a mason’s hammer or club hammer by forming a series of 4 to 5 cm wide bands of more or less parallel tool marks (horizontal, vertical, or inclined at 45°) covering the whole surface. The surface shall be tested now and then with a mason’s square and the edges and corners rendered square and true. There may however be shallow depressions on the plane surfaces.

**Two line dressed or punched or broached or stugged finish**: One line dressed stones are further dressed with a punch chisel and a mason’s or club hammer at close intervals to a depth of 0.3 cm to form a series of parallel ridges. Here the chisel marks shall be left over the whole surface. This finish shall be used where even surfaces are required.

**Three line dressed or close picked or sparrow picked**: Two line dressed stones are further dressed with a pointed chisel and mason’s or club hammer to obtain finer surfaces, the ridges or projections of the chisel marks being very tiny (0.3 cm deep).

A stone surface shall be specified as one line, two line, or three line dressed according as the gaps formed by keeping a straight edge on the surface along any line are > 0.3, 0.2, and 0.1 cm respectively in depth.

**Fine tooled**: The three line dressed surface is then fine tooled with the many-pointed serrated or saw-like chisel and mason’s or club
SCABBLING OR SCAPPLING HAMMER

SPALLING HAMMER

MASON'S SQUARE

MASON'S HAMMER

PITCHING TOOL

DRAG

DRAFTING CHISEL

CLAW OR SERRATED CHISEL

SOFT STONE CHISEL

PUNCH POINT CHISEL

PLANE CHISEL

CLUB HAMMER

DUMMY

ALL DIMENSIONS ARE APPROXIMATE AND IN CENTIMETERS.

Fig. 40 to 53.
hammer. By this operation, all the projections caused by the dressing in the earlier stages are removed and a fairly smooth surface is obtained. A fine tooled surface will be ready for being polished. It is only the exposed faces of the stone blocks that are two line and three line dressed or fine tooled. It is usual to have 3 to 4 lines per cm width depending on the hardness of stone and degree of fineness required. This is a common dressing for ashlar work. The beds and side joints are generally one line dressed as this is sufficient to obtain proper and satisfactory bed and side joints. Where large quantities of dressed stones are required expeditiously, dressing of stones is done with machinery run by electric or other power.

Dragging or combing: This finish is given to soft lime stone by the application of drags which are steel plates with serrated edges and graded into coarse, second, and fine according to number of teeth. After the surface of the stone has been brought to the required level by the dummy and soft stone chisel, the coarse drag alone or this and the second or all the three, according to the degree of evenness required, shall be dragged backwards and forwards.

Tools and appliances used: depend upon the particular rock or stone upon which the masons have to operate. The commonly used ones (Fig. 40 to 53) can be classified as: i Hammers e.g., scabbling or scapping, spalling, mason’s, and club, dummy; ii Jumpers; iii Chisels e.g., drafting, punch, pointed, plane claw or serrated, and soft stone, drag; iv Drawing equipment for marking e.g., trammel and scriber, set squares, sinking square, double sinking square, bevel, compasses, etc.; and v Saws e.g., frame, hand, fillet, cross cut, whip, etc.

Precautions to be observed while using stones: i Before quarrying ascertain the thickness of the available bed. Quarry the stones in rough rectangular blocks where the wastage during dressing is a minimum; ii Adopt stones freely in compression, with caution in lintels, and never in tension; iii All mouldings and carvings must be done by sinking hollows below the natural surface and not by adding stones on; iv Arrange the load such that it is at right angles to the natural bed of the stone and in the case of slate at right angles to its cleavage; v Do not allow water to accumulate on stone masonry. In external work, avoid water retaining carvings and soffits unprotected by drips; vi Avoid using hard and laminated stones for elaborate and undercut details; vii Avoid friable stones, for sharp arrises and exposed situations; and viii Avoid very compact stones, which become slippery, for stair landings, pavements, etc.
Polishing of Stones: Stones like granite, marble, etc., are polished and used for ornamental work, and flagstones are polished and used as paving slabs. They are polished by holding them firmly on the top of a revolving table to which some abrasive material like chilled shot or sand or crushed carborundum is fed. The final polishing is done by using putty and finishing with rubbers of felt. Hand polishing is done as under 'Rubbed'—'Varieties of Dressing'.

Artificial or Cast Stones: Where durable natural stone blocks are not available at a reasonable cost, processes have been invented for manufacturing cast stones. Their adoption is a question of comparative costs. One merit with cast stones is that they can be moulded to most intricate forms and, in this respect, they are more economical than similar carved natural stones. Cast stones are practically forms of good setting mortar or concrete, covered or impregnated with a preservative. These can be cast into one monolithic piece of any size and are suitable for face work since all rebates, grooves, etc., can be easily cast. They weather more uniformly than natural stones. The strength of such stones can be increased by providing steel reinforcement. The varieties of these stones are:

1. Simple cement concrete blocks: are made at site as in the construction of piers, etc., or cast in moulds for steps, window sills, etc. Artificial paving slabs and stones composed of cement concrete, carefully made, and sometimes treated with silicate of soda also come under this class.

Terrazzo: is an artificial stone made by mixing marble chips with cement and some pigment. It is either pre-cast or laid in situ and used for face of concrete or brick walls, or for floors. Ornamental patterns are invariably incorporated when laid in situ and after initial set, the surface is polished well.

2. Cement concrete subjected to some hardening process: e.g., Victoria stone, Imperial stone, Indurated stone, etc.

Victoria stone: A concrete of 4 parts of crushed granite with one of Portland cement is allowed to set for 3 days or more into a hard block to the required shape. It is then immersed in silicate of soda for 7 or 8 weeks. This is chiefly used for pavings, window sills, copings, caps for piers, stairs, etc.

3. Chemical stone: e.g., Ransome's patent artificial stone. This is made by mixing dry sand with silicate of soda (obtained by melting Na₂CO₃ with flint in a mortar mill or pug mill). The mixture, while in a plastic state, is poured into moulds; and the castings, on withdrawal, are
immersed in a solution of CaCl₂, CaSiO₃, which cements the particles of sand, is formed, the by-product NaCl being washed out under a discharge of water. This stone weighs 120 lb./c. ft. and stands a crushing stress of 2 tons. This can be dressed and carved like natural stone. This is used for caissons or hollow block foundations, for grind-stones, and filters. The disadvantage is that this is more costly than natural stone.

4. **Reconstructed stone**: This is made by taking the debris of limestone quarries, crushing into grit, mixing with lime made from dolomite, heating in a closed retort up to 980° to drive off the CO₂, slaking the powdery residue of CaO and MgO, mixing with water, and consolidating under great pressure into blocks. They are then dried and CO₂ is admitted until the carbonization of the hydrate of lime blocks is complete.

5. **Bituminous stone**: Diorite and other granite stones are often impregnated with prepared or refined tar, to form, when laid, a durable noise, wear, and dust resisting stone surface.

6. **Artificial marble**: may be either pre-cast or made in situ from sand and either Portland cement or one of the gypsum or magnesite cement. Marbles made from the former can be used for external work also. The colouring cements are used as thin facings. The pre-cast marble is made on glass-face plates with a thin and uniform coating of water-clear oil. The slab is removed after 3 days, treated with a liquid fluoride of magnesia solution on the fifth day, then washed and wrapped in paper for another day, and again treated with the liquid. After 3 to 5 weeks, polishing is done by rubbing emery over the surface with a linen rag ball dipped in a mixture of limewater and silicate of potash and repeating without emery. For internal use, the glass plate is treated with white beeswax dissolved in white turpentine and a glossy slab requiring no polishing is obtained. For in-situ work, the mix laid on canvas is applied to the surface and a brass trowel is worked over the canvas till the facing is 1/16 in. greater than the required thickness. The canvas is then peeled off from bottom upwards, the surface rubbed over and air holes filled with the mix. Grinding is done by hand or machinery. In the former, a first grinding is done with fine-grained pumice till the surface is smooth; then with fine-grained carborundum under running water, then rubbing with a polishing stone using a little water; and finally rubbing with a ball of wool moistened with alum water and dipped into a 1:3 mix of hartshorn powder and diatomite.

**Cement Concrete Blocks**: (Fig. 54 to 63). Concrete blocks have been adopted in the construction of many prominent buildings in
CONCRETE BUILDING BLOCKS

Fig. 54 to 56.

LIGHTER THAN BLOCKS. HAVE 50% TO 75% AIR SPACE. ALSO MADE IN LIGHT WEIGHT CONCRETE
CONCRETE BUILDING TILES

Fig. 57 to 60.

ALSO OBTAINABLE AS TWO CORE TYPES OR AS SOLID UNITS
THREE CORE TYPE PARTITION BLOCKS

Fig. 60 to 62.

Fig. 63.

12" WALL USING 6" WIDE TILES

Fig. 64.

BREEZE CONCRETE BLOCKS 12"X6X4 1/2
AIR SPACE 2"
CAVITY WALL

WALL TIES
some of the big cities. The adaptability of concrete to architectural treatment, and the ease and rapidity of construction are the main factors which induce the architects and owners to give preference to concrete over other materials. Concrete blocks, slabs or bricks can be used for walls of buildings, floor pavings, well linings, roads, steps, and bridge arches. Concrete is used in two forms viz., monolithic and blocks. The latter are more popularly employed, the main reasons being: i the method of laying which is more or less similar to that of masonry and is more familiar than concrete moulded in position; ii the formwork required for moulding concrete in situ is both expensive and difficult to construct; and iii the delay caused in waiting for the concrete moulded in situ to harden before proceeding with the upper storey of the building.

Its advantages over brick or stone are: i cheapness because a. of the saving of material and labour, b. of the ease with which the concrete units can be made on the site and c. of the rapidity and economy associated with its manufacture; ii Greater resistance to fire and explosion; iii Durability and capacity to resist wear and damage during building operation; iv In the hollow blocks the air spaces in the walls result in a more uniform temperature inside a building making it cool in summer and easily heated in winter; v The air spaces provide insulation against damp and wetness; and vi The cavities can be used for conveying pipes and electric wires.

The principal types are: solid block, hollow block, two piece block, aerated concrete building block, and building brick. Hollow blocks have cavities running vertically through the units, while two piece blocks provide a continuous air space in the wall, the inner and outer sections being bounded together by means of lugs on the blocks which overlap in alternate courses. Hollow blocks are usually light but the difficulty of making them waterproof and handling unduly large blocks has led to preference being given to double walls constructed with two skins of solid blocks bounded together by cross ties of wire in the joints so as to give a continuous cavity wall (Fig. 64). Solid blocks are provided with a groove all round the block. When laid, these grooves are filled with cement mortar which provides the key.

Craze: is the development of a network of fine cracks on the surface of the cast stone, due to the action of atmospheric CO₂ on the stone on exposure and formation of a ‘carbonated’ skin which shrinks as it forms and cracks. It is pronounced when the stone receives a surface finish by the application of a fine slurry of cement and sand, or cement
and stone dust. Nowadays surface finish is given only to cheaper stones and for better qualities tooing, grinding, acid etching or sand blasting are adopted. Processes to artificially carbonate cast stones and prevent crazing have also been patented. In general, coarse-textured cast stones are less likely to suffer from crazing than smoothly finished ones. Also adequate maturing of the stone before use reduces the tendency to crazing.

**Efflorescence**: (white incrustation on exposed faces) is less likely to occur with stone than with manufactured materials since to a large extent the soluble salts on a stone are leached out by water before the stone is quarried. It may be due to soluble salts in the jointing or backing material, soil, atmosphere, or unsuitable methods of cleaning or preservation. Where bricks are used as backing for stones, efflorescence appears on the surface of the stone. Similarly in cornices and exposed surfaces, the rainwater is absorbed and on drying, the dissolved salts appear on the surface. It is recommended that a coating of bitumen is given to the back of all masonry with brick or concrete backing and all exposed stone faces be waterproofed with asphalt and preferably lead. To remove efflorescence, wash with water at intervals. To prevent efflorescence, use bricks free from soluble salts as backing, minimise penetration of exposed parts by water, and see that the soil on the outside of the building does not reach above the level of the damp proof course.

**Staining**: occurs in limestone masonry due to the action of alkaline solution derived from the mortar on organic matter present, to a very small extent, in the stone. This reaction results in a soluble organic salt being deposited as a brown stain on the surface.

**Decay of stone**: is not usually so great as to endanger the structure, but it mars the appearance and renders necessary repairs and replacements. i *In granite*, it is due to the presence of inherently unstable minerals or decomposition products. Though acted by frost, wind, and rain, yet, in view of its low porosity, the life of the structure is not endangered. Changes in colour or staining due to the presence of the two micas in grey granite spoil the appearance, though the strength is unaffected. ii *In limestone*, it is due to: a. action of CO₂ dissolved in rain water, b. action of SO₂ in air, and c. expansion of water in the pore spaces when freezing takes place. Though rain water containing CO₂ dissolves limestone slightly, yet it enables the exposed parts to cleanse themselves of soot and dust. But considerable damage may be done by the formation of a hard skin of CaSO₄ due to the reaction of SO₂ on CaCO₃. The resultant skin flakes off, blisters, and unsightly decay results. The mechanical stresses set up in the stone on freezing of water (which
expands 10% by volume) can only be relieved by cracking, which results in flaking and crumbling when the ice melts. iii In sandstone, decomposing felspar and white mica render the stone soft and non-resistant to frost action or the disintegrating effect of wind and rain. Non-siliceous cementing materials are dissolved and the stone gradually crumbles. Close-textured stones are far more weather-resisting than loose-textured ones. Most sandstones are relatively porous, the rate of absorption of water being slower in the weaker and less durable ones than in the stronger and more durable types. Soot disfigureation occurs on surfaces of non-calcareous sandstones.

Cleaning: with water is used for removal of deposits accumulated during long periods of exposure. The methods are: i Scrubbing: removes dirt and soluble salts (though partially) and reduces the rate of decay; ii Spray treatment: to soften the deposits, is very effective in the case of limestones; and iii Steam cleaning: effects a more perfect renovation than water-washing.

Preservatives: are intended to prevent the decay of building stones by protecting the surface from the deleterious action of the weather. A perfect preservative should: i penetrate easily and deeply into the stone and must remain there on drying; ii harden sufficiently to resist erosion and not concentrate on the surface and form a hard crust; iii prevent penetration of moisture, and at the same time allow it to escape; iv not discolor or disfigure the stone; v expand and contract uniformly with the stone and thus prevent flaking; vi be non-corrosive and harmless; vii be cheap and easy to apply; and viii retain its effect indefinitely. The preservatives can be classified as: A. Surface coatings: These are applied to the surface, after expelling the moisture from the surface of the stone, with either a. coal tar bitumen, colourless paraffin oil, linseed oil either mixed or unmixed with paint. (These interfere with the pleasing appearance of the stone and require constant renewal), or b. A solution of silicate of potash or soda which hardens the surface of the stone, or c. Any one of the various patent solutions. B. Those which impregnate the stone without chemical action e.g., wax in benzene. Silicone R-220 (Synthetic polymeric organosilicon compound containing Si, O, and organic groups) repels water by soaking into the capillary pores of stone (concrete, brick, and plaster) and providing a water-repellent film both on surface and in depth. It is diluted in a toluene/white spirit mixture and applied either by brushing, dipping or spraying. C. Those which act by chemical action with the stone e.g., baryta for H₂SO₄ (interiors), water-glass, and magnesium fluosilicate. Ordinarily in India all stones are dur-
able and the atmosphere of almost all the towns is so free from coal gases and other factory smoke that the surface of stones in structures requires no preserving material for protection. Therefore this is not practised in India.

**Stone Reparation**: may be: i *Replacement* of decayed stone by a new one of the same material. If the new stone differs from the original, care should be taken to see that it is of the same texture and geological kind, as otherwise serious decay may result e.g., limestone and sandstone or close-textured and open-textured stones being used together. ii *Plastic repairs*. It is carried out with care and skill under expert supervision with oxychloride cements and Portland cement mortars. In the former an aggregate to match the existing stone is mixed with ZnO, with or without some MgO and gauged with a solution of ZnCl₂ to which small quantities of other salts are added to retard the setting time. In the latter, the aggregate is mixed with Portland cement gauged with water. The oxychloride cement with limestone may become permanently damp due to the formation of CaCl₂ which absorbs moisture from the air and with Portland cement a similar trouble may arise if acids or soluble salts are added to the mix.

**Pointing**: The mortar used for repointing must be chosen with care and used with skill. In an old building, the joints are much more decayed than the stone. This shows that the mortar has served to act as an outlet for moisture and salts in the masonry. If this outlet is sealed with dense mortar, decay spreads from the pointing sideways into the stone. Hence the mortar used in repointing or jointing should neither be stronger nor denser than the stone which it binds.

### CHAPTER II
**BRICKS AND TILES**

**BRICKS**

**General**: Bricks are really a variety of artificial stones. Bricks are made of clay prepared in different ways and are formed to the required size and shape in moulds and then dried. In this condition, they may be used for building kutchha buildings and are then known as *sun dried bricks*. For permanent works, the bricks are hardened by strong heat in a clamp or a kiln and when thus prepared, are called *burnt or kiln bricks*. The quality and properties of the bricks depend on: i the chemical and mineralogical composition of the earth used; ii the processes through
which the bricks pass before burning; and iii the kind of fuel used, the temperature of burning, and the care with which the burning is carried out.

Constituents of Brick Earth and their Properties: Brick earth consists of alumina and silica, either alone or in combination with lime, magnesia, oxide of iron, pyrites, sulphates of Ca, Mg, Na, and K, etc.

Alumina: is the principal constituent of every kind of clay and imparts plasticity and density. While in the plastic state, clay is capable of being moulded, extruded, and shaped. But it shrinks and cracks during drying and warps and becomes very hard under the influence of heat.

Silica: exists in all clays in chemical composition with alumina and it is also found in mechanical mixture as sand. The presence of sand prevents cracking, shrinking, and warping, and also provides the silica necessary for a partial vitrification of the materials. The higher the proportion of sand, the more shapely and uniform in texture will the brick be. But too much of sand makes the brick brittle and useless.

Lime: in brick earth diminishes the contraction of raw bricks in drying, enables the silica to melt in burning and bind the particles of brick together. In excess, however, it will cause the brick to fuse too readily and the shape will be lost. Lime should be in a finely divided state and be thoroughly interspersed with the silica, otherwise some of it will exist after burning as quick lime which, by slaking when the brick is wetted or exposed to the atmospheric moisture, will break up the brick. Limestone changes to quick lime during burning, and slakes and splits the brick when wetted or exposed to weather.

Iron oxide: is beneficial up to 10% beyond which it becomes a fusible deterrent in the clay. It enhances the impermeable and durable qualities. Iron and lime in small quantities give a creamy colour. The colour gradually deepens to red and then purple as the iron goes up to 10%. By adjusting the kiln temperature and oxygen draft, red colour due to ferric oxide or black due to magnetic oxide of iron can be produced.

Iron pyrites: cause crystallization and disintegration in burning.

Magnesia: in small quantities, decreases shrinkage and gives a yellow tint.

Alkalies: (chiefly soda and potash) produce a dark greenish hue on the surface. They cause the bricks to fuse, twist, and warp during burning. Alkalies in bricks absorb moisture from air and on drying cause efflorescence. Reh or Kollar, which is found in many places in India and
which consists of sulphate of soda mixed with more or less of common salt and carbonate of soda render an earth utterly unsuitable for brick-making.

**Organic matter**: in small quantities assists burning. If it is not completely burnt, the bricks will be porous.

**Grit or pebble**: does not allow the brick earth to be worked readily and causes the bricks to crack.

**Classification of Brick-Earths**: Brick earths are further classified as: i *Plastic, strong, pure or stony clays*: which contain little free silica and a low percentage of impurities. These are therefore liable to excessive shrinking and warping and are improved by adding sand. As these clays are pure, they will have to be baked rather than burnt. ii *Loamy, mild or sandy clays*: contain considerable amounts of free silica in addition to alumina and so a flux of lime is added both to take up the excess of sand and to aid in binding the particles together. iii *Marls, calcareous or chalky clays*: contain a high proportion of CaCO₃ and a low percentage of silica. Sand is added to avoid fusion of the bricks in the kiln.

**Analysis of Brick - Earths**:

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<td>1</td>
<td>Pure clay</td>
<td>60</td>
<td>34</td>
<td>8</td>
<td>6</td>
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<td></td>
<td>Loam</td>
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<td></td>
<td>Marl</td>
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<td>48</td>
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A good brick earth should contain 20 to 30% of alumina, 50 to 60% of silica, and the remainder chiefly of iron oxide, lime, magnesia, etc.

**Tests for Brick-clay**: If it adheres to the fingers, it is too clayey. If it leaves the fingers clean, it is good. The required quantity of clay is found by making a few trial bricks, and either sun drying them or putting them over ordinary fire. If the bricks crack while drying, it shows that there is too much clay. If they break easily when dropped on to the ground, it shows the presence of too much sand. If the burnt bricks do not come up to the required standard, chemical analysis will show the components to be added to improve the clay.

**BRICK-MAKING**

**The Stages**: 1. **Preparation of Earth**: *Unsoiling*: The top vegetation on the selected site is removed, as also stones, if any, and top
soil by digging out a few inches in depth. The stuff dug out is removed to a distance. In alluvial soils, bricks made up of the upper earth, because of its friable nature, are apt to crack in drying, and warp in burning, however well tempered or mixed with other ingredients. Such soil should therefore be removed and better clay sought for below.

The next step is clay digging and weathering. When a large number of bricks is required to be made, the brick earth is dug up before the rains and allowed to weather throughout the monsoon. The earth so dug up is spread 2' deep on level ground; such ground, if it is a little below the surrounding surface, is better. About 260 c. ft. of earth will be required for making 2,000 bricks. At the close of the monsoon, when brick making commences, the spread earth is again dug up with hoes for 2 or 3 days. The weathering mellows the clay and renders the brick made from it less liable to warp. When small quantities of bricks are required, the earth is thoroughly watered and turned over for at least 48 hours before use and tempered, until stiff enough for moulding.

Tempering: If sand is required, it is added; if not, the brick earth is tempered without it i.e., cut, slashed, and well worked with spades and kneaded thoroughly till soft and pasty, by the addition of water. The quantity of water to be added will depend on the quality of the earth, but not more should be used than will suffice to make the clay so plastic that it can be moulded easily. ¾ c. ft. of water to 1 c. ft. of earth will generally be the required quantity. If too much water is used, the bricks will lose shape when set to dry and will be brittle but if properly tempered, they will be smooth, solid, hard, and durable. If the clay is
gravelly or of a hard marly character and full of lumps or contains fragments of limestone, the gravel or limestone is either separated and removed or the stuff is passed through rollers or mills previous to tempering so that it is reduced to powder. Pebbles and stones, if any, should be picked out by hand. The stuff should be well worked and left till the end of winter, when, the sun getting warmer, the whole would have become a uniformly soft and yielding mass. It is then tempered in a pug mill (Fig. 65): This consists of a conical vessel of W. I. 5'-6' high, sunk 2½ into the earth. It is provided with a revolving shaft to which are attached cutting knives. The knives are fixed at right angles to the vertical shaft and their blades are inclined at 45° to the vertical so that the clay, which is thrown at the top along with addition of water, besides being cut up and the lumps contained in it broken, is gradually forced out of an aperture at the base of the mill. The mill is kept constantly at work when the pugging of the clay is going on, the shaft being turned either by a pair of bullocks or by mechanical power.

2. Moulding: Having prepared the brick earth as described above, the next process is moulding bricks. Moulding may be done either by: i Hand Moulding or by ii Machine Moulding. In hand moulding it may be: i Ground Moulding, or ii Pallet or Table Moulding either with simple pallets or with stock boards.

![Fig. 66.](image1)

![Fig. 67.](image2)

Moulds are rectangular boxes (without top or bottom) made of any hard wood, sometimes lined with iron or brass where accurate moulding is necessary (Fig. 66). The edges are protected with thin strips of iron to prevent wearing of the mould. Moulds are sometimes made of iron or of brass (Fig. 67). The mould is generally made for one brick, its size being determined by the dimensions of the brick required after burning. It is usual to make the internal dimensions of the mould about 1½ larger than the size of the burnt brick to allow for shrinkage.

The mould is placed either on the ground made smooth and even.
or on a table, these producing ground moulded or table moulded bricks. The brick earth is dashed into the mould and pressed by hand carefully and thoroughly so as to fill the mould. The surplus earth at the top of the mould is removed by passing a piece of wood 12" long, 2½" wide, and ½" thick called a strike along the top of the mould. (Wooden strikes are used either for wooden or iron moulds. The edges of wooden strikes can be corrected by planing when they are worn out; metal strikes cannot so easily be corrected). Before the mould is filled as above, the mould is frequently dipped during use in water to prevent the earth sticking to the mould. This is called 'Stop moulding.' Another method to secure the same object is to sprinkle fine sand or ashes over and into the mould, instead of dipping in water. This is called 'Sand moulding.' This method is considered to produce cleaner and sharper bricks.

**Ground Moulding:** When bricks are moulded on the ground, large plots of ground are levelled, smoothed, and sprinkled with sand. The mould is placed directly on this ground from one corner of the plot, and the bricks are moulded in situ, the brick being left on the ground in rows where it was moulded by removing the mould, until the whole plot is filled with bricks. When the bricks are partly dry and hard, they are turned on their faces for further drying. For these ground moulded bricks, the brick earth is prepared merely by treading under foot, without the use of a pug mill and without any further attempt at tempering. The moulder sits on the ground and moulds the bricks by the slop moulding process, removing excess earth by passing his wetted hand over the top of the mould. Very fine bricks for ordinary use may be made by this method, if the use of a strike is insisted on instead of the wetted hand.

**Table Moulding:** (Fig. 68). The process described here applies to sound work under efficient technical supervision. The moulder stands behind a table 6' × 2'-10" × 2"
placed on two supports. A piece of wood 1\(\frac{1}{4}\)" thick and of the same size as the inside measurement of the mould, called the 'stock' is bolted to the table and shod with \(\frac{1}{2}\)" iron all round, for the mould to be placed upon. On the 'stock' is fixed a plate of iron about \(\frac{3}{4}\)" thick, 5" long, and 2" wide, bearing the maker's initials or trade mark. Another piece of wood 3" in sides and 3' long, called 'sounding post' is placed below the table vertically under the centre of the stock to resist the force by which the earth is thrown into the mould. The moulder stands facing the stock and close to it. He places the mould on the stock and sprinkles fine sand over the stock and into the mould. His assistant, called clot moulder, takes a clot of the tempered clay kept on the ground by his side, shapes it roughly to the shape of a brick and hands it to the moulder. The moulder dashes it into the mould, presses the clay into the corners of the mould with his fingers, wets the 'strike' in the water tub, and removes the excess clay by passing the strike over the top of the mould. Then, he lifts the mould with the moulded brick in it and places it side downwards with a smart blow on the bars of the page, which, by their spring, shake the wet brick loose. He then places a pallet board (smooth teak boards 12" \(\times\) 6" \(\times\) \(\frac{1}{4}\)"") against the bottom of the mould and putting the board flat on the bars of the page with the wet brick and the mould resting on it, removes the mould, and slides the pallet with the brick on it along the page to a hack-barrow for being wheeled to the drying ground (Fig. 69 & 70). The barrows are provided with springs and run on smooth W. I. wheeling plates so as to shake the green bricks as little as possible. The drying ground is termed the 'hack ground' and is located between the moulding place and the kiln. It is laid out in terraces 9' or 1' above ground level, with brick courses. Each terrace should be 3 bricks wide and its aggregate length should be at least sufficient to hold the days' work of the moulder (1,000 bricks). The green bricks are stacked diagonally to the hack' and on edge. The next day's bricks are laid at right angles to these bricks until the pile is 8 or 20 bricks high. It is usual to clean the mould and stock after a set of 26 bricks is made.

Box Moulding: The disadvantages of table moulding are that
various articles are required for moulding bricks, such as table, sounding posts, page, pallet boards, etc., which cause inconvenience to the moulders and increase expenditure to the brick maker. The bricks are generally a little out of shape as they are generally placed on their edges on the ground when they are soft, and they are more deformed by pressure from bricks placed over them before they have time to harden. Moulds without bottom require clay to be stiff and such clays require to be well pugged to turn out good bricks. These disadvantages are avoided by moulding bricks in box moulds, i.e., moulds with a bottom plate, moulding on prepared ground or better still on a terraced platform. The moulder sits near the heap of earth, fills his mould with the prepared clay, after sprinkling the inside of it with sand, and then cuts off the superfluous clay with a strike. He then carries the mould with the brick in it in both his hands to the platform when he inverts the mould and rests the brick on the side of the one previously laid. He then goes to the heap of earth to refill his mould. The bricks retain their shape and edges well and they are preferred because of their even surface and neat shape.

**Machine Moulding**: Where a large quantity of bricks has to be manufactured at the same spot, and in cases where the clay is hard and strong, it is economical to use machinery. There are two types of machines. The Plastic Clay Machine combines the processes of crushing, pugging, and moulding. The raw clay is tipped into a hopper at the top of the machine. The clay passes between crushing rollers, and the crushed clay then passes through a horizontal pug mill. The pugged clay moves on to a moulding box and is forced from the box by a reciprocating piston moved by a rock and pinion movement, alternately from either end of the box through two roller dies on a smooth and greased or oiled platform in a continuous rectangular bar or band which is sufficient to produce 8 to 12 bricks edgeways, the width of the clay band corresponding to the width of the brick. The band as it comes over the platform is cut into bricks by means of wires stretched across a frame, the distance between the consecutive wires corresponding to the thickness of the brick. Because the bricks are cut by wire, these bricks are called wire-cut bricks. The bricks are then dried as usual. By the action of the reciprocating piston, the clay is, the whole time, under uniform pressure whereby uniform size and density are secured. Some wire-cut bricks are partially dried and then pressed. In the stiff plastic process using the dry clay machine, stony clay is first ground to powder and mixed with a small proportion of water so as to form a stiff plastic paste. This paste is fed through a power driven press where it is first formed into a rough clot and
then shaped accurately. The bricks made by this process are very hard and are passed direct to the kiln without going through a dryer. In the semi-dry process, some hard clays and shales are ground to powder, mixed with a small proportion of water and passed into a power-driven press. The bricks are shaped and passed direct to the kiln. The semi-plastic process is similar to the semi-dry and the screened clay is pressed mechanically to shape by pistons. The shape and appearance of bricks made by the above machine processes are improved and the "frog" given by repressing.

3. Drying: The bricks having been moulded, the next process is the drying of the bricks. After the moulded bricks have dried enough to be handled, they are dried further in stacks. The ground on which the stacks are formed should be raised about 9" to 1' above the surrounding ground level, so as to prevent rain water collecting. It should also be sanded. The best form of a stack is of a breadth equal to two bricks, laid longitudinally with intervals between the bricks, the alternate tiers being along and across the stack, all on edge. Eight or ten tiers of bricks should be left in the stack until thoroughly dry. Damp bricks when burnt, dry too suddenly, and become damaged by splitting or otherwise. Brickfields should be protected from rain. When raw bricks become thoroughly wet, they will not recover their former consistency, though they may retain their shape and thoroughly dry again. Bricks dry up in 3 to 10 days according to the season. Brick making is suspended during the rainy season.

4. Burning: Bricks are burnt in 'clamps' or in 'kilns.' Burning requires great skill and attention. Underburnt bricks will be soft and useless. Overburnt bricks will vitrify and run together. Clamps are temporary structures while kilns are permanent. Kilns are used in brick fields of constant supply. Clamps: are stacks of dried raw bricks skilfully built up over a system of flues roughly formed with burnt bricks. The ground for clamp is first carefully levelled and consolidated and the bottom set with a large rectangle. A trench is cut all round it to intercept rain water.

Clamps: English Practice: Burnt bricks are then set on the ground either 3 courses on edge or 5 courses flat placed 4¼" apart for air flues which run at right angles to the fire flue. The fire flues are 1' wide, 15" deep (height) and about 7' apart. Over the fuel flues are laid 2 courses of flat bricks, making a level flooring. On the level flooring, the first course of raw bricks is set in pockets. The fuel flues are filled with dry wood before they are covered. The largest rubble coals are then put on by measurement, and carefully levelled. Alternate layers of kutch
(raw) bricks for 3 or 4 courses and coal, where available, of size \( \geq 1'' \) are laid 13 or 14 times. After thus setting the clamp, burnt bricks are placed flat over the last course of coal and about 2'' thick of earth put on the top and mud plastered on the sides to prevent the escape of heat and to protect the clamp from rain. If the clamp is set carefully and good coal is used, the clamp will produce 60 to 65% of first class bricks, 18 to 20% of second class and third class bricks, 10 to 12% of overburnt and vitrified bricks, and the rest brick bats. Wood fuel alone, tamarind wood being the best, may be used, but coal gives better results.

**South Indian Practice:** (Fig. 71). In the clamps the bricks and the fuel are arranged in alternate layers. In a modified form of this type, the fuel is arranged in tiers of flues. Rectangular clamps give better results than circular clamps. The site for the clamp is first levelled, consolidated, and a trench cut round to intercept rain water. The two lower courses of the flue walls (termed "benches") are laid with burnt bricks. If unburnt bricks are used and the site is damp, they are sure to fail under the weight of the upper courses. The benches between the flues are then built with raw bricks to about 2' in height, the two upper courses being corbelled out to meet over the flues, leaving a space between each pair of bricks through which the firing reaches the layer of firewood placed immediately above them. On this layer of wood, 3 or 4 courses of raw bricks are stacked on edge, then another layer of wood, and so on, brick and wood in alternate layers until the clamp reaches its intended height. The top is covered with two courses of broken bricks. A space of about 1' is left clear all round the top of the trenches, and on this the casing, which is generally brick in mud, is built. It is usual to give the outside a batter inwards all round. Wood fuel is then placed in the flues at bottom and lighted and the draught afterwards regulated by opening or closing the flues. A slow fire is kept up until all the steam, as indicated by the white smoke (water smoke) turning to black smoke, has disappeared from the top of the clamp. The top is then covered with a layer of earth, and the firing allowed to go on rapidly for about 3 days or until the
sweating of the clamp is within a foot of the top of the casing. This
can always be seen and is a good guide. All the flues are then closed
and the clamp allowed to cool.

Kilns: Bricks may also be burnt in kilns which, as already stated,
are permanent structures. Kilns are of: 1. intermittent (updraught or
downdraught), 2. continuous (flame as in Hoffmann’s or trench as in
Bull’s), and 3. tunnel types.

1. a. The Intermittent Updraught Kiln: A brick kiln, as
usually constructed, is formed of bricks in a square block, like a house
with very thick side walls and a wide doorway at each end for taking in
and carrying out the bricks. These doorways are built up with sun-dried
bricks while the kiln is burning. A temporary roof of any light material
is generally put up over the kiln to protect the raw bricks from rain
while arranging or setting them in the kiln and is so made that it can be
removed when the kiln is fired. Such kilns are generally 13’ long, 10’
wide, and 12’ high, which size contains and burns 20,000 bricks at a time.

Setting: The dried bricks are first laid in regular rows 2 or 3
bricks thick and 6 or 8 bricks high with an interval of 2 bricks between
each row, so as to form arched or rounded flues connecting the fire holes.
The flues are filled with brush-wood or any wood that will kindle easily,
then with larger brush-wood cut in short lengths and lastly with logs or
split wood. The arches are formed by corbelling out each course 1½” for
4 or 5 courses height, care being taken to well back up the over-spanning
bricks. The intermediate spaces between the arches are now filled up
so as to bring the whole surface to a level. The bricks are set over this
surface with spaces between them, from bottom to top (not only in the
body but also in the arches) but the ends of the bricks are allowed to
touch one another. The bricks are placed on edges; three upon three
and reversing the direction of each course. The top course is laid with
flat bricks, so disposed that one brick covers part of three others, the
operation being called platting. The end doors are now built up and
plastered over with clay.

Firing: For the first 3 days and nights, there should be a slow
fire, until all the moisture is driven off as indicated by the white smoke
turning to black smoke. This slow fire is secured by shutting, fully or
partially, some of the fire flue arch holes or mouths. Thereafter the vents
of the flues may be opened to admit full draught and a strong fire kept up
for 48 or 60 hours, taking care to see that the heat does not become white
heat (Dull red heat 700°; brilliant red heat 800°; white heat 1,300°).
By this time, if the kiln had 35 courses of bricks, it would have sunk by 9". The stronger the clay, the more the sinkage will be. The extent of sinkage is an indication to the workmen about the sufficiency of the burning. Then the fire vents and all chinks and holes are closed with brick and clay to prevent the entry of air. The kiln remains there until it is cool enough for the bricks to be taken out.

**Demerits of this kiln:** The fire is applied only from the bottom. So the portion nearest to the fire will give overburnt (arch) bricks; the middle portion satisfactory bricks; and the top portion underburnt (salmon) bricks; 1 lb. of wood is generally allowed for every brick, but when a large quantity of bricks is burnt, 900 to 950 lb. of tamarind or karuvelam (babool) wood will suffice for 1,000 bricks.

1. b. **The Intermittent Downdraught Kiln:** is usually rectangular, circular or beehive in form and is provided with a floor, closed roof, and independent furnaces connected to a common chimney stack through flues beneath the floor. The hot gases enter the kiln a little above floor and rise up a series of vertical flues until they reach the roof of the kiln. From this they are reflected vertically downward between the bricks to be burnt and then pass to the chimney through the flues. Coal, oil, or gas is used as the fuel. This kiln is more economical in fuel than the updraught and gives a more controlled and uniform product. It is used in burning structural clay tile of all types, terra cotta, pottery and brick.

2. a. **Hoffmann's or Continuous Compartment Kiln:** (Fig. 72) is used chiefly in brick-making on a large scale, where a large number of bricks is required annually, and a continuous supply has to be kept up. The kiln is circular in plan and consists of an annular tunnel-shaped chamber of brickwork lined with firebricks. This chamber is divided into 12 or more compartments by equidistant brick partitions with small openings at bottom. Each chamber is connected by a flue passing under the chambers to a central chimney. Ordinarily a 12 chambered kiln is found to be economical. Each flue can be cut off from the chimney by lowering upon it a C.I. damper. Each chamber is provided with a leading door through which green bricks are introduced and burnt bricks are removed. This doorway can be filled up with dry brick walls. Fire holes with covers are provided through which dust coal may be supplied to the bricks. The object of these arrangements is to utilise all the heat produced by the fuel and thus to save expense in firing, as heat is fully made use of before escaping through the chimney. The kiln is continuous, each chamber performing a function in succession, namely receiving raw bricks, drying them, heating, burning, cooling and being emptied of cold
burnt bricks. Each compartment, if made about 36' long, 15' mean width, and 8' high, will hold 25,000 bricks; and $12 \times 25,000 = 300,000$ bricks may therefore be burnt in the whole kiln in 12 days. Such a kiln would therefore burn from 70 to 80 lakhs of bricks annually.

**Advantages of this kiln are:**

i. **Economy of fuel:** In an ordinary kiln, a great deal of heat from the burning fuel and all the heat from the cooling bricks are wasted.  

ii. **Equal burning of bricks:** As there is no rapid draught, the hot gases fill the chambers.  

iii. **Regulation of heat:** The bricks can at any time be examined and the burning regulated through the fire holes.  

iv. **Supply of fuel:** Fuel can at any time be thrown into the chambers as required.  

v. **Regularity of supply:** As the charging and emptying of the kiln go on continuously, regularity of supply can be maintained.  

vi. **High percentage of good bricks:** As the height of the chambers is only 8 or 9', there is no danger of crushing the lower courses when the bricks are raw or at a high temperature. Further, the bricks are not liable to injury through sudden changes of temperature. The only
disadvantage is the high first cost of constructing the kiln. From 60 to 100 lakhs of bricks must be turned out before any profit can be expected. As this kiln is built above the ground, it is termed flame kiln. As opposed to flame kilns, we have Trench kiln, a typical example of which is:

2. b. Bull's Trench Kiln: This is rectangular, oval, or circular in plan. The trench for the kiln is 5 to 7½' below the ground. If full depth cannot be reached, a portion is above the ground with banks of earth packing. These kilns are also continuous, as there are facilities for loading, drying, burning, cooling, and unloading simultaneously.

The improved Hoffmann, or Warren's perfected kiln, is similar in most respects, except that it is rectangular with round ends, and usually contains 14 chambers. The hot air line is used in warming the raw bricks and the fresh air is preheated by the cooling bricks.

3. The Tunnel Kiln: which is continuous in operation, consists of a tunnel 200' long, straight, circular, or oval in plan. The tunnel is provided with air locks at both ends. The furnaces (2 to 16), which are usually fired by coal dust supplied through fire holes in the roof, are staggered along the sides near the middle of the tunnel. Raw bricks on trolleys pass from one end of the tunnel to the other on rails. A draught of air travels in the opposite direction to the trolleys, so that the raw bricks are warmed before they reach the furnace zone. As they leave this zone, they preheat the air required for combustion and thus get gradually cooled. As the temperature is under control, better and much more uniform bricks can be produced at a lower cost than by intermittent kilns. But the tunnel kiln is very expensive in cost and upkeep and to be economical must have a considerable output.

Comparison of Kiln and Clamp Burning: The following advantages are claimed for the former over the latter: i This gives a larger and greater out-turn of first-class bricks; ii The time required for burning and cooling is shorter; iii Bricks are more uniform in quality and colour; iv This is not affected by wind and weather; and v Kutchea bricks need not be so thoroughly dry as in the case of clamps as moisture could be driven off gradually. Moist bricks put into a clamp warp. In the case of a clamp, on the other hand, the initial cost is lower, fuel required is less, no supervision is required once started and fired, and hence suitable when bricks are required in small numbers and not at a time.

Characteristics of Good Bricks: Good bricks for building purposes should be sound, of compact structure (as seen when broken), free from cracks and flaws such as air bubbles, stones or lumps of any
kind. Lumps of limestone, however small, are dangerous. They should be regular in shape and of uniform size with plane faces and sharp edges. Bricks of different sizes should never be used in the same course or piece of work. The length should be equal to twice the width plus the thickness of one mortar joint to obtain good bonding and uniform work. Its arrises should be square, straight, and sharply defined. The surface should be even, without hollows, and not too smooth, or the mortar will not adhere to them. The colour should be uniform and of deep red or copper colour. The colour depends upon the composition of clay, the kind of sand used for moulding, the dryness of the bricks before burning, the temperature at which they are burnt, and the amount of air admitted into the kiln while burning. A good brick should not absorb more than ⅓ to ⅔ of its own weight when soaked in water for 24 hours. Insufficiently burnt bricks absorb a larger proportion and are sure to decay in a short time. Bricks to be used in hydraulic work shall not absorb more than ⅜ of their own weight of water. Bricks should neither be over nor under-burnt. Correct firing promotes toughness. A well burnt brick should be hard and when scratched with the finger nail no impression should be formed. When struck, the brick should give out a clear ringing or metallic sound. When struck against one another or thrown on end on hard ground from a height of 7', the bricks should not break.

Size, Weight, and Strength of Bricks: The usual dimensions of bricks used for first class works are $8\frac{1}{2}'' \times 4\frac{1}{2}'' \times 2\frac{1}{2}''$, which, with the thickness of $\frac{1}{4}''$ mortar joints, give the standard result of $9'' \times 4\frac{1}{2}'' \times 3''$ for each brick. Country bricks are usually $8\frac{3}{8}'' \times 4'' \times 2\frac{1}{8}''$. The weight of a brick depends on the size of the brick and on the degree of compactness secured in moulding. The weight of a table moulded, wire cut or face brick $8\frac{3}{8}'' \times 4\frac{1}{2}'' \times 2\frac{1}{2}''$ is, on an average, taken as 6 lb. The weight of a country brick is about 5 lb. Bricks are mostly subjected to compression and rarely to tension. A good brick has a crushing strength of < 1,000 psi; a tensile strength of < 200 psi; and a shearing strength of about 12% of its crushing strength.

Shapes of Bricks: Bricks are made in a variety of shapes to suit the particular work for which they are required. Ordinarily bricks for building works are rectangular in section, both longitudinal and transverse, and solid throughout (Fig. 73). Frog: (Fig. 74). Most hand made bricks have a hollow on one of the larger surfaces called the 'frog'. This is to afford a key to the mortar. Bricks should be laid with the hollow surface uppermost. Bull-nose bricks: (Fig. 75) are employed to form a rounded quoin. Queen closers: (Fig. 76) having the same length, depth,
and half the width of an ordinary brick are placed next to the quoin header to obtain the lap. *King closers* (Fig. 77) with one end cut as shown are used in the construction of reveals to avoid having any face brick < 4\(\frac{3}{4}\)" on the bed. *Squint quoins* (Fig. 78) cut to form angles other than right angles in plan are used to show \(\frac{1}{2}\) brick on one face and \(\frac{1}{2}\) brick on the other, no closers being used on the front of the work. Sometimes bricks are perforated to assist in proper burning (Fig. 79). Bricks of other shapes are also made for copings, cornices, window sills, drains, basement edges, etc. (Fig. 80 to 84). *Tapering bricks* called voussoir bricks, taper, and are used for the construction of important brick arches, though ordinarily rectangular bricks are also used for the same purpose. *Curved tapering*
Plinth brick  Jamb brick  Gutter brick

Fig. 82 to 84.

Bricks: are used for the lining or steining of circular wells. Curved sector bricks: are used for the construction of brick masonry pillars of circular section and chimneys. Hollow bricks: are made in different patterns for building hollow walls. The advantages are economy, lightness, and freedom from damp. They would secure greater coolness for the interior of buildings whilst the hollow spaces might be used for ventilation. Tubular bricks: are hollow bricks having one large perforation running through their lengths. The shape is round for pillars with several of the bricks going to make up the full height of a pillar. Hollow arch bricks are also made. Pressed bricks: are made by placing ordinary raw bricks, when nearly dry, in a metal mould or die and subjecting them to compression under a piston in hand or power presses. Such treatment gives the bricks good faces and arrises, but much care is required in drying and burning. The oil used in the process gives the bricks a glazed surface, which, however, peels off on exposure to the weather.

Special Bricks: Sand-Lime Bricks: are usually made from a mixture of 95 to 92% of sand and 5 to 8% of lime (CaO) by weight with just sufficient water to allow the mixture to be moulded under pressure (up to 15,000 psi) and hardened by exposure to steam (up to a pressure of 180 psi maintained for a period up to 10 hours) when the hydrated calcium silicate is formed. These are also made of special shapes, of waste products like slag, ash tile, waste, etc., in place of sand, and of pumice, diatomaceous earth, etc., alone or with sand, for light-weight bricks. If desired, these are coloured by adding mineral pigments. The sand should contain less than 4% clay, be free from soluble salts and organic matter, and be well graded to reduce the voids to a minimum. The lime should be of high calcium type with low carbonate, magnesia, and hydraulic constituents. These bricks are uniform in size and shape, light coloured (without pigments), reflect light very well, and do not show any tendency for efflorescence to form. They compare favourably with clay bricks as
regards strength, durability, resistance to frost action, shrinkage on drying, expansion on wetting, and fire-resisting qualities. They are acted only by atmospheric SO₂ and CO₂; the former forms the sulphate which does not impair their strength, and the latter reacts with the hydrated calcium silicate and forms CaCO₃ and hydrated silica which increase their strength.

**Blue Bricks**: are made from clay and marl containing 7 to 10% iron oxide. They are durable, impervious to water, and resist pressure. They are used for lining the interior of built up sewers.

**Paving Bricks**: are made from shales or rock clays. The clays are crushed, screened, pugged with just sufficient water, moulded to proper shape, dried, and burnt in down-draft or continuous kilns to a temperature much higher than that for ordinary bricks. Paving bricks are used in streets and are able to resist the the abrasive action of traffic.

**Refractories**: **Characteristics**: For the interior of boilers, flues and chimneys, fire-places, etc., fire-bricks are required to withstand high temperature without melting or becoming soft. Fire-bricks are made from fire-clay by processes very similar to those adopted in making ordinary bricks; the clay is dug, weathered, tempered, ground under rollers, pugged, moulded, burnt, in Hoffmann's Kilns at a heat slowly increasing until it attains a very high temperature and then allowed to cool slowly. Fire-clay is the name given to any clay which is capable of resisting high temperature without melting or becoming soft. Such a clay is called refractory. This consists of nearly pure hydrated silicate of alumina. The more alumina there is in proportion to the silica, the more infusible or refractory the clay will be. The composition of different fire-clays varies considerably. They contain: i 56 to 96% Silica; ii 2 to 36% Alumina; iii 2 to 5% iron oxide; and iv A very small percentage of lime, magnesia, potash, and soda. Oxides of iron and alkalies should, if at all, be in negligible proportions, not exceeding about 5% as their presence in large proportions will act as a flux and cause fusion and the clay is then no longer fire-proof or refractory. A good fire-clay should have a uniform, texture, a somewhat greasy feel, and free from any alkaline earths. It may be remarked that the infusibility of the clays does not depend altogether upon their chemical composition alone but also on their degree of fineness. Coarse open grains make the clay more refractory than a close even texture. Fire-bricks must always be set in a mortar of fire-clay and not in the usual lime mortar for, under the surrounding intense heat, the chemical union of the free mechanically mixed silica of the clay and the lime of the mortar, will produce a fusible silicate and thus cause rapid destruction of the structure.
The Principal Types: 1. Acid refractories: are used most extensively. They are made of silica and silicates. Ordinary fire bricks: are made from a hard type of clay usually found under the coal measures. They are used in kiln’s, furnaces, ovens, flues, etc. Silica is desirable but impurities like CaCO₃, MgCO₃, oxides of iron, etc., are objectionable. These bricks are fired at 1,370°. Silica bricks: are made from pure sand (96% SiO₂), calcined flint (93% SiO₂), or ganister (85% SiO₂, 10% clay) in powder form. The powder is mixed with 12% lime, moulded under pressure, and fired up to 1,760°. These bricks are very hard and stand very high temperatures.

2. Basic refractories: are used in the basic steel processes. Magnesite bricks: Magnesite (MgCO₃) is calcined at an intense white heat (dead-burning) when it loses CO₂. The remaining magnesia, which is not affected by the atmospheric CO₂ or water vapour, is powdered, mixed with a little iron oxide, moulded into bricks, and fired at 1,650°. These bricks are very satisfactory but expensive. Dolomite bricks: are made as above from dolomite. They are cheap and are used to keep monolithic magnesite furnace bottom in repair. They are not used to produce refractory bricks because CaO combines with water and CO₂ and causes the bricks to disintegrate. High alumina bricks: are made from bauxite, corundum, and diasporé clay (which contain more than 50% of alumina) or from mixtures of these high alumina materials with fire-clay. As the Al₂O₃ percentage increases to 100, the softening temperature also increases from 1,820 to 2,040°.

3. Neutral refractories: are used for separating the acid and basic linings of furnaces to prevent them reacting together. Chrome bricks: are made from chrome iron ore (Cr₂O₃ 30 to 45%, FeO 11 to 17%, MgO 14 to 18%), bauxite (Al₂O₃ 15 to 33%), and a little silica (3 to 6%). They are powdered, made into bricks, and fired like silica bricks at a temperature of 1,590°. Fosterite bricks: are made from olivine rock and magnesia. The bricks possess excellent stability and strength at high temperatures. Graphite (m. p. 3,480°), carborundum (m. p. 4,930°), thoria ThO₂ (m. p. 2,763°), zirconia ZrO₂ (m. p. 2,763°), beryllium oxide (2,480°), and zirconium silicate (2,480°) are also used. Sillimanite bricks: (SiO₂, Al₂O₃), are used for reheating furnaces, glass furnaces, pottery kilns and roofs of electric arc furnaces because of their stability up to the melting point not obtainable from ordinary firebricks, low coefficient of expansion, neutral character, high resistance to abrasion and equal efficiency in oxidising and reducing atmospheres.

Colour of Bricks: depends on: the chemical constituents of
the clay; ii the kind of sand sprinkled in moulding; iii the degree of dryness before burning; iv the degree of the heat at which burnt; v the amount of air admitted into the kiln; and vi the kind of fuel used in burning. The natural colour due to various constituents of clay will be as follows: Clay free from Fe-white; Clay with a little lime and Fe-cream; Clay with excess lime-brown; Clay with excess Fe-red; Clay with a large proportion of iron oxide-bright red, dark blue or purple; Clay with Mn-black; Clay with magnesia and Fe-yellow; and Clay containing alkalis burnt at a high temperature-bluish-green.

Artificial Colouring: is effected by any one of the two following methods: i by mixing certain colouring matters with the clay before burning; and ii by dipping the brick in colouring liquid after it is burnt. The first method may be adopted where the colouring matter is cheap and plentiful and the latter when it is expensive.

1. Colouring by mixing: Note that red ochre burns yellow; yellow ochre burns red; iron oxide burns red at comparatively low temperatures and black at high temperatures; Mn burns black, and light red, Indian red, and French ultramarine retain the colours even to a white heat.

2. Colouring by dipping: besides being adopted for expensive colours, admits of a great variety of colours being produced cheap and without trouble, and also admits of being applied to walls already built. The colouring matter is added to a mixture of linseed oil and turpentine with a little litharge as a drier. An earthenware box is provided, a few inches larger each way than a common brick or tile, and it is half filled with the colouring liquid of about the consistency of thick cream. The bricks or tiles to be coloured are laid on an iron plate with a fire underneath the plate. The plate may be large enough to contain 40 or 50 bricks or more of tiles. They are heated to the extent of being handled and each brick is dipped in the solution kept in the box for a few sec. and then placed on a table to dry, which they do in a few min. They are then taken and slightly washed with cold water and allowed to dry. The colouring matter penetrates an ordinary brick about ½" and is thoroughly lasting.

A modified form of this method is to heat the liquid and apply it hot with a brush. This method is particularly adopted where existing walls have to be (coloured. The colouring matters in general use are given in Table in Pa 65.

Efflorescence on Brickwork: Efflorescence is the white snow-like incrustation that appears on surfaces of brickwork due to salts, which are dissolved by moisture, drawn through the pores to the surface of the wall, and left in thin layers on evaporation of the moisture. It produces
ugly damp patches, eats through the surface coatings, and gradually disintegrates the structure. It is normally of a temporary nature, disappearing during wet weather and reappearing during dry weather. Sulphates of Mg, Ca, and Na, and certain nitrates, carbonates, and chlorides cause efflorescence. MgSO₄ is most dangerous, and CaSO₄ is least harmful. The sources are: i Ground: Where the soil contains the above salts, Porous building materials absorb the solutions of these salts by capillary action; ii Storing soluble materials against the wall: Even when a damp-proof course is provided, piling up earth or other materials which contain the above salts against the wall may cause efflorescence; iii Mortar: is the chief source. Efflorescence is caused by using polluted fine aggregate like unwashed sea sand or clinker containing appreciable amounts of sulphur compounds or dense mortar containing a high proportion of cement or hydraulic lime; and iv Brick: if porous, underburnt, or containing pyrites, excess sulphur, or much magnesia.

Test: A brick kept on end in a shallow dish containing pure distilled water for about a week and showing a white incrustation at the top is an indication of a tendency to effloresce, if the brick is used in a building.

Avoidance of exterior efflorescence: The usual precautions adopted in new buildings are: i Use of a ‘high-lime’ mortar e.g., a cement-gauged lime mortar, b. moderately hydraulic lime mortar, and c. lime-ash mortar, black or furnace ash mortar (this may sometimes contain sulphur compounds and cause efflorescence), and lime-crushed brick (or tile) mortars; ii Use of hard-fired bricks; iii Provision of damp-proof courses; iv Use of water free from salts; and v Proper covering of the works at night and during rain to exclude superfluous water.

Avoidance of interior efflorescence: Interior efflorescence is much more serious than the exterior since the former surface cannot be washed by rain water. If the efflorescence has occurred, then the surface will have to be dry wire brushed. If it is likely to occur, then it can be
avoided by diverting the deposition from inside to outside walls by applying a colourless water-proofing material to the interior surfaces. All the precautions given under ‘Avoidance of exterior efflorescence’ will have to be adhered to.

Treatment of existing efflorescence: The cause should be located and steps taken to prevent further passage of salt-bearing waters into the brickwork. The existing incrustation is then wire brushed and the surface washed by a hose with powdered stone, clean sand, and water during dry weather. Application of paint, paraffin oil, barium salts, sylvestor washes (one wash of soap and water and the other of alum and water) to the surface, and addition of fatty matter to the lime and hydrofluosilicic acid to potash salts prevent efflorescence.

Staining: denotes deposits of a permanent nature on the brickwork. It is due to: i Corrodible metal, like iron and copper, embedded in brickwork, giving rise to brown and green stains respectively. Application of dilute HCl and washing with water remove the stains. A protective coating is necessary in the case of iron where staining recurs, while in the case of copper the surface film prevents further development of staining; ii Vanadium compounds in the brick earth leaching out to the surface and developing a green stain. As vanadium is a rare element, such stains are also rare; iii Iron in the sand for mortar or developed by the action of air on iron compounds in the bricks. Such brown stains are seen on light-coloured bricks or on pointing. They are removed by washing the sand well and pointing after sometimes so that the oxidation of the iron in the brick is complete; iv Lichens, moss or moulds caused by damp vegetable packing materials or bricks stacked on the ground. It is removed by wire brushing during dry weather followed by applications of a solution of ammonia and a solution of copper carbonate; v Leaching of cement. This is found as a white stain (due to the action of atmospheric CO₂ on lime from cement to form CaCO₃) beneath precast work or dense cement mortar. It is removed by washing with dilute HCl.

TILES

General: Tiles are used for roofing, flooring, and drainage purposes. Tiles require more care in manufacture than bricks, as from their greater delicacy they are more liable to derangement or deformation. The clay should be much stronger than that for bricks, very little sand being used, and that only for very plastic kinds of clay. The best clay will usually be found below the brick clay and the blue clay is particularly
good for tile making. The same previous preparation of the clay and the same mode of working and tempering is necessary. The prepared clay is carried to the moulding sheds. Moulds or patterns made of well-seasoned wood and of the exact form of the tiles to be made, as well as forms on and in which tiles are to be moulded should be used. The required form should be given to the tiles by moulding in one piece and not by sticking on additional clay afterwards. The drying of the tiles should be in the shade, as otherwise they will, being thin, warp in the heat of the sun or suffer damage in the rain. When set firm, the tiles should be laid on edge for proper drying.

**Roofing Tiles:** *Important varieties: 1. Pot-tiles: (Fig. 85)*
also known as *locking tiles* are either used as the sole covering to the roof or combined with flat tiles for the same purpose. These tiles are made on the potters' wheel from a clay better tempered and much stiffer than ordinary tile clay. The potter produces the shape for the tile with his wetted hand and finally polishes the inner and the outer surface with a wet cloth or a wetted strip of leather. On the wheel, the tile is first made into a tapering tube. Just before taking the tile off the wheel, the potter makes two vertical cuts, one at each end of a diameter, the cut not being to the full thickness of the shell of the tile. These cuts are intended to assist in easily cutting the tube into two pot-tiles after the tube has been burnt. After drying, the tiles are *burnt* with flat tiles (stacked on the top of the pot-tiles) in an open clamp with dried cow-dung cakes, which are excellent fuel for the purpose as they give a strong and steady heat without burning (into a flame as in the case of wood-fuel).

The pot-tiles are semicircular in section, about 6 to 8" long, 3\(\frac{1}{2}\) to 4" diameter at one end, and 4\(\frac{3}{4}\) to 5\(\frac{1}{2}\)" at the other end. The tiles are laid on the roof, from the eaves towards the ridge, in such a manner that the adjacent rows are laid alternately with concave and convex sides uppermost, so that the tiles with convex side up cover the two adjoining edges of the two lower rows of tiles with the concave side up. (The concave side up tiles are laid with their larger width in the direction of the ridge and the smaller width in the directions of the eaves. The convex side up tiles are placed in reverse directions). *The objections to the pot-tiles are: i Want of uniformity. No mould being used, the size and curve of the tile will not be the same in all tiles but depend on the dexterity of the moulder; and ii Extreme brittleness which causes the tile to break under a little pressure, and makes the repairing of the roof a difficult matter.*
2. *Pan-tile*: is similar to the pot-tile in shape and differs from it only in being shorter, heavier, and less curved. A pan-tile made from the same clay as a pot-tile is preferable to the latter, being equally good as regards quality and having the advantage of uniform size. The implements required are the mould, the bow, the horse, and the strike (Fig. 86 to 89).

First, ash is sprinkled over the mould. A lump of clay slightly more than sufficient to fill the mould, is shaped and dashed into the mould and well pressed into all the corners. Excess earth is cut away by passing the string of a bow across the surface of the mould. The strike is passed over the clay backwards and forwards, till the surface is tolerably smooth and level with the top of the mould. The moulder then places his moistened left palm with widespread fingers over the tile and gently lifts the sticking tile and places it over a burnt pan tile beside him. Twenty tiles are thus heaped one over the other, and then another heap is started.

When the tile has dried a little, but still plastic, it is *horsed*. The horse (a rectangular piece of wood, with a handle, tapering sides and top curved to the curvatures of the tile) is first sprinkled with ashes. The flat tile is gently bent over it and smoothed into shape with the moulder's wetted hand. The tile is removed and gently placed on the ground. After 5 or 6 hours, when it becomes hard, it is again rehorsed, the edges trimmed with a knife and the ashes cleaned off. It is then left on the ground to dry for another 8 or 10 hours until it is *hand hard* for being placed on its narrowest edge against a wall or board. Subsequent tiles are placed one over the other until quite dry for burning.

3. *Flat tile*: varies in size from $6'' \times 6'' \times \frac{3}{4}''$ to $8'' \times 8'' \times \frac{3}{4}''$. The larger variety called paving tile is used on floors while the smaller variety is used on terrace underneath roofing tiles. This variety is moulded in moulds similar to those used in moulding pan-tiles while the large sized tiles are moulded on specially prepared hard ground under a covering in open moulds. The process of moulding is the same as that for pan-tiles and bricks. On the third day after moulding, the tiles are lightly
beaten with a flat mallet like a cricket bat to correct the shape which would be warped in drying and in taking them off the mould. On the fourth day they will be hard and then lifted up and the edges and under surfaces scraped with a hoop iron ring 5" in diameter. They are placed on edge in herring-bone bond and left in the shed to dry for a couple of days or so. They will then be stacked outside the shed ready for loading on kiln. The tiles are also machine moulded and then pressed under a press after they are stacked for a short period under cover, close together.

**Burning of tiles:** is done with wood. The kiln (Fig. 90) is circular and of a size to burn about 30,000 to 50,000 tiles. The kiln is set by forming a floor made of bricks laid flat and somewhat open over the tops of flues. On this flooring, the tiles are packed as closely as they will lie on edge, course upon course. When the kiln is full, the doorways (openings about 2½' wide used for loading and unloading the kiln) are bricked up and the top covered with a course of old tiles laid loosely. The fire must be gentle at first until the disappearance of all white steam when it may be raised until the interior of the flues has been brought to red heat, 800°. The fire is again slackened for 6 hours, and again raised until the interior of the flues has been brought to white heat, 1,300° and kept so for about 3 hours. The fire is then slackened for 6 hours when it is again raised to the same temperature as before which is kept up for about 4 hours. The flues are then quite filled with fuel and their mouths closed with brick and mud, the fire being allowed to burn gradually out. The burning generally takes 72 hours. When only a small quantity of tiles is required, it is usual to burn them on the tops of clamps in which bricks are being burnt for the same work.

4. **Patent tiles:** (Fig. 91) such as Mangalore, Quilon, Feroke, and Railway pattern tiles. There are also ridge, valley, and hip tiles to suit and also ceiling tiles. These tiles are made of specially good clay, thoroughly well prepared by mechanical means, and are moulded in iron moulds, producing the pattern and shape required. They are burnt in
patent kilns. Afterwards, the tiles are sorted, according to quality into 1st, 2nd, and 3rd class, the 1st class being the best in all respects. The size of the roofing tiles is 14" × 8½", 125 tiles covering 100 sq. ft. 100 tiles weigh about 560 lb. The advantages claimed for these tiles are: i Appearance; ii Comparatively small weight; iii Adaptability to roofs of flat slopes; iv Simplicity and ease of arrangement; v Immunity from annual repairs; and vi Facility for repairs when necessary. The disadvantages are: i The room is rendered very warm (if no flat tiles are used below); and ii As these tiles are not available at all places, a stock of a few tiles will always have to be kept for occasional replacement.

**Plain tiles:** (Fig. 92) are made out of stiff clay which is thrown on to a flat slab, and kneaded by hand to ¼" thickness. It is given a slight longitudinal camber, so that the various courses of tiles when fixed on to a roof, may sit down snugly on each other. Two top nibs are provided to hang them on to the roof batten and nail holes adjacent to the nibs to fix them permanently.

**Concrete roofing tiles:** made in various shapes and shades from 1:3 ordinary or rapid-hardening cement mortar with powdered colouring pigment like Fe₂O₃, Cr₂O₃, MnO₂, etc., have excellent weather resistance, lasting properties, and strength. The colour and texture of the face of the tile are obtained in two ways: i by applying to the body of the tile a mixture of coloured cement (or a mixture of coloured cement and sand); or ii by applying a mixture of coloured cement and then sifting on the trowelled surface an even layer of burnt sand (called ‘topping’), sometimes mixed with a small proportion of pigment.

The sand and cement are mixed in an open pan mixer with rotating blades for one min. before addition of water and pigment and for another two min. afterwards. The sand and pigment for the topping are mixed dry for 15 min. in a ball mill or rod mill. The tiles are made on steel or C. I. pallets accurately shaped to the underside of the tiles and provided
with recesses to form the nibs. Pallets are placed on the bed of the machine and pass in a continuous line under an atomizer which coats them with oil on the upper surface. Concrete is delivered through a chute, and the pallets with the concrete on them then pass under a roller which compresses the material and under a press-blade which shapes the upper surface of the tile. A rotary knife cuts the concrete longitudinally, forming two tiles on each pallet. A shaking box with a wire mesh bottom sprinkles the topping on to the tiles, and finally a transverse knife and punches descend to cut the tiles at the ends of the pallets and form the nailing holes. The pallets with the tiles are then carried along the bed of the machine by a roller conveyor. The tiles are kept on their pallets for at least a day in nests of shelves in the form of racks. The tiles are then taken in cradles, dipped in certain chemical solution in tanks to quicken setting of cement, and the cradles are then taken out in trucks.

Flooring Tiles: The size varies from 8" square up to 12" square and the thickness ranges from ½ to 2". These are made exactly like the flat tiles. These are machine made and pressed, so as to make them compact to stand wear and tear of feet.

Drain Tiles: These are curved tiles, either circular (pipes) or semicircular, used for conveying water for irrigation or other purposes or for conveying sullage water from houses. Formerly, they used to be made with hand with wooden moulds and were naturally of a rough shape. As made with hand, they were 3 to 16" internal diameter and 18" long, either cylindrical, tapered or egg-shaped in section. At the present day such hand made drain tiles are rarely used, cement and stoneware materials or earthenware pipes, made with machines, having superseded them.

Interlocking Hollow Tiles: are used in outside walls to improve the bond, eliminate joints extending through the wall, prevent moisture passing through the wall and provide air space in all parts of the wall.

Encaustic or Glazed Tiles: are made from a purified 'slip' (intimate mixture in water) of finely ground china clay (20 to 30%), ball clay (16 to 25%), flint (20 to 30%), and felspar (30 to 35%), by extracting the water, drying, again grinding to powder, and moulding in a press with about 10% water. The tiles are then dried and carefully fired at 1,260° for about 5 days. They are next dipped in a glaze (vide 'opaque glazing') and fired in an oxidising atmosphere for about 2 days at 1,040°. These are used for decoration of floors and walls and also in walls of bath rooms, hospitals, and other important buildings for cleanliness. They are made in various shades and designs. The usual sizes are 6" square for walls,
6" × 3" for borders, 6" × 1½" for corners, the normal thickness being ¾". These are fixed with 1 : 2 cement mortar and finished and pointed with plaster of Paris. In the 'under-glaze' method adopted for ornamental tiles of the pictorial type, the decoration is applied in the biscuit stage, i.e., after it has been first fired, then lightly fired, then glazed, and finally fired.

Characteristics of Good Tiles: They should: a. be of the regular intended shape and size, free from twists, cracks, flaws, and bends and should fit in closely and square when held in position on the work; b. be well burnt and of uniform colour (ordinarily deep red or copper colour); c. possess a clear ringing sound when struck; d. be sound and hard and possess an even and compact structure when examined on a broken section.

Terra-Cotta: a kind of earthenware, is made from a carefully selected and prepared refractory brick clay which vitrifies on the face at a moderate temperature with a smooth hardened surface. This is used as a substitute for stone on the ornamental parts of buildings such as cornices, bases and capitals of pillars, etc. To get over the difficulty due to the uncertainty of the shrinkage of the clay, different clays are mixed together and a large proportion of ground glass, pottery, and in some cases, sand is added. The mixture is ground to fine powder, thrown into large water tubs, finely strained, pugged, kneaded, forced into plaster moulds, smeared with soft soap, very carefully dried, gradually baked in a pottery kiln, and slowly cooled. It is more durable, lighter, stronger, harder and cheaper than most building stones but gets slightly twisted due to unequal shrinkage in drying and burning. Warping is reduced by the hollow casting of blocks in comparatively small sizes. It is grey or buff in colour, but any desired colour can be given by glazing before burning. Porous terra-cotta or terra cotta lumber is made by mixing straw or saw dust in the clay and burning like ordinary bricks. It is fire-proof, can be sawn, holds nails easily, and sticks well to plaster. This is very rarely used in India.

Faience: is similar to terra-cotta but the clay moulds are twice fired. They are first fired like terra-cotta to the 'biscuit' stage. They are then removed from the kilns, allowed to cool, coated with the glazing compound, and fired again. This is used in industrial areas, since it is ordinarily unaffected by adverse atmospheric conditions.

Earthenware: is made from ordinarily milder clays, similar to brick or tile clays, burnt at a comparatively low temperature, more or less weak and porous, the body of the ware not completely fused and especially liable to be deranged by frosts. It approximates to terra-cotta in character. It is used in making ordinary drain pipes, electrical cable conduits, partition, and patent floor blocks.
Stoneware: is the name given to articles made from plastic clays containing about 70% silica, 24% alumina with a very small percentage of other ingredients. The clay contains very little infusible matter and is generally mixed with a certain proportion of powdered stoneware, ground decomposed granite, or sand to prevent excessive shrinkage. Sewer pipes, sanitary fittings, etc., are made of stoneware material. Having moulded accurately to required shapes and dried, the materials are burnt in domed kilns, raising the heat gradually to a high temperature, maintaining the same for 24 to 72 hours according to the size of the kiln and the articles in it, and allowing it to cool down gradually.

Glazing: The surfaces of bricks and tiles are sometimes, and if stoneware materials, invariably, glazed for the protection of the surfaces from the action of the atmosphere or other destroying agents, and sometimes for appearance. Glazing may be transparent like glass or opaque like enamel.

Transparent glazing: may be effected by the following methods: Salt-glazing: consists of throwing wet NaCl into the kiln when the articles are at a high temperature and when the fire is expiring. The heat of the fire volatilises the NaCl, the Na combines with the silica in the clay to form silicate of soda which again combines with the silicates of alumina, lime or iron in the clay to form a surface coating of glass. The vapour of the volatilised salt gets into every pore of the article and coats it with an impenetrable film of glass. This method is applicable to ware rich in silica serving to unite with soda. It is chiefly appropriate to sanitary ware, where acid and sewage proof surfaces are required. Lead glazing: is carried out by dipping the article to be glazed, after it has once been burnt, into a bath containing oxide of lead and tin; or by covering it with a composition of lead ashes and powdered calcined flints, and then placing it in a potter's oven till the composition begins to run. The particles of these different materials adhere to the surface of the article dipped and when the article is reburnt, as stated, in a potter's oven, the high temperature causes the particles to run together, forming a film of glass on the whole surface. Lead glazing is used for wares made of inferior clay which cannot stand the high temperature required for salt-glazing. But lead-glazing will chip off easily.

Opaque glazing: is used in cases where it is desired to give the whole or any portion of the article an appearance superior to that presented by the ordinary burnt article. The article to be thus glazed is dipped, before burning, into a slip (a mixture of felspar, flint, kaolin,
boric acid, and certain metallic oxides, such as those of Zn, Sn, and Pb so proportioned that its fusing point is lower than that of the ware, is fused to a glass, ground in water to a creamlike consistency), dried, and fired to bring the glaze to its fusing point, so that its pores are filled with the glaze. Sanitary ware tanks, lavatories, etc., are glazed in this manner.

CHAPTER III
LIMES AND CEMENTS
LIMES

General: Lime is used in buildings as a matrix for concrete, in preparing plastic mortar for joining stones or bricks in walls, in plastering and whitewashing walls and embedding tiles on roofs and floors. Lime is a more or less impure CaO and is obtained by the calcination of shells, corals, chalk, limestones, kankar and other calcareous substances composed of almost pure or impure CaCO₃. The first three are found in nature as pure carbonate while the rest are found mixed up with sand, magnesia, ferro oxide, etc., as impurities.

Definitions: Calcination: is heating to redness (700 to 800°) in air. Quick or Caustic Lime: is the result of limestones after burning. Slaking: When water, to which quick lime has great affinity, is added, it crumbles to powder, evolving much heat and increases in volume 2½ to 3 times. This white powder Ca(OH)_2 is termed slaked lime and the above process is termed slaking. Hardening or Setting: The colloidal fat lime suspension in the slaked lime hardens by the loss of water. The strength is then developed by the adsorption of CO₂ from the atmosphere, and the formation of crystals of CaCO₃, evolving water. As CaCO₃ is impervious, the superficial layers hinder the access of CO₂ to the interior of the mortar. Addition of sand increases the porosity and hence the area available for carbonation. Lime and silico react only very slowly at ordinary temperatures. Hydraulic limes set without combination with CO₂. They are intermediate in properties between limes and cements and they set like cements. Hydraulicity: is the property, the lime or cement has of setting under water or in situations free from access of air, when mortar or paste is made from it. It is due to the crystallising energy of the aluminate and the silicate of lime. Mortar: is composed of lime, sand, and surkhi occasionally, mixed with water into a paste. Mortar is of two kinds: 1 Common mortar, a mixture of lime and sand ordinarily used in buildings;
and ii **Hydraulic mortar** that sets under water and is also used in building construction. Mortars made from pure CaCO₃, such as white marble, limestones, shells, etc., cannot set without free access to the air, while mortars made from impure carbonates, clay, containing magnesia, ferric oxide, etc., can set under water.

**Constituents of Limestones**: Limestones exist in nature either as pure CaCO₃ or as impure CaCO₃, such as stones containing from 8 to 30% of clay with other ingredients from which hydraulic limes are formed; lias lime, kankar, etc., are examples of impure carbonates. Pure CaCO₃ and sand as a mechanical mixture give the lime no hydraulic properties whatsoever. But the following constituents produce hydraulicity:

i **Clay**: in small quantity retards slaking and in a large proportion arrests slaking. It causes setting of lime and renders it insoluble in water. It should therefore be proportioned properly with the remaining constituents and the whole calcined at the proper temperature. With 8 to 30% of clay, the lime will make excellent mortar. ii **Soluble silica**: as in clay, pozzolana, etc. Hydraulic properties occur only when both silica and alumina are present in chemical combination with the carbonate. Silicates of Ca, Mg, and Al also give hydraulicity. They are inert at low temperatures and combine with the lime at high temperatures. iii **Magnesium carbonate**: is like CaCO₃. Magnesium limes slake more slowly, evolve less heat, expand less, set more slowly, but finally gain greater strength. 30% MgCO₃ renders lime hydraulic without clay. iv **Alkalies and metallic oxides**: up to 5% when subjected only to low temperature sometimes tend to produce soluble silicates, and thus to cause hydraulicity. v **Sulphates**: in small quantities suppress the slaking action and increase the rapidity of setting. vi **Iron**: up to 5% is desirable in hydraulic limes. On calcination, the iron is converted into Fe₂O₃ at low temperatures and combines with the lime and silicates at high temperatures to form a complex silicate. vii **Pyrites**: are objectionable.

**Classification of Building Limes**:

**Class A**: **Eminently hydraulic limes**: These slake very slowly, but can also set under water due to the presence of 20 to 30% of clay in such limes. Hence these are used for masonry in foundations for thick walls and bridges, for dams, etc. All hydraulic limes are obtained from limestone or kankar. The setting of such limes is mainly due to the decomposition of a complex silicate of Ca and Al into simpler compounds of CaSiO₃ and CaOAl₂O₃, with the formation of Ca(OH)₂, which takes place only in the presence of water. The CaSiO₃ and CaOAl₂O₃ crystallise and form a hard mass in the interior, while the Ca(OH)₂, which
is soluble in water, comes to the surface and crystallises to form CaCO$_3$ under the action of atmospheric CO$_2$. These set very rapidly attaining the hardness of limestone in 6 months. Their slower setting, compared with cement, renders them plastic for a sufficient time to allow the slight settlement of new foundations. The structure is thus free to take its permanent position and cracks are thus avoided. Where much strength is not required, these are used in place of cement. However these limes should not be mixed with cement as a rule. As they do not shrink and crack, only a small amount of sand need be added.

**Class B**: Moderately hydraulic, feebly hydraulic, and non-hydraulic limes: These are used for mortar for masonry work in superstructures of building and plastering. Moderately hydraulic limes: contain 15 to 20% clay, slake only after an hour or two and that too not violently, set firm under water in 7 days, and become as hard as soft stone after one year. Feebly hydraulic limes: contain 5 to 14% clay, slake after a few minutes with cracking, evolve heat and vapour and reduce to powder, set in 2 to 3 weeks after immersion in water, and become only soap hard after one year. Non-hydraulic (poor, meagre or lean) limes: contain no clay, slake slowly, do not evolve much heat, seldom reduce to an impalpable powder, yield a thin paste (slaked lime being less smooth and plastic) and expand less than fat limes. The colour varies from yellowish white to grey or brown according to the impurities. These limestones, if overburnt, can slake only when ground to fine particles to help slaking. Such slaked limes will produce mortar which will become harder than that from fat limes and resist wear better. It is not economical to use lean limes, as the increase in volume in slaking is less, as it cannot admit of a mixture of such a large ratio of sand and as it is not superior to fat lime in setting.

**Class C**: Fat, rich, high-calcium, or white limes: These are used mainly for finishing coat in plastering, whitewashing and with suitable admixture such as surkhi or any other pozzuolan material to produce artificial hydraulic limes. These are obtained from calcining chalk, marble, or shells. These contain no clay and hence are not hydraulic. The quick lime obtained after calcination slakes when water is added or when left exposed to the air by absorbing moisture from the atmosphere. In mortars made of fat limes, setting is only at the surface where they come into contact with the atmospheric CO$_2$, by the formation of a thin surface crust of CaCO$_3$. So these mortars are not suitable either for foundation work below the ground level or in very thick walls since atmospheric CO$_2$ cannot easily reach the mortar. A certain percentage of cement is added when building with these limes. These require a larger
proportion of sand to make a mortar which will not shrink excessively. Also the addition of sand, in virtue of the porosity caused by such addition, enables the atmospheric air to reach the fat lime in fairly thick walls not exceeding 2½ in superstructure, thereby assisting the setting of the lime and the evaporation of the water which is produced as a by-product in the process of setting.

When MgO exceeds one tenth of the CaO and the MgO in the lime, the lime shall be termed magnesian lime, and when MgO exceeds one quarter of the CaO and MgO, the lime shall be termed as dolomitic lime. MgO aids hardening of the lime, but it does not hydrate as readily as CaO. Hence in limes with over 10% of MgO, precautions shall be taken during slaking to conserve the heat.

Pozzolanas: are siliceous materials which, while possessing no cementitious value, will in finely divided form and in the presence of moisture chemically react with Ca(OH)₂ (lime) at ordinary temperatures to form compounds possessing low solubility and cementitious properties. They are classified as: i Natural Pozzolanas: Volcanic tuffs, trass, pumicites, diatomaceous earth like kieseguhr, shale, etc., and highly siliceous rocks. ii Processed aggregates: Clays such as kaolinite and montmorillonite and shales. iii Artificial pozzolanas: Brick jhama made by burning clay with overburnt and fused bricks, granulated iron slag, and finely divided fly ash from burning powdered coal. Typical composition of fly-ash is SiO₂ < 40%, Al₂O₃ < 15%, MgO > 3%, SO₃ > 3%; Loss on ignition to be > 10%.

Fat lime is rendered artificially hydraulic by admixture with pozzolanas. The advantages of pozzolana cement concrete over ordinary cement concrete are: i Less heat of hydration and volume change; ii Higher degree of watertightness; iii Higher tensile strength; iv Lower compressive strength at early ages, but approaching equality in strength with age; v Higher resistance to sulphate attack; vi Increased plasticity, reduced bleeding, and segregation; vii Greater resistance to expansion due to alkali-aggregate reaction; and viii Saving in cost. The optimum proportions of pozzolana generally lie between 10 and 30% of cement. The disadvantages are: i Some loss of early compressive strength although it may be regained at later ages; ii Less resistance to erosion, weathering, and alternate freezing and thawing, although air entraining counteracts these effects; and iii Slightly greater expansion on wetting and contraction on drying.

They are generally used: i in the lean mixes of mass concrete
e.g., dams, bridge piers, abutments, etc., (where low strengths are permissible and the properties of low water gain, satisfactory workability, freedom from segregation, and low heat of hydration are essential) by substituting a part of cement for economy; ii in hydraulic structures where extreme water tightness is desired; iii in marine structures, where impermeability and resistance to the action of sea water are matters of importance; iv in sewers, sewage works, water supply lines and other structures subject to attack of acid or sulphate waters; and v in underwater construction where concrete is placed by tremie, bucket or other means.

In India, surkhi is prepared by burning bricks made from ordinary soils and then grinding the burnt bricks. The soil shall i contain $>0.3\%$ of soluble salts, ii contain $>3\%$ of $\text{CaCO}_3$, iii have a residue of $<10\%$ retained on 100 mesh sieve and $<25\%$ retained on 200 mesh sieve, iv have $<20\%$ clay (This limit may be relaxed in case of silty soils), and v be free from kaolins nodules. After manufacture, the surkhi shall be kept dry and clean. It shall weigh 70 to 90 lb. per c. ft., have a sp. gr. of between 2.65 and 2.75, and not lose more than 5% on ignition. The chemical composition shall be: $\text{SiO}_2 < 50\%$; $\text{Al}_2\text{O}_3 < 10\%$; and $\text{MgO} > 3\%$. Indian resources for the production of processed pozzolana from calcined shales are extensive. Owing to the great shortage of cement in India, for the Bhakra-Nangal Project, shale, which is available in abundance at the project site, is calcined, finely-ground, mixed with cement, and used for mass concrete resulting in a saving of about 20% of the cement required for the project.

Opinion is divided regarding the degree of burning of surkhi. Over-burnt surkhi is recommended by some authorities, while well-burnt surkhi is used in Madras and underburnt in Mysore. Recent experiments show that underburnt surkhi possesses the following advantages: i It is easily ground to any fineness. ii It has higher specific surface and hence gives a more impermeable mortar. iii Its pozzolanic activity as judged by lime absorption and chemical analysis is greater than that of the other two varieties. iv Its hydraulic strength is not lower than that of the others. v Since it increases the stickiness in cement paste, it prevents the bleeding of concrete and mortar. vi All tests on grindability, unit weight, porosity, water absorption, lime absorption, chemical analysis and strength prove conclusively that this will behave best. vii Its cost of production is the lowest.

The action of surkhi may be explained as follows: The burning of the clay renders it anhydrous. When the burnt clay and lime are
intimately mixed, the addition of water is sufficient to set up chemical reaction, resulting in the formation of hydrated calcium silicate and aluminate which set hard and are insoluble in water.

**Limed surkhi**: which gives good results, is made from bricks prepared from clay with which 10 to 20% quick-lime has been mixed previous to burning.

**Limestone Burning**: Limestones are burnt in clamps and kilns, to economise fuel. The kilns are of two types, one in which the limestone is in contact with fuel and another in which it is separated from it. The contact with fuel contaminates lime on account of union with ash, but tends to economise fuel. The system of burning may be either **continuous** or **intermittent**. In the **continuous running system**, the fuel and limestone are placed in alternate layers and the burnt lime is gradually removed from the bottom of the kiln and fresh limestone and fuel are added on top to make up the clearance. In the **intermittent system**, the kiln is loaded and fired. The burnt limestone pieces are removed after the kiln cools down. There is waste of fuel owing to the kiln having to cool after each charge is burnt but the limestone or shells are uniformly burnt. The kilns are classed as **tunnel** or **flare kilns** both of which are workable on any of the above systems. In the tunnel kilns, alternate layers of fuel and limestone are packed, while in the flare kilns, the coal is under the arches and lowermost and the limestone is packed above so that the flame only reaches the stone in the upper portion of the kiln. A description and working of these kilns is given below:

1. **Continuous tunnel kiln**: (Fig. 93). Fuel in contact with limestone. This type of kiln is protected from the weather by a shed. The kiln is shaped internally, like a cylinder, an inverted cone or a pair of vertical cones placed base to base. It is lined with fire-brick with hollow space behind and an opening below. At the lower end of the cone is a grating of loose fire bars over which is placed a layer of brushwood and then alternate layers of fuel (wood, charcoal, or coal) and moistened limestone reaching up to the top, the largest pieces being in the middle where it is hottest. Burnt lime is withdrawn through the grating, fresh charges of fuel and stone being added at the top. The bottommost layer of limestone is about 25 c. ft., the remaining layers being of convenient quantities. It takes 3 days to be ready for drawing the burnt
lime, and then daily. The limestone should be broken into 8" or 10" lumps.

2. **Continuous kiln**: (Fig. 94). Fuel not in contact with limestone. The kiln is built in two sections, the lower A and the upper B. A small quantity of the fuel is mixed with the stones on charging, the remaining part being introduced through the shafts C at the sides of B, which serves as a hopper to store the stones. These are charged through the opening D. The waste heat due to the combustion in A is utilised to heat the stones in B. A is lined with fire-bricks. Stones in A rest on a grating E fitted with a movable door and are drawn off after calcination.

3. **Intermittent flare kiln**: (Fig. 95). Fuel not in contact with limestone. In this, the broken limestone rests upon arches roughly formed from large pieces of the same material. Proper non-splitting stones should be used for the arches, and the heat applied gradually so as not to split the arch stones. The fire is lighted below. The flame only will be in contact with the limestone. This type of kiln is more easily managed than the continuous kiln. When burning shells, the layers of shells are 6" thick; and of fuel (wood) 12" thick. 1 T. of wood is required for a charge of 70 c. ft. of shells. The charge takes 2 days to burn and a day to cool.

4. **Intermittent kiln**: (Fig. 96). Fuel in contact with shells. Shells are mixed with charcoal in the proportion of about 2 : 1 by measure or volume. A layer of charcoal 2 or 3" thick is laid on the broken tile layer and ignited. The mixed shells and charcoal are placed on this in small heaps a little apart. When the fire has reached these heaps, the intervals between the heaps are filled with shells and charcoal, and as the burning proceeds, additional layers are put on until the kiln is full. The air-draught openings are kept open on the windward side. Air is drawn in through them and into the longitudinal opening. In calm weather, artificial draught is furnished by rotary fans. The kiln contains about 6 c. yds. shells and 3 c. yds. charcoal and delivers a volume of quick lime equal to that of the shells.

**Points to note in lime burning operations**: 1 *Gradual heating*: Otherwise CO₂ and moisture will be driven out too quickly and the stone or shell will be blown to pieces; 2 *Until burning is complete*, the stone
LIMES AND CEMENTS

INTERMITTENT KILN FOR SHELLS

Fig. 96.

will be dull red in colour. Thereafter it becomes bright, which indicates the completion of calcination; iii. The temperature for calcination, and consequently the quantity of fuel required depend on the composition of the limestone. Pure or fat limestone and shells require just enough heat to drive off the CO₂ and moisture. Stones containing clay require higher temperature for the formation of silicates and aluminates to produce hydraulic qualities; iv. Too much heat will fuse the contents in the kiln; v. The denser the limestone and the higher the temperature at which it is to be burnt, the smaller the size to which it should be broken before being put into the kiln; and vi. Dead-burnt lime: lime which has been improperly burnt and will not slake. Underburnt fat lime will not slake or overburnt hydraulic lime becomes ‘dead’ as the silicates get fused, coat the stone and thus prevent the expulsion of carbonic acid.

Slaking of Lime: has already been explained. If quick lime be left exposed to air, it gradually absorbs moisture, and falls to powder with increase of bulk but with very little heat. This process, termed air slaking, is too slow for constructional purposes. It absorbs CO₂ from the air and spoils the lime. Also the slaking cannot be controlled. The methods in use are two, viz., slaking to a paste or pulp and slaking to powder.

Slaking to paste: The best method is to spread a layer of 6" of fresh quick lime in a wooden or masonry basin and to add a sufficient quantity of fresh water to it so as to submerge it. The quantity of water required should be determined by experiment but it is generally 2½ to 3 times the volume of the quick lime. Too much water should not be added
nor too little. Too much will drown the lime and will check the slaking. Too little will result in insufficient slaking, leaving lumps. The water should be added all at the outset and not after the temperature has risen. The basin is covered with planks. The lime slakes and swells gradually and, in 5 to 10 min. with pure lime, heats the water to boiling point when a large increase in the volume of the lime takes place and its reduction to pulp or paste ensues. The plank covering helps to retain the heat and the water vapour which ensures the proper slaking of the upper portions of the layer of quick lime. The lime should not be stirred while slaking.

**Slaking to powder:** This is done in one of two ways: i The quick lime is broken to pieces of the size of an egg in the case of quick lime obtained from limestone blocks. The quicklime is then taken in baskets and immersed in water for a few sec., the period of immersion being decided on experience and then withdrawn and thrown into a heap. It falls to powder. ii The second method, which is the one more commonly used for slaking quicklime obtained from shells, is to spread the quick lime in a layer about 6 to 8" thick and sprinkle water over it from the rose of a watering can. The quicklime slakes and is converted into powder.

It is important, whether the slaking is to paste or powder, that all lumps should be reduced to pulp or powder. Lumps, if any, which do not get reduced will generally be improperly burnt pieces and they should be hand picked and removed. When quick lime is slaked to powder, the slaked lime should be screened in a sieve of 8 meshes to the inch before use in making mortar. Slaked lime obtained from shell lime should be used within a fortnight from the date of slaking, protecting the lime in the meantime from contact with air. Slaked lime obtained from kankar should be left over for a day or two to ensure thorough slaking and used up within a week after slaking. One part of fat quick lime gives 2 parts of slaked lime powder or 1 1/2 parts of paste. Slaking to powder is adopted generally for making mortar for construction purposes and slaking to paste for mortar for fine plastering and whitewashing.

**Slaking of hydraulic limes:** These slake with difficulty. Hence the quick lime should first be *ground dry* in a mortar mill and then sifted. Water should not be added until the lime is required for use. Moderately hydraulic quick lime 1 part gives 1 1/2 parts of slaked powder or 1 of paste.

**Practical Tests for Lime:** (Vicat Tests). The freshly burnt lime, broken to walnut size, is put into a basket and immersed in pure water for 5 seconds, then drained, and emptied into a stone or C. I. mortar. If the lime begins at once to hiss, evolve steam, swell, and decrparate, it
is fat lime. If the activity begins within 5 min., the sample is a lean lime. If it takes 15 min. or more and the activity is not marked, the sample is a hydraulic lime.

As soon as the lime shows signs of breaking up, add water carefully down the sides of the vessel, stir the lime well, and work it up into a stiff paste. Place it to 2/3 height in a glass jar of height greater than width. Cause the lime to settle down by tapping the bottom of the jar and then place the whole standing in a vessel of water, so that the jar is immersed. Fat lime dissolves away almost entirely if the water is pure and frequently changed; lean limes behave similar to fat limes except that after repeated changes a residue, devoid of any consistency, if left; and hydraulic limes harden after setting and frequently changing water does not affect the paste.

**Tests for Limestones:** Hydraulic limestones are ordinarily bluish grey, brown, or some darkish colour, as white indicates a pure limestone. They have an earthy texture and weather to a brown colour. Glistening particles indicate presence of free sand. When breathed upon or moistened, a clayey odour is emitted from the stone. Dilute HCl will not produce on it so great an effervescence as upon pure limestone and will leave a larger proportion of sediment. Select a few pieces of the stone of 1/16" size, heat them gradually in a common fire and keep them at full red heat for 3 hours. If overburnt, the colour will be found to be darker. If underburnt, effervescence will take place when dilute HCl is poured on it. ii Heat test: Weigh a piece of dried limestone. Heat it to redness in an open fire for 4 hours to expel CO₂. Allow the stone to cool and weigh again. From the loss of weight, the amount of CaCO₃ in the specimen can be determined. This is adopted if the sample does not contain MgCO₃. Clayey and siliceous impurities require a higher temperature to drive out the CO₂ and this indicates the extent to which the limestone is hydraulic. iii Acid test: Add dilute HCl to the specimen. The effervescence is profuse and the residue small if the proportion of CaCO₃ is high; and iv Pound a sample of about 150 grains of limestone well in a mortar, sift it and dry it by gentle warmth so as to expel the moisture. Weigh it. Let the weight be w grains. Put the powder into a tumbler and add dilute HCl gradually, stirring and adding HCl until effervescence ceases. The acid combines with the lime, setting free the CO₂ which passes into the atmosphere. Strain the contents through filter paper and wash well with fresh water, which will dissolve out the CaCl₂ and acid and leave the insoluble clay and sand on the filter paper. Carefully dry the residue and weigh it. Let the weight be w₁ grains. Then \((w - w₁)\) will be the weight of CaCO₃ in the sample and 50% of this \((w - w₁)\) is pure lime CaO,
To separate the clay from the sand in the residue, stir up the residue with water. The sand, being heavier, will settle to the bottom, while the particles of clay will be in suspension. If the water is decanted, it will carry the clay with it. Repeat the process till all the clay is removed. Dry the remaining sand and weigh. Let the weight be \( w_s \) grains. Then \( w_e = w_s \) will be the weight of clay. A limestone containing 75% \( \text{CaCO}_3 \), 6% clay and the balance sand will furnish lime of fair quality for general purposes.

**Specifications for Limes:**

<table>
<thead>
<tr>
<th>No.</th>
<th>Detail</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Quick</td>
<td>Hydrated</td>
<td>Quick</td>
</tr>
<tr>
<td>1</td>
<td>CaO &amp; MgO</td>
<td>60% to 70%</td>
<td>70% min</td>
<td>70% min</td>
</tr>
<tr>
<td>2</td>
<td>Silica, Alumina &amp; Ferric oxide</td>
<td>25% min</td>
<td>15% min (For semi &amp; mildly hydraulic lime only)</td>
<td>15% min</td>
</tr>
<tr>
<td>3</td>
<td>Insoluble residue in HCl less silica</td>
<td>2% max</td>
<td>3% max</td>
<td>2% max</td>
</tr>
<tr>
<td>4</td>
<td>Loss on Ignition</td>
<td>—</td>
<td>5% max (Lump lime) 7% max (Ground Lime)</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>CO₂</td>
<td>5% max</td>
<td>5% max</td>
<td>5% max</td>
</tr>
</tbody>
</table>

ii) The cementation value as calculated by the formula \( (2.8 \text{SiO}_2 + 1.1 \text{Al}_2\text{O}_3 + 0.7 \text{Fe}_2\text{O}_3) / (\text{CaO} + 1.4 \text{MgO}) \) shall be between 0.6 and 1 for Class A limes and 0.3 and 0.6 for Class B limes. iii) Residue on slaking: The residue on IS, Sieve 85 and IS, Sieve 30 (for material passing through No. 85) shall each be \( > 5\% \) by weight of quick lime Class C. Similarly for quick lime Class B the residue on Sieve 85 shall be \( > 10\% \). iv) Physical requirements: Pure water at 27 ± 2° shall be used for all tests. For Class A and Class B limes: a) Fineness: The hydrated lime shall leave no residue on IS Sieve 240 and shall leave \( > 5\% \) on Sieve 85, and \( > 10\% \) on Sieve 30 (for material passing through No. 85). b) Setting time: The hydrated lime paste (for Class A limes only) adjusted to standard consistency as specified in IS 269 shall not develop an initial set in < 2 hours and attain final set within 48 hours when tested by the Vicat apparatus. c) Workability: The lime putty shall require < 10 bumps to cause it to attain an average spread of 19 cm on the flow table.
d. Soundness: Le Chatelier expansion to be \( \geq 10 \) mm. e. Strength: For 1:3 lime-sand mortar of Class A limes, adhesive strength shall be \( \leq 32 \) psi, tensile strength shall be \( \leq 35 \) psi after 14 days (and shall show an increase in tensile strength over that at 14 days after 28 days immersion in water), and compressive strength shall be \( \leq 200 \) psi after 14 days curing and \( \leq 400 \) psi after 28 days curing. The compressive strength of 1:3 lime-sand mortar of Class B limes (semi-hydrated only) shall be \( \leq 175 \) psi after 7 days curing and \( \leq 250 \) psi after 28 days. Further, the modulus of rupture shall be \( \leq 100 \) psi at 28 days. For Class C limes: a. Fineness: The hydrated lime shall entirely pass through Sieve 85, leave \( \geq 5\% \) on Sieve 30 and \( \geq 10\% \) on Sieve 20 (for material passing through No. 30). b. Volume yield: The volume yield of the lime putty shall be \( \leq 1.7 \) ml per g of quick lime. For magnesian limes, the volume yield shall be \( \leq 1.4 \) ml per g. c. Workability: The lime putty from quick lime shall require \( \leq 12 \) bumps on the flow table to cause it to attain an average spread of 19 cm from 11 cm. The lime putty from hydrated lime shall require \( \leq 10 \) bumps on the flow table to cause it to attain an average spread of 19 cm.

**Unsoundness of Quicklimes and Hydrated Limes:** may be due to: i General expansion caused by the inclusion of a large number of fine particles of slow-slaking materials. These slake, expand slowly, and so produce an increase in volume; and ii Popping, pitting, and blowing are due to the presence of coarse unslaked or only partially slaked particles. On final slaking these cause dislodgement of pieces of the surface of the plaster, usually in the form of a cone, which causes a corresponding pit on the plaster surface.

**Comparison of Hydraulic Lime and Cement:** The advantages of hydraulic lime are: i It is pliable and bails better into the stone or brick; ii It cracks less as the joint dries out; iii It does not develop contraction and cause percolation fissures, known as flat capillaries which result in a steady passage of damp, as in the case of cement mortar; iv It does not lack elasticity and spoil pointing, bedding of tiles, etc.; v With porous sand faced bricks or soft stones, lime mortar, being porous, enables a downward flow of the absorbed moisture and thus increases the durability of the wall; vi Around flues and fireplaces where rapid drying and contraction result, this is the best and cement is ruled out; and vii In tall chimneys this is preferred because the heat causes the concrete to crack. The disadvantages are: i Low compressive, tensile, and shear strengths; ii Takes a long time to set and harden in damp weather; and iii Quality cannot be controlled. In order to combine the advantages of both, a
composition matrix of 1 lime to 2 cement and 1 of this matrix to 3½ of sand is finding favour.

CEMENT

General: Cements are calcareous substances, similar in many respects to the strongly hydraulic limes but with far greater hydraulic properties. Cements differ from limestones in that the former do not slake with water nor do they break up. Cements are very useful and superior to limes under the following conditions and requirements: i For construction of structures in wet places and under water; ii Where great strength is required; iii Where the mortar or plaster has to set quick and attain its strength; iv Where a hard surface is required for the protection of exposed surfaces of structures against the destroying influence of the weather and certain organic or inorganic chemicals; v For watertightness of structures; and vi For pointing works.

Chemistry of Portland Cement: It is composed of lime, silica, alumina, iron oxide, magnesia and other oxides, the percentages of which range as follows: Lime (CaO) 60-67; Silica (SiO₂) 17-25; Alumina (Al₂O₃) 3-8; Iron oxide (Fe₂O₃) 0-5-6; Magnesia (MgO) 0-1-4; Soda and Potash (Na₂O + K₂O) 0-2-1; Sulphur trioxide (SO₃) 1-2-75; Free Lime (CaO) 0-1. For practical purposes, cement may be considered as being composed of four principal compounds, though small amounts of CaSO₄, MgO, alkalies, and other materials are present. These are: i Tricalcium silicate 3 CaO.SiO₂ (abbreviated to C₃S), ii Dicalcium silicate 2 CaO. SiO₂ (C₂S), iii Tricalcium aluminate (C₃A), and iv Tetra calcium aluminoferrite 4 CaO. Al₂O₃. Fe₂O₃. (C₄AF). C₃S and C₃C₃S control most of the strength-developing characteristics and constitute 72% of the whole for most types of cement. A high percentage of C₃S results in rapid hardening and early strength with high heat generation. Decreasing C₃S and increasing C₃C₃S develops the strength more slowly and evolves less heat. C₃A develops the greatest heat followed by C₃S, C₄AF, and C₃C₃S and is responsible for most of the undesirable qualities in cement. A cement with a low percentage of C₃A will develop a higher ultimate strength, generate less heat during hydration, exhibit more marked volumetric stability, and consequently less tendency to cracking, and will be more resistant to acid attack, than a cement with a high percentage of C₃A. C₄AF is an ineffectual adulterant replacing desirable silicates and should not be present in unduly large quantities. In small quantities, it imparts sulphate resisting qualities. Also as aluminates facilitate manufacture by lowering the sintering temperature, C₃A and C₄AF cannot be completely eliminated.
Functions of Ingredients: Lime: (60 to 70%). A high lime content, but not enough to be excessive, makes the cement slow setting and rapid hardening. Too little lime results in a weak cement, and if underburnt in a quick setting cement. Free lime: (1½ to 2%). Excessive free lime leads to unsoundness in cement causing expansion and disruption of the concrete at a later date. It may also be one of the factors that cause leaching and efflorescence in concrete and masonry work. Silica: (20 to 24%). A high silica content, which is usually accompanied by a low alumina content, produces a slow setting and rapid hardening cement. If the reverse is the case, the cement is quick setting and rapid hardening. Too much silica produces a contracting quick setting mixture. Alumina: (3 to 8%). Since it lowers the clinkering temperature, an excess of alumina weakens the cement and produces a contracting quick setting mixture. Magnesia: (1 to 4%). If it is over 5%, it causes unsoundness. Iron oxide: (2 to 4%) imparts the grey colour and acts like a flux reducing the temperature at which fusion of the ingredients takes place. Reducing it to a minimum gives white cement but very high temperatures requiring adequate refractory lining to the furnaces will be necessary. Sulphur: calculated as sulphuric anhydride SO₃ is limited to 3%) in excess causes unsoundness. Alkalies: (< 1%) are carried away by the flue gases. If in excess, they cause expansive reaction between aggregate and cement and give rise to surface crazing, checking, and cracking. Gypsum: (4%) when added during the final grinding of the clinker retards the setting time, improves soundness, and renders the cement fit for use. Calcium chloride: (up to 20%) gives rapid hardening properties.

Types of Cement: 1. Pozzolana cement: is a volcanic substance found at Pozzuola, near, Naples, and consists of a compound of alumina, silica, and traces of some of the metallic oxides, lime, potash, and magnesia. It is found, if mixed with preferably lias limes, to produce a hydraulic cement. An artificial pozzolana is made and largely used by grinding brick bats and tiles, and adding to lime in lieu of sand to make mortar.

2. Natural cement: is made by calcining Cement stones or Nodules found in thin strata among those of hydraulic limestones. These stones or nodules are of compact texture, brown in colour and composed of 20 to 40% clay, the balance being CaCO₃ alone or CaCO₃ and MgCO₃. The calcined stones do not slake with water. They are ground, sifted and when made into a paste with water, the paste sets and hardens in 5 min. to 5 hours depending on the composition of the stone. Stones containing 3% or more clay give quick-getting cement which does not possess a high ultimate strength. Stones containing 22% clay yield a slow setting cement.
3. **Roman cement**: is a natural cement of the Portland type. It is prepared by burning at a low temperature nodules found in the London clay (containing 40% clay). It weighs, when ground, 60 lb. per c. ft. It is kept in barrels, as on exposure to the atmosphere it absorbs CO₂ and moisture, and becomes inert. It should, therefore, be used fresh. It is about one-third as strong as Portland cement and is much weakened by the addition of sand which should never be used in a ratio > 1 : 1. It sets within 15 min. after mixing and hence it should be mixed only in small quantities. It is not in use in India.

4. **Artificial cement**: Portland cement is an artificial cement made by heating, to a clinkering temperature an intimate mixture of calcareous, siliceous and aluminous constituents and finally grinding the resulting clinkered mass, which is a mixture of cementitious silicates and aluminates of lime. It is so called from its fancied resemblance in colour to Portland stone. The percentage analysis is lime 63, silica 21, alumina 6, iron oxide 4, and the percentage composition is C₅ 40, C₆ 30, C₇ A 10, and C₈ AF 10.

5. **Quick setting cement**: is made by adding a small percentage of Al₂(SO₄), and also grinding the cement well. The setting starts within 5 min. after addition of water and the cement becomes stone hard in <30min.

6. **Rapid hardening cement**: (Swasticrete, Katnicrete, etc.): is made by finer grinding, burning at higher temperature, and adding excess lime. In a certain type about 2% CaCl₂ by weight of the ordinary cement is used. The rapid hardening enables forms to be removed quickly, the works to be put in service earlier, and owing to greater heat generated during hardening, this is less liable to damage by frost than ordinary concrete. The percentage analysis is lime 64, silica 21, alumina 5, iron oxide 3, and the percentage composition is C₅S 50, C₆S 20, C₇ A 10, and C₈ AF 10.

7. **Low heat cement**: To reduce the heat evolved during the setting and hardening of cement, low heat cements are produced by reducing the C₇ A or adding trass, the action of which is similar to that of surkhi. Such cements are used in large mass concrete works, like dams, bridge abutments, and large retaining walls. The rise in temperature is very small and hence the heat is dissipated quickly with the consequent reduction in cracks due to tensile stresses caused by shrinkage on cooling. The reduction in the heat of hydration is mainly attained by fine grinding. The percentage analysis is lime 60, silica 22, alumina 5, iron oxide 5, and the percentage composition is C₅S 25, C₆S 45, C₇ A 6, and C₈ AF 14.
8. **Blast furnace cement**: is obtained by grinding together > 75 % and < 35 % of Portland cement clinker with < 25 % and > 65 % of granulated blast furnace slag which is a non-metallic product consisting essentially of silicates and aluminosilicates of Ca which is developed simultaneously with Fe in a blast furnace and is granulated by rapidly chilling or quenching the molten material in water, steam or air. It has the same properties as ordinary cement. It is more resistant to attack by sulphate soils and waters, has a lower heat evolution, and the speed of hardening falls off more rapidly as the temperature decreases. With excess sulphides in the slag, the cement disintegrates on exposure to weather. It is used with advantage for marine works.

9. **Magnesium oxychloride cement**: (Sareol Cement) is prepared by adding slightly calcined magnesite to a cone solution of MgCl₂. The MgO and MgCl₂ react to produce the oxychloride 3 MgO. MgCl₂. 11 H₂O, though some free Mg(OH)₂ is always present. It is used for flooring, as a filler and as a pigment. It is very hard but is strongly corrosive to iron pipes, etc. The setting and hardening depend slowly upon the formation of crystalline oxychloride by chemical interaction. It is mixed with sand, saw dust or some fibrous material and used for the manufacture of plaster boards and tiles for interior use. Artificial stones made with this cement take a high polish and have high compressive strengths. This cement is mixed with emery for making emery wheels.

10. **High alumina cement** (Ciment Fondu): is manufactured by fusing together a ferrous bauxite of low silica content with lime. It contains 35 to 44% of aluminates. This cement hardens rapidly giving out great amounts of heat, reaches practically full strength in 24 hours, and is extremely resistant to the corrosive action of sea water, etc. It does not expand on setting. It is stable without shrinkage up to 1,300° and hence used for refractory work. It is immune from attack by frost during setting and hardening as the heat generated is a sufficient safeguard. It is used for floors and containers in breweries, dairies, garages and works where oils from tar or cotton-seed, or sugar solutions are handled. The setting and hardening are due to the formation of mono-calcium aluminate. Portland cement cannot be added to high alumina cement as the free lime of the former will combine with the Al, Zn, and Fe of the latter and form unstable C₃A which causes expansion and cracking.

11. **Supersulphate cement** (Sealithor): is obtained from granulated blast furnace slag to which a small amount of lime and a larger quantity of CaSO₄ have been added. It possesses excellent mechanical pro-
properties, and exceptional resistance to chemical corrosion. It expands very slightly on setting and is practically impermeable to water. It is used where acid conditions exist without sulphates being present. It absorbs moisture and CO₂ from the air and deteriorates quickly. Lean mixes and very fine sands should be avoided to ensure that the early strength is adequate.

12. Sulphate resisting cement (Sulacrete): is particularly useful where structures such as canal linings, culverts, and syphons are exposed to severe alkali conditions. The percentage analysis is lime 64, silica 24, alumina 4, iron oxide 4, and the percentage composition is C₃S 40, C₂S 40, C₆A 5, and C₆AF 9.

13. White cement (Snowcrete): is just a variety of the ordinary cement obtained by reducing the iron oxide to a minimum. White chalk and china clay are used instead of limestone and ordinary clay for its manufacture. Also oil, fuel, instead of coal, is used for firing. It is pure white and is used for face-plaster to walls, cast stone, concrete floors, etc.

14. Coloured cements (Colorcrete): are produced by mixing very intimately < 15% of mineral pigments with ordinary or white cements. Fe₂O₃ gives red and yellow, Cr₂O₃ gives green, Co blue gives blue, and MnO₂ gives black.

15. Air-entraining cement: is one in which an air-entraining agent (Viscol resin NVX or Darex AEA or Aerosin-HRS developed at the Hirakud Research station) is interground with the clinker during manufacture. The effect of adding these agents is to introduce into the mass a larger amount of air than is found in ordinary cement. When this cement is shaken vigorously with water, a foam is found which increases the workability of the concrete, renders the concrete more plastic and resistant to frost, decreases bleeding and the tendency for the ingredients to separate when placing, and reduces the weight and strength of concrete. The air content shall be between 3 and 6% (below 2% the advantages are not marked and above 6% the reduction in strength is considerable).

16. Expanding cement: contains ordinary cement, an expanding medium (sulpho aluminate cement) and a stabilising agent. It expands while hardening and is used for: i Balancing the shrinkage of ordinary concrete; ii Underpinning where expansion exceeds shrinkage; and iii Prestressed concrete work.

17. Wood cement: Wood in the form of fibres, chips, and sawdust is mixed with cement and is used in the manufacture of various types of block, partition slab, and floor surfacings.
18. **Masonry cement**: Cement mortar, is harsh to work and because of its rapid stiffening due to water being sucked out of it into the masonry, often fails to bond satisfactorily. To overcome this disadvantage mixtures of lime and cement are used. Special masonry cements are also made by mixing ordinary cement with hydrated lime, crushed limestone, diatomaceous earth or granulated slag with or without small additions of calcium stearate, petroleum and highly colloidal clays.

19. **Waterproof cement**: *(Super cement)* is obtained by adding during grinding a small percentage of integral waterproofer such as calcium, aluminium or other metal stearate, a non-saponifiable oil, or gypsum treated with tannic acid. It is used in making more impermeable mortar and concrete than ordinary cement.

20. **Hydrated cement**: is used as an admixture for concrete to increase its strength at early ages. The cement is partially hydrated, allowed to harden for a day at 110°, cured for 7 days, and reground. The resulting powder is added to the concrete in the proportion of 1 to 2% of the weight of the cement.

21. **Air setting cement**: has the maximum workability and high plasticity. It is used as a bonding mortar with fire brick and insulating fire brick. It pours readily from the drum and is easy to thin with water.

**Manufacture of Cement**: is made by fusing together two materials one calcareous such as limestone or chalk, and the other argillaceous such as clay or slate. The treatment before calcination may be by the dry or wet process. In the former the materials are roughly crushed and dried, if necessary in inclined rotating cylinders generally by the kiln waste heat, and held in storage bins until analysed. From these bins, the materials are drawn and mixed in proportions indicated by the analysis, ground first in a ball mill and then reduced to a fine size in a tube mill. The fine dry powder is pumped to a series of vertical silos. Each silo is connected to the kiln and to the pump delivering the ground meal from the mill to the silo. This process is adopted in the case of hard dry limestones and shales. In the wet process the materials are crushed and mixed in the presence of water and ground in the wet condition to a slurry—a thick creamy liquid containing 32 to 42% water. The slurry is pumped into deep vertical tanks with a conical bottom and a valve. Compressed air is admitted form the bottom and the slurry thoroughly mixed. Then it is discharged into main storage tanks from where it is fed directly into the kiln. This process is adopted in the case of chalk and marl which are soft and moist. The slurry is tested as follows: Take a small quantity of it in a test tube and add HCl. Heat the mixture till the contents are
dissolved and a precipitate is obtained. On cooling a jelly will be formed. A stiff jelly shows that one of the ingredients must be augmented.

In both the processes the heating is done in a rotary kiln (Fig. 97). This consists of a slightly inclined (1 in 25 or 30) cylindrical tube (lined with fire bricks) of steel plate 1” thick, length 100 to 500’, and diameter 6 to 14’. The ‘slurry end,’ the ‘burning zone,’ and the ‘calcining zone’ are enlarged in diameter. The tube is mounted on roller bearings supported on pillars and is rotated at one R. P. M. by a train of gear wheels. The charge is fed at a uniform rate at the upper end and it travels by gravity to the other end. Finely ground coal is injected into the lower end by a jet of air issuing from a blast fan. When the kiln is started, the fuel is ignited and white heat is obtained at one-third the distance from the lower end. The charge as it comes, loses its water, gets heated, loses CO₂, and due to incipient fusion between the CaO and the argillaceous constituents forms little rounded balls (clinker) which drop in a white heat condition into coolers (either below or in continuation) and get cooled by the entering air. The hot gases that leave the kiln at the upper end heat the entering charge and dry it. Thus heat losses are reduced to
a minimum. As the clinker is very quick setting, a retarding agent like raw-gypsum (3 to 4%) is added and ground with the clinker in ball and tube mills.

The ball mill (Fig. 98) is a cylindrical drum (lined with stepped and perforated steel plates) mounted upon and rotated by a steel shaft. Steel balls of from 5 to 2" diameter are used as the charge. The material fed to the mill is crushed and partly ground by impact as the balls fall from step to step. Grinding takes place: i through the holes in the stepped plates, ii through an inner sieve plate, and iii through a very fine outer sieve plate. The oversize from each is returned to the mill but the product passing the outer goes to the finishing mill.

The tube mill (Fig. 99) is used for fine pulverizing. It is a cylindrical shell 20 to 40' long, 4 to 8' diameter, supported on trunnion ends and lined with silica or metal blocks. Metal pellets (white iron balls 1" to 1\(\frac{2}{3}\)" diameter or pieces 1\(\frac{1}{2}\)" diameter, 1' long or 3" diameter, 1' long) are used for grinding. The material is fed and pulverized as in the ball mill.

The compound or multiple chamber mill is a ball and tube mill combined with the object of simplifying the grinding process, saving floor space, and reducing installation, operation, and maintenance costs.

**Setting and Hardening of Cement:** When cement is mixed with water to a plastic state and allowed to stand, the cement chemically combines with the water and the whole mass gradually solidifies, either in air or water, to a rocklike hardness while at the same time binding together any materials with which it is in contact. This is termed *setting*. When set, cement is almost impervious to water. The rate and manner of setting vary greatly. Some set within a few minutes while others take several hours. Some begin to set comparatively early and take considerable time to complete, while others do not set for a considerable time and then set quickly. Regauging a quick setting cement destroys the continuous film of gelatinous material produced by the hydration of C, A, exposes the unhydrated core to the action of water, and thus improves the cement. Similarly finer cements develop greater degree of hardness. Too much water separates the particle and makes the mix set slowly. Increase of
temperature increases the setting and hardening. The completion of the set can be identified by the failure of a pencil point or thumb nail to scratch the surface. Ordinarily the normal-setting cements are preferable, since they allow of greater latitude in mixing and need not be mixed rapidly and may be mixed in larger quantities and give time for transporting, placing, tamping, and for any free lime to be acted upon and slaked; but occasionally, especially in tidal work, or when an inflow of water is to be prevented, or in plaster work, a quick setting cement is preferable. The hardening of cement is the process involving the strengthening of the mortar that commences after the initial set and proceeds first at a fairly rapid rate, slowing down appreciably as time elapses. The principal advantage to be obtained from the use of rapid hardening cement is that the shuttering can be struck at an earlier date owing to the high early strength of the concrete. A subsidiary advantage is that the structure is more immune from possible damage due to overloading at any age. Such cements may be: a. rapid hardening Portland cement, and b. high-alumina cement. The former is chemically the same as normal hardening cement except that it is more finely ground. In the latter the alumina is between 35 to 40% as against the 5 to 10% in normal cement. The increased alumina content leads to rapid-hardening properties. Alumina cement hardens more than the Portland cement.

Theory: On addition of water, $\text{C}_3\text{A}$ hydrates very rapidly within 24 hours with great evolution of heat. Hydrated $\text{C}_3\text{A}$ is first formed in an amorphous form and then it crystallizes. In presence of gypsum heat evolution is less and the setting occurs more slowly. The hydrated $\text{C}_3\text{A}$ reacts with gypsum and forms calcium sulfoaluminate. During this period the low-burned and finely ground limes get hydrated. The hydration of the lime and the crystallization of the $\text{C}_3\text{A}$ decreases the strength of the cement. The retarding action of gypsum is due to its preventing the hydrated $\text{C}_3\text{A}$ from precipitating from its solution to form a gel. The hydration of $\text{C}_2\text{S}$ begins within a day and gets completed in 7 days forming crystalline $\text{Ca} (\text{OH})_2$ and amorphous hydrated $\text{C}_2\text{S}$. This latter compound is a gel. The greater part of the early strength of cement and some of the early heat evolution is due to the formation of this gel. $\text{C}_2\text{S}$ reacts with water only after 7 days slowly up to 28 days and forms hydrated $\text{C}_2\text{S}$. The greater part of the increase in strength after 28 days is due to this reaction. $\text{C}_3\text{AF}$ hydrates very slowly and since it has no great cementing value, it is only of minor importance. Since hydration of cement continues for over a year, provision must be made for heat dissipation in massive concrete structures like dams.
M. Freysinets' latest theory considers concrete to be a complex of solid, liquid, and vapour phases which are continually interchanging due to the influences of external pressure and changes of temperature and moisture content, and that the laws of thermodynamics are applicable to concrete. According to this theory the mixing water dissolves slightly the grains of cement. Saline ions are dispersed in the liquid and, where the solution is sufficiently rich, they form with the molecules of water relatively stable hydrated crystals. The largest crystals are less soluble and tend to absorb the smallest, and also to retard the formation of small crystals by reducing the concentration of the solution. On the other hand, a crystal can grow if ions reach its surface by passing through the liquid by channels which are more restricted and sinuous as the number of crystals increases, so that the ions may become grouped into new crystals where the solution is sufficiently concentrated. The average size of the crystals will be smaller as the circulation of the ions becomes slower. Therefore the number and size of crystals depend on the rate of circulation of the ions in the paste during setting, and circulation is made more difficult by compression of the paste and reduction in the amount of water. Setting is accelerated as the temperature is raised, but the structure of the set paste is coarser because of the formation of large crystals; and the strength is less. If, however, the size of the crystals can be reduced by compressing the paste, it is possible to apply heat of 100° or more and still have great strength.


**General:** The cement shall be cool to the feel when the hand is introduced into a barrel or bag of cement. A handful of cement thrown into a bucket of water should gradually sink. Floating stuff indicates adulteration chiefly with ashes. Colour: A good cement will be grey with a slight greenish blue tint. If bluish grey, there is probably an excess of lime and such a cement is likely to blow. If blackish, an excess of underburnt particles and brownish an excess of underburnt particles. White indicates best cement which is expensive and used for artistic works. The colour test is not always reliable. **Thoroughness of burning:** The higher the temperature, the greater is the weight of the clinker. On this principle the quality is determined by weight and sp. gr. **Weight:** 1 c. ft. of packed cement should weigh 90 lb. or one bushel of 1-233 c. ft. should weigh about 112 lb. **Specific gravity:** ranges from 3-15 to 3-19. This is a better test than weight.

**Chemical composition:** a Percentage of lime, after deduction
of that necessary to combine with $\text{SO}_4$ present, to silicas, alumina and iron oxide when calculated (in percentages) by the formula:

$$\text{CaO}$$

$$\frac{2.8 \text{SiO}_2 + 1.2 \text{Al}_2 \text{O}_3 + 0.65 \text{Fe}_2 \text{O}_3}{\text{to be } > 1.02 \& < 0.66;}$$

b. Ratio of percentage of alumina to iron oxide to be $< 0.66$; c. Weight of insoluble residue to be $> 1.5\%$; d. Weight of magnesia to be $> 5\%$; e. Sulphur, calculated as $\text{SO}_3$, to be $> 2.75\%$; and $f$. Total loss on ignition to be $> 4\%$.

**Fineness**: The object of this test is to check the proper grinding of the cement. a. *Sieve test*: 100 gm of cement shall be continuously sifted for a period of 15 min. on a IS Sieve 9 and the residue by weight shall not exceed 10%. b. *Specific surface test*: This is an alternative test. The sieve test, while simple, does not indicate the uniform distribution (of the various particle sizes) upon which depends the strength of concrete. If the cement is too fine, the cost of grinding is very high and the cement gets hydrated even before mixing with sand, stone, and water. If it is too coarse, the necessary surface area for chemical reaction is not available and the concrete made from it will be of poor workability and require a large amount of water. Bleeding also occurs i.e., even before initial set, water comes to the top due to the settlement of solids. Turbidimeter or air permeability apparatus is used to determine the *specific surface* (total surface area of all particles in 1 mg of cement, the particles being considered as spheres) of cement. The specific surface, being a measure of the frequency of the average size, affords a more satisfactory measure of the uniformity of fineness than the sieve test. The cement shall have a specific surface of $< 2,250 \text{ sq cm/gm}$.

**Consistency**: The percentage of water required for obtaining a cement paste of standard consistency is used to determine the water content of pastes for setting time test, for soundness test, and of mortar for tensile strength test. The Vicat apparatus with the polished brass plunger G of 10 mm diameter and 50 mm length with a projection at the upper end for insertion into the movable rod B (Fig. 100) and a flat
lower end is used. It consists of a frame D bearing the rod B with the cap A at one end and either the above plunger or a needle C 1 mm. square or 1·13 mm diameter in section with a flat end (for initial setting time) or another similar needle F fitted with a metal attachment hollowed out so as to leave a circular cutting edge 5 mm in diameter, the end of the needle projecting 0·5 mm beyond this edge (for final setting time). The rod B carries an indicator which moves over a graduated scale attached to the frame D. The mould for the cement paste consists of a split ring E, 80 mm diameter and 40 mm high, which rests on a nonporous plate. Weigh the cement and add a known percentage by weight, of water. Mix well, and fill the mould E. The interval from the moment of adding water to the cement to the moment of commencing to fill the mould is called the time of gauging which must be $< 3$ min, and $> 5$ min. Gently lower the plunger on to the paste. If the settlement is between 5 mm and 7 mm from the bottom of the mould, the water added is correct. Otherwise repeat with varying percentages of water until the desired penetration is obtained.

**Setting times:** are determined with the Vicat apparatus. Neat cement paste shall be formed by gauging cement with 0·85 of water required to give a paste of standard consistency. **Initial setting time:** Fill the mould E completely with the above paste and smooth off the surface of the paste level with the top of the mould. Lower the needle C gently into contact with the surface of the paste, quickly release it, and allow it to sink into the paste. Repeat this process until the needle when brought into contact with the test block, and released as above shall not pierce it by about 5 mm from the bottom of the mould. The period elapsing between the time when water is added to the cement and the time at which the needle ceases to pierce the test block as above gives the initial setting time, which shall be $< 30$ min. **Final setting time:** Remove needle C and use needle F. The cement shall be considered as finally set when, upon applying the needle gently to the surface of the paste, the needle makes an impression thereon, while the attachment fails to do so. The final setting time shall be $> 10$ hours.

**Strength:**
- **Tensile Strength:**
  - a. **Sand:** shall be standard Leighton Buzzard (English) and of the white variety. The ISI is considering the question of recommending alternative Indian standard sand like that from Ennore (Madras). It shall be thoroughly washed and dried and lose $> 0·85\%$ by weight on extraction with hot HCl. It shall pass through IS Sieve 85 and $> 10\%$ by weight shall pass sieve No. 25.
  - b. **Mortar and water:** The mortar of 1 cement to 3 standard sand by weight,
shall be gauged with water, the percentage to be used being given by
\[ \frac{0.78P}{4} + 2.5 \]
where \( P \) is the percentage of water required to produce a paste of standard consistency.  

c. Preparation of briquettes: The mortar, ganged as above shall be placed in a mould of specified shape, resting on a non-porous plate. After filling the mould, a small heap of the mortar shall be placed upon that in the mould and beaten down with the standard spatula (Fig. 101) until the mortar is level with the top of the mould. This last operation shall be repeated on the other side and the mortar beaten down until water appears on the surface. The briquettes shall be finished smooth with the blade of a trowel, and kept at 24 to 30° in an atmosphere of at least 90% relative humidity, for 24 hours after gauging when they shall be removed from the moulds, submerged in clean water at a temperature of 24 to 30° and left there until taken out just prior to breaking.  

d. Tests: Six briquettes, prepared as above and as in Fig. 102 shall be tested and the average value taken. These shall be held in strong metal jaws and the load steadily and uniformly applied, starting from zero, and increasing at the rate of 100 psi of section in 12 sec. The strength at the end of 3 days shall be \(< 20 \text{ kg/sq cm}\) and at the end of 7 days shall show an increase on the strength at 3 days and be \(< 25 \text{ kg/sq cm}\).

ii. Compressive strength: Sand, and mix will be as under item i. The test specimens shall be 2.78" cubes. The moulds shall be of metal and rigidly constructed in such a manner as to facilitate the removal of the specimen without damage. The cement and sand shall be mixed dry on a non-porous plate for 1 min. and then with 10% (by weight of dry materials) of water for \(< 3 \text{ min.}\) and \(> 4 \text{ min.}\) until the mixture is of uniform colour. The assembled mould shall then be placed on the table of a standard vibrating machine and firmly held in position by means of a suitable clamp. A hopper shall be attached to
the top of the mould to facilitate filling. After mixing, the mortar shall be placed in the hopper of the mould and then compacted by vibration for 2 min. at 12,000 vibrations per min. Curing is done as in (i). The cubes shall be tested on their sides without any packing. One of the platens of the testing machine shall be carried on a ball and shall be self-adjusting, and the load shall be steadily and uniformly applied starting from zero at a rate of 2,000 psi per min. Three cubes shall be tested and the average value taken. The strength at the end of 3 days shall be \( \geq 155 \text{ kg/sq cm} \), and at the end of 7 days shall show an increase on the strength at 3 days and be \( \geq 210 \text{ kg/sq cm} \). This test is specified in lieu of the tension test for certain types of works.

**Soundness**: The purpose of the test is to find out in advance whether a cement is in danger of disintegrating or expanding or contracting so as to cause distortion or cracking in the structure. If a cement passes the *hot test*, it may be used immediately with reasonable certainty of its ultimate soundness. If it fails, it should be regarded with suspicion and be thoroughly tested. Disintegration of work in cement, properly mixed and laid, is usually due to an excess of lime in a form which can readily be attacked by the elements. This may come about either: i by the use of too high proportion of lime in the raw materials from which the cement is made, or ii by underburning the cement, or iii by too coarse grinding. The expansion caused by an excess of free lime is due to the hydration or slaking of CaO, which, when slaked expands in volume 2 to 3 times. Unsoundness is caused only by the presence in excess of CaO or quick lime and not by the presence of fully slaked lime. On the other hand, fully slaked lime is sometimes added to cement mortar either to slow down the setting action or to render the mortar more watertight. The small amount of free lime which frequently occurs in first class cement may be hydrated and rendered harmless by *air-slaking*, say 2 or 3 weeks' storage or after spreading the cement out in the air in an enclosed and covered building. The presence of magnesia in excess in a thoroughly burnt cement may produce a gradual expansion which will disintegrate the concrete after several years.

**Tests**: a *Pat test*: Take about \( \frac{1}{4} \) lb. cement and mix by kneading for 1½ min. with 0·78% of the water required to give a paste of normal consistency. Press portions of the paste on to 3 pieces of window glass 4" square, so as to make 3 *pats*, each about 3" in diameter and \( \frac{1}{2} " \) thick at the centre tapering to a thin edge, and place in moist air for 24 hours. Then, keep one pat in air at a temperature of 16 to 21° for 28 days, keep second pat in water for 28 days, and place the third pat in a loosely closed vessel
in boiling water and keep there for 5 hours. Reject cement if any pats show radial cracks or curl or crumble. The air pat should not change colour. Cement may be accept-
ed on steam test alone, if time is limit-
ed; b. Bottle test: Cement is mixed with water and filled into a bottle while stil wet and struck level with the top. If the cement is unsound or not sufficiently air slaked (that is to say, too fresh), it will expand and crack the bottle. If it has been exposed to air too long, it will shrink on setting and rattle in the bottle. If neither cracks the bottle nor shrinks on setting, nor rises out of the bottle, it may be considered sound and in a fit condition for use; and c. Le Chatelier Test: The apparatus consists of a small split brass cylinder 0.5 mm thick, and 30 mm internal diameter (Fig. 103). On either side of the split are two long prongs with pointed ends. The distance of the ends from the centre of the cylinder is 165 mm. The Le Chatelier cylinder is placed upon glass and filled with cement paste formed as above. It is then covered with another piece of glass, upon which a small weight is placed and the whole is then placed in water at a temperature of 24 to 35° and left there for 24 hours. The distance between the points AA is then measured, and the mould is placed again in the water, which is brought to boiling point in 25 to 30 min. and kept boiling for one hour. The mould is removed from the water, allowed to cool, and the distance between AA again measured. The difference between the two measurements represents the expansion of the cement. This shall be > 10 mm for uncorrected cement. If this test fails, perform another similar test on a sample after aeration (by being spread out to a depth of 7.5 cm at a relative humidity of 50 to 80%) for 7 days when the expansion shall be > 5 mm. This test is considered more severe than the pat test.

2. Rapid Hardening Cement: Chemical composition, setting
time, and soundness same as for ordinary cement. Fineness: Residue on IS. Sieve 9 to be > 5% and specific surface to be < 4,250 sq cm/g. Strength: Tensile at the end of a day to be < 20 kg/sq cm and at the end of 3 days to show an increase and to be < 30 kg/sq cm. Compressive at
the end of a day to be < 155 kg/sq cm and at the end of 3 days to show an increase and to be < 245 kg/sq cm.

3. Blast Furnace Cement: **Chemical composition**: Cement clinker same as ordinary cement. Weight of insoluble residue to be > 1%. Weight of magnesia to be > 5%. Sulphur as sulphuric anhydride to be > 2% and as sulphide to be > 1.2%. Total loss on ignition to be > 4%. All other test values are as for ordinary cement.

4. High Alumina Cement: **Chemical composition**: Alumina to be < 32% and the alumina-lime ratio to be between 0.85 and 1.3. **Fineness**: Residue on IS Sieve 9 to be > 8%. **Setting**: Initial to be < 2 and > 6 hours, and final to be > 2 hours after the initial set. **Soundness**: Expansion of Le Chatelier mould to be > 1 mm. **Strength**: Compressive to be < 420 kg/sq cm at the end of a day, and must show an increase and be < 490 kg/sq cm after 3 days.

5. Low Heat Cement: **Chemical composition**: Percentage of lime after deduction of that necessary to combine with SO₂ present, shall be > 2.4 times the percentage of silica plus 1.2 times the percentage of alumina, plus 0.65 times the percentage of iron oxide, and < 1.9 times the percentage of silice, plus 1.2 times the percentage of alumina, plus 0.65 times the percentage of iron oxide. Rest as for ordinary cement. **Fineness**: Specific surface to be < 3,200 sq cm/g. **Setting**: Initial to be < 1 hour and Final to be > 10 hours. **Soundness**: Same as for ordinary cement. **Strength**: No tensile specified and compressive at the end of 3 days to be < 105 kg/sq cm, at the end of 7 days to show an increase and to be < 155 kg/sq cm, and at the end of 28 days to show an increase and to be < 265 kg/sq cm. **Heat of hydration**: When tested as specified in IS8, to be > 65 calories per gm at the end of 7 days and to be > 75 calories per gm at the end of 28 days.

**Note**: The ISI is proposing to revise IS 269-1951 on the following lines: i. To introduce an autoclave expansion test for soundness of cement as an **optional** test. 25 mm x 25 mm x 254 mm neat cement specimen (after 24 hours storage in a moist room after moulding) shall be kept in an autoclave and the temperature of the autoclave shall be raised at such a rate as will bring the gauge pressure of the steam to 20-75 kg/sq cm in 1 to 1½ hour. The automatic pressure control shall be capable of maintaining a pressure of (20-75 ± 0-70) kg/sq cm at (215-7 ± 1-7)°. This pressure will be maintained for 3 hours after which the heat supply is shut off and the autoclave cooled at a rate such that the pressure will be < 0·70 kg/sq cm at the end of 1 hour and any pressure remaining
shall be slowly released by partially opening the vent valve until atmospheric pressure is attained. The specimen is then taken and placed in water at a temperature of > 90°. The water is cooled uniformly to 21° in 15 min, by addition of cold water, and maintained at this temperature for another 15 min. The specimen is then surface dried and its length measured. The difference in length (a contraction being denoted by a—sign) is reported as the autoclave expansion of cement. This expansion shall be > 0.5% for ordinary, rapid-hardening, and low heat cements. To make the compression test strength which is at present optional as compulsory and to make the compulsory tensile strength test as optional and to be made only if required by the purchaser.

**SAND**

**General:** For building purposes, lime and cement are generally mixed with sand. Though the addition of sand weakens the mortar, yet it confers on the other hand certain important advantages: i Its chief function is to add a hard ingredient and thus give greater strength to mortar against crushing; ii It prevents cracks and minimises shrinkage of mortar in drying; iii It reduces the amount of lime or cement necessary to make a bulk of mortar, thus decreasing the cost; and iv It improves the setting power, if the binding material is lime. It subdivides the fat lime into thin films, thereby making the mortar porous, which absorbs the CO₂ from air and becomes hard.

**Natural Sources of Sand:** i *Pit sand:* The grains of pit sand generally have sharp and rough angles due to the accretion of particles by their being cemented together by iron oxide. It is also often found rounded and wanting in sharpness. It consists of silica with a considerable amount of mica, hornblende, felspar, CaCO₃, clay, etc., which are easily decomposed by the atmospheric actions and the acids of rain water. ii *River sand:* is not sharp or angular in its grains, owing to the action of currents. This is preferable to pit-sand as a rule, as it is more free from particles of clay and dirt but is lacking in adhesion on account of round and smooth surfaces. It is largely used for plastering, owing to its fineness and light colour. iii *Sea sand:* is also rounded, owing to wave action and, in addition, will be found mixed with alkaline salts which will absorb moisture from the air and cause permanent dampness and efflorescence. Efflorescence is removed by washing the finished surface with a very dilute solution of H₂SO₄. Sea sand must not be used except with cement for subaqueous work. Though this is the general rule, yet it is commonly used in Kerala for preparing mortar for fine plastering. No great harm is done since the thickness of the coat of fine plastering is
very thin and the plastered surface is exposed so that the dampness does not persist.

Classification of Sand: *Fine sand*: to pass through a screen with clear meshes 1/16". This is ordinarily used for mortar for plastering work. *Coarse sand*: to pass through a screen with clear meshes of 1/8". This is ordinarily used for mortar for masonry. *Gravelly sand*: to pass through a screen with clear meshes of 3/10". This is ordinarily used for concrete work.

**Bulking of Sand**: Bulking denotes the increase in volume which occurs when dry sand is moistened. This gradually reaches a maximum value of about 30% when the moisture content is about 6%. With further increase of moisture, the bulking decreases and when the sand is thoroughly saturated, the volume is the same as when dry. The explanation for the above phenomenon is that when sand is moist, every particle of it is surrounded by a film of water which tends to hold the surrounding particles apart, and this results in an increase in volume. But when the sand is fully saturated the particles come together as in the dry stage and there is no bulking. The bulking affects the volumetric proportioning of aggregates to a large extent. The percentage moisture in wet sand should be determined and the necessary allowance for bulking made in volumetric measurements. Bulking is more with fine sand than with coarse sand. Aggregates retained on a 3/16" sieve are scarcely affected. Fig. 104 shows the bulking effect of moisture for three sands covering the range ordinarily used in concrete. Proportioning by weight is more satisfactory, and, if necessary, allowance can be made for the weight of water in damp sand by determining the moisture content. Failure to allow for bulking increases the cost of the concrete and results in under-sanded mixes which are harsh and difficult to place. e.g., suppose a sample contains 5% moisture and bulks 30%. 1 c. ft. of this sand will contain only 100/130 or 0.77 c. ft. of dry sand. So a 1:2:4 mix by volume, with correction for bulking, will only have 2×0.77 or 1.54 c. ft. of sand. The mix will only be 1:1.54:4. The actual quantity of sand to be used is 2×1.3 or 2.6 c. ft. The field mix will be 1:2.6:4.

**Characteristics of Good Sand**: The sand should be sharp, clean, chemically inert, coarse and gritty to the touch and the grain should be composed of durable minerals and the sizes of the grains should be so
graded as to get the minimum of voids. It should be highly siliceous. Sharpness; ensures adhesion of cement, and offers greater resistance to sliding when under compression. The voids in fine and rounded sand are small. Such a sand conduces to tensile strength, economy, and water tightness. Sharpness is tested by the cutting action of the grains of sand when rubbed in the hand. Sharp sand is difficult to obtain. Cleanliness: The sand should be free from loam or organic impurities which prevents the adherence of cement. These impurities are removed by washing in water. The sand should not contain leaves, straw, paper, etc. Fineness: Coarse sand makes the stronger mortar provided the voids are filled with cement or lime. But if the voids are not likely to be properly filled, as in the case of lean mortar, then coarse and fine sand should be mixed in the proper proportions. Durability: Lime or cement improves by age but the strength of sand remains the same for ever. A fine sand of a strong stone like gneiss will give a better mortar than a coarse stuff containing soft materials. The mixing should be properly done so as to ensure each grain of sand being coated with cement. Fine sand is best for this purpose. Pour a small stream of water over the mortar just taken out from the mill. If the mixing is complete, lime and sand will not separate, separation is instantaneous in the case of insufficiently ground mortar. Voids: The voids of natural sand when rammed, vary from 30 to 37%. The sand should be used dry.

Tests for Sand or Fine Aggregate: 1. For silt content: a. Field settling test: Place, without drying, a sample of the sand in a 200 ml measuring cylinder up to the 100 ml mark. Add clear water up to the 150 ml mark. Shake the contents vigorously and allow it to settle for 3 hours. The height of the silt visible as a layer above the sand is expressed as a percentage of the sand below. This should be limited to 6 to 10%. b. Laboratory decantation test: Dry about a lb. of the sand by heating to $>110^\circ$. Place a known weight $w_1$ of the dried materials in a dish about 9” diameter and 4” deep and add sufficient water to cover the sand. Shake the contents of the dish vigorously for 15 sec. and then allow it to settle for a similar period. Pour off the water through IS Sieve No. 7. Repeat this process of adding water, shaking and pouring off, until the wash water is clear. Dry the remaining sand by heating to $>110^\circ$. Find its weight $w_2$. The percentage of silt, etc., in the sample is given by $100 \left( \frac{w_1 - w_2}{w_1} \right)$%. This must not exceed 5%. This test has now been superseded by c. below. c. Sedimentation test: Sieve (1 oz. for sand, 1 lb. for $\frac{1}{4}$” size aggregate, and 14 lb. up to $2\frac{1}{4}$” size) on IS Sieve 240. Set aside the material passing the sieve and treat the residue with sodium
oxalate solution. Pour through IS Sieve 240. Rub the wash liquid with the material passing IS Sieve 240 in a mortar with a soft rubber pestle (30 min. for natural sand and 5 min. for crushed stone sand). A known weight of this liquid is then taken, dried at 110° to constant weight, and the percentage of fine silt and clay calculated. It shall not exceed 4% in natural sand, 10% in crushed stone sand, and 1% in coarse aggregate.

ii **For organic impurities**: Shake the sample with an equal volume of a 3% solution of NaOH and allow to settle for 24 hours. Then examine the colour of the liquid above the sand. Clear or pale yellow shows that the sample is tolerably free from organic impurities; while dark yellow shows that the sand should be washed and tested again. If the dark yellow persists or if in the original test the liquid assumed a dark brown tinge, the material should be rejected.

Alternatively prepare a standard colour solution by adding 1½ cc. of a 2% solution of tannic acid in 10% alcohol to 97½ cc. of a 3% NaOH solution. Shake well and allow to settle for 24 hours. Any sand showing a liquid not stronger than the standard can be accepted.

iii **Aggregate crushing value**: is determined mostly for coarse aggregates. See 'Tests for coarse aggregate' under 'Concrete'.

iv **Size of aggregates**: Tabular values are per cent passing.

<table>
<thead>
<tr>
<th>IS Sieve</th>
<th>Class A</th>
<th>Class B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Natural sand or crushed gravel sand</td>
<td>Crushed stone sand</td>
</tr>
<tr>
<td>480</td>
<td>95 - 100</td>
<td>90 - 100</td>
</tr>
<tr>
<td>240</td>
<td>70 - 95</td>
<td>60 - 90</td>
</tr>
<tr>
<td>120</td>
<td>45 - 85</td>
<td>40 - 80</td>
</tr>
<tr>
<td>60</td>
<td>25 - 60</td>
<td>20 - 50</td>
</tr>
<tr>
<td>30</td>
<td>5 - 30</td>
<td>5 - 30</td>
</tr>
<tr>
<td>15</td>
<td>0 - 10</td>
<td>0 - 15</td>
</tr>
</tbody>
</table>

v. **Soundness**: For concrete liable to be exposed to the action of frost, aggregates shall pass a Na₂SO₄ or MgSO₄ accelerated soundness test, except that aggregates failing in this test may be used if they pass a satisfactory freezing and thawing test (Pa. 14). Test results by the use of the two salts differ considerably and care must be exercised in fixing proper limits. Wash the sample, sieve on IS Sieve 30, dry to constant weight at 110° and obtain 100 gm in each of the five following sizes:
<table>
<thead>
<tr>
<th>Retained on IS Sieve No.</th>
<th>30</th>
<th>60</th>
<th>120</th>
<th>240</th>
<th>480</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passing IS Sieve No.</td>
<td>60</td>
<td>120</td>
<td>240</td>
<td>480</td>
<td>3/8 in.</td>
</tr>
</tbody>
</table>

Immerse the samples in Na₂SO₄ or MgSO₄ solutions for < 16 and > 18 hours in such a way that the solution covers them to a depth of < 1/4". Remove them, dry to constant weight, and allow them to cool. Wash with BaCl₂ solution to remove the salts and again dry to constant weight. Again sieve each through the same sieve and find the weight of particles retained. The loss of weight is a measure of the soundness of the sample.

The moisture content, sp. gr., absorption, and bulk density are specified as optional tests.

**MORTARS**

**General:** Mortars consist of the matrix (lime or cement) and fine aggregate (sand or sand and surkhi). Their functions are: i To form an even bed for the stones or bricks or broken stones in a building and thus to distribute uniformly the superincumbent weight; ii To provide an adhesive substance binding the bricks or stones or broken stones (as in concrete) together into a solid mass; iii To furnish a hard smooth covering for walls, roofs, etc.; iv To fill up the joints and make the wall weather tight; v To serve as a matrix in concrete; vi To enable mouldings to be made; and vii To improve the appearance of a structure. The covering is white or sometimes coloured.

**Mixing Lime Mortar or Lime Surkhi Mortar:** In places where shell lime (which is fat lime) is largely used, the quick lime is slaked in advance and stacked. When mortar has to be mixed, the sand and the slaked lime powder are measured out in the specified proportion. If surkhi is to be added, it is also measured out in proper proportion. These materials are first mixed together dry with the help of shovels. Another practice is that the required quantity of quick lime for a batch is measured on a platform. Water for slaking it is sprinkled over it. The heap is then covered with the specified proportion of sand. Or the required quantity of sand is measured on the platform, a hollow scooped out in it, the required quantity of quick lime is placed in the hollow and slaked by sprinkling water on it and covered over with the sand. The heap is left for a day or so, and then well turned over with shovels.

**Pounding:** Before the mortar could be used in construction, it should thoroughly be amalgamated by pounding when only a small quantity of it is required, and by grinding in a bullock mill or a power
driven pan mill when large quantities are required, the latter being the best ground, and usually adopted in large and important works. In pounding mortar, a trough about 6' long, 18'' wide at top and 15'' at bottom and about 18 to 20'' deep is made by digging a trench in hard ground and lining its bottom and sides either with stones, bricks or planks. 4 or 5 heavy wooden pestles or pounders, about 4 or 4 1/2'' diameter and 4 1/2 to 5' long, the top end being rounded into a handle, are got ready. The mortar mixed as above described is put into the trench, consistently to its size, a little water is added and 3 or 4 persons, each with a pounder, pound the mixture, raking up the mixture now and then and adding water little by little to the extent required, until the mortar reaches a pasty consistency or that of thick honey and looks and feels to the touch thoroughly amalgamated. This is not a very efficient method.

**Grinding in a Bullock Mill:**

(Fig. 105). The mill consists of a circular trench lined with stones or bricks (bottom and sides about 8 to 12' radius, 12 to 15'' wide and 10 to 12'' deep, in which a heavy stone roller about 2 1/2 to 3' diameter revolves at the end of a stout wooden axle bar, drawn by bullocks, the other end of the bar being swivelled to a pivot fixed to a stout wooden post fixed into the ground at the centre of the circle. The dry mixture is put into this trench, water added, and ground by the wheel. Sometimes, the ingredients are measured out directly into the trench and turned over in it. It is usual to specify that the mortar should be ground by 60 turns or rounds, round the circular trench. The ground mortar of the consistency of thick honey is then removed and placed in a storage pit, dug into the ground.
and lined with stones or bricks, from where it is removed for use.

**Grinding in a Power Driven Mortar Pan Mill** (Fig. 106). The mill consists of an iron pan or dish in which two heavy cast iron edge wheels or runners revolve, worked by steam engine, oil engine, or electric motor, through belting and gear wheels. The dry mixture is placed in the pan, water added, and ground to the consistency of thick honey. It is then removed to a storage pit as described above. The grinding in a mill of this kind is quite efficient and gives very good mortar.

**Cement Mortar**: In mixing cement mortar, the measured quantities of the cement and sand, according to the specified proportions, are mixed dry first on a platform and then mixed in a wooden trough with water, by turning over with shovels. The cement mortar is neither ground nor pounded. 1 c. ft. of 1:2 mortar requires about 1-53 gal. of water.

**Cement Surkhi Mortar**: has the same strength as cement mortar and is flexible, workable, impermeable and obviates the need for elaborate cooling arrangements to dissipate the large heat of hydration inherent in massive dams built entirely of cement. Another advantage is that it readily combines with the free lime liberated in the setting of cement and avoids the disintegrating effect of free lime. In large structures, the saving in cost on account of its substitution for part of cement is something appreciable.

**Proportions of Ingredients for Mortars**: (By volume)

<table>
<thead>
<tr>
<th>Mortar</th>
<th>Cement</th>
<th>Lime</th>
<th>Surkhi</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FAT LIME</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masonry, Plastering 1st cost</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Plastering 2nd cost</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Pointing</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1 1/2</td>
</tr>
<tr>
<td><strong>HYDRAULIC LIME</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masonry</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>2 to 3</td>
</tr>
<tr>
<td>Very strong masonry</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td><strong>SURKHI</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strong Masonry &amp; Foundations</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Rapid setting in water</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Rubble Masonry</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>2 1/2</td>
</tr>
<tr>
<td>Pointing</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>1/2</td>
</tr>
<tr>
<td><strong>CEMENT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masonry</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>2 to 6</td>
</tr>
<tr>
<td>Cement surkhi masonry</td>
<td>4</td>
<td>-</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Plastering and Pointing</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Reinforced Concrete</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1 1/2 to 2</td>
</tr>
<tr>
<td><strong>COMBINATION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastering</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>5 to 6</td>
</tr>
</tbody>
</table>

**Precautions in Using Mortar**: i The moisture in mortar,
especially hydraulic, should not be allowed to be absorbed by the materials in contact with it. For compact stones, such as granite, marble, watering the surface, just at the time of using them, will be sufficient while porous materials such as sandstone, bricks, should be well-soaked in water for at least 2 hours before use. The object is to retain moisture in mortar sufficient for it to harden. ii The consistency of the mortar should be such as a trowelful of it may be taken up by the surface of the wall with ease. The stone or other work should be free from dirt and, if dry, the surface should be wellwetted with water. The mortar should be evenly spread on the surface to allow an even bed for the stone or brick, placed over it, and pressed with a mallet or trowel. The joints must be flushed well and any surplus of mortar brought to the surface should be neatly taken off with the trowel but not spread on the face. iii. To prevent rapid drying of the mortar after it has been applied, the masonry or plaster should be kept well watered for at least a week. iv. In frosty weather the work must either be stopped or executed in a cement mortar which will set more quickly than it will freeze, as alternate freezing and thawing, before setting, damages the adhesive and cohesive strength of the mortar.

Tests for Mortar: (Vide ‘Specifications’ under ‘Limes’ and ‘Tests for Cements’ under ‘Cements’). Ordinarily lime mortar should develop a strength of 50 psi, good hydraulic mortars, including mortars made of fat lime, surkhi and sand being stronger. The adhesive strength is about 1/10 the tensile strength. The tenacity or cohesion of mortar can be tested by making briquettes of mortar and tearing them by suspending weights, and the crushing strength by the pressure of heavy weights on a pillar of brickwork. The sp. gr. of good mortar is 1-5 to 1-9, its weight per c. ft. is 90 to 120 lb., and tensile strength 40 to 120 psi.

CONCRETE

General: Concrete is a composition of broken stone, broken bricks, gravel, etc., with mortar in such proportions that, when consolidated, it sets into a single monolithic mass. The broken stone, brick or gravel, (3/16" to 3" size) is called the coarse aggregate, as distinguished from the fine aggregate which is sand (0-0059" to 3/16" size). Aggregates of 3" to 6" size are called cyclopean aggregates or cobbles. The mortar may be of lime and surkhi or cement. The quantity of mortar to be used should be a little more than the total volume of the voids in the coarse aggregate.
Proportions of Ingredients for Concrete: (By volume).

<table>
<thead>
<tr>
<th></th>
<th>Concrete</th>
<th>Cement</th>
<th>Lime</th>
<th>Surkhi</th>
<th>Sand</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIME</td>
<td>Dry work, Roof, Floor</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>4 to 5</td>
<td></td>
</tr>
<tr>
<td>SURKHI</td>
<td>Damp Foundation</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>4 to 5</td>
<td></td>
</tr>
<tr>
<td>CEMENT</td>
<td>Ordinary Foundations</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>4 to 6</td>
<td>8 to 12</td>
</tr>
<tr>
<td></td>
<td>Strong Foundations</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Foundations in Damp Soil</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Ordinary Reinforced concrete</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Watertight concrete</td>
<td>1</td>
<td>-</td>
<td>1½</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Long Bridge Arches</td>
<td>1</td>
<td>-</td>
<td>1½</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Tests for Coarse Aggregate for Concrete:

i. For silt content:
Same as under 'Tests for sand'.

ii. Aggregate crushing value: is determined for aggregates ranging from 2" to ½" size. Dry the sample for 24 hours at 110°. Cool and weigh. Fill up the test cylinder with the sample, compacting properly. Weigh the balance and thus find the weight \( W \) of the sample in the test cylinder. The cylinder is fitted with a piston at the top. Fix the cylinder in a testing machine and apply at a uniform rate a compressive load (from 10 to 160 T. depending on the size of the cylinder which depends on the size of the aggregate). Resieve the crushed stuff through specified smaller size sieves and find the weight \( w \) of the fines formed during test. The aggregate crushing value equals \( 100w/W \) and this shall be \( \geq 45\% \) for aggregates used for concrete and \( \geq 30\% \) for those used for wearing surfaces.

iii. Size of aggregate: Tabular values are per cent passing.

<table>
<thead>
<tr>
<th>IS Sieve</th>
<th>Nominal Size (Ins.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2½</td>
</tr>
<tr>
<td>3 In.</td>
<td>100</td>
</tr>
<tr>
<td>2½ ..</td>
<td>85-100</td>
</tr>
<tr>
<td>1½ ..</td>
<td>0-30</td>
</tr>
<tr>
<td>¾ ..</td>
<td>0-5</td>
</tr>
<tr>
<td>½ ..</td>
<td>-</td>
</tr>
<tr>
<td>⅛ ..</td>
<td>-</td>
</tr>
<tr>
<td>No. 480</td>
<td>-</td>
</tr>
<tr>
<td>.. 240</td>
<td>-</td>
</tr>
</tbody>
</table>
iv **Soundness**: The aggregates are sorted into either close sizes or graded sizes (as in IS 383/1952) and tested as under ‘Tests for sand.’ Also a qualitative examination of particles coarser than \( \frac{3}{4} \)" brings to light the effects of disintegration, splitting, crushing, cracking, flaking, etc.

v **Other tests**: are described for absorption value, sp. gr., bulk density and shape. The absorption value gives an indication of the suitability of the aggregate for concrete walls of liquid containers, but it is equally important to remember that porous aggregates are liable to spall and flake under frost action. Formerly it used to be held that a good concrete aggregate should be rough and angular. If the concrete is thoroughly compacted it may be true that the angular, nearly-cubical aggregate might give the highest strengths but it is now generally realised in practice that with a smooth rounded aggregate it is possible to use a lower water-cement ratio and get better consolidation and thus obtain a strong mix. Aggregates containing shale, mica, coal, chalk, etc., should be suspect. Certain dolerites containing olivine decompose rapidly and cause the concrete to disrupt. Where required, petrographic examination shall be carried out and the aggregates classified as: **good** where the constituents contribute to superior strength, abrasive resistance, and durability under any climatic conditions; **satisfactory** where the constituents contribute to high or moderate strength, abrasive resistance, and durability under any climatic conditions; **fair** where the constituents contribute to moderate strength and abrasive resistance, but under rigorous climatic conditions they contribute to physical breakdown of concrete; and **poor** where the constituents contribute to low strength and abrasive resistance of concrete under any climatic conditions and cause physical breakdown under rigorous climatic conditions.

**Proposed ISS for natural and manufactured aggregates for mass concrete**: A. **Natural aggregates** shall consist of naturally occurring stones, gravel, and sand. B. **Manufactured aggregates** shall consist of crushed stone, gravel or other material.

These shall be classified as i **coarse aggregate** in A and **crushed coarse aggregate** in B, and ii **fine aggregate-sand** in A and **crushed fine aggregate-manufactured sand** in B.

**Coarse aggregates** (A & B): **Quality**: They shall consist of uncoated hard, strong, dense, and durable pieces and shall be free from injurious amounts of disintegrated stones (A), soft, flaky or elongated particles, salt, alkali, vegetable matter and other deleterious substances. **Limits for deleterious substances** (by wt.): Coal and
lignite > 1%; clay lumps > 1%; Materials finer than IS Sieve 8 > 3% in A and > 1% in B; soft material > 3%; other deleterious materials to be such that total of all deleterious materials is > 5%. Abrasion test: Wear to be > 16% and crushed particles to be > 20%. Soundness test: After 10 cycles, weight average to be > 12%. Water absorption test: For A alone, 3 to 5%. Sizes: a. Very large (3 to 7). Passing IS Sieve 3"—0 to 10% in A & 0 to 15% in B), b. Large (3 to 1¼). Passing Sieve 3"-90 to 100% and 1¼"-0 to 10% in A and 0 to 15% in B), c. Medium (1¼ to ½). Passing Sieve 1½"-90 to 100% & ½"-0 to 10%), d. Small (½" to IS No 480. Passing Sieve ¼"-90 to 100% & IS No 480-0 to 5% in A & 0 to 10% in B & IS No 240-0 to 2% in B).

Fine aggregates (A & B). Quality: They shall consist of siliceous material (A) or crushed stone, gravel or other inert materials (B) having hard, strong, durable, uncoated particles, free from injurious amounts of dusts, lumps, soft or flaky particles and other deleterious substances. Limits for deleterious substances: (by wt.) Coal and lignite > 1%; Materials finer than IS Sieve 8 > 3%; Shale > 1% (A); Clay lumps and sandstones > 1% in A & clay lumps alone > 1% in B; Alkali, mica, and coated grain (deleterious) > 2% in A; other deleterious materials to be such that total of all deleterious materials is > 5%. Soundness and organic impurity: Tests shall be performed as given in Pa. 105. Sizes: For A, a. Coarse sand (Fineness modulus 3-5 to 4-2, Passing IS Sieves 480-95 to 100% & 60-0 to 20%), b. Fine sand (F. M. 1:2 to 1:8, Passing IS Sieves 60-90 to 100% & 15-2 to 15%), c. Well graded sand (Passing IS Sieves 480-95 to 100%, 240-80 to 95%, 120-45 to 80%, 60-30 to 45%, 30-5 to 30%, and 15-1 to 5%). For B, Manufactured sand (Passing IS Sieves 480-95 to 100%, 240-75 to 90%, 120-50 to 70%, 60-30 to 50%, 30-15 to 30%, and 15-8 to 13%).

Grading: For good grading-adopt i for natural aggregates 10 to 15%, very large, 13 to 15% - large, 15 to 5% medium, 15 to 25% small, and 25 to 30% - coarse & fine or well-graded sand, ii for manufactured aggregates 15 to 25% - very large, 12 to 23% - large, 12 to 20% - medium, 12 to 18% - small, and 25 to 38% - manufactured fine aggregate.

Bulk density, surface dry weight, crushing test, and petrographic analysis are recommended as optional tests.

Mixing Concrete: Small quantities of concrete may be mixed by hand by repeatedly turning over the ingredients by shovel till the whole is uniformly and intimately mixed such that every bit of the aggregate has a coating of mortar, but large quantities are preferably mixed by machinery. The mixing should be as rapid as possible consistent with
thoroughness, as the concrete should be placed in position before it has begun to set. Lean mixtures require more time for mixing than rich ones and dry mixtures more than wet ones. The mixing should be done on a clean, dry, level platform of wood or slabs with tight close joints so that there may be no leakage through, of mortar or water. The required quantity of water is added gradually through the rose of a watering can. The aggregate, both coarse and fine, should be properly graded, cleaned by washing, and wetted to saturation before mixing.

*Cement Concrete*: **Hand mixing**: Measure the specified quantity of sand and over this the cement. Turn the whole over repeatedly, at least thrice, till the mixture is of uniform colour. Place the mixture on the coarse aggregate, properly proportioned and levelled on another platform. Add the measured quantity of water through the rose of the can, and turn over the whole for another 3 times, until the colour of the cement is uniformly distributed throughout the whole mass. Mixing must be so timed that the concrete is placed within 20 to 30 min. of adding water to concrete. Water *just enough* to secure correct consistency should be added, usually \( \frac{1}{3} \) of the volume or weight of mortar. Cement concrete should be mixed in small lots (if by hand, say 4 c. ft. at a time) and laid at once in the work. An extra 10% of cement is recommended to make up for the insufficient mixing.

*Machine mixing*: is adopted in large works to save time and to ensure thoroughness of mixing. The precautions to be followed are:

- Water should be added to the mixer before the ingredients are put in;
- Mixer should be run at the proper speed until the concrete is of uniform consistency and colour;
- Mixer should not be overloaded;
- Mixer should be set such that the axis of rotation of the drum (except in the tilting drum type) is horizontal;
- Mixing should be for a period of 1\(\frac{1}{2} \) to 2 minutes;
- The whole batch should be discharged at a time into a suitable container;
- Concrete should not be allowed to stand in the mixer;
- At the end of the day's work or on the completion of a job, the inside of the drum should be thoroughly cleaned, by scouring it with water and stones;
- Mixer blades should be kept in good condition; and
- Mixer should not leak.

The principal types of mixers are: i) **Rotating drum**: where a single drum is mounted on rollers and rotated by an engine about a horizontal axis. The blades inside the drum work the concrete towards the discharge end. ii) **Rotating double drum**: where the second drum is refilled while the first is completing the mixing of the previous batch. iii) **Tilting**
drum: Here a drum with internal blades revolves and when mixing is complete, it is rotated about a horizontal axis through its base and the concrete discharged. iv Pan type: is the most efficient, especially for stiff mixes, which are inclined to ball up in rotating drum mixers. It consists of a rotating pan, fitted eccentrically with a mixing spar carrying cast-steel paddles. v Continuous type: is used where a steady discharge of concrete is required. The ingredients are mechanically fed, mixed, raised by a bucket elevator and tipped into the mixing drum fitted with internal blades. Water is admitted from a cistern at top. The mixed concrete is dropped into a hopper from which it falls into a lorry for transport.

Lime and surkhi concrete: Before making concrete, the specified mortar should be prepared. The aggregate, previously graded and washed, is placed to an even thickness on a clean platform of sufficient size to have enough room for mixing 10 c. ft. of concrete. The mortar in the proper proportion is measured and evenly spread over the aggregate, and the whole turned over until thoroughly mixed. Water may be added, if necessary, to the mortar but not to the concrete. Watering, mixing, etc., will be as in cement concrete.

Transport of Concrete: must be arranged such that workability is maintained, segregation is reduced to a minimum, and continuous concreting is kept up. The methods are: Wheel barrows, hand carts, light trucks, skips carried on bogies running on rail tracks, motor lorries, etc.; Steel buckets transported by truck, derricks and cableways; iii Chutes with a funnel shaped pipe at lower end to allow re-mixing to some extent; iv Belt conveyors with remixing arrangements at end to avoid segregation, drying, and stiffening; and v Pumping of concrete. This is adopted in places with limited operating space like lining of tunnels and sewers, construction of bridge decks and complicated cellular foundations. The concrete is poured in the hopper of a direct acting reciprocating pump, which in turn pumps the concrete through a pipe line to its destination. Pumped concrete is also called 'pumcrete'. A satisfactory pumpable mix should have max. size of coarse aggregate as 3", uniformly graded and (2 to 4% more than in an ordinary mix) with > 30% by weight passing through 15 Sieve 30 and a slump of 2 to 5". Before pumping, the pipe line should be lubricated with 1:2 mortar and a 6" slump concrete pumped. The end of the pipe should be kept buried in concrete in order to prevent splashing and blow-outs at the delivery end. The pipe line should be thoroughly cleaned and flushed after pumping.

Laying Concrete: All concrete should be deposited in horizontal layers; if not, the water trickling from the higher level will carry
away the cement or lime with it. The concrete should be gently tipped into position, and not thrown from a height, nor shovelled into a trench containing water, as the heavier pieces of the aggregate would separate from the mortar. Care should be taken to cover any joints in one layer by the succeeding one as the joint between two days work is always a weak point.

**Lime concrete**: must be laid, while quite fresh, in layers of 6" thickness; and well rammed with heavy wooden rammers, until the mortar creeps to the surface. Each layer should be thoroughly rammed and consolidated before the next layer is laid. No water should be added during ramming nor ramming done after mortar has begun to set. Sufficient labour and materials should be employed to make up concrete foundations, layer by layer, simultaneously throughout the building. When this is not practicable, unfinished layers of concrete layers shall break joint. Such break joints must be tapered over a length of 18" for a 6" layer and made rough to ensure proper bond, before laying new concrete. The surface of each completed layer shall be watered, well scored with a point of trowel, and wire brushed before the next layer is added. The surface of concrete must be kept moist continually for at least 7 days.

**Cement concrete**: After mixing, this should be taken rapidly and in as small masses as possible to the place of final deposit. When deposited, the concrete should be thoroughly compacted until all the ingredients have settled and the surplus water has been forced to the surface. Excessive tamping should be avoided. Tamping should be completed within 20 min. of adding water in mixing. The surface should be kept wet for at least 14 days; if it is allowed to dry too soon, it would never develop its full strength.

**Depositing Concrete under Water**: is not recommended if it can be avoided. When it is found necessary, the following procedure shall be adopted: i Concrete shall have a temperature of < 16° and > 50° and the water < 2°. ii Concrete shall contain 24 lb. of cement per c. ft. and have a slump of < 4" and > 7". Coarse aggregate shall be < 1/5 and > 2 times that of the fine aggregate. iii Velocity of flow of water through coffer dams or forms shall be < 10 ft./min. Coffer dams in still water shall be sufficiently tight to prevent loss of mortar through the walls. Pumping shall not be done either during concreting or until 24 hours thereafter. iv Concrete shall be deposited continuously until it is brought to the required height. No tamping or ramming shall be done until the concrete surface rises above the water level; and even after that, the surface shall be gently tapped, so as not to squeeze out the mortar,
Concrete shall be deposited by:

a. **Tremie**: It is a large watertight pipe temporarily sealed at bottom. It is held vertically and filled with concrete. The pipe is then lowered so that the sealed end rests on the bottom and the open end rests above the surface of water. When the bottom seal is removed and the tremie is just raised, the concrete flows at the bottom. The flow is checked by forcing the tremie into the green concrete.  
b. **Drop bottom bucket**: It is open at the top and the bottom door automatically opens when the bucket filled with green concrete reaches the proper position. It is completely filled and slowly lowered to avoid backwash.  
c. **Bags** of at least 1 c. ft. capacity of jute or other coarse cloth, \( \frac{3}{4} \) filled with concrete, and securely tied are placed carefully in header and stretcher courses.  
d. **Grouting**: A series of round cages, made from 2" mesh of \( \frac{3}{4} " \) steel is laid vertically over the area to be concreted so that their centre to centre spacing and their distance from concrete faces are \( > 3' \). Stone aggregates (2" to 8") are deposited outside the cages over the full area and height to be concreted to prevent displacement of the cages.  

1:2 cement grout \((w/c \text{ ratio } < 0.6 \text{ and } > 0.8)\) under a pressure of 30 psi is sent through \( 1\frac{1}{2} \) to 2" diameter pipes terminating in steel cages, about 2' above the bottom of the concrete. As the grouting proceeds, the pipe is raised gradually up to a height of \( > 2' \) above its starting level, after which it is withdrawn and placed into the next cage for further grouting in the same way. After finishing the whole area for a height of about 2', the same operation is repeated in stages.  
e. **Concrete pump**: Concrete is placed under water by pumping it into position. The pipe line is plugged at the end, lowered until it rests on the bottom, and pumping started. When the pipe is completely filled, the plug is forced out, the concrete surrounding the lower end of the pipe and sealing it. The pipe is held in this position until the pressure becomes too great when it is raised a foot or two to ease the discharge. This process is repeated removing the pipe sections at intervals, till the concrete reaches the desired height.  

vi To minimise the formation of laitance, concrete shall never be disturbed while it is being laid.

**Precautions against Weather**: Concreting should not ordinarily be done above 50° or below 4°. In hot weather, the aggregates should be wetted, and the wet concrete protected from the heat of the sun. Horizontal surfaces should be covered with wet straw or sacks and vertical surfaces with wet sacks. If concreting is done in wet weather, the area should be covered with some light and temporary roofing to prevent the working out of mortar. In frosty weather, a. the ingredients will have to be heated, b. the surface should be kept insulated from the atmos-
sphere by covering with canvas or straw or sawdust, e. salts or other chemicals added to lower the freezing point of water, and d. the concrete should be heated by passing A. C. (D. C. causes electrolytic decomposition of water). Alternate freezing and thawing of immature concrete causes severe damage, but freezing of hardened concrete causes no permanent injury.

Bleeding: is the accumulation of water at the top even before the concrete begins to set. It is very harmful to the production of sound construction joints. It is produced when vibrators are used. Fineness of grinding reduces bleeding.

Segregation: is the separation of the constituents of the concrete due to differences in size and sp. gr. The coarser and heavier particles settle down, and the finer and lighter ones, especially water, tend to rise to the surface. It is due to too much water, bad grading (use of insufficient sand) and unsatisfactory handling like dropping from a height.

Latance: is a whitish scum, consisting of the fresh flocculent matter in the cement together with dirt from the aggregates, washed out of concrete when there is excess of water. It hardens very slowly and seriously interferes with the bonding of successive layers, if not removed. It is a minimum in the uppermost portion of the lift. It is removed from forms by wet sand blasting followed by air and water jetting, from green concrete by wire brushing, and from old concrete by bush-hammering or chiselling.

Clean-up methods: denote methods employed in the treatment of joint surfaces before placing new concrete. In ordinary construction the surface is cleaned and roughened with a stiff fibre or steel broom a few hours after placement when the concrete is still soft enough to allow removal of same but hardened enough not to permit loosening of aggregate particles. The surface is then kept damp and protected until the new concrete is laid. In massive work with horizontal joints, the initial clean-up method is used. The surface of the concrete is cut with a high velocity air jet to remove the surface layer and expose a clean surface of sound concrete before final set takes place. This is usually done between 4 and 12 hours after placing the concrete, leaner concretes and wetter consistencies requiring a larger time interval. The surface is then protected and cured by covering with a 2 in. layer of wet sand until concreting is resumed when it receives a final clean-up. Wet sandblasting and washing, immediately before placing of fresh concrete is another usual method. In walls and R. C., the inside wall construction is stopped exactly at the level of the joint, overfilling the form by ¼", and then removing the excess just
before setting occurs. The concrete is then finished with the stiff brushes or given a float finish. In thin walls or water-tight construction, the surface is roughened thoroughly, cleared of foreign matter and lattance, and slushed with a thin grout of either neat cement or rich mortar (1 : 2). Whatever be the clean-up method used, mortar with the same water cement ratio as the concrete and a slump of 6 to 8" should be placed to a thickness of \( \frac{1}{2} \) to 1" and broomed thoroughly into all irregularities and depressions of the joint surface to prevent stone pockets and secure a tight joint.

**Testing Lime Concrete for Consolidation:** Dig a hole in the surface of the finished concrete, say about 8 to 9" diameter and 4 to 6" deep. Pour water in this pit, after removing the debris completely. The water should not sink rapidly into the concrete, if the concrete has been mixed well in proper proportion and consolidated well.

**Varieties of Concrete:** 1. **Vacuum concrete:** involves the extraction of the excess mixing water, which is not needed for the hydration of the cement, but is required to obtain plasticity of the concrete, by subjecting the surface of freshly deposited concrete to a partial vacuum. The water is withdrawn through suction mats connected to a vacuum pump. A suction mat of a tight impermeable backing faced on the concrete side with a filter fabric has a series of channels behind through which the extracted water flows to the suction outlet. During this process the concrete gets consolidated under atmospheric pressure acting on its surface. Also the removal of water lowers the water cement ratio and increases the compressive strength of the concrete. This method is used in pavements, bridge slabs, building floor and roof slabs, canal linings, reservoirs, etc. It reduces shrinkage and enables lighter forms to be used and removed in a shorter time.

2. **Shock concrete:** is ordinary concrete compacted by jumping it up and down. The mix is carried by conveyors to the moulds fixed to special shock-tables where the consolidation is effected by applying to the mix 200 to 210 shocks per min. The articles are allowed to harden for 5 to 8 hours in a room where a temperature of 27 to 50° is maintained. This process differs from all vibrating processes. The fall of the mix is suddenly arrested. By this sudden stop each particle is subject to a strong downward pull, forcing all the particles closely together and filling up the voids by squeezing out superfluous water and air. It has the following advantages over ordinary concrete: Reduction in cement for the same compressive or tensile strength; low shrinkage; impermeability; absence of cracks when used as piles and driven with hammers and high adhesive and abrasion resisting properties.
5. Lightweight concrete: is adopted for floors, partition slabs, etc., because of its lightness, fire resistance, and high insulation against heat and sound. The methods of producing it depend on: i the presence of air voids in the aggregate; ii the formation of air voids in the concrete by omitting sand; or iii the formation of air voids in the cement paste by the addition of some substance which causes a foam. Lightweight aggregates are made by pelleting without a binder (other than water) pulverized-fuel ash (residue from combustion of powdered coal in modern boiler furnaces) and sintering the "green pellets" by means of the residual fuel of the ash. These pellets are treated with a bitumen solution to reduce water absorption. These are used for making concrete blocks and insulating concrete toppings on roofs. Concrete made with these pellets has a high degree of workability due to the spherical shape of the pellets.

The varieties are: a. Breeze and clinker concrete: (Density 50 to 100 lb./c. ft.) is used for making blocks and slabs for internal partitions and walls. It is unsuitable for R.C. due to its porosity and absorptive properties. b. Pumice concrete: (Density 45 to 70 lb./c. ft.) should be of pumice free from fine volcanic dust and clay. This gives the best thermal insulation. c. Foamed blast furnace slag concrete: (Density 60 to 90 lb./c. ft.). The thermal insulation is not so good as the pumice concrete. It has a higher moisture movement than in ordinary concrete. d. Expanded shale, clay or slate concrete: (Density 40 to 80 lb./c. ft.) is made by heating the material, crushing, screening, and using. This is found to be sufficiently resistant to the deteriorating effects of sea water. e. No-fines concrete: (Density 100 lb./c. ft.) is made from cement and coarse aggregate only, the fine aggregate being omitted to obtain uniform voids throughout the mass. This does not segregate and the formwork need not be close-jointed. This offers no resistance to the penetration of water, and has very little capillary action. Thus water will not be drawn into the wall and normally a 1:1:6 cement, lime, sand rendering is sufficient to make the structure waterproof. f. Cellular, gas, foamed or aerated concrete: (density 20 to 60 lb./c. ft.) may be poured in situ or used as perfect units. Its advantages over ordinary concrete are: i Lighter weight; ii Greater thermal insulation; iii Better fire resisting qualities; iv More resilient; v Less liable to crack; and vi More waterproof within a certain range of density. High pressure steam curing increases the strength considerably. It is made by: i Processes in which gas is formed by chemical reaction within the mix before it sets. When water is added to
cement mixed with finely ground Al powder, the cement expands and bubbles of H₂ are released forming cavities in the concrete. This mixture is then added to aggregates (< 3/4" size) of broken brick, clinker or ash. No sand is used. Other metal powders, and H₂O₂ and bleaching powder (which generate O₃) have also been used for generating a gas. ii Processes in which a foam-producing substance is added to the mix to introduce and stabilise air bubbles. In the preformed foam process the mixing water and the foaming agent are beaten into a foam before the solid ingredients are added. iii Processes involving the use of excess water which on drying leaves air-filled pores. Lime and very finely-ground sand are used. g. Fibrous concrete: (Density 40 to 50 lb/c. ft.) is made from saw dust, wood shavings, wood-wool, straw, reeds, etc. The fibres are mineralized by immersion in tanks containing Na₂SiO₃ for 24 hours. It is light, takes nails and screws, and can be cut with a saw and drilled. h. Highly porous concrete: (Density 30 to 40 lb/.c. ft.) is made from 2 of cement, 3 of chalk and a small amount of powdered Al. Slabs made from this concrete can be sawn. It is cheap and when used for external walls requires an ordinary concrete rendering.

6. Air-entrained concrete: is defined as concrete in which minute air bubbles are purposely included and these are widely dispersed in a reasonably uniform manner throughout the hardened mass. Air-entraining agents are added to cause entrainment of very small spheroids of air during the mixing period, the action of the agent being to stabilize foam or froth generated during mixing. They may be interground with the cement or added during the batching operations. The principal agents in use are: Vinsol resin, neutralized Vinsol resin, darex AEA, and organic compounds like natural resin, tallow and oils. 3 to 5% of entrained air in concrete greatly improves durability and workability, resists the action of sulphate waters and disintegration from alternate freezing and thawing, permits a saving in material and reduces the passage of capillary water, the temperature rise, bleeding and segregation of concrete. At the same time it increases the strength of lean mixes, and overcomes deficiencies of poorly graded aggregate. Entrained air makes practical the use of mixes of low cement content, which otherwise would be unworkable and harsh, and would bleed excessively. The disadvantages are slightly increased drying shrinkage, increased air voids on form surfaces, reduced strength for rich mixes, and reduced abrasion resistance when the strength is reduced. This concrete is used in highways, dams, bridges, and tunnels.

7. Colcrete: is made by first mixing in a colcrete mixer, cement and water to form a colloidal mixture, then adding sand, mixing again,
and pumping the grout into the coarse aggregates packed in forms. It is economical, speedy, and sound and is used in large mass concrete, R. C., and underwater works e. g., roads, reservoirs, precast units, piers, weirs, dams, piling, canal lining, etc.

8. *Cheecol grout process*: Coarse graded dry aggregate is placed in the forms. Cement and sand are mixed together with an admixture of cheecol to form a grout. Cheecol stabilizes the mix and makes it flow freely round the aggregates. This grout is then poured over the dry aggregate and it fills the voids and produces a solid, waterproof and homogeneous mass. The surface is screeded off in the usual way. This can be used for all works where colcrete can be used, but it is very suitable for roads and under-water work.

9. *Prepakt concrete*: is made by packing well graded dry coarse aggregate in the forms and pumping in under pressure the Intrusion mortar (an admixture of cement; a finely divided patented siliceous material, called ‘Alfesil’, about 50% of cement; a proprietary intrusion agent which prevents early stiffening of grout mixes, reduces the water required for a given consistency, prevents agglomeration of cement particles, tends to hold the solids in suspension, and produces a grout which expands slightly before final set; and water) into voids either through the forms or through pipes placed within the aggregates. While this can be used for all purposes for which colcrete and cheecol grout processes are employed, it is cheaper and more resistive to salt water.

10. *Electro-concrete*: Wet green concrete is, to a certain extent, electro-conductive and at low voltages allows a large current to pass through it. Owing to the resistance of the concrete, the electric power is transformed into heat and the temperature of the concrete is thus raised. This results in accelerating setting and hardening of the concrete, or in preventing it from freezing very quickly. This method is applied to precast units and to monolithic units like floor slabs, frames, and lightly reinforced foundations.

11. *Koocast*: is a high temperature (1,650°) resisting concrete. It shows excellent stability and resistance to disintegration under repeated heating and cooling cycles. It has a small volume change on initial firing and lacks shrinkage or expansion under continuous use at high temperature. It is supplied in dry form, ready mixed, and requires only water to make it ready for use.

12. *Gnite*: (Shotcrete 1:3½) is finely graded cement mortar (1:3) projected into place with great force in a continuous stream by
compressed air under a pressure of 40 psi with the cement gun and with the minimum of water as finely divided sprays. The outstanding features of gunite are cheapness, rapidity and ease of execution, high adhesion, high impermeability, and increased compressive strength. It is applied with or without reinforcement in the form of wire mesh to a thickness of $\frac{1}{2}$" for plaster, 2" for walls of buildings, 2 to 3" for roofs, and 3½" for floors. It is chiefly used for repairs in R. C., steel, timber, or masonry structures, construction of water tanks, waterproofing surfaces, lining tunnels, sewers, etc., protection of steel from fire, corrosion, etc., protection of roofs in mines, and finishing of walls and roofs of buildings especially those near the seashore.

13. **Colloidal concrete**: Here the wet mix is injected, as in gunite, under pressure, into the coarse aggregate. It is used for underwater work and for concreting in horizontal layers.

14. **Acid resistant concrete**: (Oerated concrete). It is made by treating ordinary concrete with $\text{SiF}_4$ gas. As the gas reacts immediately with water and is decomposed, the concrete shall be dry before the treatment. The gas reacts with the free lime in the concrete, and the $\text{CaF}_2$ which is formed is very resistant to acid attacks. Also the calcium monosilicates formed during the hardening of the concrete react with the $\text{SiF}_4$ gas and are transformed into more resistant compounds. Oerated concrete is about 4 times more resistant against attacks from $10%$ HCl compared with ordinary concrete. It is used for artificial stone products, concrete pipes for sewerage, and piles.

15. **Sawdust concrete**: Sawdust passing through a $\frac{1}{4}$" screen is mixed with cement in the ratio of 3 to 4 : 1 and used like concrete. It is used as an insulator and to a limited extent as a floor topping in pens for livestock and for cow stall platforms where strength is not important.

16. **Translucent concrete**: consists essentially of R. C. slabs, grids or arches in which glass tiles or blocks of annealed or toughened glass are inserted to improve the lighting in the interior of buildings.

17. **Prestressed concrete**: Here by prestressing the tensile steel, compressive stress is induced in the concrete which is under tension due to its weight and external loads. Under loading, the final stress in the concrete in the tensile zone becomes zero. The stress in steel becomes $> 18,000$ psi and this is taken care of by using high tensile steel. The advantages are avoidance of cracks in the tensile zone, reduction of deflections, and use of lighter sections.

**Methods of Testing Concrete**: i. **Proportions of constituents**
of freshly mixed concrete: A sample of the fresh concrete is weighed in air \( w \). A bucket containing the concrete is filled with water and the contents stirred thoroughly to remove entrapped air. It is then weighed in water \( w' \). The concrete is thoroughly washed and the weights under water \( w_n \) of coarse aggregate (retained on 3/16 in. sieve) and \( w_s \) of fine aggregate (retained on IS Sieve 100) found. If the specific gravities of coarse aggregate, fine aggregate, and cement are \( s_n \), \( s_s \), and \( s_c \) respectively, then weight of coarse aggregate in sample \( w_n = w_n \cdot \frac{s_n}{(s_n - 1)} \)

\[
\begin{align*}
\text{fine} & \quad w_f = w_n \cdot \frac{s_n}{(s_n - 1)} \\
\text{cement in sample} & \quad w_c = (w - w_n - w_f) \cdot \frac{s_c}{(s_c - 1)} \\
\text{water} & \quad w_w = w - (w_n + w_f + w_c)
\end{align*}
\]

Water cement ratio by weight \( = \frac{w_w}{w_c} \).

ii Determination of weight, yield, cement factor, and air content of freshly mixed concrete: 
a. Weight per cft.: Concrete is thoroughly compacted inside a cylinder (for coarse aggregates up to 1 1/4 in. size - 1/4 c. ft. capacity, 10 in. dia., 11 in. high, and 0.157 in. thick wall and over 1 1/2 in. size - 1 c. ft. capacity, 14 in. dia., 11-25 in. high, and 0.222 in. thick wall) and its weight found. Then the weight per c. ft. equals the weight of fully compacted concrete divided by the capacity of measure.  
b. Volume V in c. ft. of concrete per batch = \( \frac{112 N + W_f + W_n + W_w}{W} \) where \( N \) = Number of 112 lb. bags of cement per batch, \( W_f \) = Wt. of fine aggregate per batch in lb., \( W_n \) = wt. of coarse aggregate per batch in lb., \( W_w \) = Wt. of mixing water added to batch in lb., and \( W \) = Wt. of concrete in lb. / c. ft.  
c. Yield Y in c. ft. per 112 lb. bag of cement = \( \frac{V}{N} \).  
d. Cement factor N, (Number of 112 lb. bags of cement per c. yd. of concrete) = \( 27/X \) or \( 27 N/V \).  
e. Air content A (\% of voids in concrete) = \( \frac{100(T-W)}{T} \) or \( \frac{100(V-V_A)}{V} \) where \( T \) = Theoretical wt. of concrete in lb. / c. ft. computed on an air-free basis, and \( V_A \) = Total absolute volume of component ingredients in the batch in c. ft.

iii Air content of freshly mixed concrete: Pressure method. Refer ISS.

iv Determination of change in length on drying and wetting: This test is made both on laboratory specimens and specimens cut from structures or units. They are 7.6 cm square and between 15.2 to 30.4 cm in length. Cast specimens shall be stored for 3 to 7 days in moist air. During this period, two reference points of 6.4 mm diameter steel balls or other suitable reference providing a 6.4 mm diameter hemispherical bearing shall be cemented with rapid hardening cement into the centre of each end of the specimen after drilling or cutting a shallow depression.
After fixing, the surface of the balls shall be cleared of cement, dried, and coated with grease to prevent corrosion. For cut specimens also, the balls or reference points shall be fixed and treated in the same way. All specimens shall be kept moist for at least a day after fixing the balls in order to allow the cement to harden. They are then kept under water at 24 to 30° for 28 and 4 days in the case of cast and cut specimens respectively.

The balls shall be cleaned immediately on removal of the specimen from water. The difference in length between the specimen and a standard invar rod of approximately the same length, called the 'original wet measurement,' is then found out accurately. It is then dried in an airtight oven, (min. volume 0.3 c. ft. per specimen and 1.8 c. ft. total) provided with a fan for air circulation, at 50° for 44 hours; the relative humidity of the air in the oven being kept at 17% by saturated CaCl₂ solution kept in trays in the oven with an exposed solution area of < 0.3 sq. ft. per c. ft. volume of the oven. The specimen shall then be removed and cooled for at least four hours in a desiccator with solid CaCl₂ in a saturated solution of CaCl₂. Again the difference in length with reference to the standard, called 'dry measurement,' is found out. This cycle of drying, cooling, and measuring shall be repeated till two consecutive readings do not differ by more than 0.0005 cm for a 15-2 cm specimen. The final 'dry measurement' and 'dry length' are found accurately. The initial drying shrinkage or drying shrinkage shall be calculated as the difference between the original wet and dry measurements expressed as a percentage of the dry length.

The specimen shall be kept for 4 days under water at 24 to 30°. The final wet measurement shall then be made. The moisture movement shall be calculated as the difference between the dry and final wet measurements and expressed as a percentage of the dry length.

v Compressive strength of concrete: 15.2 cm cube or 10.2 cm cube (where the largest nominal size of the aggregate is > 1.9 cm) specimens may be used. Cylindrical specimens shall be 15.2 cm diameter and 30.4 cm high. All specimens shall be compacted properly. Specimens made in the laboratory shall be cured for a day at 24 to 30° in moist air of 90% relative humidity and then kept under water at 24 to 30° until taken out just prior to test. Specimens made in the field shall be kept under damp matting, sacks, or other material for a day at a place under 16°. They shall then be kept under water at 24 to 30° until they are taken out, and well packed in damp sand, or damp sacks so as to arrive at the testing laboratory in a damp condition at least a dry before the test. On arrival,
they shall be stored in water at 24 to 30° until the time of test. They shall be tested at 7 and 28 days. Tests at 13 weeks and 1 year are recommended if tests at greater ages are required. Tests are carried out in a testing machine as given in Pa 98. For specimens with ratio of height/diameter < 2, the measured compressive strength is multiplied by the correction factor, (1.75-0.98, 1.50-0.96, 1.25-0.94, 1.00-0.90, 0.85-0.85, 0.75-0.70, and 0.50-0.50) to get the equivalent strength of a cylinder having a height/diameter ratio of two. The equivalent cube strength of the concrete shall be found by multiplying the corrected cylinder strength by 4/3.

vi **Flexural strength of concrete**: The standard size of specimens shall be 15.2 cm sq. and 71 cm long. Where the largest nominal size of the aggregate is >1.9 cm, 10.2 cm sq. and 50.8 cm long specimens may be used. They shall be stored in water at 24 to 30° for 2 days before testing. The specimen shall be placed in the testing machine in such a manner that the load shall be applied to the top surface along two parallel lines at 4 points (i.e., spaced 20-32 or 13.54 cm apart). The load shall be applied increasing continuously at a rate such that the extreme fibre stress increases at 7 kg/sq cm/min. i.e., at a rate of loading of 408.2 kg/min. for the longer specimens and at a rate of 181.4 kg/min. for the shorter ones. The load shall be increased until the specimen fails, and the max. load is noted. The position of the cracks is noted. From the dimensions of the specimen and the load, the modulus of rupture is calculated. When the tensile crack occurs within 17.3 cm (for 71 cm long specimen) and 11.43 cm (for 50.8 cm long specimen) from either support, the results of the test shall be discarded.

vii. **Modulus of elasticity of concrete**: The compressive strength 3C of concrete is determined vide v above. Two extensometers (mirror type with roller or rocker) capable of measuring strains up to 2 × 10^-6 with a gauge length of < 10.2 cm and > half the length of the specimen are required. The specimen is removed from water, the extensometers attached on opposite sides of the specimen parallel to its axis in such a way that the gauge points are symmetrical about the centre of the specimen, and then accurately centred in the testing machine. The load shall be applied continuously at 140.6 kg/sq cm/min. until an average stress of (C+7) kg/sq cm is reached. The load shall be maintained at this stress for at least one min and then reduced gradually to a stress of 140.6 kg/sq cm taking extensometer readings. The load shall again be increased at the same rate to a stress of (C+1.4) kg/sq cm. After taking extensometer readings, the load shall be reduced gradually. The load shall then be applied a third time and extensometer readings taken up
to a stress of \((C+1.4)\) kg/sq cm. If the overall strains at the second and third readings differ by 6%, the loading cycle shall be repeated until the difference between two consecutive readings at \((C+1.4)\) kg/sq cm is \(>5\%\). The stresses and strains are calculated at various loads and for the two extensometers. The results are plotted, the two straight lines drawn, and their slopes worked out. If these values differ by \(<15\%\) of the average value, this average value is recorded as the modulus of elasticity of concrete. If the difference is \(>25\%\), the test is repeated.

The modulus of elasticity can also be found by an electrodynamic method viz., by measuring the natural frequency of the fundamental mode of longitudinal vibration of a concrete prism. For details refer to the ISS.

For design of mix, water cement ratio, slump, consistency compacting factor, and flow tests, properties of reinforcement, proportioning, curing, surface treatments, formwork, decay of concrete, and joints, refer to Ch. VII 'Reinforced concrete'.

**Concrete in Sulphate-bearing clays:** CaSO\(_4\), MgSO\(_4\), and Na\(_2\)SO\(_4\) are usually found in clay soils. The salts from the top few feet of the soil are leached by water, but considerable amounts of them are found at depths from 3 to 6 ft, or even more below the surface. The ground water in which these salts are found will be neutral or even slightly alkaline. Free acids will rarely be present in clay soils, but they may be found in conjunction with sulphate salts in marsh areas. The rate of attack of concrete by sulphate salts depends on: i The amount and nature of the salts present; ii The general level of the water-table in the ground and its seasonal variation; and iii The type and quality of the concrete and the form of construction. Concrete is attacked only by sulphate solutions in water. As Na\(_2\)SO\(_4\) and MgSO\(_4\) are far more soluble than CaSO\(_4\), they must be regarded as potentially more dangerous. The lower the alumina content and the higher the iron oxide content of the cement, the greater is the resistance. In sulphate resisting cement the ratio of iron oxide to alumina is carefully adjusted and controlled to minimise sulphate attack. Addition of pozzolanic materials to the cement also gives the same resistance to attack.

**PLASTERING**

**General:** The art of covering rough walls and uneven surfaces in the construction of houses and other edifices with a plastic composition, so as to produce a hard, smooth surface is known as *plastering*. *Plaster* is practically the same in composition as mortar but as it is not required to have so much adhesive strength, it is usual to mix a higher percentage of
sand than ordinary mortar to prevent plaster from shrinking and cracking in drying and setting. The objects of plastering are: i To give a true, plane, smooth and finished surface to the work and improve the appearance; ii To preserve the surface from weathering. Surfaces of terraced roofs, buildings built of brick and mud masonry, water channels, etc., require protection against rain and weather; iii To cover defective workmanship; iv To form cornices and ornamental patterns; and v To receive paint, paper, whitewash, etc. The exterior of good masonry composed of well-burnt bricks and good mortar, requires in general no plastering either to preserve or beautify it.

**Lime Plastering:** *First coat or rough course:* The proportion of the lime mortar used is usually 1 : 2 with chopped hemp and jaggery added for good work. The average thickness of the first coat of plaster is generally \( \frac{1}{4} \)" on brick or laterite masonry and \( \frac{3}{8} \)" on rubble masonry, the larger thickness for rubble masonry being due to the roughness or unevenness of its surface and the necessity to ensure at least \( \frac{1}{2} \)" of mortar covering to the rubble. Before the plastering is commenced, the joints in the masonry should be raked, cleaned of all moss and other dirt, if any, well washed, wetted with clean water and kept wet for at least 6 hours. The mortar joints would already have been raked as the construction of the masonry was in progress and before the mortar got quite dry. Vertical mortar *screeds* or bands are made at all corners and on the walls at intervals not exceeding the length of the mason's straight edge (5 to 7'). The surface of the screeds are made so as to be on one true plane by a free use of the straight edge. After the screeds are made, the spaces between them are applied with the plaster mortar with mason's trowels, fairly spread out, tested, pressed and rubbed with the straight edge. Then water is lightly sprinkled over the plastered surface and rubbed well with floats applying pressure with the hand during the rubbing. If a second or fine coat is to be applied, the surface of the first coat is either scored with the trowel point or beaten with a thin cane when the plaster is still moist. The surface of the first coat is kept damp till the second coat is applied.

**Second coat or floating course:** Before applying this coat, the first coat should be allowed to set but not to become dry and shall be roughened if the scoring with the trowel point or beating with the cane, as aforesaid, had not been done. The mortar for the fine coat consists of 2 parts by volume of slaked lime (not powder) and 1 part by volume of very fine, clean, sharp, white sand, screened to remove all impurities and big sized grains. Jaggery solution in water in which crushed gall-nut is
steeped is added to the mortar. The third or finishing coat is applied in a thin coat 1/4" thick, with a surface perfectly plane, and the paste well rubbed with a straight edge. It is then floated with a wooden float or rubber, and polished with a trowel or a polishing stone, water being sprinkled on as may be required, till no trowel marks are seen on the surface.

Cement Plastering: The wall should be prepared as described for lime plastering. The first or rough coat consists of cement mortar 1:3 by volume. The average thickness of the first coat will, as before, be 3/4" for rubble masonry and 1/2" for brick or laterite masonry. On concrete, the thickness will be 1/2" to 3/4". The method of application of the first coat is the same as that for lime plastering first coat. If no second or flushing coat is to be applied, the plaster should be floated with a wooden float. If second or fine flushing coat is to be applied, it should be applied without much delay. The only delay permissible is the short time within which the excess water in the rough coat which would have come to the surface in the process of rubbing with the straight edge or the float, would have been absorbed. When this water has been absorbed, the first coat will still be moist and damp and the cement in it would not have fully set hard. It is in this condition that the second coat should be applied. The mortar for this coat will be a loose paste of pure or neat cement mixed with water. The consistency will be that of thick cream. It should be applied in a thin layer not exceeding 1/2" thickness over the damp first coat, well trowelled and rubbed perfectly smooth. The finished plastered surface, whether one or two coats should be kept wet for at least 7 days commencing from the day next to that on which plastering is done. This is done by sprinkling water gently but profusely.

Moghu Plaster: 4 lime, 1 surkhi, and 3 sand are ground properly in a mortar mill and mixed with jaggery, glue, and powdered gali-nut (soaked for a day in water). The whole is ground into a stiff paste and old rope, chopped fine, is added. It is done in two coats. For plastering roofs the surface is well wetted, enough mortar applied and the mortar beaten down to 1/2" thickness with wooden knives (adding jaggery water) till it hardens. Then another coat of the same mortar is applied and rubbed smooth to a total thickness of 1" applying freely jaggery and gali-nut water. The mortar should be used up in a day and the roof kept wet for 3 weeks.

Stucco: is the name given to an ornamental facing coat of mortar on walls. It is usually done to a thickness of 1" in three coats. The scratch or rough coat, which bonds with the wall and provides the strength,
is $\frac{1}{8}$ to $\frac{3}{8}$" thick and is made up of 1:2 cement mortar with 10% by weight of hydrated lime. The second or brown coat, which straightens and trues up the surface, is of the same thickness and composition as the scratch coat. The third or finish coat, which provides the texture, is applied when the building is practically finished. Ordinarily this coat is $\frac{1}{4}$ to $\frac{3}{8}$" thick and is of 1:2 or 1:3 mortar. Coloured cement may be used, if desired. All the coats should be cured properly in order to develop strength and hardness.

**Gypsum Plasters:** General: If the gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is pure, they are white, but, if impure, they are pink or grey. Setting of such plasters is due to the absorption of water by the hemihydrate or anhydrous plaster to form gypsum and is accompanied by expansion, in contrast with lime plasters which shrink. These possess the same strength as cement mortar after a few days and too much sand causes a rapid fall in strength. The hardness of these plasters is greater than that of lime plasters. Continuous damp conditions, even 1% of water, and alternate wetting and drying affect these plasters adversely. Metals are not corroded unless soluble salts or acids are present. The sand used shall be well graded, free from impurities and sea salt, and contain the minimum of loam and clay. Hair, wood shavings, jute and coir cuttings are sometimes added in small quantities to reduce droppings, facilitate placing, and improve the key on lathwork. Different types of sulphate plasters shall never be mixed with each other or hydraulic limes and cement added as the setting and strength are affected. But all other limes may be added to reduce the expansion on setting. Gypsum plasters shall be applied only to well-set under-coats.

**Varieties:**

1. **Hemihydrate plasters:** are obtained by heating raw gypsum to 77° when it becomes the hemihydrate $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ (called plaster of Paris). This is powdered and used in two forms: a. **Plaster of Paris** (or gauging plaster). When the hemihydrate is mixed with water, it sets rapidly and hardens to gypsum in half an hour. By adding retardants like kertain and other glue-like substances the time of initial set can be delayed and the plaster made usable. Unretarded plaster is mixed with lime to reduce shrinkage and fine cracks, and used in finishing coats. b. **Retarded hemihydrate plasters:** are used for sanded under-coats, as a gauging material for lime sand under-coats, and lime and sand coarse stuff, and used neat or lightly sanded as a finishing coat to under-coats, for concrete soffits, plaster partition blocks and plaster boards. It is not suitable for positions exposed to moist conditions.

2. **Anhydrous plasters:** are made either by burning gypsum to drive
out the water or from the anhydrous natural compound anhydrite. When mixed with water, these do not set or harden. Accelerators like $K_2SO_4$, $ZnSO_4$, alum, borax etc., are added to induce slow and continuous setting. Artificial heat, dry weather, or absorbent backing causes the plasters to dry before setting. If water is absorbed by the dried plasters, it again begins to set, expand, and tend to result in buckling and cracking of the hard plasters. Hence these are not suitable in exposed damp situations. The different grades are:  

a. **Lightly burnt anhydrous plasters** are made by burning gypsum between 77° and 204°. These combine the properties of plaster of Paris with those of anhydrite and have a quick initial set followed by a slow and continuous set. These are used for the same purpose as 1 b. except on plaster boards.  
b. **Moderately burnt anhydrous plasters** are more hard burnt than 2a and are not as good as the hard burnt plasters.  
c. **Hard-burnt anhydrous plasters** are thoroughly ‘dead burnt’ and have a slow and continuous set. They are used as finishing coats and as a medium for running moulds and arrieses. The following proprietary plasters belong to this class: **Keene’s cement** (Gypsum calcined with alum) when applied as a plaster sets hard within a few days and is suitable for skirtings, angles, etc., in internal work. **Pariam cement** (Gypsum calcined with borax), **Martin’s cement** (Gypsum calcined with pearl ash), **Sirapite** (Gypsum slaked in petroleum) and **thistle hardwall** (a product of high grade gypsum with a marble like polish) are used in internal work.

**Rough-Cast or Spatter Dash**: consists of washed sand, grit or washed gravel mixed with hot hydraulic lime in a semi-fluid state. It is a cheap protection to external walls. The surface of the wall is first prick-ed up with a layer of coarse stuff upon which a coat of similar composition is evenly spread while this is wet and as fast as it is done in small portions. Rough-cast in a semi-fluid state (1:3 cement mortar) is thrown upon it with large trowels from buckets, forming a rough adhering crust, which is at once coloured with limewash and ochre. **Depeter** is a form of rough-cast where a 1:3, $\frac{1}{2}$" thick cement coarse sand rendering is given to the wall and pieces of gravel or vari-coloured flint are pressed by hand over the rendering coat while it is wet.

**Floated Surface**: The base coat is as in rough cast and the finish coat ($\frac{1}{4}$" thick) is trowelled level. When the mortar has partially set, the surface is rubbed with a wooden float till the sand comes to the surface. It is then lightly rubbed with a moist sponge to remove float marks.

**Pebble Dash**: differs from rough cast in that pebbles are wetted, thrown against the finish coat, and tamped with a broad wooden float.

**Scrapped Texture**: Here the rough cast rendering is finished to
\( \frac{1}{4} \)" thickness, and then the surface scraped with a steel rule or wood float covered with expanded metal, so as to remove the top 1/16".

**Lathing:** is fixing thin strips of timber at right angles to and on the underside of joists to form a ground for receiving the plaster. Wire netting and perforated sheet iron are now used instead of wood laths for ceilings, partitions, girders, etc. (See also ‘Laths’ Ch. V.)

**Scagliola:** is an imitation marble made from dissolving Keene's cement mixed with colouring matters in glue or isinglass; also with fragments of alabaster or coloured cement interspersed through the body of the plaster, added while the cement is in a soft condition. This is used for panels, pilasters, and columns.

**Marezzo:** is an imitation marble formed of Keene's cement, coloured and used like scagliola. It is formed upon a smooth surface.

**Sgraffito:** is a system of decorated covering for walls, and consists generally of designs in two or three colours, obtained by forming the covering in as many coats as there are colours required, and by cutting away the upper coats where required to a depth sufficient to expose the layer of the tint required. Cement is employed for external and lime for internal work.

**Painting in Fresco:** is a system of decoration in which figures are painted on the finished stucco surfaces of walls and ceilings while freshly laid and still wet, with earth colours ground with water and mixed with lime, applied to the absorbent surface of the wet setting coat of chalk lime putty and fine sifted washed river sand. The fresco basis and the colours become inseparable, the work is as hard as chalk stone, and durable if kept free from dampness. *Secco (Dry) Fresco Tempera; Mezzo (Half) Fresco and Florentine Fresco* are substitutes for true fresco on the ordinary three coat plaster work. After the work has thoroughly dried, the surface is made smooth by rubbing well with pumice stone. The surface is well wetted with water containing a little lime both on the evening of the day before painting and the morning of the next day and the work executed by tracing the outline and painting as in the case of true fresco.

**Glazed Cement Finish:** is given to a surface finished smooth with a wooden float. Three coats of cement gauged to the consistency of a thick paste with a patented liquid, which controls the set, are applied. The first two coats are brushed and the final coat is finished with a rubber stippler and then sprayed twice with cellulose.

**Parging of Chimney Flues:** For a plastic and adhesive plaster,
1 of lime putty to 3 of cow-dung by volume are mixed with enough water and applied immediately.

**Mud Plastering:** is used on walls of temporary sheds and country-side buildings. This keeps the rooms cool, besides being cheap. The plaster consists of stiff clay to which is added an equal bulk of chopped straw and cowdung, the whole being thoroughly mixed and flooded with water and left for a week or two. After this, it is floated on as for lime plaster, only in thin coats, any extra thickness required being obtained by increasing the number of coats and not the thickness of each. The subsequent coats are laid after the first coat has set (but not dried). The surface is smoothed with a wooden float and polished with a trowel. When the mud plaster has dried, it will be *leaped*, with a mixture of cow-dung, clay, and, if necessary, sand. Leaping is applied on walls with trowel and float; for flooring it may be applied by hand. Leaping is prepared as follows: The cowdung is steeped in water to free it from grass, straw, and other impurities. Equal volumes of finely powdered clay and cowdung are then thoroughly mixed in a tub.

**Defects that may arise in Plastering:**

1. The plastered surface is likely to blister due to unslaked particles of lime in the plaster. The remedy lies in keeping the slaked lime for some weeks to cool before use and screening it.
2. Cracks may be caused by injudicious hurry in attempting to lay one coat before the previous one has sufficiently set.
3. *Efflorescence:* is due to the presence of salts of soda, potash, etc., in the lime or cement and appears as a growth of crystals on the surface and in the pores of the masonry when the salt solution evaporates. The solvent is probably always water. The salt is leached from the walls by water as it slowly percolates through the pores. Some Ca(OH)$_2$ (soluble) is always found as an inevitable product of the reaction between cement or lime and water. When this soluble salt is brought to the surface by water it combines with the CO$_2$ in the air and forms CaCO$_3$ which appears as a whitish deposit called efflorescence. It usually appears after long rainy periods. In summer the rain evaporates so quickly that very little salt is brought to the surface. As it is due to absorption, measures to limit absorption to the point where insufficient water enters the mass to dissolve the salts and transport them to the surface are the best remedy. It can be entirely removed with scrubbing brushes and HCl diluted with 5 to 10 times its volume of water. Before applying the acid, the wall should be well wetted. After scrubbing, the acid should be applied and finally the surface should be washed thoroughly with water. Cast stone made from properly graded aggregates with low water-cement ratio, compacted to pro-
duce maximum density and thoroughly cured will have minimum absorption. Stucco, made from cement, and with properly graded aggregate is relatively free from efflorescence. If lime is added, it should be hydrated and free from CaSO₄. Lighter shades of stucco are not affected as much as darker shades. In the case of porous concrete, curing in presence of CO₂ enables the pores at or just below the surface to be filled with CaCO₃ and thus prevent the passage in or out of sufficient water to produce efflorescence. In cast-in place concrete structures used to retain water, watertight concrete and watertight joints must be obtained. iv Ordinary lime plaster is porous, and if the wall is not dry, damp will inevitably show through. Deposits of moisture on the interior walls or floors of a heated room are more probably due to sweating than to actual percolation of water from rains or ground drainage. Moisture from warm air will condense on a cool surface of concrete, brick, stone, metal, or glass. To prevent this condensation on walls they may be insulated either by heavy damp proof courses or by furring and plastering, thus providing an air space as insulation. Ground floors may be insulated by bedding them on 6° of well-drained gravel or cinder while upper floors seldom need insulation.

**POINTING**

**General:** Where the material (stone blocks, bricks, etc.,) can stand the action of the weather, where the workmanship is neat and good, where a smooth and even surface is not required and the natural beauty of the material is to be exhibited to view, the joints alone are pointed, instead of plastering the entire surface. Pointing prevents the displacement of the stone from the masonry or the cracking of the mortar in the joint, due to the effect of the expansion and contraction of the masonry on the less dense and hard mortar in the joint near the surface. This may be done either as the work proceeds or as the scaffold is taken down on completion of the work; the former is the stronger and more durable, while the latter is cleaner and has a better appearance. Pointing does not last permanently and hence requires repointing from time to time.

**Kinds of Pointing:** (Fig. 107 to 118). i **Flat or flush pointing:** This is flush with the face on the wall and to the width of the joint. The edges are neatly trimmed with a trowel and straight edge. It is durable and does not afford a lodging place for dust. This is adopted in the case of brick masonry and random rubble walls. ii **Keypoint pointing:** is the same as above except that an iron tool with a half round edge, called a jointer, is drawn along the centre against a straight edge to exhibit regularity in work and to make the mortar more dense. For stone masonry, the groove is made broader and deeper. iii **Flat
<table>
<thead>
<tr>
<th>Joint Type</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Flush Joint</strong></td>
<td>Same as (1) with a V-like face made by an iron tool having a similar edge. This is done for ashlar, coursed rubble, flooring, etc.</td>
</tr>
<tr>
<td><strong>Flat-Joint Jointed Keyed Joint</strong></td>
<td>Good for the bed joints and in the vertical joints of brickwork. Mortar is raked out to a depth of 1/2 to 3/4 before it has set. Pointing is done, just before the removal of the scaffolding, with the vertex of 'V' projecting beyond the surface.</td>
</tr>
<tr>
<td><strong>V-Groove Joint</strong></td>
<td>Good for the bed joints and in the vertical joints of brickwork. Mortar is raked out to a depth of 1/2 to 3/4 before it has set. Pointing is done, just before the removal of the scaffolding, with the vertex of 'V' projecting beyond the surface.</td>
</tr>
<tr>
<td><strong>Weather Joint</strong></td>
<td>V Tuck or raised pointing is used for new or old work, but more often for the latter. The joints are raked out, brushed, well-watered, and then filled flush with coloured mortar to match the masonry. A groove 1/4&quot; wide and 1/4&quot; deep is immediately formed along the centre of each joint, and filled or tucked in with white lime putty, which is left to project beyond the face of the joint by 1/2&quot;. This looks neat and attractive, but the band of lime putty, called ridge or fillet, is not durable.</td>
</tr>
<tr>
<td><strong>Tuck Pointing</strong></td>
<td>V Tuck or raised pointing is used for new or old work, but more often for the latter. The joints are raked out, brushed, well-watered, and then filled flush with coloured mortar to match the masonry. A groove 1/4&quot; wide and 1/4&quot; deep is immediately formed along the centre of each joint, and filled or tucked in with white lime putty, which is left to project beyond the face of the joint by 1/2&quot;. This looks neat and attractive, but the band of lime putty, called ridge or fillet, is not durable.</td>
</tr>
<tr>
<td><strong>Bastard Pointing</strong></td>
<td>V Tuck or raised pointing is used for new or old work, but more often for the latter. The joints are raked out, brushed, well-watered, and then filled flush with coloured mortar to match the masonry. A groove 1/4&quot; wide and 1/4&quot; deep is immediately formed along the centre of each joint, and filled or tucked in with white lime putty, which is left to project beyond the face of the joint by 1/2&quot;. This looks neat and attractive, but the band of lime putty, called ridge or fillet, is not durable.</td>
</tr>
<tr>
<td><strong>Overhead Struck</strong></td>
<td>V Tuck or raised pointing is used for new or old work, but more often for the latter. The joints are raked out, brushed, well-watered, and then filled flush with coloured mortar to match the masonry. A groove 1/4&quot; wide and 1/4&quot; deep is immediately formed along the centre of each joint, and filled or tucked in with white lime putty, which is left to project beyond the face of the joint by 1/2&quot;. This looks neat and attractive, but the band of lime putty, called ridge or fillet, is not durable.</td>
</tr>
<tr>
<td><strong>Struck Joint</strong></td>
<td>V Tuck or raised pointing is used for new or old work, but more often for the latter. The joints are raked out, brushed, well-watered, and then filled flush with coloured mortar to match the masonry. A groove 1/4&quot; wide and 1/4&quot; deep is immediately formed along the centre of each joint, and filled or tucked in with white lime putty, which is left to project beyond the face of the joint by 1/2&quot;. This looks neat and attractive, but the band of lime putty, called ridge or fillet, is not durable.</td>
</tr>
<tr>
<td><strong>Recessed Joint</strong></td>
<td>V Tuck or raised pointing is used for new or old work, but more often for the latter. The joints are raked out, brushed, well-watered, and then filled flush with coloured mortar to match the masonry. A groove 1/4&quot; wide and 1/4&quot; deep is immediately formed along the centre of each joint, and filled or tucked in with white lime putty, which is left to project beyond the face of the joint by 1/2&quot;. This looks neat and attractive, but the band of lime putty, called ridge or fillet, is not durable.</td>
</tr>
<tr>
<td><strong>Pointing Old Work Joint in Rendered Wall</strong></td>
<td>V Tuck or raised pointing is used for new or old work, but more often for the latter. The joints are raked out, brushed, well-watered, and then filled flush with coloured mortar to match the masonry. A groove 1/4&quot; wide and 1/4&quot; deep is immediately formed along the centre of each joint, and filled or tucked in with white lime putty, which is left to project beyond the face of the joint by 1/2&quot;. This looks neat and attractive, but the band of lime putty, called ridge or fillet, is not durable.</td>
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**Fig. 107 to 118.**

Joint V shaped groove pointing: is same as (1) with a V like face made by an iron tool having a similar edge. This is done for ashlar, coursed rubble, flooring, etc. iv Weather pointing: is good for the bed joints and in the vertical joints of brickwork. Mortar is raked out to a depth of 1/2 to 3/4 before it has set. Pointing is done, just before the removal of the scaffolding, with the vertex of 'V' projecting beyond the surface. v Tuck or raised pointing: is used for new or old work, but more often for the latter. The joints are raked out, brushed, well-watered, and then filled flush with coloured mortar to match the masonry. A groove 1/4" wide and 1/4" deep is immediately formed along the centre of each joint, and filled or tucked in with white lime putty, which is left to project beyond the face of the joint by 1/2". This looks neat and attractive, but the band of lime putty, called ridge or fillet, is not durable. vi Bastard or half-tuck pointing: This is similar to the tuck pointing but the projecting band is of the same pointing material. Though not so pleasing in appearance as the tuck pointing, it is more durable. vii Struck pointing: (also called ruled pointing) is done generally, to works done with cement mortar, and consists in keeping the upper side of joint about 1/4" inside face of masonry and bottom flush with exterior or face of masonry. This is done as the work proceeds and before the mortar in the joints sets. viii Recessed pointing: is used for good textured bricks and good quality mortar. The mortar is pressed behind the wall face and left vertical. This is not usually recommended. ix Overhead struck pointing: Here the mortar is finished with a slope opposite to that in the case of struck pointing. It is
not usually recommended as the water collecting in the ledges may pass through the mortar and cause dampness inside.

**Precautions:** The old mortar should be raked out from the joints of the masonry 3" deep and all the dust brushed out of the joints. The walls should be well dusted or washed with wire brushes, if necessary, so that no loose particles remain in the joints. The masonry at the joints should be damp at the time of doing the pointing. The joints are then filled in with fine mortar (Lime pointing: 1 Lime, 1 sand, a little wood apple being added at times; Cement pointing: 1 Cement, 1 Fine sand). When the joint is completely filled with the mortar, the mortar in the case of *ordinary pointing* should be rubbed and pressed hard into the joints with a trowel, narrow enough to go into the joint in order to produce practically a flush but slightly concave joint. All excess mortar sticking to the sides should be scraped away. Lime pointing should be kept wet for 3 days, and cement pointing for 10 days, after the work is finished.

**WHITE AND COLOUR-WASHING**

Plastered walls, exterior, and interior and ceilings are generally white or colour-washed for appearance, and sanitary reasons. Lime is said to possess antiseptic and disinfectant properties. The whitewash should be prepared from fresh burnt shell lime, or stone lime where shell lime is not available. The quick lime should be slaked to a paste. The lime is mixed in a tub with a sufficient quantity of clean water and the whole well mixed. When thoroughly mixed, the mixture should be strained through a clean cloth. Clean gum arabic dissolved in hot water is then added to the mixture in the proportion of 2 oz. gum arabic to 1 c. ft. of lime. Or *rice size* (a mixture of rice flour and hot water) may be added instead of gum arabic. Sometimes a small quantity of CuSO₄ is added to the dilute paste to prevent glare and give a pleasing effect. If the washing is to be colour-washing, the required colouring material will then be added.

Before whitewash or colour-wash is applied to *new walls*, the walls should be well cleaned and brushed. On walls which have been *previously white washed*, the old loose whitewash or colour-wash should first be removed and repairs to the plaster of the wall done wherever found necessary. All holes should be filled with lime *putty*. If the surfaces are discoloured by smoke, a wash made of wood ashes and water should be applied before a new coat is given. Moss or other discoloured portions of the walls should be cleaned by rubbing and washing. Whitewash or colour-wash should always be laid on with a brush; one coat with a stroke of the brush from the top downward, another from the bottom upward
over the first coat; similarly one stroke from the right and another from the left over the first brush before it dries. Three coats will be given for new work.

For whitewash or colour-wash which will not easily rub off, the following is a recipe: Take 1 cwt. of clean white shell lime. Shake it thoroughly with hot water in a covered vessel. Add 14½ lb. salt dissolved in hot water, 8½ lb. coarse rice pounded or boiled to a thick paste, and 1½ lb. glue obtained by dissolving in hot water, the dirty refuse being rejected. The above ingredients will have to be thoroughly mixed and brought to the consistency required, by the addition of hot water, and then allowed to simmer over a fire for a few hours. Then strain and lay on hot. This quantity will suffice for whitewashing 112 ÷ 6 = 18 2/3 or say 18 squares, 3 coats. According to the tint required, wash may be prepared by the addition of the following pigments: Yellow—Yellow earth or Ochre; Blue—Burnt cocoanut shells; Pink—Vermilion; Buff—Raw umber and Lamp black; Fawn—Umber, Indian Red, and Lamp black; Green—Fresh mango bark and CuSO₄; Slate—Lamp black and burnt cocoanut shells.

CHAPTER IV
TIMBER

General: Timber: Wood suitable for building purposes with a girth of < 24". Sapling: Wood with a girth of < 24". Standing timber: Standing tree capable of conversion into timber. Rough timber: Standing timber felled. Log: Rough timber with barks removed and roughly hewn. Converted timber: Timber sawn from the log. Timber: a. When < 3" wide and under 6 sq. in. sectional area, it is called as 'fillet' or 'batten for roofing'. b. When 3" × 2" and over, and 2" thick or over with sectional area 6 sq. in. and over, as ' scantlings' without any upper limit, and c. When < 2" thick and the width is 3" or over, as 'boarding'.

Growth and Structure of Trees: Trees grow in two ways: i By the addition to their external surfaces, of rings of young wood. Such trees are called exogens e.g., Teak, Sal, Babul, etc.; and ii Partly by the formation of layers of new wood crossing and penetrating the fibres of the wood previously formed and intermixed with them; such trees are called endogens e.g., Palmyrah, Cocoanut, etc. Timber for engineering works is obtained from exogenous trees only as the stems of endogenous trees, though light and tough, are too flexible and slender to furnish materials for carpentry work. These are classified as: i deciduous or
shedding leaves in winter; and 2. evergreen or not shedding their leaves until the new ones have grown. Timber is obtained from the former.

Timber trees grow and increase in girth by the addition of roughly concentric rings under the bark. These rings are added every year. They are often well marked and their number indicates how many years old the tree is. The new wood from the bark for some distance towards the centre is called sap-wood or alburnum and it is generally lighter in colour than the wood nearer the centre. This new wood is called sapwood because it is chiefly through this portion of the tree that the sap rises to form the leaves. Sap is the juicy food for the tree and it is drawn by the roots of the tree from the soil of the ground on which it has grown. In tropical countries like India, the sap rises during the rainy season and the spring which follows it and the tree puts on leaves. It descends during the dry season when the leaves which have ripened gradually fall off. Thus the ascent and the descent of the sap can be recognised respectively by the tree putting forth new leaves and by its shedding the leaves. The circulation of the sap entirely stops during a portion of the year when the leaves also fall off the tree (during the dry season in tropical climates, and during the winter in temperate and polar climates). So, the wood and the bark are usually formed in distinct layers at the rate of one each year, though the rule is not universal. The sap gives out its moisture through the leaves and takes in CO₂ from the air, and the organic matter, which makes for the growth of the tree, is formed. When the sap descends, this organic matter is deposited in the cells of the interior portion of the sapwood and hardens it and a hard ring is thus formed. It also feeds similarly the interior rings and makes them harder and stronger. Thus the older wood in the interior gradually hardens and becomes heart-wood or duramen, the change from sap-wood to heart-wood occupying 10 to 30 years. The concentric rings in the heart-wood are closer to one another than those in the sap-wood. This is softer, weaker, less compact and sometimes lighter in colour than the heart-wood and can generally easily be distinguished. The strengthening of the wood is caused in nature by: i the drying up of the sap and consequent hardening of the rings; and ii the compressive action of the bark. Heart-wood near the pith gradually ceases to convey sap. Trees grown in large forests produce the greatest length of timber; but those grown in dry open situations yield the hardest and most compact wood.

The wood and bark consist of: i Cellular Tissue: formed of clusters of minute cells; and ii Vascular Tissue: or woody fibre, which are bundles of slender tubes. The fibres or tubes of vascular tissue are simply
elongated cells tapering to points at the ends and breaking joint with each other. When a tree is cut across, we notice the following, (Fig. 119) starting from the interior; 

**Pith, medulla, or heart:** is the soft portion at the centre of a tree. This consists entirely of cellular tissue and varies in size and shape according to the species; **Medullary sheath:** is the layer in the immediate neighbourhood of and enclosing the pith (vascular tissue). **Medullary rays or transverse septa:** are thin partitions of cellular tissue radiating from the pith to the bark. Between these medullary rays, additional medullary rays extend inwards from the bark to a greater or less distance but not reaching to the pith. The cells in these rays act as reservoirs of tree food. **Annual rings:** consist of innumerable closed cells (not longitudinal tubes) of woody fibre and cellular tissue. Transfer of moisture takes place by absorption through the cell membranes. Solids can be absorbed only when in solution. **Woody fibre:**; bundles of vascular tissue, lies between the medullary rays arranged in nearly concentric rings or layers, round the pith. These rings, as already explained, result from the annual deposit of sap. The rings are not of the same thickness all round. The rings are thicker on that side of the tree which is exposed to sunshine and rain, on which the roots have grown with most vigour due to the nature of the soil or greater nutrition or food. **Bark or cortex:** is the outermost covering surrounding the stems. The bark protects the exterior of the tender sap-wood and consists of cells and woody fibre. **Cambium layer:** is the soft ring surrounding the outermost ring of sap-wood and is protected by the outer dead and the inner living bark.

**Grain of Wood:** is a term which denotes the general direction or arrangement of the fibres and other wood elements. Wood is coarse-grained if its annual rings are wide, and fine-grained if they are narrow. When the direction of the wood fibres is parallel to the axis of the stem or branch in which they occur, the wood is said to be straight-grained. If spiral or twisted round the tree (as in the case of the casuarina tree) or
oblique in different directions, the wood is said to be twisted or cross-grained. Generally speaking, trees growing in large forests are straight-grained while those growing in open plains are cross-grained. Owing to heavy gusts of winds bending trees and making them sway in different directions depending on the direction of the wind, the even and straight growth of the fibres is disturbed giving rise to cross-grained wood. When the medullary rays are large and distinct, they are called silver grain (e.g., Oak, Chittagong wood, white cedar).

**Classification of Timber:** Timber used in buildings is classified into two classes: i Soft or Fir or Pine wood; and ii Hard or Leaf wood. This division has been established by long usage and is not in accordance with the relative hardness of the woods (as certain soft woods are harder than hard woods) but is concerned with the specific species of the trees. Thus soft woods are a group which is confined to conifers which are evergreen (having leaves throughout the year) trees having needle-like leaves and which bear cones (seeds contained in conical sheaths), whilst hard woods form a class of broad leaf trees which cast or shed their leaves as stated previously.

1. **Soft woods:** are characterised by: i distinct annual rings; ii indistinct medullary rays; iii comparatively light colour; iv heartwood and sap-wood are not readily distinguished; v pores filled with resinous matter; vi fibres straight and able to resist pull or tension; vii lateral adhesion of fibres weak; and viii consequently they split easily. Pine, fir, etc., belong to this class and are useful for masts, spars, etc.

2. **Hard woods:** are characterised by: i less distinct annual rings which are closer together than in soft woods; ii distinct medullary rays; iii richer colour; iv darker coloured heart-wood which is readily distinguished from sap-wood; v non-resinous; vi nearly equally strong along and across the fibres; vii wood more flexible, tough, and strong; and viii capable of bearing tension, compression, and transverse strain such as bending and so suitable for building work. Teak, mahogany, sal, oak, etc., belong to this class.

**Felling of Timber:** After the tree passes maturity, which is attained in about 30 to 200 years, the heart-wood is liable to shaves and cracks. The tree is most valuable for timber just before this occurs and therefore the tree should be felled just before its maturity. If the topmost branches look green and put forth shoots, maturity is not passed. Immature trees contain too much sap-wood and are therefore not strong. Felling should be done as near the ground as possible. In tropical countries, the dry season is the best and in cold countries either mid-summer
or mid-winter. During these periods sap, evaporation of moisture, and shrinkage will be comparatively small. In the case of valuable trees, like sandal, the anchor roots are cut and the tree is pulled over with a common hack or chain lever. Felling should be done with axes, saws, wedges, and wire cables taking care to prevent splitting of timber when falling. Trees on slopes should be so felled as to fall on the uphill side. The branches are lopped off, the bark is stripped, the ends cut square, and then the timber converted into required sizes by saws.

Teak and similar timbers, which are toxic to fungi, are girdled or ringed 2 to 3 years before felling. The process consists in cutting a chase all round the trunk of the tree, just a little above ground. The essential oil and moisture evaporate. The timber, thus treated, is easy to work, but loses its strength and durability. Though Burma teak is ringed, yet Malabar teak is not ringed. Hence the latter retains its oil, is stronger, more durable, and less easy to work. At both these places, the logs from the forests are dragged by elephants to the nearest river and floated down in rafts.

Preliminary Treatment and Storage: As the process of drying starts soon after the tree has been cut, the timber shall be protected from the early stages of seasoning against rapid drying caused by exposure to sun and hot winds. The bark shall be removed and the log kept submerged under fresh water. If this is not possible, it shall be stored on land or raised platforms under shade. Before stacking, a prophylactic treatment (vide 'Preservation of Timber') will have to be given. The logs, for a distance of 3 in. from either end shall be coated with thick coal tar, bituminous paint, resin, and lamp black (melted, mixed, and applied hot), hardened gloss oil, paraffin wax, or molasses and lime to prevent end-splits. These shall be stacked in closed stacks in one or more layers on foundation prepared as follows: Vertical pillars of treated timber, brickwork, or concrete 30 cm sq. and 30 to 45 cm high are arranged at 120 to 180 cm along the length and width of the stacking yard on high ground, under shady trees, and well-fenced. Long beams 10 cm sq. and above are placed over the pillars to form the framework. The logs, kept over this framework, shall, if possible, be frequently turned as irregular drying will cause splitting.

Railway sleepers: shall be stacked according to i the one-in-nine method for moderately heavy timbers, particularly coniferous sleepers in hot climates and for heavy timbers in moist climates; and ii the close crib method to give slower seasoning for refractory timbers like sal
in hot and dry localities. The open crib method (Fig. 120) is a modification of the close crib method and allows more air circulation. **Poles:** shall be stacked either in closed heaps (butt ends and top ends alternating to keep the stacks level) or with crossers 3.8 cm sq. placed 2.5 to 3 m apart. While fence posts shall be stacked in open crib fashion, **bamboos** shall be stacked in closed heaps with vertical pillars fixed on the ground at 2.5 m apart on the two sides of the stack running along the length. **Scantlings and baulks** shall be stacked like poles with crossers and **planks** on level foundations of skids in a shed. Longest planks shall be at the bottom and the shortest ones at the top.

**Conversion of Timber:** The process is somewhat as follows: The ends of each log having been cut square to the length, the proposed scantlings are marked on each end with twine rubbed with chalk or dipped in a mixture of charcoal and linseed oil. A string rubbed with chalk is then stretched along the log, connecting the extremities of **through cuts** with corresponding points at the other end of the log, and the chalk line thus produced serves as guide to the sawyer. The sawing is then proceeded with, other longitudinal lines, being afterwards marked on the cut surfaces as a guide for the cuts which are horizontal. The scantlings are built up again in order to measure the area of saw cut, according to which the sawyers are paid. Sawing on a large scale is done by machinery driving circular saws or vertical saws fixed in a frame, or endless band saws. In converting timber as described into planks and scantlings, due allowance should be made for shrinkage, squaring, and planing—generally ½ to ¾”. Beams should be sawn out of timber in such a way that they should not contain the pith of the tree. This is done by first sawing the tree into halves through the pith. The strongest pieces of timber are
those obtained by making the saw cuts as nearly as parallel to the direction of the medullary ray, and at right angles to the annual rings, as shrinkage takes place chiefly parallel to the direction of the annual rings.

The usual methods of conversion and the effect of shrinkage on them are given below: Wood shrinks most circumferentially, the medullary rays resisting lateral shrinkage. The sapwood shrinks much more than the heart-wood. Fig. 122 shows the effect of shrinkage upon planks obtained by means of saw cuts, tangential to the annual rings, called ordinary sawn which is most economical as far as out-turn of useful timber is concerned. The plank A in Fig. 121 containing the heart will not shrink much at the centre, but will shrink in thickness at the edges and become round as in Fig. 122. The intermediate planks B, C, etc., shrink and warp becoming convex on the side nearer the heart and concave on the further side, which decrease considerably in breadth. The thickness is the same at the centre, but decreases slightly at each end. The two outermost

![Diagram of Shrinkage on Quartered Log](image1)

![Diagram of Tangential Sawn](image2)

![Diagram of Rift Sawn](image3)

Fig. 124.  
Fig. 125.  
Fig. 126.

planks retain their thickness but have warped to a maximum. With quarter sawing, (Fig. 123) the wood tends to curve in a transverse direction. In the case of woods with distinct medullary rays, this method produces very fine figurewood. Fig. 124 B shows one quarter of a log when freshly cut. After some time it changes to the shape shown in A. The lines ac and ab retain their lengths but are not at right angles, the circumference bc having contracted considerably. The annual rings contract and bring the stiff medullary rays closer retaining their lengths. Tangential sawing (Fig. 125) produces boards which are not quite suitable for flooring.

**Hard timber** is converted by rift radial sawing (Fig. 126). Method A which is most wasteful, is employed for cabinet work and other ornamental purposes; B is next best; C is inferior to A and B; but that at D is similar to quartering and is most economical where large scantlings are required. **Soft timbers**: like fir, pine, etc., are converted as shown in
Fig. 127. In A there are 4 deals. Cut thus, the pith comes to the surface of the deal. The pith is allowed to remain in carpentry but disposed of in resawing in joinery. If the pith remains in the middle as in the case of 3 deals from a log, dry rot may set in from the early decay of the heart. B shows another method where a square piece sufficiently large to include the pith is cut off. Two deals are obtained and the two side pieces are resawn into battens or planks.

**Measurement of Logs:** The usual method of measuring round or rough squared tapering timber log is to take quarter-girth under bark at the middle and at each end. Calling these G, \( g \), and \( g' \) respectively, the area of the mean section is \( \frac{(G + g + g')^2}{3} \) or more roughly, the mean section may be taken as \( G \). Quarter girth is obtained by dividing the girth measured by a tape by 4. Thus, if the girth is 40", the quarter girth is 10". Convert the mean area into s. ft. and multiply this by the length of the log in feet to get the contents in c. ft. in terms of which the timber is sold. If the bark is on, deduct 1/12 of the girth before dividing by 4 to obtain the quarter girth. If the girth is \(< 24"\), it is not considered as timber, so that, in measuring standing timber, the height should be taken only up to where the girth is 24". ISS gives volume as \( (\text{Mid-girth})^2 \times \text{length}/4\pi \).

**Maximum permissible moisture content:** IS 287/1951 divides India into four zones and recommends the following for timber used in different climatic zones (the lower figure is for the dry area like Rajasthan and the higher for a humid area like Assam and West coast):

*For toys, household goods, pattern making, automobile bodies, shuttles and bobbins 8 to 12%; ii For furniture, doors and windows, carts and vehicles, sports goods and deck of ships and boats 10 to 16%; iii For agricultural implements, beams and rafters, and frame and planking of ships and boats 12 to 20%; and iv For sleepers, posts, and poles - To be left stacked in open air for at least six months.

**Seasoning of Timber:** denotes means adopted to reduce the moisture to an amount suitable for the purpose for which the timber is to be used. The objects of seasoning are:

1. To increase its strength,
durability, workability, and resilience; ii To reduce the tendency to split, shrink and warp; To make it immune from the attack of insects and fungi; iv To reduce its weight and thus minimise the cost of transport and handling; v To make it receptive to finish (preservatives, paints, and polishes); and vi To make it burn readily, if used as a fuel. The ISS gives, for various kinds of timber, the permissible moisture content at different temperatures and relative humidity.

The methods of seasoning are:

1. **Natural or air seasoning**: This is a slow process. It is carried out in three types of sheds: i with roof, side walls, adjustable shutters at top and bottom of walls to control ventilation and gates at two ends for movement of timber. This is used for refractory hardwoods like sal, asna, etc., in hot and dry climates; ii With roof, and walls on three sides, north being open. This is used for moderately refractory timbers like teak and shisham, practically all over India except in very moist climates; iii With roof supported on pillars, all sides being open. This is used for refractory and moderately refractory timbers in very moist climate and non-refractory timber in a dry climate. The time required for seasoning depends on; a. the kind of timber, b. the moisture content of the timber, c. the method of stacking, and d. the atmospheric conditions during drying. The approximate time required is 3 months for 1" thick softwood, 4 months for 2", 6 months for 1" hardwood, and 12 months for 2". The moisture content of the timber should be determined when it is first piled, then at regular intervals, and thus the process of seasoning checked. An air-seasoned timber contains about 25% moisture. Timber is considered seasoned for carpenters' work when it has lost 1/5 of its original weight; for joiner's work when it has lost 1/4. Many timbers require a second seasoning after they have been worked. They should be left as long as possible after being worked, and before being jointed and fitted. Success or failure in air-drying depends to a large extent on the weather. A hot dry spell after stacking a refractory timber causes it to split badly. A warm humid spell in spring or summer causes freshly-stacked softwoods to stain badly. Drying can be slowed down by restricting the flow of air. Timber seasons faster under cover than when left exposed.

2. **Artificial seasoning or kiln drying**: reduces the time required for adequate seasoning and produces timber with lower moisture content than is obtainable under the most favourable natural conditions. Here drying is faster than in air seasoning because circulation of air is more rapid and the use of higher temperature causes the moisture within the timber to move more rapidly to the surfaces from where it can be
evaporated. As ordinary saturated air becomes undersaturated when warmed, a certain amount of moisture should be added to the air so as to maintain the evaporation of water from the timber at a safe level. The temperature of the kiln (82 to 100°), and the humidity of air should be controlled. Uniform circulation of air should be maintained. The steaming treatment prescribed is meant to relieve the case hardening stresses in timber during and towards the end of seasoning, to accelerate the drying process, and to control degrade, particularly cracking and splitting.

**Types of kilns:**

*a.* **Natural draught or compartment kilns:** in which circulation of air is maintained in accordance with the laws of convection. Air is heated in the basement of a long kiln, 8' wide, 10' high, built with cavity walls to minimise heat losses, humidified by steam or water jets, and rises. It comes up between two stacks of timber, stacked as for air-seasoning. As the top of the kiln is closed, and as the air is sucked from the sides, the air enters between the rows of timber, gets cooled and humidified and either escapes out completely or enters in part into the basement and gets mixed up with fresh air. The temperature of the kiln is kept low for timber likely to warp, of a resinous nature, and when the white colour of certain varieties is to be preserved; while it is kept high if the timber has no marked tendency to split, but retains patches of moisture in the centre. This kiln can also be worked as a forced-draught kiln.

*b.* **Progressive kilns:** in which the timber travels progressively from one end to the other in the opposite direction to a current of hot air. The timber thus gets gradually dried. The air is usually of the natural-draught type, but forced-draught may be used.

*c.* **Natural-draught kiln with reversible circulation:** Its advantage over the simple type *a* is that hot dry air is admitted to just those points most likely to accumulate damp, heavy air. This is effected by reversing the direction of the circulating air by duplicating the heating, humidifying, and air exhaust arrangements. This kiln shows a decided saving in drying time in the case of wet timber.

*d.* **Steam-jet kilns:** is just a natural draught kiln with steam-pipes provided with special nozzles (instead of mere holes) which are surrounded by metal truncated cones open at both ends for humidifying the air. Increased circulation of air and faster drying is possible in this kiln.

*e.* **External-fan kilns:** is a forced-draught kiln with the air circulating mechanism outside the kiln. This dries timber more rapidly than natural-draught kilns. Uniform delivery of air is not possible owing to the long duct.

*f.* **Internal-fan kilns:** is a forced-draught kiln with the entire circulating apparatus inside the kiln. Several fans operate at different points and ensure uniform circulation of air. With steam heating, sec.
tions up to 5 cm thickness of most of the hardwoods (except the very refractory ones like sal) and thicker ones air-seasoned up to 30% moisture content can be seasoned. With furnace using sawmill waste, packing case timbers can be rapidly seasoned. In either case, electric power is required for driving the fans.

3. Water seasoning: The time occupied in seasoning is much reduced by this process. By this method, the logs may be floated down a river to the timber depot, or totally immersed in water (in the river with their butt ends facing upstream) for sometime, generally about a fortnight or a month. By doing so, a greater part of the sap is washed out. They must then be taken out of the water and stacked on the sandy bank in an inclined position and thus dried by exposure to air. Timber thus seasoned is less liable to warp and crack but is rendered brittle and its strength is reduced. Boiling in water shortens the period and reduces the shrinkage but is expensive and in most cases impairs the strength and elasticity. Bapul tree, however, gains strength by boiling, the only condition being a cover free from a current of air is necessary for subsequent drying. Steaming or subjecting the timber to hot saturated air produces the same effect as boiling. It prevents dry rot and enables the timber to be bent to any shape.

4. Chemical or salt seasoning: The green timber is soaked in saturated salt solution, then removed, and seasoned in the ordinary way. The principle of this method is: The vapour pressure of a salt solution is less than the normal vapour pressure of water. Hence unsaturated air will not evaporate moisture from the solution until the humidity (75%) is below the point at which it will be in equilibrium with the vapour pressure of the solution. As it is only a surface dipping that is effected, the interior moisture is drawn out and the inside dries in advance of the outside. The tendency for external splits to form is reduced. The same principle can be applied using a mixture of organic vapours and water vapour, in which case hot gases can be passed instead of air through timber in a kiln.

5. Electrical seasoning: uses ultra-short waves (of wave length about 5 metres) and dries the timber very rapidly. The timber gets heated internally and the moisture flows to the surface.

Defects in Timber: 1. Natural: These are due to the nature of soil on which the tree has grown and by the vicissitudes to which it was subjected while growing. These may be classified as:

a. Knots: (Fig. 128) A knot is a branch or limb embedded in the
tree which has been cut through in the process of conversion. It is almost impossible to obtain certain converted timbers, entirely free from knots. Timber containing many knots is difficult to work. Knots are a source of weakness if present in timber to be used as struts, pillars or similar members. They are classified as:

- **Pin knot**: > 6.5 mm in diameter;
- **Small knot**: > 6.5 mm and > 20 mm in diameter;
- **Medium knot**: > 20 mm and > 40 mm in diameter;
- **Large knot**: > 40 mm in diameter.

They are classified according to form as:

- **Dead knot**: A knot in which the fibres are not completely intergrown with those of the surrounding wood.
- **Decayed or unsound knot**: A knot infected by fungi.
- **Loose or large knot**: A knot not held firmly in place by growth or position. Timber with these knots should not be used, as they are unsightly and readily removed.
- **Tight knot**: A knot firmly held in position and hence is not objectionable.
- **Sound or live knot**: A tight knot, free from decay and cracks and firmly joined throughout to the surrounding wood.
- **Unsound and rotten knot**: A knot which is decayed and is softer than the surrounding wood.
- **Spike or splay knot**: A knot sawn lengthwise to its axis.
- **Round knot**: A knot cut at right angles to its long axis. The cross-section may be round or oval.
- **Knot cluster**: A group of knots so formed that the wood fibres are entirely deflected round the group.

b. **Wind cracks**: (Fig. 129) are shakes or splits on the outside of a log caused by the shrinkage of the exterior surface caused by atmospheric influences.

c. **Rindgalls**: (Fig. 130) are peculiar curved swellings, caused generally by the growth of layers over the wood remaining after a branch has been imperfectly chopped off.

d. **Wandering heart or twisted grain or spiral grain**: (Fig. 131). Fibres are twisted by wind to such an extent that a relatively large number is cut through when the log is sawn into planks, etc.; such timber will twist or warp. These can be used only as poles in unsawn condition when the twisted fibres may give them even extra strength.
e. *Upset or rupture:* (Fig 132). A fracture of the fibres more or less across the log caused by excessive compression induced by bending resulting from natural or other causes like floating of the log.

f. *Shake or crack:* A partial or complete separation of the fibres along the grain. *Heart shake:* (Fig. 133). A radial shake beginning at the heart or pith of the log. A single shake is not very serious. The shakes are in some cases hardly visible; in others, they extend almost across the tree, dividing it into two to four segments. The worst form is the one in which the splits twist in the length of the tree. *Star shake:* (Fig. 134). A number of heart shakes more or less in the form of a star. This renders the conversion of the timber difficult and uneconomical. This is an early sign of decay and is caused by shrinkage in an overmature tree. *Ring or cup shake:* (Fig. 135). A crack or cleft developed between two adjacent annual rings. It interferes with conversion of timber, resulting in waste. It is caused by the sap freezing during its ascent in the tree. A number of such shakes makes the tree generally useless for conversion into scantlings or planks. *Shell shake:* Part of a ring-shake showing on the surface of converted timber.

g. *Deadwood:* Timber produced from dead standing trees, usually applied to redwood. This is distinguished by its light weight, abnormal pinkish colour, and low strength.

h. *Coarse grain:* It is caused by the tree growing very rapidly. The annual rings are very wide and the timber, though strong, is not durable.

i. *Chemical stain:* A discoloration caused by chemical action between the wood and some extraneous substance.

j. *Water stain:* A discoloration caused by water coming into contact with converted timber.

k. *Burr or burl:* A large excrescence on a tree trunk or an enlarged rootstock with highly contorted grains.

l. *Callus:* Tissue which covers the wound of a tree,
2. *Due to fungi:* Certain kinds of fungi attack timber when sufficient moisture and air, adequate food material, and proper temperature exist and cause its decay. The kinds of decay are:

a. *Wet rot:* is caused by chemical decomposition of the wood of the timber, when it is exposed to acidulated atmospheric moisture and dryness alternately, especially when the moisture cannot evaporate freely. The structure of the trees (fibres and material connecting them) is specially susceptible to such conditions which act not only at the part exposed to them but considerably spread in all directions. Alternate swellings (due to moisture) and shrinkages (due to dryness) soon destroy the fibre cohesion and result in comparatively rapid oxidation (which shows itself by a reddish purple tint) and the final conversion of the wood into powder. It may also be due to the fungus *Ceratosonella* which gives rise to 'blueing'—a grey or greenish blue stain initiated in the sapwood of softwoods, and spreading to the heartwood. The fungus attacks only unseasoned or poorly seasoned wood left exposed to wind and rain.

b. *Dry rot:* which is also a serious form of decay, is on the other hand, caused by the attack of fungi, especially *Merulius lacrymans* on the timber, then feeding on the wood and causing putrefaction of the wood. It chiefly attacks sapwood and unseasoned softwoods. Insufficient and improper seasoning of the timber and the speed with which the construction of modern buildings is rushed to completion are favourable contributions to this attack, and highly conducive to the setting of dry rot. The fungus growth is propagated by spores which are spawn of the fungus. These spores have the capacity of lying latent or dormant for an indefinite period until they find themselves in environments favourable to their growth. Any timber, healthy or otherwise, may be infected with these spores in the following ways: i In the forest, after felling, if the timber is stored in the neighbourhood of infected wood or ground; ii during storage in the timber yard or depot; or iii by transmission of the spores on the clothes or tools of the workmen.

The favourable environment for the development of the spores and the growth of the fungus is warm, damp, and stagnant atmosphere, such as exists in unventilated cellars or basement stories of buildings, and where timbers are covered in by air-tight, hard, plaster ceilings below and carpets (such as linoleum) above. Once the developed spores have reached the seeding stage in the form of snuff coloured powder, moving air simply assists the distribution. Apart from this, the resulting fungus has the power of spreading by attracting to itself sustenance from the moisture in
the air or from the material on which it grows to such an extent that water may sometimes drip from the surface of the fungus.

Red stripes on the sawn wood are first evidence of dry rot. The result of dry rot is that the timber becomes speckled, and loses weight. Dry rot can be discovered or identified by the characteristic smell, the dull muffled sound on tapping, and the soft powdery nature of the wood on boring. The spores can be destroyed by thorough seasoning and drying before the erection of the timber. Partial seasoning renders the spores only latent or dormant. Other precautions to be taken to prevent the development of rot are the following: i The timber, should not be subjected to alternations of wetness and dryness. This is effected by proper painting or varnishing of the timber, taking care that the timber is thoroughly dry before applying the paint or varnish; ii Where such alternations are unavoidable, and when painting or varnishing is inappropriate or much too costly, as in the case of railway sleepers, or timber pile foundations in damp soil, suitable class of timber should be used (such as thembagom, teak, ironwood or eruvoor) and they should be impregnated with creosote. Treatments with magnesium fluosilicate, sodium salt of 2:4 dinitrophenol, and sodium salts of dinitroresol, and soaking in boric acid are also adopted; iii No timber, to be used in a structure, should have any sap-wood in it; and iv In erecting timber in a structure, especially at the ends, which rest on masonry or are built into masonry, ample provision should be made for the circulation of air round the timber.

When present, the only safe remedy is to cut out the portion of wood attacked, in its entirety, and then to kill spores in the walls by flame treatment, followed by washing with a solution of formalin or HgCl₂.

c. Heart rot: is caused by fungus 'Fomes annosus' when a branch is blown from a tree since the exposure of the vulnerable heartwood to the air initiates the attack. Such a tree gives a hollow sound when struck.

d. Brown rot: is caused by fungus which removes the cellulose compounds from the wood (chiefly coniferous) leaving it as a brown friable mass rich in lignin.

e. White rot: is caused by fungus which removes mostly lignin (chiefly in deciduous woods) leaving a white mass which is mostly cellulose.

f. Sap stain: is a discoloration caused to the sap-wood by certain fungi which derive their nourishment from the cell contents but do not cause decomposition of the timber. It rarely occurs if the moisture content is < 20 to 25%. 
g. **Blue stain**: is a type of sap stain bluish in colour.

3. **Due to insects**: The insects attacking timber may be divided into three classes:
   a. **Beetles**: The furniture beetle (anobium punctatum) or wood worm lays eggs in any available crevice. The hatched lava, or worm, then bores into the wood (holes about 1/16" diameter) and finally comes out as a small brown insect. The death-watch beetle (xestobium tesellatum) is a similar type of insect, but much larger. The decay is very rapid, and if left unchecked, the timber is completely destroyed.
   b. **Worms or marine borers** (found in salt water): attack timber by boring holes in the line of the grain for themselves to live in. Such a timber loses colour and strength, is completely honeycombed, and finally falls into decay.
   c. **Termites or white ants**: found largely in tropical and subtropical climates, eat the core of a timber balk, and leave the outer shell intact. The balk appears to be sound right up to the moment of collapse.
   d. **Pin holes**: Holes in wood not more than 1/16" dia. due to pin-hole borers.

4. **Due to seasoning**: The various defects are:
   a. **Bow or camber**: (Fig. 136) a curvature of the timber in the direction of its length.
   b. **Cup**: (Fig. 137) a curvature in the transverse section of plank.
   c. **Spring**: (Fig. 138) a curvature of a plank in its own plane.
   d. **Twist or winding**: (Fig. 139) a spiral distortion along the length of a piece of timber.
   e. **Warp**: a distortion causing departure from a plane form.
   f. **Split**: a separation of the fibres along the grain which extends through the piece from one surface to another.

![Bow, Cup, Spring, Twist](image)

**Fig. 136 to 139.**

**g. Check**: separation of the fibres along the grain forming a
crack or fissure in the timber, not extending through the piece from one surface to another.

h. **Collapse**: flattening of the wood cells during drying, which sometimes results in excessive and/or uneven shrinkage.

i. **Honey-combing**: separation of the fibres in the interior of timber due to drying stresses.

j. **Radial shakes**: (Fig. 140) similar to star shake, occurring in felled timber during seasoning, are caused by the outer tissues drying faster than the inner ones and are fine, irregular and numerous. These appear to start a few inches within the bark, run a short distance towards the centre, then follow an annual ring and again towards the centre. Radial shakes will be serious defects in plywood.

k. **Case-hardening**: As a result of drying, the more rapidly drying surfaces of timber become set and are under compression while the interior surfaces are in tension. It takes place in the bottom sections of heavily loaded stacks kept for seasoning.

5. **Due to manufacturing**: The various defects are:

   a. **Chipped grain or torn grain**: a defect caused by the breaking away of the timber below the finished surface by the action of the tool.

   b. **Chip mark**: Indentations on the finished surface of timber made by chips or other small pieces that have been carried round on the planing knife edges from the preceding cut. These may also be caused by chips being impressed by the rollers or pressure guides of a planing machine.

   c. **Wane**: The original rounded surface of a tree remaining on a piece of converted timber.

**Preservation of Timber**: Thorough seasoning is the first and most effective means of preservation. Normally timber used in buildings will be immune to attack by fungi, termites, borers, marine organisms, etc., if there is adequate ventilation (good circulation of air) and freedom from damp. Where such conditions could not be attained, the timber should be treated with a preservative.

**Requirements of a preservative**: i It should penetrate readily into the timber; ii It should have no destructive influence on the strength of the timber; iii It should be strongly toxic to fungi, insects, etc.; iv It should be harmless to human beings and animals; v It should neither be soluble in water nor subject to decomposition under ordinary climatic condi-
tions; vi It should cover a large surface and protect it with a comparatively small quantity of the preservative; vii It should be highly resistant to water and dampness; viii It should be cheap and available in large quantities; ix It should not render the timber treated with it more inflammable; x It should be non-corrosive to metals; and xi It should be pleasant in colour and give an attractive appearance to the woodwork.

**Types of preservatives:**

A. **Oil type:** Oils (creosotes) obtained from distillation of coal (or wood) tar, either alone or in admixture with fuel oil, are widely used especially for treatment of timber for exterior use viz., railway sleepers, piles, etc. These are not suitable when the timber is to be painted. **Coal-tar creosote:** is a black or brownish oil which is heavier than water. It is a mixture of oils with boiling points over 93° and sp. gr. between 0.94 and 1.07. In the case of railway sleepers, creosoting doubles the life. As creosote bleeds under hot sun, petroleum oils and waxes are used to fix the creosote in the timber. Undesirable odour and colour, tendency to stain and discolour plaster, and inability to take paint well, limit its use. **Coal-tar:** which is highly viscous but less toxic than creosote is always applied hot. It gives an unsightly colour and objectionable smell. **Water-gas tar creosote:** Water-gas tar is formed during the decomposition of the petroleum oils which are used for enriching water-gas. As the distillates from water-gas tar are poorly toxic, they are used to dilute true coal-tar creosotes. **Wood-tar creosote:** Wood-tar is a by-product in the preparation of charcoal by the destructive distillation of wood. As the creosote oils obtained on distillation of wood-tar are more costly and corrosive towards metal than coal-tar creosote, it is only used in conjunction with the latter, as it imparts a warm brown tone to the wood. **Petroleum oils:** are used admixed with coal-tar creosote for railway sleepers. **Coal-tar derivatives:** There are several products having certain advantages over creosote. i **Carbolineum:** is a strong disinfectant and antiseptic. Applied with a brush, it penetrates the wood by its own action. It prevents dry rot and renders timber immune from the attack of white ants and other vermin. ii **Solignum:** is used for doors, windows, flooring, panellings, etc. This protects the timber from the attack of white ants. It is coloured with pigments of various tints to make the treated timber attractive in appearance. It is applied hot with a wire brush.

B. **Water-soluble ‘Leachable’ type:** These are odourless, non-creeping, non-staining and non-inflammable, but somewhat corrosive to metals. They may, however, be leached out of the timber by reason of their solubility and hence are not satisfactory for external use. These are cheaper than the oil-soluble varieties and are used for timber in building
construction and coachwork of various vehicles. After treatment with such preservatives, the dried timber can be painted with oil paints. The types are: Zinc chloride (Burnettising): It is adopted for protection of roofing timbers of factories in which there is a high humidity and of timber in mines to reduce the risk of fire. A solution of 3 to 5% by weight of ZnCl₂ in water is applied either in an open tank or by pressure process. Sodium fluoride: 2 to 4% of NaF is dissolved in soft water (as insoluble fluorides are precipitated by hard water) and applied. It is a little more costly than ZnCl₂, but is highly toxic to fungi and inert towards iron and steel. Magnesium silico-fluoride: prevents dry-rot. It is corrosive towards metals and glass, and hence is kept in wooden containers. Copper sulphate (Boucherie): is very toxic to fungi and is used for treating green poles. Its high solubility in water renders it a temporary rather than a permanent preservative. Mercuric chloride (Kyanising): Its extreme toxicity even to animal life and corrosive action limit its use. Iron sulphate: is used in the Chapman's process. Sodium pentachlorophenate: is effective against fungi causing sap stain. Benzin hexachloride (disperable powder) is used in spray or brush treatment as a prophylactic against borers.

ii. Water soluble 'Fixed' type: These consist of mixtures of various salts described above with the addition of a fixative salt, usually sodium dichromate. The chromium fixes the toxic element arsenic, copper, zinc, etc., in the wood so that the toxic salts are not leached by water. The treated timber should be allowed to dry for 3 to 6 weeks to complete the fixation process. Such treated timber can be used for outside locations, and, unlike creosoted timber, can also be painted over. These preservatives shall be applied cold as they are liable to get precipitated when heated due to interaction with certain wood constituents. These are compositions of: i CuSO₄,5H₂O, As₂O₅,2H₂O, (Na or K)₂Cr₂O₇, 2H₂O in the ratio of 3:1:4; ii CrO₃, CuSO₄,5H₂O, Na₂Cr₂O₇, 2H₂O in the ratio of 1:68:50:47.5; iii ZnCl₂, (Na or K)₂Cr₂O₇, 2H₂O in the ratio of 1:1; iv H₃BO₅, CuSO₄,5H₂O, (Na or K)₂Cr₂O₇, 2H₂O in the ratio of 3:6:8; v As₂O₅, ZnO in the ratio of 3:2 with acetic acid just sufficient to keep the salts in solution under operating conditions; and vi H₃BO₅, ZnCl₂, Na₂Cr₂O₇, 2H₂O, H₂O in the ratio of 1:3:4:100. Asec: treatment denotes forcing under pressure the mixture given in (i) above.

C. Solvent type: These consist of a toxic chemical compound like metallic soaps, and copper and zinc salts of suitable organic acids, dissolved in a non-aqueous solvent, like volatile oils, spirit, naphtha, etc., which evaporate after the timber has been treated leaving the toxic compound impregnating the wood. These are clean and permanent, cause
no swelling and shrinkage of wood, and in most cases the treated timber can be painted, waxed or polished. As some of the solvents are inflammable, care is necessary in handling the solutions. The types are:
i Copper naphthenate and zinc naphthenate, ii Pentachlorophenol, iii Benzene hexachloride, and iv DDT (pp'-dichloro-diphenyl-trichloroethane).

**Types of treatment:** Whatever be the process of treatment adopted, the timber will have to be conditioned to the required moisture content before treatment. The methods are:

A. **Surface application:** These may be either by brush, spray or dipping in the preservative fluid for a short period. With brush treatment, the second coat should be applied before the first has dried. The moisture content should be between 10 to 14% for oil type preservatives and between 20 to 30% for water soluble types. Surface treatment has limited scope only viz., treating material at site and for cut surfaces.

B. **Soaking and diffusion treatments:** The treatment can be done either by soaking the timber in the solution or applying a paste of the preservative on the green timber and covering the timber stacked in solid piles with a waterproof covering. While this process is not time consuming with veneers, it is however slow with thicker sizes of timber.

C. **Cold steeping:** Where the timber is left to soak for several weeks in a tank containing the preservative.

D. **Hot steeping:** As absorption of a preservative by the timber occurs only during cooling (vide E below), this method of dipping timber in the hot preservative is now falling into disuse.

E. **Hot and cold steeping or open tank process:** The preservative is heated to about 90° with the timber submerged in it, and allowed to cool. During heating, the air in the timber expands and is partially expelled. When the timber cools, a partial vacuum is created, which sucks in the preservative. This treatment also ensures sterilization of the timber against fungi and insects that may be present. In the absence of facilities for pressure treatment, this process is recommended.

F. **Boucherie process:** In this process, sapwood of all green timbers with the bark on and of bamboos in green condition, soon after felling, is treated with any of the organic water-soluble preservatives. The treatment is carried out by attaching to the butt end of a pole with the bark on, a rubber hose connected to a reservoir containing the preservative solution and placed at a sufficiently high level. The pole is kept at 45° to the horizontal with the butt end up. Due to pressure, the preservative displaces the sap in the timber which is then forced out at the thin
end. The treatment is stopped when the concentration of preservative in the drip is nearly the same as that of the solution in the reservoir. In the case of bamboo, the basal internode may be made use of as a reservoir and since the inner surface of the bamboo is not permeable, it is incised near the septum of the node used as the reservoir. The bamboo is generally kept vertical. If an air pressure of 15 to 30 psi is applied on the surface of the preservative in the reservoir, the reservoir need not be raised high above the ground and the treatment is very much hastened.

G. Pressure processes: ensure that the sapwood, at least, is impregnated with the preservative. The processes are: a. Full cell or Bethell process: It is used where the largest volumetric injection of the preservative is desired e.g., for timber treated with a water soluble preservative and used under water or in damp soil. The timber is placed in a closed cylinder and subjected to a vacuum of at least 22" of Hg. The object of this is to remove as much air from the wood cells as possible. At the end of the vacuum period, about 30 min., the preservative is introduced into the cylinder without breaking the vacuum. When the vessel has been filled with the preservative, it is subjected to pressure (50 to 175 psi depending on species, size, etc.). This injects the preservative into the timber. The pressure is held until the desired amount of absorption is obtained (or to refusal i.e., till the timber refuses to absorb any more preservative), when the preservative is withdrawn from the cylinder and a final vacuum (15 to 24" of Hg) is applied to free the timber from dripping preservative b. Empty cell processes: aim at a max. penetration of the preservative with a min. of net retention, i In the Lowry process, the cylinder is loaded with the timber and closed. It is then filled with the preservative at atmospheric pressure, and when the cylinder is full, a pressure of from 50 to 175 psi, as in a, is applied. When the pressure is released, part of the preservative injected into the timber is expelled. The cylinder is drained and a final vacuum of 15 to 24" of Hg is applied. ii In the Rueping process, the timber in the cylinder is exposed to an air pressure of 25 to 75 psi for a specified period. This pressure is maintained during the filling up of the cylinder with the hot preservative, which is followed by a further antiseptic pressure treatment of 75 to 175 psi, as in a. At the end of this, the cylinder is drained and a final vacuum of 15 to 24" of Hg is applied. This process is adopted for oil type preservatives. It costs less as the walls of the cells are impregnated with the preservative, the cells themselves containing only air.

H. Boulton process: The timber is immersed in creosote at 60°,
and a vacuum of 15 to 27" of Hg is applied, while the temperature is raised to 93°. This vaporises the water in the timber, which is then pressure treated.

Fire-proofing of Timber: Timber cannot be made entirely fire-proof, but only fire-resistant. The methods are: a. Impregnating the wood, under pressure or by hot and cold soaking, upto 2 to 3" depth, with (NH₄)₂ SO₄, NH₄Cl, (NH₄)₂ PO₄, Na₂AsO₃, H₂BO₂, MgCl₂, ZnCl₂, etc. b. Brushing or spraying the surface with fire-retardent solutions like Na₂SiO₃, K₂SiO₃, (NH₄)₂ PO₄, or CaSO₄-base paints. Mineral wood or asbestos is also applied in the form of a slurry with a suitable binding solution of borax-linseed oil, casein, or casein and borax.

These chemicals decompose on heating and give out non-combustible gases and water vapour which retard combustion of wood. They form a dense layer of charcoal and a fused viscous mass which cut off the oxygen supply and thus protect the timber from flames and radiant heat.

Veneers: are thin sheets of wood (5/₄ to ½" thick) produced by slicing, rotary cutting, or sawing from a log of wood having extremely handsome curly figures. The thin slices are matched up to form decorative designs, and are glued (see 'Adhesives' Ch. V) upon an inferior wood and polished (called veneering). These veneers can also be bent round mouldings, and the effect produced is to show that more expensive wood has been used throughout. Aini, rosewood, sissou, white cedar, walnut, jack, mango, mahogany, teak, silver oak, etc., are timbers suitable for veneering.

Plywood: (See 'Engineering Laminates' - Ch. V) denotes an assembled product made up of piles (individual layers of veneer) and adhesives, the chief characteristic being the crossed layers which distribute the longitudinal wood strength. Boards formed of more than three plies are designated multi- ply (Fig. 141 & 142). Laminboard: is a board having a core of strips each < 7 mm in thickness, glued together face to face to form a slab which in turn is glued to two or more outer veneers, with the direction of the grain of the core strips running at right angles to that of the adjacent outer veneers (Fig. 143). Blockboard: is a board having a core of strips each > 1" in width, laid separately, or glued or otherwise joined together to form a slab.
which is glued between two or more outer veneers with the direction of the grain of the core blocks running at right angles to that of the adjacent outer veneers (Fig 144). Battenboard: is a board having a core of strips, each ≥ 3" in width, laid separately, or glued or otherwise joined together to form a slab which is glued between two or more outer veneers with the direction of the grain of the core battens running at right angles to that of the adjacent outer veneers (Fig. 145). Metal faced plywood: is the board faced on one or both sides with Al, Cu and its alloys, bronze and Ni alloys, stainless steel (and even bakelite). It is rigid, can be easily cleaned, and prevents buckling. Decorative plywood: is made by bonding various layers of ornamental veneers in one operation or by bonding the veneers with synthetic resin-bonded plywood. Composite board: is made of several plies with layers of asbestos fibre or other insulating material (soaked in weak glue size, dried, and casein glued between the plies). When used in a building, it renders the room cool in summer and warm in winter, reduces sound transmission, and is relatively non-inflammable.

Plywood is extensively used for panelling walls, partitions and ceilings, doors, furniture, stair balustrades, railway coaches, buses, boxes, barrels, and as shuttering for concrete. Its advantages over timber are:

i. Much less sensitive to moisture;
ii. Shrinkage and expansion much less and more uniform under similar conditions, owing to its cross-grained construction;
iii. Not liable to axial splitting;
iv. Obtainable in large single pieces which are not fragile;
v. Beauty of grain and figure can be displayed;
vi. Economical use of rare and valuable timbers can be made.

Although of great strength, it is unsuitable in situations subject to great knoks.

Classification of Timber: A. Based on durability: i. Most durable species (average life over 10 years) whose heartwood is highly resistant to fungi and borer, and which can be expected to give satisfactory service in outdoor location and which can be used for railway sleepers, etc., in the untreated state, treatment being given for members placed in the ground e.g., teak, sal, deodar, irul, blackwood, vengai, etc,
II. Durable for inside and protected locations but not as durable as class I for outside locations. When used in contact with the ground, it would be best to treat the lumbers if long life is required e.g., benteak, sissoo, etc. iii Moderately durable in inside and protected locations and a brush treatment would do except for floor boards and members in contact with the ground which should be pressure treated e.g., jack, laurel, etc. iv Not very durable. They should be kept permanently dry and preferably given a light open tank treatment for inside use and a pressure treatment with a good preservative for outdoor use e.g., axle-wood, babul, mango, etc. v Non-durable (average life below five years). They require rapid extraction and careful handling to avoid deterioration and should be well treated with an approved preservative e.g., walnut, spruce, elm, etc.

B. Based on treatability: i Heartwood easily treatable—can be used with satisfactory results for outside locations after treatment if their properties are suitable for the purpose in view e.g., mango. ii Heartwood treatable, but somewhat erratic in penetration can be used for sleepers, bridge flooring, etc. If these are to be buried in ground, only timbers which have shown satisfactory penetration of the preservative can be used e.g., babul, palmyra palm, chir, etc. Items iii to v of A can be used for poles only if heartwood is durable. They can be used for sleepers and inside location. iii Heartwood only partially treatable e.g., deodar, karenwood, etc. iv Heartwood refractory to treatment, incision being necessary for $\frac{1}{4}$" to $\frac{1}{2}$" penetration e.g., fir, spruce, etc. This can be used only in outside locations after incision and treatment. v Heartwood very refractory to treatment-side and end penetration nil e.g., axle-wood, ben-teak, irul, teak, sal, etc. This can be used for outside when the heartwood is very durable as in sal, teak, etc.

C. Based on refractoriness to air-seasoning: i.e., Depending upon the behaviour of the timber with respect to cracking and splitting during normal air-seasoning. i Highly refractory e.g., axlewood, laurel, sal, casuarina, irul, etc.; ii Moderately refractory e.g., benteak, blackwood, teak, babul, etc.; and iii Scarcely refractory e.g., mango, deodar, fir, etc.

Properties and Uses of Indian Timbers:

I. Aini (Artocarpus hirsuta) (*M-Aampionsu, Ta-Anjili, K.-Hobba-lasu): is yellowish brown, light, tough, elastic, strong, close-grained, and durable; takes polish and lasts well under water. It is found in Madras, A. P., Kerala, and Bombay and is used for all purposes for which teak is used.

* M, Ta, Te, and K denote Malayalam, Tamil, Telugu and Kannada respectively.
2. Axle wood (Anogeissus latifolia) (M-Vellanava, Ta-Vellanagi, Te-Chirumanu, K-Dinduga): is very strong, hard, extremely tough and heavy and takes a smooth finish but is liable to cracking, and splitting. It is found in Madras, A. P., Bombay, M. P., Bihar, and U. P., and is used for carts, poles, and heavy construction.

3. Bobul (Acacia arabica) (M-Karvelam, Ta-Karuvai, Te-Nalla-tumma, K-Karijali): is strong, hard and tough and takes a smooth finish. It is found in Madras, A. P., Bombay, M. P., U. P., and Bengal, and is used in house construction and agricultural implements.

4. Bamboo (Bambusa): is a common tree, which grows up to 60' length and 5 to 8' diameter. There are two varieties: Male, about 1\ to 2' diameter, with a narrow hollow inside, which is strong and is used for roof work to support pan or pot tile roof covering; and Female, about 5 to 8' diameter, with a large hollow inside, which is used as scaffolding posts, rafters, etc., and when split, as reepers for thatched roofs.

5. Benteak (Lagerstroemia lanceolata) (M-Venteak, Ta-Venthekhu, K-bendek): is strong and works well to a smooth surface. It is found in Madras, Kerala, and Bombay and is used for furniture, and in house and boat construction.

6. Bijosal (Pterocarpus marsupium) (M-Venga, Ta-Vengai, Te-Yegi, K-Honne): is light brown, strong, durable and coarse-grained; contains an essential oil, like teak, which preserves the timber; not easy to work; specially suitable for exposed work; not attacked by white ants. It is found in Madras, A. P., Kerala, Bombay, Orissa, M. P., and U. P., and is used for house construction and furniture.

7. Casurina (Casurina equisetifolia) (M-Chulamaram, Ta-Savukku, Te-Chavuku, K-Kesarik): is a common tree which grows straight; is reddish brown; strong and fibrous but badly twisted; much used for scaffolding purposes in Madras, and also as posts, etc., for temporary sheds.

8. Deodar (Cedrus deodara): is light and moderately strong. It is found in U. P., and Punjab, and is used for structural work, pattern making and packing boxes.

9. Rosewood or Blackwood (Dalbergia latifolia) (M-Veeti, Ta-Itti, Te-Jittegi, K-Biti): is very dark in colour; close-grained; takes a high polish; and is handsome. It is found in Kerala, Bombay, and M. P., and is used for high class furniture and ornamental furnishings.

10. Irul (Xyilia xylocarpa) (Te-Konda tangedu, K-Jambo): is very hard, heavy, durable, but difficult to work. It is found in Madras, A. P.,
Kerala, Bombay, and Orissa, and is used for railway sleepers, paving blocks, and agricultural implements.

11. **Kathal** (*Artocarpus heterophyllus*) (M-Pilavu, Ta-Pila, Te-Panasah, K-Halasah): is yellow to deep brown in colour; heavy and hard; liable to split on exposure to sun; lasts well under water and in damp soil; and is not attacked by white ants. It is found in Kerala, Madras, A.P., and Bombay, and is used for platforms of wooden bridges, piles, and frames and panels of doors and windows.

12. **Laurel** (*Terminalia tomentosa*) (M-Karumarudu, Ta-Karimaru-rudu, Te-Nallamaddi, K-Banappu): is dark brown in colour; heavy, hard, tough, and durable; and is liable to split and dry rot but is free from attack by white ants. It is found in Kerala, Madras, A.P., M.P., U.P., and Bihar, and is used for house construction, structural work, boat building and sleepers.

13. **Mango** (*Mangifera indica*), (M-Mavu, Ta-Mamaram, Te-Mamidi, K-Mavu): is a common tree; is coarse and open-grained; grey coloured; liable to rot and attack by white ants; and lasts fairly well in salt water. It is used as planks for walls and salt sheds and formwork of R.C. work.

14. **Palmyra** (*Borassus flabellifer formis*): is a common tree. The ripe wood in the outer crust is dark brown in colour. It is fibrous, very strong, and durable. It is used for rafters and joists in kutcha building work. The leaves are used as roof covering in temporary and kutcha sheds.

15. **Sal** (*Shorea robusta*): is strong, tough, hard, heavy, and durable. It is found in A.P., Bombay, M.P., Orissa, U.P., and Bihar and is used for house construction, structural work, and railway sleepers.

16. **Sissoo** (*Dalbergia sissoo*): is strong, handsome, durable, and takes a fine polish. It is found in Mysore, Bombay, U.P., and Bengal and is used for furniture, bridge piles, sleepers, and plywood.

17. **Teak** (*Tectona grandis*) (M & Ta-Theku, Te-Teku, K-Thega): is brown, easily worked, very durable, fire-resistant, lasts in water, and not attacked by white ants. It is found in Kerala, Bombay, and Burma, and is used for house construction, structural work, furniture, flooring, etc.

18. **Hopea** (*Hopea*) (M-Irumbogam, Ta-Vellaigongu, K-Bogimair): is light to deep brown, heavy and hard; liable to split on exposure to sun; lasts well under water and in damp soil and is not attacked by white ants. It is found in Kerala and Madras and is used for piles, and frames of doors and windows.
CHAPTER V

METALS AND MISCELLANEOUS MATERIALS

METALS

General: The metals largely used in building construction are: Iron (C. I., W. L., and M. S.) Cu, Pb, Zn, Mg, Ni, Sn, and certain alloys. Hard steel: is used for cutting tools. Cast iron: is used as castings such as hollow columns, hollow piles, water pipes, etc. Formerly it was used as girders but now rarely so. Wrought iron: is employed for nails, screws, bolts and nuts, flat and square bars with which scroll work is done for hand rails, gates, etc., as sheets, plain or galvanised for various purposes such as gutters or corrugated, plain or galvanised as roof coverings and enclosing sides of godowns and the like. Mild steel: is employed for beams, or R. S. girders, solid piles, round square or flat bars, angles, tees, channels, etc., either by themselves or as members in steel roof trusses, built up girders etc., and as reinforcements in R. C. structures. For uses of other metals, see later in this chapter.

The iron ores of importance are: i Magnetite (Loadstone): or black oxide Fe₃O₄ contains 72% iron, when pure. It is found in Sweden, Ural mountains in Russia, and Gaya. ii Haematite: or red oxide Fe₂O₃ contains 70% iron when pure. It is the ore used in Mysore, U. K., U. S. A., Germany, and France. iii Limonite (Brown or bog iron ore): 2Fe₂O₃·3H₂O contains 60% iron. This is used at Jamshedpur, in U. K., and Spain. iv Siderite (Spaethic iron ore): FeCO₃ mixed with carbonate of lime and magnesia contains 40% iron. This is used in U. K. Clay iron stone-FeCO₃ mixed with clay and sand, and black band-clay iron stone with bituminous matter contain 30 to 40% iron. v Iron pyrites: FeS₂, containing 47% iron are not used because of the high S content.

Pig Iron: Manufacture: Pig iron is an impure form of iron containing C, Si, S, P, and Mn. Some ores are treated in one or other of the following ways before charging: i Calcination: is resorted to for removing water from hydrous ores, removing CO₂ from carbonates; oxidizing a portion of the gangue of dense ores (magnetites); or rendering the ore magnetic. ii Roasting: is for removing S from ores. The FeS₂ is decomposed at a moderate heat into S and FeS. The FeS is oxidised by air to FeSO₄, which, on further heating, becomes Fe₂O₃, liberating SO₃ and O₂. iii Concentration: is for freeing the ore of a part of the gangue. Wet concentration is used to remove clay, loam, etc., by washing. Jigs are used to separate pebbles and sand from the ore by agitation of perforated
trays set in tanks of water. Dry concentration is accomplished by magnetic separators.

The iron is first reduced from the ores in a blast furnace (Fig. 146) to form pig iron. The process of smelting consists of charging a mixture of fuel (coal, coke, and charcoal, coke being the most common), ore, and flux (a fusible slag added to remove the non-metallic portion of the ore—a basic flux like pure limestone is required for acid gangues high in silica, alumina; and an acid flux, very rarely used, is required for basic gangues high in lime and magnesia) into the top of the furnace and blowing in a current of hot air at the bottom. The air burns the fuel, forming heat for the reactions and for melting the products; the gases formed by this combustion remove the O₂ from the ore and reduce it to metallic state. The flux makes the earthy materials fluid. The gaseous products escape through the top of the furnace and the liquid products are tapped off at the bottom. The combustible escaping gases are conducted through pipes to hot blast stoves (vertical steel cylinders, 20' diameter and 80' high), where, after removal of ore dust, they are used for heating the air blast. Each furnace has 3 to 5 such stoves. Each stove contains two fire-brick chambers, the central one open and the outer annular one divided into a large number of small flues. The escaping gases and a definite proportion of air are admitted to the bottom of the open chamber and burned. The products of combustion rise to the top, pass downwards through the small flues and thence to the chimney. The heat is taken up by the brickwork of the flues. Air from the blowing engines is now admitted in a reverse direction at the bottom of the small flues. The hot blast enters the furnace through the tuyeres. The O₂ in the blast combines with the C in the fuel to form CO₂, which under the intense heat, gets reduced by C to CO. The CO reduces the ore to the metal which, in the molten condition, absorbs C, Si, Mn, and P. The heavy molten pig covered by the light molten slag collects in the crucible. The former is drawn once in every 4 hours to ladles by opening
the tap hole and taken to steel furnaces. Formerly it was cast into pigs. The slag is tapped once in every 2 hours by opening a tap hole located at a higher level.

**Classification:** i Based on purpose for which it is used:  
- a. Bessemer pig: For Bessemer or acid open-hearth process. This should be free from S, P, and Cu.  
- b. Basic pig: For basic open-hearth process.  
- c. Malleable pig: For malleable C. I.  
- d. Gray or foundry pig: For C. I.  
- e. White or forge pig: An inferior gray pig used for manufacture of W. I.  
- f. Mottled pig: lies between d and e. It contains a large proportion of combined C, is stronger, and is used for heavy foundry work.

ii Based on method of manufacture:  
- b. Charcoal pig.  
- c. Anthracite pig.

iii Based on chemical composition:  
- a. Silicon pig.  
- b. Low phosphorus pig.  
- c. Special cast irons.

**Cast Iron: Manufacture:** C. I. is obtained by remelting pig iron in a cupola furnace (Fig. 147). This is similar to the blast furnace, but operated under a very much lower blast pressure and of a smaller size with a door near the top for the introduction of the charge (which consists of pig iron, limestone, and coke). The top is open and below the tuyere the furnace is provided with tap holes and spouts for withdrawing slag and molten iron.

**Classification:** The principal varieties are:  
- i Gray C. I.: Carbon occurs chiefly in the graphite state. This is made from gray pig. It is gray in colour with a coarse crystalline structure, melts readily and is suitable for making castings.  
- ii White C. I.: Carbon occurs chiefly as cementite (Fe₃C). It is silvery white in colour with a metallic fracture, melts with much difficulty, is machinable only by grinding, and is used for making malleable or wrought iron.  
- iii Mottled C. I.: is a mixture of particles of gray iron with particles of white iron. The fracture possesses a mottled appearance. It is used for small castings. These are strong
and slightly ductile. iv *Chilled C. I.*: is one where it is hardened greatly for a certain depth, giving to the exterior of the iron the characteristic appearance of white iron, while the body of the casting remains a gray iron. Chilling is adopted for wearing surfaces of castings. v *Malleable C. I.*: is iron of special composition (2.2 to 3.6% C, 0.4 to 1.1% Si, 0.1 to 0.4% Mn, 0.03 to 0.3% S, and 0.1% P) which, after having been cast to its final form without any graphite, is rendered malleable by annealing. It is used for railroad equipment, automobiles and trucks, pipe fittings, agricultural machinery, hardware, etc. vi *Toughened C. I.*: made by melting C. I. and 1/4 to 1/3th of its weight of W. I. scrap. vii *Inoculated C. I.*: It is difficult to cast low-carbon C. I. since the reduction in graphite content causes increased shrinkage during solidification. Instead of introducing the Si as a compound of pig iron, if inoculated in a crushed state in the form of a soluble compound (ferrosilicon or calcium silicide such that 0.5 to 1% Si is added to the metal) into the molten metal, graphite of the fine and random type is formed imparting improved mechanical properties to the cast iron.

*Properties:* It contains from 2.5 to 4.5% of C. It is hard but brittle and therefore two pieces cannot be connected by riveting or welding but only by bolts and nuts fixed to flanges. It is fusible and as such is adapted for making ornamental castings, such as gates, railings, lamp posts, fluted columns, brackets, etc. It is strong in compression but weak in tension. Hence it is adopted for columns carrying heavy loads but not for tension bars and also the tension flange of a C. I. beam has to be much larger than the compression flange. Salt water corrodes it. Si combines with a part of the iron to form Fe$_3$Si which forms a solid solution with the ferrite. 2.5 to 3.5% Si drives the carbon out of combination into the graphite form. Si below 2.5% produces freedom from oxides and flowholes, promotes fluidity, decreases shrinkage and depth of chill and acts as a pronounced softener producing soft gray iron. Sulphur tends to drive the carbon into combination as carbide and produces hard, brittle, white iron. If present as FeS, it affects the behaviour of iron in solidifying and cooling. Even 0.1 to 1% sulphur tends to crush the sand of the mould setting up internal stresses in the iron, causes rapid solidification, and gives rise to blowholes and sandholes. It hardens the iron, retards fluidity, prevents the formation of graphite, decreases strength, and makes the iron brittle. Mn, because of its great affinity for sulphur, tends to rob the FeS of its sulphur and forms MnS which is less potent than FeS in affecting the proportion of combined carbon. A given amount of sulphur is neutralised by about twice as much Mn. Mn above this limit combines with carbon to form Mn$_2$C, which
unites with the Fe₃C to form (Fe Mn), C. Mn up to the extent required to combine with sulphur to form MnS tends to lower the proportion of combined carbon and consequently decreases the hardness and brittleness of the iron. 0.2 to 1% Mn causes the carbon to assume the combined form and yields a strong, hard iron with high resistance to wear and a great depth of chill. Phosphorus tends to increase the proportion of combined carbon, especially when Si is low and P is high. When over 0.3%, it produces a hard white iron, lacking in toughness, workability, and shock resistance when cold. It increases the fluidity and hence 1 to 1.5% is sometimes used in making very thin castings.

**Casting Processes:** are classified on the basis of the materials and methods employed in moulding. They are:

1. **Sand casting:** A mould is made by packing foundry sand (natural or synthetic, green or dry), or loam (a mixture of moulding sand, fireclay, and chopped straw ground into a thick mud or slurry), or compo (a mixture of old firebricks or crucibles, ganister, fireclay, and coke or graphite, all crushed together with sufficient water) round a wooden or iron pattern (core) of the cast iron article to be cast in the two halves of a cast iron, steel, brass, or aluminium box. The core is then withdrawn when the sand has well dried, and the two halves are put together and, in the hollow so formed, the molten pig iron is run through holes provided for the purpose in the upper half of the mould box. Openings (vents) are provided for the escape of gas from the metal and mould. Most iron, brass, and steel castings are made in air-dried moulds, but for intricate work and special quality castings the mould is dried in an oven. Where the mould is made in the floor sand, the top left open, and the metal is poured in to the required level, it is called open sand moulding. After the mould and therefore the casting has cooled, the casting is removed from the mould box and irregularities, if any, on the surface of the casting is carefully chipped and removed. Instead of sand, a permanent or metal mould may be used for mass production of identical objects, as in casting steel ingots in cast-iron moulds, and in casting automobile pistons, and rims, instead of building up a new mould of sand each time. Very large castings are moulded in a permanent pit (in the foundry floor) lined with cast iron plates and provided with strong cross bars across the top for clamping the cope securely to the floor prior to casting. A bed of coke is laid on the bottom of the pit, covered with straw and then a layer of sand, which is rammed and levelled. Vertical vent pipes are provided in the corners of the pit from the coke bed.

2. **Hollow casting:** For columns and piles, the mould is made as
in (1), but a solid core is suspended in the middle of the mould cavity so that the annular space represents the thickness of the shell or walls of the column or pile. After the poured molten metal has cooled, the mould box is removed, the core withdrawn, and the casting touched up as in (1).

3. **Vertical sand castings**: C. I. pipes for carrying water under pressure, are cast by this method. The mould box and the solid core suspended in it are held in a vertical position instead of being arranged horizontally. After the casting has cooled, the core is lifted off by an overhead travelling crane. C. I. pipes cast in this manner are stronger than those cast horizontally; for, in horizontal casting, the joints between the two halves of the mould box are always a source of weakness as honeycombing in the metal may occur at these seams. In the vertical casting of water pipes, the pipe is cast 9 or 12" longer than the desired length, the object being that the weight of this excess metal will help to drive out any air getting locked up in the metal in the required length. The extra length is then cut out. In casting these pipes, the socket ends will be at the bottom end of the mould and the spigot end near the top.

4. **Chilled casting**: Cast iron being cheaper than steel, attempts are always made to improve the composition and method of casting so as to render the castings strong enough to be acceptable for most engineering purposes. Chilled castings are made by giving a metallic lining to the mould or making the mould itself by a metal of high melting point. By rapid conduction of heat through the metal surface, the outside of the casting becomes intensely hard. The interior becomes soft and tough owing to the great pressure brought into play over the molten metal by the sudden cooling and therefore contraction. These are therefore adopted for wearing surfaces e.g., tyres and axle holes of railway carriage wheels, anvils, etc.

5. **Die casting**: processes are more economical than sand foundry methods. Pressure and gravity die-castings are produced from metallic moulds which are not destroyed after the pouring of each casting. The former is used in the mass production of small parts (a min. economical quantity being 20,000). High rates of output, accuracy, decorative finishing, and elimination or minimizing of machining characterize the pressure process. The latter are used for comparatively smaller quantities (5,000), or for larger and heavier castings in Mg or Al. These are generally less costly, structurally superior to and stronger than pressure castings.

6. **Centrifugal casting**: The innumerable defects like blow holes, scabs, etc., due to improper pouring, incorrect temperature, inefficient or
excessive ramming, inadequate drying, lack of shrinkage allowance and poor technique, found in all sand and permanent metal castings are removed by centrifugal casting. This is made by pouring a carefully controlled quantity of metal in a refractory or metal cylindrical mould which is rotated at speeds up to 10,000 R. P. M. for castings of small diameter. This method is adopted for large size pipes of C. I., steel, bronze, etc. There are three types of this casting viz.,

a. Centrifuging: Here the moulds are spaced around the periphery of the revolution, and the metal is poured from a central down gate into the moulds through the radial gates. 
b. Semi centrifugal casting: Here the mould is spun about its axis, and the centrifugal force generates pressure from the centre outward to the rim-section. It is used for wheels, gears or other disc-shaped parts.
c. True centrifugal casting: Here the mould is spun about its own axis and at least a part of the interior surface is shaped by centrifugal force without a central core.

It is further subdivided into two main classes according to the position of metal mould, in which they are set in the casting machine.
a. Where the metal moulds of steel or high test cast iron are set in a horizontal position in the casting machine. Piston rings, cylinder liners, bushings, bearings, etc., are made by this process.
b. Where the vertical centrifugal casting machine is used for production of castings in sand or metal moulds. Irregular shaped castings are made by this process.

7. Lost wax process or investment casting: Here a metal or alloy is cast into a one-piece refractory investment mould, from which a pattern or cluster of patterns has been removed, ordinarily by heat, and into which the molten metal is cast, usually under pressure. Nowadays, buckets for aircraft engine superchargers, integrally cast turbine wheel micronizer nozzle disc, and various other parts, under adverse conditions of temperature, pressure, and wear resistance are made by this process.

Characteristics of a Good Casting: It should have a smooth outer surface and perfect and sharp edges. Cracks are a common defect and they give a dull sound. Cooling cracks are found in brittle alloys like C. I., and shrinkage cracks in nonferrous alloys. Cavities of various sorts are found in solidified castings and they give a hollow sound when lightly tapped. They are sources of weakness. A fresh fracture should be fine grained, bluish grey in colour, and of a metallic lustre. A good casting should be soft enough to be drilled or chiselled.

Alloy Cast Irons: 0.05 to 0.1% Al acts as a deoxidizer, limits the penetration of the chill below the surface, and aids the breaking down
of the cementite at high temperatures. 0.8% Cr gives great chill depth and hardness, and high resistance to heat, wear, and corrosion. 0.25 to 2.5% Cu yields a tough, hard, and strong iron, highly resistant to wear, shock, heat, and corrosion. Mo (0.25 to 1.25%) forms stable complex carbides and yields a cast iron having uniformity of structure in heavy sections, great wear resistance, fine grained structure, high hardness, and reasonable strength at elevated temperature. 0.25 to 5% Ni gives strength, resistance to wear and corrosion, and machinability. White cast iron with 4.5% Ni & 1.5% Cr (Nihard) is wear-resisting; with 10 to 30% Cr & 1 to 3% C (Niresist & Nicrosilal) is heat resisting. Ti (> 0.1%) makes the C. I. stronger, more resistant to wear and corrosion than those without it. 0.1 to 0.5% V stabilizes the carbides, gives hardness, and improves resistance to wear. 4.5 to 17% Si confers high resistance to oxidation at elevated temperatures, heat, and acids but increases brittleness and difficulty of machining. 0.1 to 0.3% Zr is added to scavenge and deoxidize. It gives high strength and shock resistance. Acicular C. I. (2.8 to 3% C, 1.5 to 3% Ni, 0.7 to 1% Mo, Si 1.8 to 2.8%) has high hardness and machinability. It is used for heavy-section castings, such as forging dies, gear, crankshafts, and levers. With 10% Ni and 0.6% Mn (Nomag) for non-magnetic electrical machinery parts. Ni-Resist: denotes a group of high Ni or Ni-Cu cast irons. The types are: i With 14% Ni and 6% Cu-used in handling mineral acid corrosives and where maximum expansivity is desired, ii With 20% Ni-for heat resistance and steam service, and for handling caustics, food, etc., (where Cu contamination cannot be tolerated), iii With 30% Ni-for thermal shock service under repeated heating and cooling, and iv With 30% Ni, 5% Cr, 5% Si-for heat and corrosion resistance, high hardness and strength for food handling, and where strain-resisting properties are desired.

**Wrought iron: Manufacture:** W. I. is nearly pure iron containing, if at all, only a trace of C, the impurities being very small quantities of P, S, and Si; the first and the last making it brittle when cold and the second making it brittle at white heat. It is manufactured by the *puddling process*. This consists in melting the forge pig well mixed with oxidising substances like haematite ore, oxide of iron, etc., in the hearth of a reverberatory furnace (Fig. 148) which is lined with iron oxide. The lining material acts as the oxidising agent and eliminates most of the C, Si, Mn, P, and S present. The fuel, soft coal or coke, burns with a long flame in the grating situated in the side opposite to that of the chimney. The flame of the producer gas heats the metal in the shallow bath. The puddler rabbles the contents of the hearth vigorously and exposes them to the flames. The C in iron is converted into CO₂ and
escapes out. Si, Mn, P, and a small part of the S get oxidised and join the slag which is removed through the slag door. The pure metal gradually attains a stiff consistency and collects in the bath. The pasty metal is gathered into one mass and removed by the puddler. This is then taken for shingling which consists in forcing out any slag remaining in the puddle either by a steam hammer or by passing it through a squeezing machine. In the latter case it is obtained as a bloom. Rolling consists in passing the bloom while still hot, through grooved rollers to give bars $4" \times 4" \times 12"$. These bars are fastened together by wires, reheated and rerolled a number of times until all the slag is removed.

The Aston process, a recent one, involves melting the pig in a cupola, tapping it into ladles where it receives a special desulphurising treatment, and then refining it in a Bessemer Converter until most of the oxidizable impurities are removed. The refined metal is then poured into the ladle of the processing machine. Iron oxide and sand are fused in an open-hearth furnace to form a slag which is poured into a ladle and moved directly below the processing machine. The molten iron (freezing at 1,480°) is allowed to flow uniformly into the molten slag (freezing at 1,120°) when the iron is continuously and rapidly solidified at the bottom of the slag and the gases in the iron go off. The resulting puddle ball is very uniform as regards character and distribution of slag. It is then squeezed and rolled in the usual way.

**Different forms or sections in use:**

i. **Plate iron** is obtainable in lengths up to 15', widths ranging from 1 to 4' and thickness $\frac{1}{2}$ to 1".

ii. **Sheet iron**: Plate less than $\frac{1}{2}$" in thickness is called sheet iron. It is more costly.

iii. **Bar iron**: includes square, round, flat, half round, oval, hexagon, etc. "Square iron" and "Round iron" are from $\frac{1}{4}$ to 34" side and diameter respectively, the length being 30'.

iv. **Angle iron**: L varying from $1\frac{1}{4}" \times 1\frac{1}{4}" \times \frac{3}{4}"$ to $6" \times 6" \times \frac{3}{4}"$.

v. **Tee iron**: T varying from
METALS AND MISCELLANEOUS MATERIALS

1\" × 1\" × 1/4\" to 6\" × 6\" × 3/8\". vi Channel iron: I varying from 3\" × 1\" 1/4\" to 17\" × 4\". vii Girder iron or rolled W. I. beams: I varying from 3\" × 1\" 1/8\" to 24\" × 7\" 1/2\". viii Flat footed or double headed rails: are made in 36\' lengths. These are specified by their weight per yard. W. I. is also rolled into other curious forms, depending upon the use to which they are to be put.

PROPOSED I. S. SECTIONS STEEL:

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Numbers</th>
<th>Sizes (mm); h = Depth; b = Width; t = Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam</td>
<td>Junior ISJB</td>
<td>4</td>
<td>(h = 150) to 225; (b = 50) to 80; (t = 3) to 5</td>
</tr>
<tr>
<td></td>
<td>Light ISLB</td>
<td>17</td>
<td>(h = 75) to 200; (b = 50) to 100; (t = 3) to 7 to 14'7</td>
</tr>
<tr>
<td></td>
<td>Medium Weight ISB</td>
<td>14</td>
<td>(h = 100) to 200; (b = 75) to 210; (t = 4) to 21</td>
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<tr>
<td></td>
<td>Wide Flange ISWFB</td>
<td>13</td>
<td>(h = 150) to 200; (b = 100) to 250; (t = 5) to 4 to 23'6</td>
</tr>
<tr>
<td></td>
<td>Col. Section ISHB</td>
<td>17</td>
<td>(h = 150) to 250; (b = 150) to 250; (t = 5) to 4 to 13'7</td>
</tr>
<tr>
<td>Angle</td>
<td>Equal ISA</td>
<td>60</td>
<td>(20 \times 20) to (200 \times 200); (t = 3) to 25</td>
</tr>
<tr>
<td></td>
<td>Unequal ISA</td>
<td>58</td>
<td>(20 \times 20) to (200 \times 150); (t = 3) to 18</td>
</tr>
<tr>
<td>Channel</td>
<td>Junior ISJC</td>
<td>5</td>
<td>(h = 100) to 200; (b = 45) to 70; (t = 3) to 7'1</td>
</tr>
<tr>
<td></td>
<td>Light ISLC</td>
<td>11</td>
<td>(h = 75) to 400; (b = 40) to 100; (t = 3) to 7 to 14</td>
</tr>
<tr>
<td></td>
<td>Medium Weight ISC</td>
<td>11</td>
<td>(h = 75) to 400; (b = 40) to 100; (t = 4) to 4 to 15'3</td>
</tr>
<tr>
<td></td>
<td>Special ISSC</td>
<td></td>
<td>(under preparation)</td>
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<tr>
<td>Tee</td>
<td>Normal IST</td>
<td>6</td>
<td>(40 \times 40) to (150 \times 150); (t = 6) to 10</td>
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<tr>
<td></td>
<td>Wide Flange ISHT</td>
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<td>(75 \times 150) to (150 \times 250); (t = 7) to 6 to 10'6</td>
</tr>
<tr>
<td></td>
<td>Long Legged ISLLT</td>
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<td>(100 \times 50) to (250 \times 180); (t = 10) to 12'9</td>
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<tr>
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<td>Light ISLT</td>
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<td>(50 \times 50) to (100 \times 100); (t = 6) to 10'8</td>
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<tr>
<td></td>
<td>Junior ISJT</td>
<td>4</td>
<td>(75 \times 50) to (112.5 \times 80); (t = 4) to 6 to 5</td>
</tr>
</tbody>
</table>

Properties: It is malleable, ductile, and comparatively soft. At a white heat two separate pieces of W. I. can be welded together, or integrally connected together by hammering. The welded joint will be nearly as strong as the original piece. It is strong in tension, compression, and transverse strength. It lends itself easily to alteration of form by forging and consequently it is largely used for straps, rivets, bolts and nuts, railings, wire, etc. It fuses with difficulty and therefore is not suitable for making castings. If allowed to remain exposed to air at
white heat, it becomes burnt and brittle. The fracture produced by gradual cross breaking will be fibrous but when suddenly broken by a heavy falling weight, the fracture will be crystalline. When fracture occurs by a gradually increasing tensile force, there will be a considerable reduction in cross-sectional area at the broken portion.

**Corrugated Iron Sheets:** are a form of sheet iron, made by passing sheets between grooved rollers or dies which force and bend them into a series of parallel waves or corrugations. These enormously increase the strength and stiffness of the sheets and are used for several purposes for which the plain or flat sheet iron will be too weak. C. I. sheets are available in the market in the following sizes: Lengths varying from 5 to 12'; width of corrugations varying from 3 to 5'; and number of corrugations varying from 10 to 5. Thus we have $5/5^{\prime}$, $6/5^{\prime}$, $7/4^{\prime}$, $8/3^{\prime}$, $9/3^{\prime}$, and $10/3^{\prime}$. The overall width of the sheet is obtained by multiplying the width of each corrugation by the number of corrugations as shown above. The usual type is $32^{\prime}$ wide with 10 corrugations of $3^{\prime}$ (76 mm) pitch and $3^{\prime}$ (19 mm) depth. They are usually of 18, 20, 22, and 24 B. W. G. weighing 36, 29, 24½, and 19 lb. respectively for a sheet 6' long. Corrugated iron is generally galvanised.

**Galvanised Iron:** is iron sheet covered with a coating of Zn. In cold galvanising the iron articles in cold state are immersed in a neutral solution of ZnSO₄ through which an electric current of 20 to 70 amp. per sq. ft. is passed. In hot galvanising the rust is removed from the plates by pickling the iron in dilute HCl, washing and scouring with sand. Then the iron is immersed in molten Zn (460°) which is covered with NH₄Cl to prevent oxidation. The plates are generally taken out between rollers to economise Zn. Service water pipes, down pipes, manhole pipes, and C. I. sheets are usually galvanised. C. I. is difficult to zinc; W. I. and M. S. take the metal readily; but hard steel, e.g., wire for ropes, is less readily coated. The high temperature of the galvanising bath also affects the temper and tensile strength of hard steel wire. Galvanising loses its efficiency when it gets damaged. A galvanic action is set up by the Fe rusting, and it spreads and destroys the Fe. In dry galvanising or skedarising the articles are put into a tight drum with Zn (in the form of ‘blue powder’) and heated for several hours to a temperature of 300° to 420°. A coating of Zn-Fe alloy is formed by the action of Zn vapour on the Fe, giving an efficient penetration even into objects of irregular shape and rough surface.

**Rivets and Bolts:** Rivets should be of tough high class W. I. or M. S. They are used to connect M. S. plates or bars. The rivet holes for
this purpose in plates or bars may be drilled or punched. In the former
method, a steel cutting tool rotates in a drilling machine and gradually
cuts away the metal over the area of the hole; in the latter, a steel rod
with flat base is driven by a heavy flywheel through the plate. Punching
is quicker and more economical than drilling, but it injures the metal.
This injury can be remedied by annealing or rimming out the holes; in
the latter case the hole is punched smaller than the intended diameter
and then rimmed out about \( \frac{1}{2} \)" all round. A rivet hole should never be
punched nearer to the edge of the plate than \( 1\frac{1}{2} \) times its own diameter
nor nearer to another rivet hole than \( 1\frac{1}{2} \) times its own diameter. For
drilled rivet holes, the limit may be one diameter.

**Diameter of rivets:** Fairbairn's rule for rivets through punched
holes. If \( t \) = thickness of the thickest plate, \( d = 2t \) when \( t < \frac{1}{2} \)"; and \( d = 1 \frac{1}{2} t \)
when \( t = 0 \) or \( \geq \frac{1}{2} \)". When more than 2 plates, besides the covers, are
riveted together, some add \( 1/16" \) to \( d \) for each extra plate. *Urwin's rule:*
\( d = 1.2 \sqrt{t} \). This is universally adopted for all cases. The rivet holes are
made \( 1/16" > \) the cold rivets to allow for expansion when heated.

**Riveting:** All built-up sections for girders or stanchions have
their plates or parts connected by rivets, which are superior to bolts for
this purpose, for being hammered up hot, they contract on cooling, and
cause a frictional resistance between the plates, and though this is not
taken into account in estimating the strength of the member it adds con-
derably to the rigidity of the work. For the sake of rapidity in erection
the connection between the members of a steel frame structure are fre-
cently made with bolts, though riveting, by adding to the rigidity of the
connections, results in a stronger and stiffer structure. Riveting is done
either by hand or machine. In either case, the rivets should be heated
uniformly in an air furnace and cleared from the black fuel. Rivets should
not be overheated as they, in that case, soon lose their ductility. *Hand
riveting:* For this three men are required. The riveters, two, armed with
riveting hammers (2 to 7 lb.), a steel punch, a snap, and a cupping ham-
mer, stand on one side. The holder up, armed with a holder up hammer
or dolly stands on the other or rivet head side. The riveters first drive
the punch through the hole, the holder up picks up a rivet from the forge,
inserts it in the hole with its red hot tail towards the riveters and presses
his dolly to the head. The riveters hammer the iron immediately round
the rivet to bring the plates close together and prevent bulging. They then
hammer the tail of the rivet, not only to form a point of the shape required,
but also to upset the shank, i.e., to squeeze it up so as to completely
fill the hole. When the head is to be convex, the snap is used by one riveter, and the cupping hammer by the other, the dolly being pressed by the holder-up until the point is made tight and even, and its edge trimmed. **Cold riveting:** When it is inconvenient to use heated rivets, cold riveting is done. The process is similar, but the rivets must be of superior iron. This is a quick process.

**Steel: Manufacture:** 1. **Bessemer process:** By blowing cold air under pressure through molten pig iron. In the *acid* process, the converter is lined with clay, quartz, and ganister and in the *basic* (Thomas) processes, it is lined with calcined Mg, limestone, and tar. The pig contains 1 to 3% P in the latter case. The Bessemer converter (Fig. 149 & 150) consists of a pear-shaped vessel mounted on two trunnions. It may be tilted or in some cases turned entirely upside down. It is tilted to receive the charge and then turned back to the vertical position. In some cases, molten metal is run into the converter direct from the blast furnace. Air blast is forced by means of a blower through the tuyeres at the bottom of the converter up through the molten metal. Si and Mn get oxidized first. Then the C begins to oxidize and a reddish-yellow flame appears at the mouth. The flame becomes rapidly augmented until a white hot flame pours out with a loud roaring sound and sparks appear. Soon the flame flutters and shortens indicating that the C has burned out. The converter is turned down, the blast shut off and the rebarburizer (*spiegeleisen*—Mn 15 to 25%, C 6-5% max, Si 1-5% max, S 0-05% max, P 0-30% max or *ferroman-ganese*—Mn 68 to 82%, C 7-5% max, Si 1-5% max, S 0-05% max, P 0-35 to 1%
max for different grades) added. This not only serves to give the desired C to the blown metal but also in reducing the CO gas in the blown metal and preventing blowholes in the ingots. The blast is again turned on. Then the converter is tilted, the contents poured into ladles and cast into ingots.

**The Lintz and Donawitz (Austria) process:** is a modification of the Bessemer process. A jet of oxygen impinges in the centre of the molten metal in a converter, sets up a cone of high reactivity with temp, gradually decreasing from 2,000° at the centre towards the periphery, and oxidises the carbon causing evolution of gas and appearance of boiling. Unreacted metal from the sides will move towards the centre and react with the oxygen or the oxidised material. Scrap or mill scale to about a fifth of the charge is added. Lime is used as the flux. Unlike the Bessemer blow, it is not necessary to maintain any pressure to prevent the flow of the molten liquid into tuyeres. Owing to the high temperature at the centre, even small amounts of impurities in the oxygen affect the quality of the steel. Owing to the low temperature at the sides, the refractory lasts longer.

2. **Open-hearth process:** (Siemens-Martins). By subjecting pig iron and scrap to the oxidizing flame in a reverberatory furnace (of the stationary or tilting type) and restoring C after the removal of the oxides in the slag. The process may be basic (flux-lime) or acidic (flux-silica). The basic process is extensively used and the steel obtained is more homogeneous and reliable than the Bessemer steel. Also the operation is comparatively simple, the conversion period is short, no fuel is required and the plant cost is small per unit of output. The furnace (Fig. 151) differs from the reverberatory in that the air and producer gas are separately heated in a **regenerative chamber** by means of the heat carried out of the melting chamber by the burned gases. On either side of the melting chamber or hearth are the ports through which the gas and air enter and the vertical flues which lead to the regenerative chambers. The larger and outer one is
for preheating the air and the smaller one for heating the gases. Each chamber is filled with a checkerwork of bricks through which gas and air pass. When starting afresh, the regenerators are heated by fires in the flues below. As soon as one set of chambers cools, the direction of flow of air and gases can be changed and they can be sent through the other set which has just been heated by the burnt gases. Thus the waste heat is used up with a much saving of fuel. The molten metal is poured into the hearth, and then scrap iron and flux are added. During melting, the metalloids get oxidised in 5 or 6 hours. The slag retains the oxides of Si, Mn, P, and S, and acts as a protection to the bath from excessive oxidation by furnace gases and assists in the oxidation of the impurities. Recarburization in the acid process is effected by adding ferromanganese together with coal, charcoal or coke to the stream of metal as it flows into the ladle. In the basic process, ferromanganese or ferrosilicon is added in the furnace and sometimes coal in the ladle.

3. Cementation process: By carburization of W. I. without fusion. The cementation pots are filled with alternate layers of W. I. bars and charcoal, and the tops are luted tight with a material which at first permits the escape of gases but later becomes gas tight. The pots are placed in a furnace and heated gradually in 2 days time to a temperature of 800 to 1,100° and maintained at this temperature for 7 to 12 days depending on the product desired. C penetrates the W. I. at the rate of \( \frac{3}{4} \)" per 24 hours. The steel produced by this process is called 'Cement steel' because the ferrite in the W. I. is converted into cementite. The C migrates into the W. I., reacts with the slag particles rich in iron oxide and produces CO causing blisters near the surface. Hence this steel is also called 'blister steel.' Very little steel is now produced by this process.

4. Crucible process: By carburization of W. I. in a fused condition. Crucibles of 100 lb. capacity made of refractory material (equal parts of fire clay and graphite) are charged with large pieces of W. I., then charcoal and ferromanganese, and lastly small pieces of W. I., Cr, Mn, and V are added when special steels are required. After a clay cover had been put on them, the crucibles are put in a gas fired regenerative type furnace and the temperature raised to a melting heat. When the killing (holding the steel at a melting temperature until it does not evolve gases) is complete, the crucibles are taken from the furnace, the cover removed, the slag skimmed from top of the melt, and the molten steel poured into a small C. I. mould. This process has now been superseded by the electric process.
5. **Electric process**: By heating and melting the metal with electricity in a furnace. The advantages of this process are: 

- **a.** Heat is supplied quickly and very high temperatures are attained.
- **b.** Temperature is under control.
- **c.** Charge is not contaminated.
- **d.** The molten charge may be treated under oxidizing, reducing, or neutral slags, and one slag may be removed and another produced easily.
- **e.** The bath may be kept at any desired temperature to eliminate the non-metallic intrusions before tapping.

The electric furnace is an important adjunct of the Bessemer converter and the open hearth furnace in the production of small quantities of special steel and iron alloys. Such furnaces are of three distinct types: 

- **a.** Furnaces employing an open arc between electrodes above the bath. It is heated by radiation. As the losses are very high, this type is not popular.
- **b.** Furnaces employing an arc between electrodes and the bath. The Heroult direct-arc furnace (Fig. 152). This may have a basic (magnesite) or an acid (silica) lining. The electrodes (C or graphite) are suspended from the roof. They may be removed for charging. Current enters through one electrode, arcs to the metallic charge, travels through the charge, and arcs back to the other electrode. The basic process is used for making Mn, magnet, corrosion, heat resisting, carbon tool, and such other steels while the acid process is used for making steel castings.

- **c.** Electric induction furnaces where the bath forms the secondary of a transformer. The coreless induction furnace (Fig. 153). This consists of an acid or basic type pot surrounded by a water-cooled coil of flattened Cu tubing which serves as the primary. Inside this is placed a special refractory, the space between this and the pot being packed with a granular refractory. The bottom rests on the fire-clay brick which is supported by the outer shell of the furnace made of strong non-magnetic substance. When the charge is placed in the pot and the high-frequency primary current is passed, a heavy secondary current is
induced and dissipated as heat. This heat melts the charge. This furnace is used for making hard carbides, high grade die steel, low carbon alloys, etc.

6. Duplex process: By combining the acid Bessemer and the basic open hearth process. Si, Mn, and part of the C are eliminated in the converter and P and the remainder of the C are removed in the open hearth. The advantage of this over the Bessemer lies in using low grade high-P pig iron and yet producing a satisfactory open-hearth steel. The advantages over the open-hearth are the saving of time and cost of renewals of the hearth lining.

Classification: A. Based on process of manufacture: i Bessemer steel: obtained from Bessemer pig in a converter. It is used for rails, axles, tyres for railway carriage wheels, tools, cutlery, boiler plates, etc. ii Open-hearth steel: or mild steel made by open-hearth process. It is used for structural work, machinery, ship building, etc. iii Blister steel: made by adding carbon to wrought iron by the cementation process. It is used for hammers, springs, etc. iv Crucible steel: made by melting fragments of blister steel in covered fire clay crucibles. It is used for finest cutlery and hardest cutting tools. v Electric steel: It is made by the electric process. It is used for tools and special steel alloys. vi Duplex steel: It is made by the Duplex process. vii Shear steel: Bar of blister steel is cut into short lengths, tied together, sprinkled with sand and borax, and placed at welding heat under tilt hammer, which by rapid blows removes blisters and amalgamates the bundle of bars into a bar of single shear steel. The process of doubling, hammering, and rolling are repeated to improve the quality and obtain a bar of double shear steel. It is used for knives, scythes, cutting tools, etc. viii Cast steel: Blister steel is reheated at low temperature and hammered into bars. It is the strongest and the most uniform steel prepared. ix Compressed steel: It is made by subjecting molten steel to a pressure of 6 tsi to expel gases, close up cavities, and increase strength. It is used for rivets, boring tools, boilers, guns, etc.

B. Based on use: i Structural steel—low carbon and low alloy steels made by the basic open hearth process are used in buildings, bridges, ships, etc.; ii Boiler steel—high quality low carbon steel made by
open hearth process and used in making boilers; iii Sheet bar and tin bar-
low carbon steel made by basic open hearth or duplex process and used
for rolling into sheets and tin plates; iv Free cutting steel—high sulphur
steel made by open hearth process and used for bolts, nuts, screws, etc;
v Casehardening steel—low carbon plain or alloy steels made by open hearth
process; vi Forging steel—medium carbon plain or alloy steel made by
open hearth or electric process; vii Spring steel—plain carbon or alloy
steel made by open hearth or electric process; viii Rail steel—0·5 to 0·7%
carbon steel made by open hearth or duplex process; and ix Tool steel—
high carbon plain and alloy steels made by open hearth or electric process
and used for hand and machine tools.

C. Based on composition: i Plain carbon steels: a. Dead soft steel—
contains <0·1% carbon and from 0·2% to 0·5% Mn; b. Mild or low carbon
steel—(0·15 to 0·25% C and <0·7% Mn) does not respond appreciably
to heat treatment in regard to strength but the grain structure and the
ductility are improved. This is used for electrical work; c. Medium
carbon steel—(0·25 to 0·5% C and <1% Mn) requires heat treatment to de-
velop full properties; d. Half hard or medium high carbon steel—(0·5 to
0·8% C) responds to heat treatment. This is used for axles, gears, heavily
stressed parts of automobiles and aircrafts and wear-resisting forgings and
stampings; and e. Hard or high carbon steel—(0·8 to 1·3% C) responds excellently
to heat treatment. This is used for plates, springs, and tools.

ii. Alloy steels—which contain Ni, Cr, Mo, V, and W in addition to C and Mn.

Properties: The strength, ductility, and elastic properties depend
on: i the carbon content, ii the % of Si, S, P, Mn, and other alloying
elements, and iii the heat treatment and mechanical working. The
magnetic and mechanical properties are also dependent upon composition,
heat treatment, and mechanical working.

Effect of impurities: Sulphur between 0·02 to 0·1% has no effect
on strength and ductility. But it reduces the malleability and weldability,
of the hot metal. Sulphur in excess of that which is neutralised by Mn
reduces both strength and ductility. Phosphorus, if over 0·12%, is very
undesirable. It increases strength but decreases toughness and ductility.
It also increases resistance to corrosion and improves machinability in
free-cutting steels. High P steels break under very slight stress if this is
suddenly applied, or if vibration is encountered.

Alloy Steels: are those that owe their properties to some element
or elements other than carbon. Ternary steels are those which have one
element other than Fe and C. Quarternary steels have two alloying
elements e.g., Ni-Cr, Cr-V, Co-Cr. Complex steels have three or more alloying elements e.g., high speed tool steels, heat resisting steels containing Ni, Cr, W, and Si, etc. Some elements like Ni, Si, and Cu do not combine with the C and others like Mn, Cr, W, Mo, and V combine to form carbides. The principal types are: Silicon steel: Si functions as a general purpose deoxidiser, improves oxidation resistance, increases hardenability of steels and strengthens low alloy steels. Up to 0.2% it has no effect. Between 0.3 to 0.4% it increases the elastic limit and ultimate strength without decrease in ductility. Steel with 1 to 1.5% Si has the same properties as low Ni steel, is easily manufactured, and used for bridges. 2 to 4% Si in low C steel gives a high permeability, low hysteresis and eddy current losses. 14 to 15% Si makes the steel acid resisting, and 30% makes it still more resisting but it is made brittle. Nickel steel: Ni imparts strength, toughness, and ductility to the steel, thereby enabling it to be heated within a wide range without damage. 3% Ni steel is tough, elastic and is used for armour plates, wire cables, etc. With over 20% Ni and in combination with other alloying elements, the steel: i gets a low coefficient of expansion, ii becomes non-magnetic, which makes it applicable in radio work and telephone equipment, and iii gets increased resistance to corrosive media, oxidation, resistance at high temperature and high strength at elevated temperature. Steel with 30% Ni, called invar steel, has a very low coefficient of linear expansion at room temperature and hence used for surveyor's tapes and other instruments whose dimensions should not change at ordinary temperatures. Manganese steel: Mn increases hardenability inexpensively and counteracts embrittlement by inevitable S. Steels with 1.8% Mn are stronger than carbon steels but the full properties are developed only by heat treatment. These are case hardened and used for machine parts, gears, shafts, and grinding balls. Up to 6%, Mn renders the steel brittle. Over 6% Mn with high C, the steel becomes resistant to impact types of abrasion. 11 to 14% Mn makes the steel non-magnetic. It is used for crushing, and grinding machinery, curve rails, crossings, etc. Chromium steel: Cr increases corrosion and oxidation resistance, increases hardenability, contributes some strength at high temperature and resists abrasion and wear (with high C). Cr up to 2.5% with or without Mo, Cu, etc., makes steel harder than carbon steels. Steel with up to 1.25% Cr is used for engine beds, rail-road equipment, dredging buckets, boiler, and pressure vessels. 1.8 to 2.7% Cr steel is used for files, ball and rollers bearings, cutting tools, dies and stamps, etc. Over 3% Cr makes the steel brittle. Titanium steel: Ti fixes carbon in inert particles and gives high tensile strength to the steel. It is added to
Cr steels to prevent air hardening and increase the corrosion and oxidation resistance. Ti steel is used for rails. Vanadium steel: V increases strength, hardenability, gives marked secondary hardening, and resists tempering. V steel is used for castings and forgings for machines, automobiles, and rolling stock, axle springs, shafts, and gears. Steel with 1% Cr, 0-15% V is used for automobile springs. Tungsten steel: W forms hard, abrasion-resistant particles in tool steel and promotes red hardness and hot strength. 5 to 6% W gives good magnetic properties. With 16% W, the steel is known as tool steel and is used for cutting and in metal turning. Molybdenum steel: Mo deepens hardening, raises hot strength, creep resistance, and red hardness and enhances corrosion resistance in stainless steels. In small percentages it improves the machinability. Mo steel is used for airplane fuselage and automobile parts. Copper steel: Cu improves the mechanical properties of cast steel. 0-2 to 0-5% decreases rusting and 1 to 5% increases the strength of low and medium carbon steels. Cobalt steel: 3 to 35% improves the magnetic properties of magnet steels. As it is difficult, expensive, and hard to forge this steel, in the cutting steels it is usually alloyed with Cr. Boron steel: B up to 8% imparts hardness. Aluminium steel: Al deoxidizes efficiently, restricts grain growth and functions as alloying element in nitriding steel.

Special steels: Silico-chrome steel: (3-5% Si, 8 to 9% Cr, 0-4% C) is used for exhaust valves to operate at high temperatures. Silico-manganese steel: (1-5 to 2-5% Si, 0-6 to 0-9% Mn, 0-4 to 0-5% C) is used for automobile, railroad and general engineering springs. Over 0-5% Si is used in high chromium stainless steels for castings. Steel with small amounts of Cr and Mn, surface hardened by pack carburising or cyaniding, is used for transmission and ring gears of automobile and machinery. Crank shafts and piston rods are made of similar material with V added to give marked resistance to reversible stresses. Stainless steel: (Steel with Cr and Ni) is resistant to atmospheric corrosion, oxidation at high temperatures and attack by corrosive liquids and gases. It offers high strength, hardness, ductility and good creep properties. Steel with 12 to 15% Cr and 0-3 to 0-4% C is used for cutlery and is sold under various trade names. Steel with 18% Cr, 8% Ni and small amounts of Mn, Si, and C is used for railway carriages, petroleum refineries, chemical plants, and in food industries. Steel with Cr, Mo, W, and V is used for high pressure steam turbines, cracking plants, and high temperature reaction vessels of chemical plants. Steel with 9% Mo and 4% Cr is hardened and used in high speed cutting. An alloy containing 50 to 65% Co, 30% Cr, and 4 to 15% W with C in varying amounts and very little Fe has very high cutting hardness and
wear resistance. *Stellite:* (50 to 90% Co; 10 to 35% Cr; 15% W with little C, Mo, Fe, or Ni) retains its hardness even at heat and is used for tips of tools and facings of dies. As it does not rust or tarnish, it is used for surgical instruments. Ni-Fe-Al, and Ni-Co-Al-Fe steels are used for permanent magnets.

**Clad Steels:** A clad steel plate is a composite plate made up of a permanently strong material (low carbon steel plate) to one or both sides of which there is uniformly and permanently joined a veneer or cladding of a corrosion-or heat resisting metal (stainless steel, Ni, Monel, Ag, Cu, Inconel, cupro-nickel, etc). clads are formed by heat and pressure, casting, intermelting, straight rolling, sintering powdered metals on a base of strip steel and are, fusion, or resistance welding. Clad steels are clean and they transfer heat quickly. They are used on fishing boats, naval vessels, home cooking utensils and kitchen equipment, tank cars, processing equipment of all types, ornamental architectural applications, tables, tanks, hospital equipment, water supply systems, etc.

**Mechanical Treatment of Steel:** means the reduction by mechanical means of a given section of steel into a useful product. *Hot working,* which is above the critical temperature, causes the steel to recrystallize as soon as the work has ceased, while *cold working,* which is at the room temperature, does not cause the steel to recrystallize and causes only plastic deformation elongating the crystals. Hot working increases the homogeneity and soundness of the steel, forms the metal to the desired shapes, refines the crystal structure, deforms the dendrite segregation, and increases its strength and other physical properties. Hot working by rolling or extrusion provides all the structural members e.g., joists, channels, angles, rails, etc. Crankshafts, levers, tools, connecting rods, etc., are made by hot pressing or drop forging. Cold working increases the hardness, tensile strength, and yield point but decreases the ductility. Many cold-working operations are of the press-working variety in which suitable punches and dies create limitless varieties of three dimensional articles from sheet e.g., automobile bodies and associated items, numerous aircraft members, many kinds of containers such as cooking utensils, barrels, cartridge cases, housings, etc. Bolts, nuts, coins, nails, etc., are cold-formed. Rods and seamless tubes are cold-finished.

Mechanical treatment is also divided according to the operation performed: *Rolling:* is done in large specially equipped rolling mills. After being heated to the required temperature, the steel billet is passed, in succession, through different rollers until it is brought to the proper
section. ii Drawing: Wires and rods are made by this process. The metal is first passed through successive rollers until a small dia. elongated bar is obtained. This is then passed by drawing through successive specially shaped dies until wire of the required dia. is obtained. iii Pressing: means the sizing and shaping of a large number of similar articles with a press. The article to be shaped is placed on the die and the punch is then lowered slowly under the required pressure. The material is thereby pressed between the die and punch and made to take the required form. Press work, when used in the case of steel, is called stamping. iv Forging: is done by hammering the steel when it is above the critical range of temperature. The blow is sudden, the density of the steel is increased, and its grain size refined above that which it possessed after rolling at the steel mill.

Metallurgical Terms: \( \alpha \) Iron: Ferrite or pure iron in its natural condition is known as \( \alpha \) iron. It is ductile, magnetic, and dissolves very little carbon; \( \beta \) Iron: is non-magnetic and has the power of absorbing carbon. It exists between 768 and 900°; \( \gamma \) Iron: is also non-magnetic and has the power of dissolving large amounts of carbon. It exists between 900 and 1,399°. With carbon dissolved in it, it is known as austenite; \( \Delta \) Iron: is non-magnetic and absorbs very little carbon. It exists above 1,399° and becomes liquid above 1,535°; Ferrite: denotes iron in the crystal form which contains no carbon. It is weak, soft, and ductile; Cementite: \((\text{Fe}, \text{C})\) is a hard, brittle carbide of iron and it occurs in steels that have cooled slowly from a high temperature; Pearlite: is a mechanical mixture of alternate layers of ferrite and cementite produced by cooling of iron from red heat. Slow cooling produces coarse pearlite and rapid cooling fine pearlite. Pearlite is stronger, harder, and more ductile than ferrite; Austenite: is the solid solution of iron or iron carbide in \( \gamma \) iron. It can have any amount of carbon from a trace up to 1.75%, depending upon the temperature to which the steel is raised.

Temperatures: The range of colours of heat treated steel which enables a person to recognise the temperature is as shown below: 210 to 250° Yellow; 250 to 270° Brown; 270 to 290° Purple; 290 to 400° Blue; 425° Black; 700 to 1,200° Red; 1,200 to 1,500° White; and 1,600° Bluish white.

Critical temperature: If a low carbon steel is heated in a furnace at a uniform rate of 11° per min., on reaching 727° there is a lapse during which the steel itself does not become any hotter, though the temperature of the furnace rises. This is called the 'critical' temperature Ac, at which the alternate layers of iron carbide and ferrite in the pearlite are mutually dissolved to form austenite. After passing Ac, the uniform rate
of increase of temperature will be resumed until the upper critical temperature $A_c_1 (845^\circ)$ at which the last remaining excess of ferrite is absorbed by the austenite. Now if the furnace and steel be allowed to cool at the same rate, at $693^\circ$ the cooling of the steel is temporarily arrested. The steel becomes hotter and glows due to evolution of heat even though the furnace is cooling down. This recrystallization point $A_r_1$ at which the austenite breaks down into cementite and ferrite (called pearlite) is usually $33^\circ$ below the decrystallization point $A_c_1$. After passing $A_r_1$, the cooling continues at a uniform rate until normal temperature. Critical temperatures or transition points or transformation points vary by $55^\circ$ with the variation in carbon and the alloying content of the steel. There are two more arrest points designated as $A_c_2$ and $A_c_3$ during heating, and $A_r_2$ and $A_r_3 (821^\circ)$ during cooling. $A_1$ and $A_3$ mark the division between $\gamma$ and $\beta$ and $\beta$ and $\infty$ irons respectively. $A_2 (A_c_2$ and $A_r_2)$ point is called the magnetic transformation point because at this point the metal on heating loses its magnetic properties and gains them on cooling. But this point has no direct concern with heat treatment.

**Martensite:** is a transitional constituent in the breakdown of austenite to sorbite. It is a solid solution of carbon or carbide in $\infty$ iron. It is the chief and characteristic constituent of hardened steels and is brittle with little ductility. Microscopically it is characterized by needle-like structure.

**Troostite:** is formed if a steel is rapidly cooled but at a rate $< \theta$ the critical hardening velocity. This is another of the transitional substances arising out of the breakdown of austenite into pearlite, but formed at a much higher temperature than martensite. It is half as hard as martensite.

**Sorbite:** is produced at $677^\circ$ by reheating fully hardened steel. It is due to the change of troostite. It is less ductile than pearlite but has a high tensile strength and yield point.

**Iron-carbon equilibrium diagram:** (Fig. 154). All alloys above the range $a b c d$ are liquids. When liquid alloys containing up to $4\cdot3\%$ carbon are cooled to temperatures on the curve $a b c$, solid crystals begin to form. With 0 to $0\cdot6\%$ carbon, the first crystals formed are solid solutions of carbon in $\Delta$ iron, and with $0\cdot6$ to $4\cdot3\%$ carbon, the first crystals are austenite. In the zone $c b a h j e c$, the liquid melt and solid exist together in equilibrium. When cooling is continued up to $a h j e c$, the alloys become completely solid. When liquid alloys containing over $4\cdot3\%$ carbon are cooled to temperatures on $c d$, solid crystals of cementite begin to form. When they are cooled to $c f$, they become completely solid. The
alloy containing 4.3% carbon is the eutectic alloy and it completely solidifies at c forming austenite and cementite. △ iron may exist in the region abjkn, which is not of importance as it is not employed in the heat treating processes. fesk represents the range of stability of the eutectic mixture of cementite in γ iron. esg represents the condition of equilibrium between this eutectic and the solid solution in γ iron. aeg shows the limit where austenite is stable. Below gsa pure α or β iron separates out. gsa and es meet at s giving a eutectic point similar to c. Below psk the eutectoid mixture exists in the different forms shown in Fig. Alloys containing up to 1.85% carbon are classed as steels, those containing over 1.85 and up to 4.3% as hypoeutectic cast irons, and over 4.3% as hyper-eutectic cast irons.

Heat Treatment of Steel: means any timed process involving the heating and cooling of steel in solid state; i To relieve internal stresses caused by casting, rolling, bending, welding, etc.; ii To increase or decrease the hardness and strength; iii To alter and develop a more desirable microscopic structure; iv To refine or coarsen the grain structure; v To improve resistance to heat and corrosion; vi To improve the machinability; vii To modify electrical and magnetic properties; and viii To increase surface hardness by altering the chemical composition.

The principal processes are:
Annealing: This means heating the steel slowly to some predetermined temperature, holding at this temperature till the desired changes in the structure take place, and cooling slowly. The principal treatments are:

a. Full annealing: consists in heating the steel to 50° above the critical temperature range, holding above that range for a definite period, followed by slow cooling through the range. It improves the machinability and refines the grain structure.

b. Process annealing: consists in heating the steel to a temperature below or close to the lower limit of the critical temperature range followed by cooling as desired. It increases the ductility of cold-worked steel.

c. Normalising: requires heating steel articles of heavy section to 50° above the critical temperature range followed by cooling to below that range in still air at ordinary temperature. It restores steel to its normal condition after hot working, cold working, non-uniform cooling or overheating and removes the effect of a previous heat treatment. Stresses in the steel are relieved, and the grain size and structural constituents of the steel are affected at the same time.

d. Spheroidising: is prolonged heating of high-carbon steels at a temperature in the neighbourhood of, but generally slightly below, the critical temperature range, usually followed by relatively slow cooling for producing a globular form of carbide. This treatment is applied for meeting given strength requirements, either in relation to annealing operations or as a preliminary to subsequent heat treating operations.

Hardening: requires heating to a temperature above the critical range, and cooling rapidly enough through the critical range to increase its hardness, strength, and refinement of crystal structure. Quenching: is cooling of the object rapidly by immersion in water, brine oil, air, gas or even a solid in a form which absorbs heat rapidly. Water containing 3 to 10% NaOH or 5 to 10% NaCl and below 21° as a quenching medium gives a high degree of hardness to steel. Oils at 32 to 60° produce less distortion and residual stresses in steel and are therefore adopted for quenching intricate shapes. In flame hardening, the metal at and near the surface of a steel part is brought rapidly to the hardening temperature by oxy-acetylene flame and immediately quenched by a spray of water or by an air blast. Bearing areas of large shafts, spindles, cams, clutches, etc., are hardened either by this method or by electric induction heating where an alternating current of 1,000 to 500,000 cycles per sec is passed through Cu inductor blocks which surround but not touch the surfaces to be hardened and the heated areas are suddenly quenched by sprays of water delivered through holes in the inductor blocks.

Tempering: is reheating of steels immediately after quenching to
temperatures below the critical range, followed by any desired rate of cooling. This relieves the quenching strains, permits the decomposition of the martensite to proceed, forming secondary troostite between 204° and 399°, softens the steel, and develops the desired hardness and ductility. Tempering below 204° relieves only internal stresses and gives extreme hardness to steel. High-carbon steels are tempered at from 200 to 300° and leaf springs at 400°. The colour of the heated steel ranging from very faint yellow at 216° to deep blue at 400° is also taken as a guide for the correct temperature. Higher temperature treatment that "draws the temper" and appreciably softens the steel should be termed drawing and not tempering. Low carbon steels are hardened by quenching from 871° (by immersion in liquids or by contact with metal) and tempered at 500 to 600° followed by oil cooling.

**Case hardening:** gives hard, wear-resisting surfaces and shock resisting properties to machine parts by changing the composition of the steel near the surface. The processes are:  

a. **Pack carburizing:** The carbon content at the surface is increased by heating steel containing 0.1 to 0.3% C to 1,000° in a metal container packed with a carburizing compound (a mixture of wood, bone or leather charcoal) and maintaining for a proper period. Carbonates of Ba, Ca, and Na, called energizers, are added to improve the rate of carburizing.  

b. **Liquid carburizing:** or cyaniding is adopted for small components. A mixture of 20 to 50% NaCN, 37 to 40% Na₂CO₃, 18 to 30% NaCl is melted in a heat-resisting pot, kept at 870°, and the parts to be carburized are placed in a wire basket and kept immersed in the bath for 30 min. The basket is then taken out and immediately quenched in water when carbides and nitrides are formed on the surface.  

c. **Gas carburizing:** Here the carbon content is increased by heating the article in a furnace to above the critical temperature and admitting CH₄, CO, H₂, or CO gas.  

d. **Surface hardening powder:** is sprinkled on the steel heated to 900° with a blow pipe. The process is repeated to ensure that all parts of the steel are properly covered. In some cases the powder is used in the form of a molten bath. As the flame of a blow pipe causes softening of certain portions, in an improved process, the surface is heated by electric induction as under "hardening." After carburizing, the parts are heat treated by:  

i quenching directly from the box at the carburizing temperature and tempering;  
ii cooling in the box, reheating once to the desired temperature, quenching, and tempering;  
iii cooling in the box, reheating twice to the desired temperatures, each followed by quenching, and finally tempering.

**Nitriding:** is the modern process applied only to certain alloy
steels for producing an extremely hard surface and overcoming the defects of quenching. The steel articles are heated in a furnace to 500° and the stable nitrides of Al, Cr, Si, Mn, and Mo which give the case hardening effect are allowed to form by the action of NH₃ gas on the articles which contain these elements in the required proportions. They are then allowed to cool and no further treatment is necessary.

**Ageing**: is a phenomenon in many steels, occurring after mechanical or heat treatment, due to the tendency of the steel to return to a previous state of structural equilibrium out of which it was formed. It is due to the breaking down of a supersaturated \(\infty\) solid solution, leading to slow precipitation of iron carbide, or oxides, nitrides, and other compounds that occur in steel. It raises the hardness, strength, and machinability, but reduces the ductility and resistance to impact.

**Heat treatment of Cast iron**: is done, by processes similar to those adopted for steel, to improve C. I. **Annealing**: is done by heating the castings with iron scrap, slag, and sand or some patented medium like Houghton’s Liquid Heat N. D., in a furnace to 800 to 870°, keeping at this temperature until the carbides are broken and the casting is softened, and then cooling slowly to develop malleability. **Stress relieving**: is done by heating the castings to from 550 to 690° in a similar medium for about 6 hours and then cooling slowly. **Quenching**: is done by heating the castings to 850 to 900° and quenching in oil or a patented medium to increase the hardness by dissolving the graphitic carbon and retaining it in the martensitic iron. **Tempering**: is done to reduce the brittleness and relieve the hardening strain of the quenched casting by heating to 200° in a patented oil or salt medium for about an hour and cooling in still air. **Drawing**: is similar to tempering except that the temperature is 500°. This is done where maximum strength at the expense of hardness is desired.

**Welding**: ‘Welding, in perfection, is the art of joining parts of the same metal in such a way that the result is a continuity of homogeneous material of the composition and characteristics of the two parts which are being joined together’. During the process, heat is used to bring about a plastic or molten state at the surfaces of the metal which are to be joined. The processes are classified into three main groups viz.,

1. **Fusion welding** (based on method of heat generation employed):
   a. Blacksmith’s fire (forge), b. Gas (oxy-acetylene), c. Electric arc (arc), d. Gas plus electric arc (atomic hydrogen), e. Chemical reaction (thermit), and f. Electrical resistance (resistance).

2. **Pressure welding** (or plastic based on whether or not pressure is used to form the joint):
   a. Under pressure (forge and resistance), b. Without pressure (oxy-acetylene, arc, and atomic
hydrogen). 3. Based on whether or not additional filler metal is used: a. With filler (oxy-acetylene, arc, and atomic hydrogen), b. Without filler (resistance).

1 a. Forge welding: See 2 a.

1 b. Oxy-acetylene welding: The edges of the material to be welded and also the filler are heated up to melting temperature by the flame of a blowpipe, the filler material being deposited in the gap between the two parts to be joined, and the molten metal running together, the whole integrating on cooling. Oxygen and acetylene are thoroughly mixed in correct portions in a welding torch and are burnt at the tip (3,200°). Oxygen at a pressure of 2,000 psi and acetylene dissolved in a porous filler saturated with acetone at a pressure of 220 psi are kept in separate steel containers. High pressure blowpipes, with a chamber where the gases supplied at a pressure of from 2 to 14 psi get mixed, are used. The welding rod is of the same composition as the parts being welded. To remove impurities, a flux (chlorides of Na, K, Li for Mg, boric acid for Monel, etc.,) is added for all metals except steel. This is largely used for welding steel, cast-iron, and non-ferrous metals. Pipe lines from oil fields, battleships, boilers, and bridges are now formed by this process. Oxy-hydrogen welding (2,800°) is adopted for the welding of thin sheets of steel. Welding using argon is adopted for joining semi-annealed Al conductors.

1 c. Electric arc welding: Here the heat of an electric arc is used for melting the base material and also the filler metal, when used. i Carbon-arc: The arc is struck either between two carbon electrodes (A. C.) or between a carbon electrode and the base material (D. C.) or between a metal electrode and the base material (D. C.), the metal electrode providing, at the same time, the filler material. It is used for welding sheet steel, copper alloys, brass, bronze and Al. High welding speed and efficient welds are the main advantages claimed. ii Metallic arc: Here the arc, drawn between the filler metal (rod or wire) electrode and the plate material to be welded, creates a temperature of over 3,500° in a small area concentrated at the point of welding on the plate and at the end of the filler rod. While the surface of the base metal is molten and ready for welding, the end of the filler rod also melts, and small drops of molten filler metal are projected through the arc on to the welding point so as to unite with the base metal. A. C. is preferred to D. C. This process is used for welding of Class I pressure vessels.

1 d. Atomic hydrogen welding: Here a single-phase A. C. arc
is maintained between two tungsten electrodes, and a stream of H₂ gas at a pressure of 6 to 8 psi is introduced into the arc from openings around the electrodes. The electrodes and the H₂ nozzle are carried by the welding torch. The heat of the arc breaks up the H₂ molecules into atoms and these combine again a short distance beyond and in doing so liberate a large amount of heat (4,400°) which melts the metal to be welded. When additional metal is required, filler rods are melted into the joints. The presence of H₂ around the weld prevents the oxidation of the electrodes and the weld metal. Welding of boiler shells, alloy steels, thin sheet steel parts, and non-ferrous metals, and repair of dies are done by this process.

1 e. **Thermit welding**: When a 'thermit' mixture (granulated Al and Fe₃O₄ in the ratio of 1:3 by weight) is ignited by a special ignition mixture (Ba₂O₃ + Al), molten Fe at 2,800° is formed. At the correct moment, the molten Fe is tapped into a sand mould placed around the ends to be joined. The ends unite, liquid Al₂O₃ flows on to the top of the metal, and helps to maintain the temperature of the weld. The Al₂O₃ slag is subsequently removed. For welding steel, 1 lb. of nickel shot, 1 lb. of crushed ferro-manganese, and 20 lb. of steel punchings are added to 100 lb. of plain thermit. This process is extensively adopted for heavy welding including locomotive and marine crankshaft repairs, and pipe and rail welding especially where electric power is not available.

1 f. **Resistance welding**: See 2 b.

2 a. **Forge welding**: This is made by heating strongly in the forge fire and hammering together the shaped ends of the two bars to be welded. The methods of preparing the ends of the bars, known as *scarfing*, are lap weld, split weld, and butt weld. To prevent the formation of scales due to oxidation by air coming in contact with the hot iron, a thick fuel bed is maintained on the forge and in addition a flux like clean quartz sand or sal ammoniac with borax is added.

2 b. **Resistance welding**: The pieces of steel are heated to a plastic state over a limited area by an alternating current of <12 volts and brought together by mechanical pressure, no additional filler material being used. Most materials can be resistance welded. The types of welds are butt welds, spot welds, projection welds, and seam welds.

2 c. **Thermit pressure welding**: The parts to be joined are heated by the products from the 'thermit' reaction and mechanical pressure is applied to complete the weld.

In connection with steel for roof trusses, it is stated that forging
and smithy should be avoided as far as possible in connecting the members of the truss. The oxy-acetylene blow pipe and the electric welding processes are therefore obviously suitable for joining the members of a steel truss if it should not be desired to connect them by riveting.

**Uses of Non-Ferrous Metals:** *Aluminium:* noted for its resistance to corrosion under atmospheric conditions, (due to the formation of an insoluble thin layer of the oxide on the surface which is impervious to many materials including O₂) and excellent thermal and heat conductivities, lightness, relative abundance, and reasonable price is used for rolling into sheets (plain and corrugated) for domestic, industrial, and chemical purposes and for posts, panels, and balustrades. It is used as a deoxidizer for irons and steels and for maintaining large melts of metal in the fluid condition. Al because of its relatively high electrical conductivity (61% of Cu, Fe 12.4% of Cu, and Mg 33.4% of Cu) lightness, and strength is adopted as Al and steel-cored Al conductors for high, low, and medium voltage transmission lines of even long spans, as bus bars and electrolytic conductor grade Al rods in power stations, and as insulated wires for weather-proof house service connections. Because of its high specific tenacity (ratio of tensile strength to weight), it is used for aircraft structures, long span bridges and roofs as well as in beams, columns and trusses to reduce their dead weight and thereby increase their span length or alternatively to resist greater superincumbent load for the same span. The low modulus of elasticity of Al members increases their resilience so that they offer better resistance to impact. Because of the lightness in weight of Al, the fabrication of Al bridges presents no difficulty. Al lacks machinability, wears badly, and does not take fine threads. Granulated Al is suitable for use in alumino-thermics and the calorizing process. Al paints have wide commercial applications both as protective and decorative coatings for metals, woods, and many other materials.

**Copper:** It is resistant to atmospheric and sea-water corrosion. It is chiefly used as nails for fixing slates, malthoid sheets, etc., on roofs. In Kerala, Cu sheets are used as roof covering for temples, and similar structures. Cu bars are also used as cramps to bind ashlar masonry. Cu forms most useful alloys with other metals, as for example, brass, which is so largely used in building construction for hinges, tower bolts, rimlocks, door knobs and handles, etc. Occasionally, but rarely owing to its cost, eave gutters and rain water down pipes, made of Cu are used. It is also employed for locomotive fire-box plates, radiator elements, domestic boilers, refrigerator tubes, windings of dynamos, motors, transformers and other coils, for bus-bars, switchgear parts, electric power transmission cab-
les, electrodes for welding machines and furnaces, lightning conductors, etc.

**Lead:** Because of its plasticity and malleability, it is easily rolled into sheets or extruded in the form of tubes, pipes, rods, and wires. It is used for fixing sanitary fittings, and also as bedding for steel girders and roof trusses. Because of its resistance to corrosion by atmosphere, natural waters, and mineral acids, it is used as an ingredient in lead paints in the form of white lead (hydrated carbonate of lead), red lead, sugar of lead, etc. Because of danger to health, lead pipes should not be used for soft drinking waters. It is also a constituent in certain alloys and solders. It is extensively employed in the manufacture of containers for chemicals since it resists the action of H₂SO₄ and HCl.

**Magnesium:** Although commercially pure Mg is not employed in engineering, it is used as a deoxidizer to remove the last traces of O₂ from baths of molten metal or from inside radio valves. It is also used as the principal ingredient of aircraft flares and in photographic flash powder. Mg alloys e.g., the Elektron group are now used for automobile and aircraft parts as forgings, extruded bars, sheets, and castings.

**Nickel:** is widely used as a coating for other metals, such as steel, Cu, brass, etc., for both decorative and corrosion protection purposes. Nickel clad plate or strip (Ni rolled on to steel) is used in the construction of industrial chemical tanks, kettles, containers, etc. Ni alloys include a wide range of alloys of great importance on account of their high mechanical strength and high-temperature properties, resistance to corrosion, caustic alkalis and food acids, electrical qualities, decorative applications, etc.

**Tin:** is used for lining lead pipes, occasionally as a protective covering for iron plates, such as kerosene tins, and for small gas tubing. It is a constituent in several alloys and soldering materials.

**Zinc:** is used for roofing valleys in tiled roofs, light eave gutters and down pipes, cisterns, die castings, galvanising steel sheets, plain or corrugated, and steel pipes used in house services in water works. It is also a useful component part in several alloys. ZnO is used in Zn paints. ZnCl₂ is used as a wood preservative.

**Germanium:** contains 0.001 to 0.01% of Sn as an alloying agent. It is used for replacing rectifier tubes and for detector purposes.

**Tantalum:** is used in capacitors.

**Selenium:** is used as a decolorizer in glass industry, in rectifiers, in telephone system, in electro-plating, in cheaper radio and television sets replacing the rectifier tube.
Cobalt: is largely used in the television industry, in permanent magnets, speakers, and television tubes. It is also used in the ceramic industry, in ground-cast enamels, in cemented carbides, for drills and other tools and dies, in high-speed tool steels and as a colorant.

Titanium: because of its resistance to corrosion, is used in the wrought and cast forms in the chemical industries. It is easily alloyed and small increments of C, N₂, and Cr give enormous increase in strength. Its sp. gr. 4.5 and melting point 1,725° are advantageous in uses requiring higher skin temperatures than those which can be tolerated by Al (M.P. 650°). It is costly and difficult to fabricate. It is easily rolled, but hard to machine and costly to cast.

Alloys: are mixtures formed by melting two or more metals together. They are not mere mechanical mixtures as they exhibit properties quite different from those of the constituent metals. For instance, while Cu and Sn are malleable, the white alloy made with them is so hard that it cannot be cut with steel tools and is as brittle as glass. The tensile strength of the alloy is only 1/5 that of Sn and 1/50 that of Cu. The principal alloys are:

Brasses: are essentially Cu-Zn alloys which are corrosion resistant, machinable, and possess excellent mechanical properties. Their uses are as follows: Cu < 45%—ornamental castings; Cu 60%—Muntz or yellow metal, for extrusions and forgings (because of its hot rolling properties) and ornamental castings; Cu 66 to 75%—sheets, tubes, cartridges, locks, and door handles. The industrial brasses can be classified as follows: i Straight brasses: (5 to 43% Zn) are worked either cold or hot. Brasses with 30 to 37% Zn are used where ease of fabrication, by rolling, pressing, wire-drawing, etc., high corrosion resistance and medium strength are required. Those with 5 to 20% Zn are used only for decorative purposes. ii Free-machining brasses: (40% Zn, 1.5 to 3% Pb) are not as strong and ductile as the lead free alloys, but have good machining properties. They are used in the form of extruded or forged sections in applications involving extensive machining, e.g., automatic lathe work. iii Corrosion resisting brasses: Aluminium brass 2 to 3% Al and 22% Zn, and naval brass 1% Sn, 29 to 37% Zn are used for marine condenser tubes. iv High-tensile brasses: (Al, Fe, Mn up to 5% of each). These are used in ship’s propellers, certain parts of underwater craft, etc., where high strength, high fatigue resistance, and high corrosion resistance are required. v Brazing metal: (45 to 50% Zn). It is used as a solder. Strongest joints are made with lower Zn alloys, but the choice is governed by the
melting point of the materials joined e.g., high-zinc brasses of relatively low melting point require solders of higher Zn content.

Aluminium alloys: are light in weight. Mn (1 to 1.5%) gives a non-heat-treatable general purpose alloy with very good drawing, forming, and welding properties and excellent resistance to corrosion. This is used for panelling and sheet metal work, packaging, utensils and welding. Cu (3.5 to 5%) gives a heat-treatable alloy with excellent machinability, good resistance to corrosion and high mechanical properties. This is used for aircrafts and general engineering, wires, and cores for cladded sheet and plate. Si (11 to 13.5%) gives a forging alloy with a low coefficient of expansion and good resistance to corrosion. Mg (0.8 to 8.0%) gives a non-heat-treatable alloy with medium mechanical properties, excellent resistance to corrosion, and high resistance to alkaline attack. This is used for ship building, rivets, pressing and welding. Duralumin: (Cu 4; Mn 0.2; Mg 0.5; Si 0.25 to 0.60; Al 94). is used in automobile and aircraft engineering constructions, in surgical and orthopaedic work and for non-magnetic and other instrument parts. It is as strong as mild steel, is easily machined, and takes fine threads. It corrodes more readily than other Al Alloys. Y Alloy: (Cu 4; Ni 2; Mg 1.5; Al 92.5) is used for pistons in aircraft industry and also for connecting rods, cylinder heads, gear boxes, propeller blades, etc. It possesses high strength at elevated temperatures and is a good conductor of heat. Alclad: is duralumin with a thin coating of pure Al (to a thickness of 1/10 of the total) on each side to reduce corrosion due to salt water.

Magnesium alloys: are light and possess excellent machinability. Their composition is Al 3 to 10, Mn 0.1 to 1.5, Zn 0.3 to 1.3 and Mg balance. They are used in castings, forgings, extrusions and rolled sheet, strip, and plate. Al refines the grain structure, increases strength and hardness, and decreases ductility. 13% Al makes the alloy brittle and 30% Al makes it resemble glass. Zn and Mn aid corrosion resistance. Dow metal: (Al 4 to 12; Mn 0.1 to 0.4; Mg 85 to 98) largely used for tubing and machine parts in aircrafts and automobile work.

High nickel alloys: (over 50% Ni) are highly resistant to corrosion by most of the normal and special corroding agents found in industries, and to oxidation and scaling at elevated temperatures. They possess good strength, toughness and high ratio of strength to ductility. Ni-Cu alloy or Monel: (63 to 70 Ni; 20 to 30 Cu; Fe 2; Mn 1.1; Si 4; C 0.3) is used for all applications requiring strength and high resistance to corrosion as in building construction, chemical industry, marine industry, etc. Ni-Si alloy: (Ni 85; Si 10; Cu 3; Mn 1; Al 1) is used for kettles, evaporators,
pipe lines, fittings and equipment where resistance to hot or cold sulphuric, acetic, and phosphoric acids is required. **Ni-Cr alloy**: (Ni 80; Cr 20) is used for wires of domestic electric heaters. Traces of Ce increase the test life of the alloy by ten times. Addition of Ti and Al stiffens it at high temperatures and enables it to be used in jet engines of aircrafts. **Ni-Cr-Fe alloy**: Inconel (Ni 79; Fe 6·5; Cr 14; Traces of Cu, Mn, Si) is used for exhaust manifolds of jet plane engines, springs used at or below 480°, brine jacketed tanks, cooling equipment in the dairy industry and food processing equipment. **Ni-Mo-Fe alloy**: (Ni 55 to 61; Mo 16 to 32; Fe 6 to 22; Traces of Mn, Si) is used for equipment to handle, transport, and store acids and other corrosive materials. **Ni-Cr-Mo-Fe alloy**: (Ni 51 to 62; Cr 15 to 22; Mo 5 to 19; Fe 6 to 8; Traces of Mn, Si) is used for pumps, valves, spray nozzles, etc., where resistance to corrosion in strong oxidizing acids and such oxidizing agents as Cl₂, bleaching agents, and the like is required.

**Engineering bronzes**: denote Cu base alloys with or without Sn. Besides the distinctive properties of Cu, pleasing colour, acceptable anti-friction properties, and ease of fabrication are conferred by alloying. **Al bronze**: (Cu 87 to 96; Al 4 to 10; Ni 0 to 5; Fe 0 to 5) is cheap and has fine colour, high strength, good corrosion resistance and good casting properties. It is used for decorative structural work, heavy-duty transmission gear, heat-resisting applications, and marine and chemical plant equipment. **Si bronze**: (Cu 96; Si 3; Traces of Zn, Sn, Mn, Fe) is not subject to dezincification and has high tensile strength and corrosion resistance. It is used for chemical equipment, underwater marine equipment, welded work, springs, bolts, nuts, etc. **P bronze**: (Cu 90 to 96; Sn 10 to 4; P 0·5) has high strength, toughness, electrical conductivity and corrosion resistance. It is used for fasteners, springs, diaphragms, bridge bearing plates, etc. **Mn bronze**: (Cu 57 to 60; Mn 0·5; Sn 0·5 to 1·5; Fe 1; Balance Zn) possesses high mechanical strength and good corrosion resistance. It is used for studs, shafts, gears, etc. It is not suitable for cold working. **Be bronze**: (Cu 95; Be 2; Ni 0·5; Co 2·5) has good electrical conductivity and high corrosion resistance. It is used in springs, bushings, commutator segments, contact clips, gears, etc. **Cr bronze**: (Cu 99; Cr 1) is used in resistance welding electrodes, circuit breakers, commutator switches, etc. **Cd bronze**: (Cu 99; Cd 1) with high strength, abrasion resistance and conductivity is used in trolley wires. **Cupro-nickel**: (Cu 70 to 95; Ni 30 to 5) with high corrosion resistance is used in condenser tubes, salt water pipes, etc. **Constantan**: (Cu 55; Ni 45) is used in thermocouples, with Cu, up to 900° and for grid resistors,
Nickel Silver or German Silver: (Cu 60 to 75; Ni 5 to 30; Zn 5 to 30) is corrosion resistant and is used for valves, plumbing fittings, ornamental and marine hardware, automobile fittings, typewriter parts, musical instruments, etc. Commercial bronze: (Cu 90; Zn 10) is a bearing material. Pb-Sn bronze: (Cu 70 to 85; Sn 5 to 10; Pb 5 to 25) & Cu-Pb bronze: (Cu 60 to 80; Pb 40 to 20) are used as special bearing materials. Gun metal: (Cu 88 to 96; Sn 6 to 10; Zn 0 to 2) is used for machinery and bearings. Muntz metal: (Cu 3; Zn 2) is used in a variety of fittings because of its hot rolling properties. Bell-metal: (Cu 25 to 20; Sn 75 to 80) is used for making bells and gongs. Speculum metal: (Cu 70 to 65; Sn 30 to 35) takes a high polish and is used in reflectors.

**Bearing metals:** must have anti-seizure properties (resistance to scoring or galling), embeddability (ability of metal to embed in itself foreign matter), conformability or deformability, capacity to carry loads, fatigue strength, impact strength, compressive strength, corrosion resistance, and wettability (affinity for lubricants). White metal alloys or Babbitts: are the best. They are: a. Sn-base Babbitts: Sn 80 to 92; Sb 12 to 4; Cu 4 to 7; b. Pb-base Babbitts: Pb 75 to 90; Sb 15 to 10; Sn 10 to 0; and c. Graphitized Pb-base: Pb containing 10% Sn is hardened with Cu, Sb, As, and Cd. In addition, it contains 0.02 to 0.04% of graphite. These alloys are used for non-precision applications for replacement in older equipment and in large massive machinery. Cu-Pb (Cu 70; Pb 30), leaded bronze (Cu 60; Pb 30; Sn 10), phosphor bronze, Al alloys (a. Sn 6-5; Ni 1; Cu 1; Al 91.5; b. Sn 6.5; Si 2.5; Cu 1; Ni 0.5; Al 89.5; c. Si 4; Cd 4; Al 92), tri-metal type (intermediate layer of 80 Cu, 10 Sn, 10 Pb and either steel or bronze backing on either side), solid Al and cast iron are used as bearings under different conditions. Cemented carbide: Powdered carbides of W, Ta, and Ti are ground till the size of the carbides is of the order of 1 to 15 microns (1 micron = 0.001 mm). The carbide pieces are then formed by cold pressing, hot pressing or extruding. These are used for sleeve bearings in precision equipment.

**Carboloy:** (13% Co, W, and C 87%) is far more durable than steel and is used for high speed cutting tools.

Certain other alloys are given the name of soldering metals and are used for the purpose of making joints between pieces of metal. Brazing is a form of soldering at high temperature using brass alloys as the solder. Fusion welding differs from soldering in that the surfaces to be joined are actually fused and flow together.

**Solders:** are alloys used for the purpose of making joints
between pieces of metal. They are largely adopted in engineering construction. Such joints are not mere mechanical connections, for, the solder itself combines with the metal which it unites and forms a new alloy. Every solder must be more fusible than the metals which it unites. Solders are of two classes: 1. **Hard solder:** a. **Brazing solder:** consists of brass alloys (Cu 49 to 81%; Zn Remainder). It is used to join steel parts by using a gas flame to heat the metal to 870°. Borax is used as a flux to keep the surfaces clean and free from oxides. This solder gives a brazed joint of considerable strength. b. **Copper brazing:** is employed in fabrication of metal products using copper wire. The parts are heated in a special furnace to 1,150° in an atmosphere of H₂ gas when the Cu flows into the seams and combines with the steel. H₂ prevents the formation of oxides on the steel. c. **Silver solders:** are alloys of Cu, Zn, and Ag (Cu 14 to 30%; Zn 9 to 20%; Ag 42 to 62%). The melting points of these solders range from 595 to 770°. These are used for brazing steel, etc., especially in cases where the other methods are difficult. Borax is used as a flux. d. For Al, Sn-Zn alloys are used as solders. No flux of any kind is used. When the melted solder has run well over the surfaces to be jointed, they are held pressed firmly together until the solder has solidified. As Al solders are cathodic to Al, and as in the presence of moisture, an electrolytic action causing the disintegration of the joints is developed, no dependence should be placed on a soldered Al joint. For soldering Al conductors the oxide film is destroyed by applying ‘Alcoa 64’ flux and by heating to 210°. It is then treated with molten ‘Alcoa 804’ solder and then handled like copper. ii. **Soft solder:** melts at a low temperature. For plumber’s work, a solder of 2 parts Sn and 3 parts Pb, and for tinker’s work 2 parts Sn and 1 part Pb are used. These solders are available in various grades and contain 0.5 to 3% of Sb. ZnCl₂ or NH₄Cl in the form of a solution, or as a paste made of the salt slightly moistened with water, or as a paste made by stirring the finely divided salt either in vaseline or fats, with or without resin, is used as a flux.

**Hard-facing alloys:** Hard-facing is done to a metal surface to resist wear, corrosion, and heat. Hard materials are manufactured as welding rods, as insert shapes, and in powdered form. These alloys are classified as:

1. **Iron-base alloys:** a. **with < 20% alloy:** These are for arc application on large parts and heavy equipment and as a base for other more expensive hard-facing alloys. These are cheap and possess high hardness and satisfactory toughness to withstand moderate to high impact. The chief alloying elements are Cr, Mn, and Si. The carbon content is
variable. Bo, W, Mo, Ni, and Zr are also added in small quantities. The
rods are supplied as mild carbon steel rods covered with a flux coating
that contains the hardening alloys. b. with 20 to 55% alloy: These are
costly, but are harder, more resistant to abrasion, and less resistant to
impact. Over 25% Cr, W, Mo, Ni, Co, B, Mn, Si and Zr are added. The
rods are cast.

2. Non-ferrous alloys: (Cr up to 35%; W up to 40%; C up to 2-5%;
balance Co) have good flow properties, good bonding with steel and
good elevated temperature service. They undergo heat treatment subse-
quent to welding without a change of hardness and wear resistance.
These are produced in solid rod form by casting in either permanent
moulds or sand moulds. Mn, P, and Al bronze surfacings: which are re-
latively soft, are applied to soft mating surfaces to reduce friction and wear.

3. Diamond substitutes: (Intermetallic compounds): Carbides
of W, Ta, Ti and B; and borides of Cr are used. Tungsten carbide is
largely used in the form of rods, powder, and inserts. These offer
maximum wear resistance.

Colouring of Metals: is done for appearance, abrasion and
corrosion resistance, heat and light reflectivity or absorption, and the
like. The methods are: a. mechanical (buffing or polishing on plated or
untreated metals); b. organic (enamels, lacquers, paints and varnishes);
c. chemical (immersion or spray); and d. electrolytic (baths). Methods c and
d have earned a definite production role. The colour obtained and its
depth depend on the nature and temperature of the colouring solution,
the immersion time, and the type of finish on the underlying metal.
Where the colour is of insufficient intensity, the film is dyed virtually to
any colour. The corrosion resistance of the colour film is enhanced by
a supplemental waxing, oiling or lacquering which also improves the
lustre and sheen of the finished part.

Corrosion: is the slow but continuous eating away of metals
by the following to form compounds of the metal: air, soil, acids, oxidizing
agents, natural waters, chemical salts, organic materials, high temperature,
S compounds, and alkalis. It may proceed in the following forms: direct,
chemical, pitting, galvanic, concentration, dezincification, corrosion
cracking, and fatigue. The rate at which it proceeds depends on: acidity,
oxidizing agent, movement, electrolytic effect, films, and temperature.
Corrosion depends on the following properties of the metals: chemical
affinity and pressure, oxidation passivity, corrosion product properties,
composition, strain, and surface.
Metals can be protected from atmospheric corrosion by mechanically excluding air and moisture. Before applying the protective coatings, the surfaces should be freed from rust, detachable mill scale, dirt, and grease. Oil from steel parts are removed by gasoline and other organic solvents. Cleaning is also done either by blowing a stream of high pressure air into which sand or other abrasive is introduced or tumbling the steel parts in a rotating barrel with or without abrasives.

**Methods of protection of metals from corrosion**: A. **Application of non-metallic coatings**: i **Painting**: (See Ch. VI.) ii **Slushing**: Oiling or greasing (after removing contained acids in grease) will give temporary protection when machinery is transported or stored in damp atmospheres. The residue remaining in the stills after the distillation of the lighter products from crude oil is used. iii **Plastic coating**: Phenolic resin dissolved in alcohol (before final hardening) is sprayed on to steel and brass hardware, metal bodies and parts of automobiles, etc. The application of heat brings the final changes leaving a permanent coating. iv **Japanning**: (See Ch. VI.) v **Vitreous enamelling**: (See end of this Ch.).

B. **Application of metallic coatings**: i **Tin plating**: consists in automatically passing base metal or black iron sheets pickled in 4-8% H₂SO₄ at 77°C through a layer of molten ZnCl₂ or ZnCl₄ and NH₄Cl flux into a bath of molten Sn at 290°C and finally out through rollers and a layer of palm oil (Fig. 155). The rollers spread out and squeeze off excess molten Sn, while the oil cools the coating and prevents oxidation. ii **Electroplating**: is the deposition by electrolysis of a coating of metal on an object. In electroplating, the article is electroplated with Zn using a ZnSO₄ electrolyte. **Nickel plating** is done by electro-deposition, from a solution of NiSO₄.

It tends to accelerate the rusting of Fe while the presence of Zn tends to retard it. Ni plating is used as protection for parts of machinery and also for many household articles. It is done after Cu plating the articles. **Chromium plating** has largely superseded Ni plating for the outer coating, but is applied over a Ni plating for the sake of thickness. A coating of Cr resists abrasion very well. **Cadmium plating** gives a coating having a better appearance than Zn and a better protection than Ni.

iii **Metal spraying**: In the Schoop metallising process, a wire or powder of the coating metal (Zn, Sn, Pb, Al, Cu) is fed into the high temperature zone of an oxy-acetylene flame or electric arc just inside a nozzle. Com-
pressed air forces the molten metal in a fine spray through the nozzle on to the article to be coated. This process is developed further and Ni or high carbon steel is sprayed on parts made of soft materials to make their bearing surfaces hard and wear-resisting. iv Galvanising: (See Pa. 172). v Lohmann process: Iron and steel sheets are first amalgamated with Hg by dipping in a solution of HCl, HgCl₂, and NH₄Cl, then dried and finally immersed in a molten alloy of Pb and Sn at 340°. vi Sherardising: (See Pa. 172). vii Calorizing: The articles are kept in a retort with finely divided Al and Al₂O₃ in a reducing atmosphere. When the contents are heated to 820°, the Al combines with the exposed portions of the metal parts to form a homogeneous Al alloy of any desired depth. viii Chromizing: Low-carbon steel articles are packed with Cr dust and Al₂O₃ in a retort and heated to 1,320° in a H₂ atmosphere for 3 to 5 hours. The Cr diffuses into the steel to a depth of 0.01 to 0.02°. Siliconizing: Low-or medium-carbon low-sulphur steel parts are packed with silicon carbide in a retort and heated to 960°. Cl₂ is then admitted into the retort and the temperature maintained for 2 hours. A surface 0.03” thick, containing 14% Si, is obtained. Cladding: See ‘Clad steels’ Pa Pure Al clad strong Al alloys, corrosion-resistant material clad Cu, and other special combinations are used.

C. Formation of corrosion resisting compounds: i. Temper coating: Formation of a coating of Fe₃O₄. The steel is heated in an open furnace or in a fused salt bath at 370°. To give a dark blue colour to the coating, the articles are sometimes immersed for a few minutes in a mixture of fused NaNO₃ and KNO₃ and then quenched in water. In the Bower-Barff process, the articles are heated to 870° in a closed retort. Superheated steam is then admitted so form Fe₃O₄, which is reduced to Fe₂O₃ by producer gas or mineral oil. ii. Browning process: Chemicals are used to oxidize the steel. iii. Carbonia process: Steel is heated to 220° in contact with charred bone and oil to give a black oxide coating with a gunmetal finish. iv. Guerini process: Steel is treated with boiling NaOH solution containing sodium picrate. v. Deoxidine process: The surface is rubbed with a solution of phosphoric acid in alcohol and water and then washed with the deoxidine solution with water. After drying, the surface is painted. vi. a. Coslett process: The parts are immersed in a hot solution of iron phosphate and phosphoric acid when a rust-resisting coating of iron phosphate is obtained. b. Parker process: Here a dilute solution of manganese dihydrogen phosphate is used. The coated article is then rinsed in boiling water, stained black and oiled. vii. By reducing the electric potential within the metal and making it purer.
MISCELLANEOUS MATERIALS

Abrasives: are widely used for engineering and industrial purposes to remove excess material by cutting and produce attractive surface finish by polishing of other materials which are usually softer. They belong to the hardest materials and are employed in powdered form as grinding pastes with oil; with suitable bonding materials; in grinding wheels; abrasive papers or cloths and abrasive slips and stones. The hardness is expressed in terms of Moh’s scale (See Pa 9). The fineness of the abrasive is specified by a number which denotes the number of meshes per inch through which the abrasive will just pass. It usually ranges from 10 to 200. Finer powders are called as ‘flour’ and are denoted by O, OO, OOO or CF, F, FF, FFF, indicating progressively increasing degree of fineness. The widely used natural abrasives are: quartz, garnet, flint, emery, corundum, and diamond.

With industrial advancement, the need for production of abrasives commercially on a large scale was keenly felt. Silicon carbide (SiC) and aluminium oxide (Al₂O₃) are the two main synthetic abrasives which form the basis of grinding wheel manufacture throughout the world to-day. These abrasives are bonded into grinding wheel shapes with a variety of bonding mediums - ceramic and organic, the organic bonds being resinoid, rubber and shellac. The advantages of these over the natural abrasives are: i The control of quality and the exact duplication of the product; and ii High percentage of abrasive present in synthetic wheels and the ability of the manufacturer to produce synthetic wheels of any required size and shape-within reason. Natural abrasive wheels were rough and ready and no exact grinding techniques could be developed with such tools.

Al₂O₃ is used as regular and white, and SiC as regular and green. Regular Al₂O₃ abrasive is used for grinding wheel and all high tensile alloys. White Al₂O₃ is reserved for jobs where grinding must be done with the minimum of heat since white Al₂O₃ is extremely free cutting. Regular SiC is used for all low tensile strength metals such as C.I., Cu, Al, and brass, and also for grinding glass, wood, rubber and plastic materials. Green SiC is used particularly for grinding tungsten carbide tools. Diamond abrasive wheels are very efficient and economical for the grinding of tungsten carbide. Diamond wheels with a metal bond or matrix operate at 6,500 surface ft./min. Resin-bonded grinding wheels working at 9,500 surface ft./min, and resin-bonded cutting wheels working at 10,000 ft./min. are used in foundries, steel plants, etc., where large numbers of pieces of metal may be ground clean or cut to required lengths.
Rouge (red rouge Fe₂O₃, black rouge Fe₃O₄, and green rouge Cr₂O₃) is used for buffing—a process of fine polishing on rotating wheels of fibre or leather coated with the abrasives.

**Adhesives**: are used to join two or more parts into a unit. Advantages of adhesive bonding over methods of assembly like bolting, riveting, welding, etc., are: i It is applicable to all industrial materials, ii It gives adequate strength, iii It permits a wide variety of combinations in joining, iv It fits into modern mass production assembly lines. The limitations are: i The bond is organic, and so possesses limited heat resistance, ii The bond is not instantaneous, iii Adhesion is usually specific for a given set of components, service conditions, and method of application. The bond is formed by: mechanical anchoring (when the surface under the coating of adhesive is porous); ii fusion adhesion (when the surface is soluble in the bonding agent, or in the solvent in which the bonding agent is conveyed); or iii specific adhesion (when there is no penetration of the surface and no dissolving of the metal). They are classified as:

1. **Rubber adhesives**: a. *Natural*: Raw rubber: is an essential ingredient of adhesives for bonding to metals. Reclaimed rubber: adhesives are cheap, dark in colour and are used for metals, natural rubber, cotton, wool, silk, leather, paper, etc. Natural rubber latex: is used as a metal-to-wood adhesive and in the cloth-backing industry. Cyclized rubber (rubber treated with chemicals, principally H₂SO₄) is used for bonding rubber, paper, and metals. b. *Synthetic*: Neoprene rubber adhesives: (poly chloroprene) are used for bonding of leather, rubber, and metals to rubber. Acrylonitrile adhesives: are suited to bonding synthetic rubbers, especially of the same composition. Styrene adhesives (Buna S): are used for joining rubber, plastics and glass, forming plywood panels and laminating metal foil to paper. Polysulphide adhesives: are used in the cementing of lacquer hose lines and sealing of cans of organic liquids. Butyl adhesives: have the same properties as reclaimed rubber.

2. **Synthetic resin adhesives**: a. *Thermoplastic*: (See later in this Ch. under 'Plastics'). Cellulose nitrate: is used for bonding thermoplastic resins. It is a standard item in the shoe industry. Cellulose acetate: is used as the adhesive for photographic film, which is usually a cellulose acetate material. Polyvinyl acetate: is used for bonding metals and nonporous films like cellophane in the packaging of food. Polyvinyl alcohol: is used for the production of weatherproof fibreboards for packaging of food, for laminated safety glass and for laminating varnishes.
b. Thermosetting: Phenol-formaldehyde: is cheap, gives high strength, and is largely used for producing waterproof plywood. Urea-formaldehyde: is used for interior plywood work, for textiles, and for paper. Melamine-formaldehyde: is used in the preparation of laminates in which the resin is the impregnating and surfacing material in addition to acting as the adhesive for joining the laminate. The transparency of the cured surface film is advantageous in decorative laminates where the pattern is often printed on the paper layer which forms the outside ply e.g., table and counter tops. The electrical properties and heat resistance of such laminates are outstanding.

Contact resins: are a. unsaturated high-molecular weight monomer (often an allyl ester), b. a mixture of an unsaturated polyester or alkyd in a solution of styrene and/or other monomer, and c. a combination of a and b. These have better colours than the phenolics and better water resistance and flexibility than the ureas. These were used as glass cloth laminates in aircrafts during World War II. Silicone resins: (methyl and phenyl silicons) have excellent electrical properties and are stable at service temperatures considerably higher than conventional organic resins. Glass or asbestos cloth, mat, etc., are bonded with silicone resins.

The synthetic resins are sold as: i an impregnated paper film; ii an aqueous solution; iii a varnish soluble in alcohol or acetone; and iv a dry powder. Their advantages over items 3 and 4 are: i greater resistance to moisture and attack by fungi; ii high strength under stress; iii greater adhesive and cohesive viscosity; iv rapidity of setting; and v non-staining qualities.

3. Animal glue: prepared from skin or bone by boiling with water, is supplied in the form of cakes, pieces, granules, powder, liquid or jelly. It is affected by moisture but not by fire-retardant solutions. Blood albumen glue: is made by treating hides and skins with lime, mixing with water, and heating up to 66°. It is water-resisting and is used in the manufacture of plywood. Casein glue: is prepared by coagulating skimmed milk in vats. The product is washed, pressed, dried and ground into a white powder. It is also used in the manufacture of plywood and laminated timbers, in paper laminates, and in metal-to-wood adhesives.

4. Vegetable glue: is made by treating natural gums and starches such as tapioca, potato, sago, corn, wheat, and similar starch-bearing roots, grains, and tubers with acids, NaOH, etc., and processing like casein glue. It is used as paper and labelling adhesives, for forming paper board articles, and in wood-working.
5. **Natural resins and oils**: Rosin: is used in can labelling. Shellac: adheres well to wood, metals, paper, textiles and plastics. It is used as a coating to form a water barrier. Asphalt: is used in building paper, rubber, leather, metals, stone, etc.

6. **Inorganic adhesives**: Na$_3$SiO$_4$: is used for boxboards, cartons and for labelling shipping containers. MgOCl, and litharge-glycerin: are mixed and used in ceramics.

7. **Special adhesives**: are developed for bonding of metals. The Redux process consists in applying a clear reddish-brown low-viscosity solution of a thermosetting adhesive on the clean metal surface, and, while this coating is wet, saturating the surface with a thermoplastic vinyl resin powder. Similarly coated metal surfaces are bonded under heat and pressure. Cycleweld: adhesive, a modified form of rubber, is used for bonding Al sheets. Araldit: adhesive is odourless, tasteless, noncorrosive, and nontoxic, and provides excellent bond on light metals.

**Asbestos**: is mineral fibre composed of hydrous silicates of Ca and Mg with a small amount of iron oxide and alumina. It occurs naturally in chrysotile, tremolite, etc. It is an excellent heat insulator and is used for insulating furnaces, steam and exhaust pipes, boilers, etc. It is combined with MgCO$_3$, hair, or with wool felt, and used for lagging steam pipes. It is sometimes kneaded into a dough with water and used for stopping up holes and cracks in small muffles, furnaces, etc. It is used for electrical insulators and for making fire-proof suits of asbestos cloth. Asbestos sheets, introduced recently under a variety of trade names such as Everest, Eternit, Lammit, Poilite, etc., for use in hot climates, are made of asbestos fibre and cement, mixed under high pressure and formed into sheets (plain or corrugated). These are fire-proof, acid-proof, water-proof, insect-proof and non-conductive; are very light; and can be sawn, nailed, screwed, veneered, ground, and painted. They are made in red, slate grey and light grey colours. Asbestos pipes are non-corrodible, require no preservative coating, can be cut to any length or shape, specials can be had for every bore of pipe, and are thus suitable for the carriage of water, gas, and sewage.

**Asphalt**: is defined as natural or mechanical mixtures in which the asphaltic bitumen (black, sticky, ductile, resilient, malleable material prepared from natural hydrocarbons or from derivatives of natural hydrocarbons) is associated with inert mineral matter like lime, silica, alumina, etc. It is obtained in three ways: 1) Lake asphalt: is found in natural deposits as at Trinidad. This contains 40–85% pure bitumen, some water, and impurities. This is refined by boiling in a tank with metal coils in
which steam is passed. Impurities rise to the surface and water goes away as steam. The refined asphalt will have to be softened by admixture with a flux oil before use for road work. i Rock asphalt: is found in France, Switzerland, etc., where the rock is found impregnated with < 15% of bitumen. iii Residual or artificial asphalt: is obtained by the fractional distillation of crude petroleum of an asphaltic base in a petroleum refinery.

*Straight-run asphalt*: Asphalt distilled to a definite viscosity or penetration without further treatment such as is used to prepare a cutback product. *Cut-back asphalt*: Asphalt is cut back (softened by the addition of solvents such as kerosene) to make it fluid at normal temperature for cold application. The kerosene gradually comes off after the asphalt is laid on the road. *Asphaltic emulsions*: The bitumen is held in suspension in some fluid. There are two kinds viz., soap emulsions and clay emulsions. The former is used for road work and the latter for roofing. When the emulsion is applied on the surface, the water evaporates and the asphalt sets. *Asphaltic cement*: This is used for waterproofing and is made by blowing air at a high temperature through asphalt. *Mastic asphalt*: is used as a damp-proof course in wall and as waterproofing for roofs. It is made by melting lake asphalt, finely ground rock asphalt, bitumen, and fine sand and applying in several coats.

On account of its being water-resisting, non-absorbent, non-inflammable and reasonably elastic, asphalt is used for flat roof coverings (as in-situ mastic, laminated bituminous felt and tiles laid over hot bitumen) damp-proof courses, jointless floor-lining for basements, tanks, etc. It is also used as asphaltic concrete for road surfaces and with pigments for decorative, resilient, water-proof flooring.

*Celluloid*: is composed essentially of pyrolin (soluble guncotton) and camphor (oil). This is used for fancy goods, for covering metal steering wheels, bicycle handles, etc., in order to render them heat-proof and permanently clean and for accumulator cases.

*Ceramics*: are largely used in the electrical and electronics field, in the chemical and process industries, in sanitary equipment and in many special and high temperature applications. These include chinamas, porcelains, earthenwares, and others. A ceramic whiteware body is composed essentially of a flux, a plastic, and a non-plastic. The non-plastic provides the skeleton held together by the glass phase (or bond) developed from the flux on firing. The plastic (normally plastic clays but at times organic additives also) provides for workability and castability required during forming. All ceramics possess high chemical resistance, electrical
resistance, dielectric strength, mechanical strength and thermal endurance. The typical ceramics are: i Sanitary porcelain: See Encaustic or Glazed tiles Pa 71. ii Electrical porcelain: (felspar 20 to 28; whiting 0 to 3; ball clay 15 to 35; china clay 20 to 35; flint 15 to 25) vitrifies at 1,320°. Steatitic porcelain: (talc 70 to 90; kaolin 0 to 10; BaCO₃ 0 to 10) is used for insulators in high frequency work where its poor thermal endurance will not matter. Alumina: (80 to 95%) with small amounts of flux is used for spark-plug procelain and in the electronic field. iii Heat resistant ceramics: Ceramics: containing more than 80% BeO, falling within the systems BeO, Al₂O₃, ThO₂, and BeO, Al₂O₃, ZrO₂, have very high thermal endurance. Addition of MgO up to 15% reduces the maturing temperature from 1,700 to 1,500°. Cordierite type ceramics: are developed as porous, low porous, and vitrified bodies. The porous (talc 43, clay 35, alumina 22) are used in electric furnace parts, resistor tubes and bases, etc. The low porous are used for refractory bricks. The vitrified are used in exposed electrical devices. Zircon (Zr Si O₄) ceramics: (zircon 45 to 60, clay 15 to 30, alkaline earth-zirconium silicate 15 to 30) are used for spark plug, high thermal, and refractory ceramics. iv Chemical porcelain: (felspar 20 to 25, whiting 0 to 1, ball clay 0 to 5, china clay 50 to 58, flint 10 to 15) is resistant to chemical attack. It has high thermal endurance, mechanical strength, and shock resistance, constancy in weight after repeated heating and cooling, and extremely hard and stable glaze. It is used for storage vessels, reactor chambers, pipes, pumps, etc., in chemical industries. It is preferred to chemical stoneware except in certain cases where a white, hard body is desired. Chemical stoneware: (blend of clays 30 to 70, felspar 5 to 25, and silica 30 to 60) is a vitrified product which is used for containers of corrosive liquids and fumes. v Special purpose ceramics: Addition of Ti O₂ gives an acid resistant, superopaque ceramic for use in the textile industry. 60% mica bonded with 40% lead borate or boro-silicate glass gives a material used for panels, supports and insulating parts.

Cork: derived from the bark of certain trees, besides the everyday use, is used as a sound absorbing medium to obviate the effects of echo and sound conduction in buildings, as an ingredient of tiles and cork lino, to eliminate vibration in machinery, to form an insulating material in cold storage industry, to insulate machines against the transmission of noise, for the cork-lining of plate clutches in automobiles and in the form of cork dust for washers or packing pieces, for crank-cases and cylinder cover joint, for headlamp covers and petrol joints. As cork is mainly imported from Portugal, Spain, and Morocco, blocks made of cement - saw
dust mixtures (2:3) are recommended as substitutes for cork in cold storages. These have good strength, good adhesion with cement-sand plaster, and good resistance to the attack of vermin and fire.

**Diamonds**: the purest form of C, with a hardness of 10 on the Moh’s scale, are used for glass-cutting, turning of abrasive materials, wire-drawing dies, rock drills, etc.

**Emery cloth**: is used for finishing and polishing metal surfaces. It consists of ground emery of different degrees of fineness attached to calico by glue.

**Engineering Laminates**: Laminated materials are largely used because a. they combine the properties of their component parts to obtain composite properties which may be new or unique; or b. they make it easier and less costly to obtain certain properties than is possible with solid materials. The typical laminates are:

i **Glued-laminated wood**: It is largely used with or without mechanical fastenings for ships, barges, bridges, and buildings to resist exposure to weather, to resist repeated soakings in fresh or salt water, and to withstand pressure treatment.

ii **Plywood**: (See Pa 157) is used in building construction for subfloors, sheathing of walls and roofs, interior panelling, and concrete formwork. It is also used in ships, pontoons, aircraft, boxes and crates, etc.

iii **Composite laminated wood-concrete construction**: similar to reinforced concrete, is adopted for shallow beams, slabs of indefinite width, trestle construction spanning from pier to pier, and to trusses where the slabs will extend from floor beam to floor beam without stringers or other supporting media.

iv **Plastics-based laminates**: These consist of a multiplicity of sheets of fabric, paper, wood or fibrous mat material which have been impregnated with a suitable resin and subsequently pressed with or without the application of heat. For high-pressure laminates the fabric, paper or other suitable material is passed through a solution of the resin. The impregnated material is then passed through a drier to evaporate all or any part of the solvent present and to polymerize the resin to such an extent that it will have the proper flow characteristics in the subsequent pressing operations. This treatment gives better electrical properties to the finished material. Phenolic resins are used for industrial laminates where colour and high arc resistance are not important, urea formaldehyde resins for decorative laminates with alpha-cellulose paper as the reinforcing material, melamine-formaldehyde resins for electrical work
and polyester resins for low pressure and contact laminates. Fillers of cotton, glass fabric and mats, asbestos, rag, kraft, perforated metal foils, and inorganic materials like graphite, mica, and alumina are used.

v Thermostat metal: is a composite metal usually in the form of sheet or strip, comprising two or more metals which, by virtue of the differing expansivities of its components, tends to change its curvature when subjected to a uniformly distributed change in temperature. This change of curvature causes a movement accompanied by the exertion of an appreciable force. This movement is utilised either to open or close electrical circuits when a given temperature is attained or to open or close valves for regulating the flow of liquids or gases or to indicate actual temperature or to operate time switches. It is used in air heaters, air valves, circuit breakers, clocks, electric meters, hot beds, electric irons, machine tools, refrigerators, signal devices, steam traps, voltage regulators, etc.

vi Aluminium-clad products: consist of an Al-alloy core covered on one or more sides with one or more thin surface layers of corrosion-resistant Al or Al alloys. These are produced as sheet, plate, tubing, and wire.

vii Hot-dipped aluminium coated steel: (sheet, strip, or wire) is corrosion-resistant, heat-resistant, and heat-reflecting. It is used in circulating heaters, and aircrafts.

viii Copper and copper alloy clads: (see Clad steels’ - Pa 182 and Cladding’ - Pa 200). These can be bent, drawn, twisted, punched, sheared, spun, flanged, heated, and quenched or otherwise formed without any separation. These are corrosion-resistant, and heat-resistant, and can be soldered and brazed. These are used as baffles in radio-receiving sets.

ix Nickel, Monel, and Inconel cladding of steel: improves corrosion resistance.

x Stainless steel clad steel: is used where stainless steel would be too costly and chromium plating impractical. It is used extensively in the petroleum industry, particularly where sour crudes are encountered, where it has conserved several thousands of tons of mild steel.

xi Cast laminated metallic materials: chill-cast metal— for railway wheels and rolling mill rolls; chill—or sand— cast duplex metal— for lathe-bed frames and rolling mill rolls; solidified casting (surface coated with liquid metal) — for bearings of automobile and railroad industries; casting (surface coated by absorption of alloys) — for valves, fittings, pump parts, and heat—resisting surfaces; weld—coated casting—for steam valves, hot—oil pumps, valves in chemical industry, runners of turbines, etc.; spray—coated casting—for parts exposed to heat or corrosion in the petro-
leum, chemical, paper, and allied chemical industries; dip-coated casting—for pipe fittings and plumbing goods; electroplated casting—for appearance and corrosion and wear resistance.

xii **Hard-surfacing by welding**: (See 'Hard-facing alloys'. Pa 197) increases heat-resistance, corrosion-resistance, wear-resistance, and gives reflectivity e.g., cement mill-grinder rings, hammer mill hammers, wood-pulp shredder knives, engine valves.

xiii **Metal spraying**: (See 'Corrosion'. Pa 198) is used for maintenance repair, and rebuilding of machinery and manufacture of corrosion-resistant materials.

xiv **Glass-lined steel equipment**: The equipment is completely fabricated from steel, and then the glass in proper form is applied to the entire interior surface, and fused to the steel by heat. It is used wherever the following conditions are involved in the chemical industry—for processes involving nitration, halogenation (excepting compounds containing fluorine), sulfonation, oxidation, polymerization, and esterification. This should not be used for handling the fixed alkalies, HF or fluorides, and high concentrations of phosphoric acid at elevated temperatures.

xv **Composite-glass structure**: Two or more sheets or plates of glass (or sheets of dissimilar materials such as wood, fabrics, cement, and ceramic bodies) are bonded through the medium of one or more layers of plastic or non-brittle material to produce a composite structure. Plates or sheets of glass are bonded enclosing layers of air for insulating purposes. Transparent glass laminates are made as: a. laminated safety glass for cars, trains, etc., where breaking of glass constitutes a hazard, b. aircraft safety glass with greater resistance to impact and pressure loads, c. bullet-resisting glass with multiple layers of plate glass bonded together with alternate layers of vinyl plastic to produce a structure of the required thickness, and d. laminated glass (coloured glasses with transparent plastic layers) to serve as light filters to screen out almost completely certain portions of the spectrum. Translucent glass laminates (using opal glasses) are used for scientific instruments and glazing certain openings where non-directional lighting is desired and safety is essential. Opaque or structural glass laminates find wide application for partitions and stiles in toilet room construction, and also for the construction of table tops, counter tops, and glass-faced concrete masonry. Composite-glass-air-cell units, called insulating glass windows, are used for high light transmission and thermal insulation.
xvi Sandwich type building boards with insulation board cores: are largely used in building construction and furniture making.

xvii Plastic-surfaced plywood: denotes plywood surfaced with paper impregnated with thermosetting resins. These may be bonded to themselves to wood, metal, or glass with rubber-base cements.

xviii Structural sandwich construction: is adopted in aircraft, housing, boats, and truck bodies. The faces may be of metal, plastic, wood, or other structural material. The core materials are cellular plastic materials, cellular synthetic or natural rubber, expanded wood or other fibres with or without resin binder, natural low-density woods, expanded inorganic materials like glass, etc.

xix Rubber laminates: are used for belting, to protect metal pipes, tanks, and other equipment used in handling corrosive liquids, for various kinds of rolls, rollers and pulleys, for rubber hose, and for flexible mountings (in combination with metal).

Felt: a material composed of wool, or wool and cotton in a more or less compressed condition, is used to eliminate noise and vibration and for heat-resisting coverings. It is also used in the form of pads and wicks for lubricating purposes. Felt washers and packings are used in automobile work for preventing oil leakage from engine bearings, gear-box and differential housings, etc. Felt, a product of felt with an outer casing of rubber, is 30 to 70 times lighter than rubber, and possesses a wider possible variation of resilience than can be made from the usual rubber mountings. Different kinds of bituminous felts (felts impregnated with bitumen, but not coated) are used either on top of wooden ceiling beneath tiles, or in a single layer as a roof covering, or for layers of multiple layer roofs.

Ferodo: is the name given to the materials having high coefficients of friction. They are made either by impregnating compressed cotton fibre with a special fluid or by impregnating compressed asbestos with numerous brass wires, running through it. The former gives a higher coefficient of friction, but does not withstand such high temperature. The materials are used for lining the brakes of automobiles and motor cycles, winding engines, cranes and similar purposes, for the clutches of cars, and for friction drives of all kinds, etc.

Fibre: vulcanised or red, is a hard dense material composed of paper or cellulose made from cotton, rag, stock, together with ZnCl, and colouring matter, either aniline dyes or pigments. This is used for the bushes of magnetos, and for a variety of purposes in the form of paper, sheet, slabs, tubes, etc. Fibre has been employed for brake blocks also. Fibre is now being replaced by plastic materials.
Fibre building boards: (1/4 to 1/2" thick) are made, either homogeneous or laminated, by saturating timber waste or other vegetable fibre and certain proportions of artificial cementation and hardening material with water and subjecting the pulp so formed to pressure and heat. These may after manufacture be spray treated for durability and fireproofness.

These are unsuitable for external work but are increasingly used for internal linings and finishings. Insulating board having a density of > 25 lb./c. ft., medium hardboard formed under pressure to a density of < 30 lb./c. ft., and > 48 lb./c. ft., hardboard formed under pressure to a density of < 50 lb./c. ft., and super hardboard formed as under hardboard and further treated during manufacture to increase its hardness or water resistance, or both, are all varieties of homogeneous boards. The following are a few of the excellent types: Masonite: boards (12' x 4') are made in different shades by reducing wood to fibres under heat and great pressure. They take a beautiful finish, deaden sound, and act as thermal insulators. Celotex: insulating boards, made from cane fibre, are easy to handle, easy to apply, and economical to use. Cemesto: a celotex product, is used in home and industrial building jobs as wall units, room partitions and roof decks. The celotex core is given a water vapour resistant bituminous adhesive bond on both sides and then finished with 1/4" asbestos. It is available in sizes 4 to 12' long, 4' wide, 1/4, or 1 1/4 or 2" thick. Exclute: (low cost) boards are made by combining lignocellulose fibres (viz., wood wool excelsior, hemp, sisal, dried sea weed, etc.,) and a thermo-setting plastic binder (natural vegetable protein obtainable from peanuts, soya-beans, etc.,) with high-Ca quick lime and water containing 5% silicate of soda and moulding them to shape. These are fire resistant, tensile, and have water and acoustical absorption and nail holding strength.

Gilding: Leaves of Au, Ag, Pt, Al, Sn, etc., are used. It is done by cleaning the surface of the metal, giving it two coats of iron oxide paint and then two coats of lead paint of light colour as a basis for the oil gold size, upon which the gold leaf is placed. Mercurial gilding: is done to bronze. Gold amalgam, made by heating 1 Au to redness and mixing with 8 Hg, is squeezed first into a pulp with fingers and then in a chamois bag until the proportion of Au to Hg is 57:33. The amalgam is then dissolved in a solution of 10 Hg and 11 HNO₃. This solution is then diluted with 25 times its weight of water. The bronze is then coated with the amalgam with a brass wire scratch dipped in the above solution and heated to a vitrifying state over a charcoal fire when the Hg will escape as fumes. The article is turned over and shaken to get a uniform coating. Electro-gilding: is done for inferior work by coating the surface of bronze with a
solution of the double cyanide of Au and K and passing an electric current.

Glass: is made by the fusion of mixtures of silica, basic oxides, and a few other compounds that react either with the silica or with the basic oxides. When the raw materials are heated, these substances with the lower melting points liquify and act as solvents for other substances, at the same time reacting with them and enabling them to react with each other. The temperature during melting is kept as high as practical (1,500°) in order to reduce the viscosity and thereby enable the bubbles of gas to escape. Salt cake is also often used to lower the viscosity. The working temperature, i.e., the temperature at which the glass has the proper viscosity for the shaping operations is roughly from 1,000 to 1,400°. Glass furnaces are of two kinds: Pot or intermittent and tank or continuous. The former is used to make small amounts of glass that require careful control of ingredients and melting and refining operations. The individual containers or pots of fireclay (Fig. 156) filled with pure sand, soda, chalk, and broken glass are arranged on ledges in a circular or oblong furnace and exposed to a steadily increasing temperature. When the glass melts, it is cast into moulds of required shape. In the latter, melting is done in tanks or large furnaces (Fig. 157). The furnace walls serve as containers for the glass. This furnace is similar to the reverberatory furnace for puddling W. I. (Pa. 169). The lower part is built of tank blocks, refractories of proper shape, so that the furnace may be assembled without mortar, and of special composition (high alumina and electrocast) to offer the greatest resistance to attack by the glass. The top is of silica brick and the structure is reinforced by steel beams and girders. A constant level of molten
glass is maintained by adding the proper amount of raw materials. The furnace is divided into two parts: the larger melting compartment and the smaller working compartment. Molten glass flows from the former to the latter through a small opening at the bottom of the dividing walls.

**Types:** *Soda lime glass:* (71 to 74% silica, 13 to 17% Na₂O, 5 to 14% CaO, and small quantities of MgO with traces of K₂O) is used for window glass, plate glass, and container glass (bottles, jars, etc.). The high percentage of Na₂O makes the soda glass easily liable for attack by water and acids. *Flint glass:* is made by partly replacing the Na₂O by K₂O and by incorporating between 7 to 15% of PbO. These give the glass a better lustre and lower fusion temperature. It is used to make the superior varieties of glassware and optical ware. In general, glasses with high percentage of lime and silica are hard and those containing largely alkali, Pb, and Ba are soft. Glass to be used for the more expensive table-ware has a greater percentage of PbO and the alkali is K₂O. *Borosilicate glass:* which requires the temperature of the electric arc to melt and fine, has a low coefficient of thermal expansion, and is very resistant to thermal shock and attack by water and acids. This contains about 80% SiO₂ and 12% B₂O₃. The *Pyrex glasses:* used for cooking utensils and laboratory ware, are borosilicate glasses. *Colouring agents:* in glass are of three types: i Substances that dissolve in the glass and cause the absorption of certain light frequencies by the glass e.g., oxides of Ni, Co, Fe, Mn, Cr, and some others; ii Precipitated particles of submicroscopic size e.g., Cu ruby colour obtained by adding CuO which gets reduced and forms the colloidal Cu; and iii Larger particles.

**Fabrication:** i *Blowing:* With the blow pipe (½" diameter, 6' long) the glass is blown, heated for a few seconds, again blown, and the process repeated till a large hollow cylinder is formed. This is then cut and spread out to form a thin plate. Sometimes blowing is done by a tube attached to a compressed air cylinder. ii *Flat drawing:* An iron bar is dipped sideways into molten glass and on lifting up has a film of glass adhering to it. This film is then spread out as a thin sheet by passing over large rotating rollers. iii *Rolling:* The molten glass is poured on a flat iron casting table and then rolled flat with a heavy iron roller. In another method, the molten glass is passed between the heavy iron rollers and flattened out to a uniform thickness. iv *Pressing:* Glass hollow-ware is made by pressing the molten glass in moulds. v *Spinning:* Glass is spun to a very fine size and still with a tensile strength equal to
that of mild steel by being spun at a very high speed. Spun glass is proof against fire, vermin, and acids, is used in textiles and as insulators against heat, sound, and electricity.

**Annealing:** Due to sudden cooling of the exposed surfaces of molten glass under ordinary conditions unequal shrinkage strains take place and the glass is rendered brittle. To remove such strains, the glass is allowed to cool slowly either by lowering very slowly the temperature of the furnace containing it or by allowing the glass to travel slowly through a long flue of gradually diminishing temperature.

**Varieties:** *Crown glass:* To manufacture this a blow pipe is dipped into molten glass which is then blown into a globular form. The globe is then detached, heated, and rotated vigorously on a flat disc until it flattens. The glass is slightly convex. There is considerable waste as the central portion is omitted when cutting the plate into planes. It is now obsolete. *Sheet glass:* is made by blowing molten glass into a large hollow cylinder, splitting the cylinder longitudinally, and then flattening it over a disc. Flat drawing from the furnace on to flattening tables, as in plate glass manufacture has been recently introduced. This is made in sizes up to 70" × 44", the thickness varying from $\frac{1}{16}$" to $\frac{3}{32}$". *Plate glass:* is made by pouring the molten glass over casting tables and rolling it by metal rollers. This is used for mirrors and panels and is made in sizes up to 110" × 36", the thickness varying from $\frac{3}{8}$" to 1".

**Special types:** i. **Obscured glass:** a. *Frosted:* by grinding off the polished surface by a sand blast or by producing a frosted appearance by applying acid. b. *Rolled:* By rolling plate glass in a series of waves producing different degrees of diffusion and concealment. c. *Ribbed:* by providing a series of ribs to deflect the direct rays and obstruct vision. ii. **Wired glass:** By embedding wire netting in plate glass during rolling to resist fire. Even if the glass breaks, the pieces are held by the wires in position. It is used for fire-resisting doors and windows. Wired cast glass either with $\frac{1}{4}$" sq. or $\frac{3}{8}$" hexagonal welded wire mesh reinforcement is made in India by Pilkington Bros. Ltd. iii. **Safety glass:** By sandwiching sheets of celluloid between two sheets of plate and sticking the whole together by means of glue to prevent the flying of splinters when broken. iv. **Reinforced or armour plate glass:** By heating the plate glass and suddenly cooling it when it acquires the property of resisting impact and sudden temperature changes. v. **Heat excluding or anti-actinic glass (calorex):** absorbs heat without impairing light. This is used in factories, hospitals, kitchens, etc. vi. **Ultra violet ray glass (Vita):** transmits the ultra-
violet rays even though it is not in the direction of the sun's rays. This is used in hospitals, schools, etc. vii Opaque or opal glass (Vitrolite): is made by introducing fluorides and a high percentage of kaolin into the fusion and forming like plate glass. viii Coloured glass: used in food stores and as protective for certain materials can be made in a variety of shades as explained before. ix Perforated glass: By punching holes (during or after manufacture) through sheet glass by rollers. This is used for ventilating pantries. x Glass block: for walls and partitions is made up of two halves fused together so as to form a hollow inside. It resists heat, cold and noise, transmits light, and is easily cleaned.

Glass Paper: is used for polishing wood surfaces and rubbing down painted surfaces. It is made by attaching ground glass of different degrees of fineness to paper.

Laths: are used for plastering and supporting the roof coverings. They may be: i wooden (thin strips 3 to 4\(\times\)1\(\times\)\(\frac{1}{4}\) to 1\(\frac{1}{4}\)); ii metal a. Plain expanded. b. Ribbed expanded, c. Perforated, and d. Dovetailed; or iii slate (10\(\times\)1\(\frac{1}{4}\) to 3\(\times\)\(\frac{3}{4}\) to 1\(\frac{1}{4}\)).

Leather: derived from the hides of animals by tanning, is used for driving belts, friction lining material, washers for hydraulic work, etc.

Linoleum: consists of a mixture of oxidised linseed oil, pulverised cork, wood flour, pigments and colours all spread in a uniform layer on canvas or burlap backing, the surface of which may be printed in different patterns. The surface is afterwards waterproofed with an oil paint. With inlaid linoleum, the pattern goes right through the fabric, the different sections being pieced together and then passed between heated rolls. Linoleum floors are fixed with vegetable and casein glues, lignin pastes, gum spirit adhesives, and bitumen-rubber emulsions or solutions. These are satisfactory for private houses and public buildings. Linoleum is also suitable for most types of non-industrial wears. In light industry it may be used for factories involving dry processes. If it is kept wet, it expands, mildews and eventually rots. For timber sub-floors adopt tongue and grooved boarding, punch down all nail heads, and plane well. Where the floor is on concrete on ground provide an efficient damp course. For concrete sub-floors, finish the concrete over the damp proof course with a trowel and allow it to dry. Alternatively, provide a 12.5 mm thick layer of mastic asphalt over the concrete. For new work, adopt a 3.5 mm thick membrane of bitumen or pitch in between the concrete base and the fine concrete topping. For clay or concrete tiling over a dry site or damp proof course provide a layer of underfelt to
prevent the tile pattern showing through. Linoleum can be laid with non-solvent type adhesives over mastic asphalt provided the latter is not likely to be dented by point loads.

**Mica:** is a double silicate of alumina or magnesia, and potash or soda. Condensers used for magnetos and high frequency purposes employ the best clear ruby mica; sometimes however, specially selected slightly stained mica is employed. For heating and cooking, where mechanical strength considerations are concerned, the muscovite micas are used; where great heat is required, phlogopite is employed. **Micanite:** made from thin pieces of mica into large sheets, using suitable adhesives, is cheaper than mica, but is inferior in electrical properties.

**Miscellaneous Cements:** For reservoirs, cisterns, etc., take 9 burnt brick, 1 powdered litharge and mix to a plaster consistency with boiled linseed oil. For earthenware pipe joints, use **oil cement:** 5 dry slaked lime and 1 linseed oil pounded to a thin paste. For steam and water joints, use 10 lb. ground litharge, 4 lb. Parish white, 1 lb. yellow ochre, 2 lb. red lead, 4 oz. cut hemp mixed in boiled linseed oil. For joints of C.I. tanks and pipes, use **rust or C. I. cement,** 2 sal-ammoniac, 1 flour of S, and 200 iron filings. For a non-inflammable cement, use **wood cement,** a mixture of MgCl₂, powdered magnesia, and wood saw dust. This is also used with cement like patent stones. For roofing, flooring, and waterproofing, use **asphaltic cement** (Pa 205). **Necol:** cement is a nitrocellulose general-purpose adhesive used for bonding leather to leather, wood to wood, wood to metal, metal to metal, china to china, Perapex, etc.

**Nails:** i **Cast nails:** made by running molten iron into moulds, are brittle and cheap and are used for ordinary work. ii **Malleable nails:** are cast nails made malleable. iii **Hand wrought nails:** forged by manual labour, are tough but costly. iv **Plate or cut nails:** cut by machinery from sheet iron, are used in exposed positions. v **Rose nails:** wrought, cut or pressed, are used for wood work. vi **Clasp nails:** are used in soft wood. vii **Brads:** thin nails with a small head, are used for small finish. viii **Clout nails:** with broad flat heads, are used for fastening gutters and metal work. ix **Wire nails:** round or sq., are used for packing cases. x **Copper nails:** are used where corrosion resistance is required. xi **Cement coated wire nails:** are used in rust proof work. **Spikes** are large wrought nails used for heavy work. **Dog spikes** are used for nailing heavy iron work to wood.

**Papering:** is not suitable in damp climates and places infested with white ants. It is rarely used in India. The surface is thoroughly sized with rice 'congee,' dried, covered with a lining paper, (when costly paper
is used), and the paper applied with a paste made of wheat flour, glue, 
CuSO₄, and a little alum. The papers are: i Common or pulp paper: with 
designs printed on the natural colour of the paper. ii Satin paper: with 
the paper painted with colour mixed with plaster of Paris and polished 
with French chalk powder. It can be kept clean, but is affected by damp. 
iii Flock paper: with the pattern printed on the paper first in size, then 
in varnish and then cotton dust or flock from woolen cloth sprinkled. It 
looks nice, but catches dust.

Plastics: General: The word 'plastics' means capable of being 
shaped or moulded. Plastics denote organic compounds solid and durable 
under normal atmospheric conditions made from C, H₂, O₄, N₂, S, Cl₂, and 
other elements playing important roles. Metals and minerals are not 
used except as inert aggregates. Some plastics like asphalt and shellac 
occur in nature; while some others like hard rubber and celluloid start 
with materials occurring in nature. These are fast replacing wood, glass, 
porcelain, and many natural products used in Engineering construction.

They are prepared from binders (synthetic or natural resins) 
with or without fillers, plasticizers, pigments, lubricants, solvents, hardeners 
and catalysts. Fillers: are added to thermo-setting plastics to reduce 
the cost and impart certain definite properties e.g., Ba salts are added to 
make the material impervious to X rays; asbestos to increase resistance to 
heat and corrosive liquids; shredded textiles to increase impact strength; 
and wood flour to strengthen the moulded product. Other fillers are paper 
pulp, corn husks, graphite, carbon black, mica, clays, whiting, pumice, 
metallic oxides, and various metals such as Fe, Pb, Cu, and Al. Plasticizers: 
are added to improve plasticity and facilitate the moulding process, and 
also to counteract any inherent brittleness of the moulded product. They 
make up 60% of the plastics and are often used with thermo-setting plastics. 
A wide variety of materials find use as plasticizers e.g., camphor to 
increase surface hardness; tributyl and triphenyl phosphate for flame 
proofing; and triacetin and tributyl phosphate for toughening the plastics. 
Pigments: Mineral colours are usually added; Lubricants: are added to 
prevent the finished moulding from sticking to the mould e.g., a stearate 
in the case of phenol formaldehyde. Solvents: are used to dissolve the 
plasticizer e.g., alcohol to dissolve camphor in the case of cellulose 
nitrate. Hardeners: are used for hardening of the resin e.g., hexamethylene 
tetramine for phenol formaldehyde. Catalysts: are used to assist 
the hardening of the resin e.g., CaO or MgO for phenol formaldehyde, 
ester for urea formaldehyde, etc.

Advantages: i They have a low sp. gr., high tensile and impact
strength, a high coefficient of thermal expansion, and a low thermal conductivity. ii They have a high dielectric strength and are used as electrical insulators. iii They are resistant to climatic changes, clean and can be sawn like wood, and welded like steel. iv They have high colourability and afford a wide range of colour for decorative use; others are completely transparent and have relatively high refractive indices that make them suitable for optical purposes. v Many plastics do not absorb water but only a few are resistant to acids and alkalies. The effects of water absorption are to cause dimensional instability owing to swelling and loss of electrical insulating properties. Acids and alkalies decompose them.

**Types:** All plastics are moulded under the combined action of heat and pressure. The varieties are: i *Thermo-setting*: These become hardened upon heating and cannot be reformed once they are set. These contain a resin formed by condensation e.g., Bakelite. Thermo-set scrap cannot be reused. ii *Thermo-plastic*: These retain all their fluid properties when the moulding operation is completed. These contain a resin formed by polymerization e.g., cellulose, shellac, etc. The scrap and reject moulding can be reclaimed and remoulded without any chemical treatment.

**Thermo-plastic resins:** *Bituminous plastics*: are used chiefly in the electrical industry for making boxes that contain the storage batteries of the automobile. The boxes are made by mixing asphalt (hot) with diatomaceous earth and asbestos and then moulding. They become hard and strong, when cooled. Cold moulded bituminous plastics are made from asbestos fibres wetted with a solution of asphalt in a volatile solvent like benzene. The solvent is driven off by gentle heat, and then the material is pressed into shape. *Cellulose nitrate*: is obtained by the action of HNO₃ and H₂SO₄ on cotton linters kept in stainless steel vessels. It is extracted from suspension by means of a centrifuge, washed with water, and then dehydrated by means of alcohol. Camphor in the presence of alcohol is employed as the plasticizer. Cellulose nitrate is an inflammable tough plastic widely used for rayons and as photographic film base. *Cellulose acetate*: is obtained by dissolving cotton linters in a solution of acetic acid, acetic anhydride, and H₂SO₄. It is not highly inflammable, but merely burns at a slow rate, or chars. It is usually available in transparent sheet form, but can be obtained as a moulding powder; it is also supplied in the opaque form. It has high dielectric properties and is used for many types of electrical insulation; but is the poorest of all plastic materials in their resistance to water, a *Poly-styrol* or *polystyrene*: obtained by polymerization of the hydrocarbon styrene, is transparent. It has a low water absorption value and power factor and is especially
valuable to manufacturers of radio and television sets. Polyvinyl: is derived from vinyl chlorides and acetates. It is obtained as soft and readily soluble materials and also as hard but fusible in either the opaque or coloured condition. It is very slightly hygroscopic. It is resistant to acids and alkalis and is used in the manufacture of tubes and electrical accessories. Methyl-Methacrylate: is the ester of acrylic acid with methanol. The resins are only slightly affected by ageing and are extraordinarily transparent. The transparency, light weight, weather resisting qualities, and ease of moulding have made this material valuable for the windows, domes, and other transparent parts of modern aircraft. With polystyrene, achromatic lens combinations are formed.

Thermo-setting resins: Phenol-formaldehyde plastics: are produced by heating together phenol and benzene in the presence of proper catalysts. Cresols act in the same way as phenols but give different products. The resulting synthetic resin when mixed with a suitable filler and heated under pressure in suitable moulds first softens and takes the same shape as the mould; it then hardens into a solid compound. The resin is also mixed with suitable solvents and used as varnishes for impregnating electric coils, etc., for binding and insulation purposes; it is also used as a lacquer for coating painted or plain metal surfaces. It is also employed to impregnate wood, paper, etc., for decorative panels and for forming laminated products of high strength. Phenol-furfuraldehyde plastics: are produced by digesting husks of rice, oat, ground-nut shells, etc., with H₂SO₄, distilling to separate the furfuraldehyde vapours, and allowing the vapours to react with phenol in the presence of a catalyst. These plastics, though dark in colour, resist very high temperatures. Urea formaldehyde plastics: Urea, an amino compound synthesized by heating NH₂ and CO₂ under pressure, when allowed to react with formaldehyde and heated with catalysts forms a thick liquid at first and later a clear, transparent, and colourless resin. This is much more light-resistant than the phenolic resin and gives very light coloured and light-fast moulding materials, whereas the phenolic resins are amber or brown. Urea formaldehyde resins are used in the manufacture of plywood and bonded veneers. Fillers are added to the pure resin to resist the tendency to crack. The filled products are used for drinking glasses, dishes, lamps, etc. Casein plastics: Casein is a precipitation product obtained from milk by the action of acid. The casein is ground, coloured, and moulded or extruded into rods, sheets or blocks. These are then hardened by treating with formaldehyde. Casein plastics, though they lack strength, warp, and absorb moisture, are used for the manufacture of buttons, buckles, etc., for which their attractive ap-
pearlance, bright colours, and workability make them especially suitable. Lighting fittings are made from Dareic (resistant to impact and corrosive fumes), crinolene crinkle-finished in a variety of colours, and mouldrite (urea formaldehyde) odourless, tasteless, chemically stable, abrasion resistant, and available in a variety of colours.

**Fabrication:** The methods are casting, extrusion, moulding, and lamination sometimes followed by machining. *Laminated plastics* are made by impregnating sheets of paper, cloth, or even wood with a suitable resin, usually phenolic or urea type and uniting them by heat and pressure into a mass that is tougher and more elastic than other forms of the resin. They find an important use in gears. *Casting* refers to the forming of objects by pouring the liquid resin into a mould. The moulding of plastics is done around a metal insert so that the finished piece has a metal part firmly bounded to the plastic. The moulding is done in a number of ways: *cold* by high pressure and then baking, *compression* by high pressure and moderate temperature; *injection* by warming the plastic and forcing it under pressure into the cool mould; *extrusion* by forcing the plastic granules by a screw along an electrically heated barrel and out through a nozzle; *blowing* the plastic powder into the mould by air pressure or vacuum; *casting* by liquifying the plastic compound; and *transfer* by plasticizing the compound under heat and pressure and then injecting it into the mould where curing takes place under the influence of heat and pressure.

**Bakelite:** is obtained by heating together in the presence of a base, equal amounts of phenol and formaldehyde. The amber coloured substance, which is formed, has a melting point of 50° and is soluble in alcohol and acetone. This is called Bakelite Resin 'A' and is used with fillers for forming the different materials. When this resin 'A' is subjected to further heat treatment, we get a hard, insoluble, infusible, transparent, and amber-like substance known as Bakelite Resin 'C'. This is the final product employed for so many electrical and engineering purposes under the name Bakelite.

**Reinforced plastics:** denote cellulose, asbestos, or glass fibres bonded with resin to produce materials stronger than the resin itself. These are available as sheets or tubes and the reinforcement is put in as paper or fabric. Gears and bearings made from these plastics are coming into extensive use.

**Ropes:**

1. *Wire ropes:* are built up of strands of wires twisted together with a hemp core. They are used in elevators, derricks, hoists, cables, etc., where great strength is required.
2. *Manila hemp ropes:* are used for marine and general construction work. They have strength,
durability, and resistance to wear. c. Sisal hemp ropes: are second only to manilla. d. Cotton ropes: are flexible, pliable, costly and are used only for transmission of small power. e. Jute ropes: lack durability and are affected by moisture. f. Coir ropes: are used for ordinary work where no strength is required.

Rubber: Natural Rubber: is present as an emulsion in the latex of certain plants. Latex is the milky colloidal fluid oozing from superficial cuts in rubber trees. It is collected in containers. The crude rubber is obtained from the latex by coagulation using acetic acid, alcohol, air (fermentation process) blood, alum, lime, and lime juice. Certain agents, such as heat, sunshine, and smoke also promote coagulation. In certain cases the latex is mixed with appropriate compounding materials and then precipitated directly from solution in the shape to be used. The method has several advantages. It does away with expensive machinery; the rubber is not broken down and has, therefore, a higher tensile strength; and vulcanisation can be effected more rapidly. Crepe rubber is obtained from latex by coagulation with organic acids, washing the coagulum well with water as it passes between rolls and finally drying the washed sheet as it comes from the rolls. If rough rolls rotating at different speeds are used and the rubber is then hung in the air, to dry, we get pale crepe rubber. If smooth rolls rotating at the same speed are used and the rubber is then dried in a smokehouse, we get smoked sheets. The crude rubber is then treated to eliminate mechanical impurities by washing in hot water, and then torn into small pieces in a special machine through which water is constantly circulated. The pieces are then dried by passing through rollers, during which process they become flattened out into thin sheets. The rubber, plasticized as above is then mixed with S, oils, resins, tars, whiting, white lead, talcs, barytes, clays, reclaimed rubber, and rubber substitutes for hardening, filling, colouring, cheapening and generally improving the rubber for its various commercial purposes. Vulcanizing consists in mixing S with the rubber and heating the mixture to a temperature above the melting point of S. The S combines with the rubber and forms a compound which has the following properties: much less sensitive to changes of temperature; acquires increased elasticity and strength; is more durable and more resistant to the action of chemical reagents. This process is employed commercially for the repairs of cuts in treads of tyres, for patching or repairing inner tubes, and building up with rubber various proprietary articles made from rubber. Various grades of rubber are produced by this process: Soft grade: used for soft packings, tubing, and erasers; medium grade: used for rubber sheeting, canvas ply tubing, hose
piping tyres, balloon fabrics, shock-absorbers, surgical and other goods; semi-hard: used for rubber wearing surfaces, brake blocks, buffers, etc., and hard: like vulcanite and ebonite: containing a high% of S used in electrical work because of their high insulation properties. Rubber tiles: are used for quite comfortable, colourful, durable, and easily maintainable floors.

Synthetic rubber or elastomers: are derived from coke, limestone, petroleum, natural gas, salt, alcohol, sulphur, ammonia, and coal tar. They are made by emulsifying in a dilute soap solution the monomers butadiene and styrene, and then adding catalysts, modifiers, etc., which cause the small globules of liquid to be slowly transformed into solid particles of rubber. This process is called polymerisation. The latex is then curdled or coagulated by adding NaCl and H₂SO₄, and the curds of synthetic rubber are then washed and dried. They possess most of the desirable characteristics of the natural rubbers and are much more resistant to the deteriorating effects of sunlight, oxygen, heat, oil, and petrol. They are particularly suited to applications where flexible parts have to resist, satisfactorily, the action of oil, grease, temperature, and oxidising agents. They are used for gas containers, protective coverings for seaplane floats, expanded rubber for sealing and flooring, and for a variety of purposes in aircrafts. The common elastomers are: ameripol used for aeronautical and automobile purposes in view of the superiority over natural rubber: neoprene (made from coal, lime, and salt): used for the insulation of high-tension cables on aircraft engines; buna (made from petroleum, alcohol, and coal); chemigum: used for bullet-proof, puncture-sealing petrol and oil tanks and hose pipes, flexible connections for fuel lines, and numerous other purposes; and thiokol (made from natural gas, sulphur, and salt): used for rubber hose.

Uses: Rubber, in the form of sheet, either solid or sponge-backed separate tiles or inlaid tiles, is used as floor covering for railway coaches, buses, ships, and in public and industrial buildings because of its good wearing qualities, resiliency and reduction in noise. With canvas and fabrics, it is used for hose, belting, and joining materials for steam and hydraulic work. With asbestos, it forms an excellent steam band packing material. Compressed rubber and asbestos with or without brass wire bonding, forms a useful friction lining material for motor car and colliery brakes and similar purposes. Rubber is bonded to metal and used not only in compression, but also in tension and shear e.g., aircraft and automobile engine mountings, for machinery mountings, etc. Rubber expanded by forcing an inert gas into it, called sponge rubber, is used in upholstery for automobile seats and squabs, pillows, flooring, etc. Cellular
rubber insulation boards (the cells containing \( \text{N}_2 \)) which are light, have a low thermal conductivity, are oil-acid-and rot-resistant, and are unaffected by moisture.

**Screws**: *Wood screws*: made of metal with bevelled threads are used for fixing metal to wood; *flat headed*: for countersunk work and *round headed*: where the metal is too thin to be countersunk. *Coach screws*: are large, heavy, square headed screws used in heavy woodwork and for fixing iron to timber. *Brass screws*: are costly and are used for works which require easy removal.

**Tar**: is a dark black viscous liquid. The three classes are: i. *Coal tar*: is produced by heating coal in closed iron vessels and depositing in tubes cooled by circulating water. It is also obtained as a by-product in the manufacture of coal-gas. It is used for making tar macadam roads. When it is distilled, coal naptha used for dissolving India rubber, creosote oil used for preserving timber, and pitch used for asphalt are obtained. ii *Wood tar*: is obtained by the distillation of resinous trees. It has strong preservative qualities owing to the creosote it contains. The residue left after distillation is pitch. iii *Mineral tar*: is obtained by distillation of bituminous shales.

**Vitreous or Porcelain Enamel**: coatings, because of their high durability, excellent corrosion resistance, and attractive appearance are largely given to ferruginous materials used for equipment in the chemical, pharmaceutical, food, beverage, and dairy industries. *Frit*, the basic material in the enamel, is made from refractories (silica and felspar), fluxes (borax, soda ash, cryolite, fluor spar, sodium nitrate, zinc oxide, and lithium compounds), and opacifiers (oxides of Ti, Sb, Zr, Pb, and Sn). An intimate mixture of these three components in certain proportions is heated to 1,260° in a frit smelter. The molten charge, after it gives off gas, is poured into a tank of water. The sudden cooling causes the molten stuff to solidify and shatter, thus producing the basic glass-like frit. The frit is mixed with not exceeding 15% of electrolytes or set-up salts, opacifying compound, water, ball clay, certain chemicals, and inorganic colouring pigments when coloured enamels are desired and milled in a ball mill to 200 mesh size. The enamel in this form is called 'slip'. The first or ground coat is usually applied by dip methods; finish coats (1 to 3) are applied by spraying. After each coat, the parts are heated in a low temperature oven to remove water. They are then fired in an enamelling furnace to a temperature ranging from 760 to 930°, depending on the type of enamel and base metal. In the dry process for heavy iron castings,
the castings, ground-coated by the wet process, are heated to 930°. The cover coat is then applied in the form of a dry powder and the castings are again heated in the furnace till the powder coating fuses to a smooth finish. These should not be confused with enamels which are organic finishes and are cured at 200°. The household refrigerator is usually white, both inside and outside. The inside is coated with a vitreous enamel and the outside with a lacquer or an enamel.

**Wall Boards:** The varieties are: i. **Fibre boards:** (Pa 211). ii. **Plaster boards:** Plaster sandwiched between two thin layers of cardboard. Lengths up to 12' and widths up to 4' are obtainable. Asphalted gypsum sheathing boards are made with tongue and groove edges out of a gypsum core impregnated with an asphalt emulsion and treated on either side with water resistant Triplesail. There are waterproof, fireproof, and can be scored and snapped right on the studs. iii. **Plaster lath boards:** are similar to plaster boards but are smaller in size and are prepared to take plaster. iv. **Fibrous plaster boards:** are plaster lath boards reinforced with fibre. v. **Plywood:** (Pa 157). vi. **Asbestos cement sheets:** (Pa 204). vii. **Special boards:** which include plywood faced with galvanised steel, Cu, Zn, Pb, Al, etc.

## CHAPTER VI

### PAINTS AND VARNISHES

Paints and Varnishes are used in building and other engineering structures and for furniture, for covering the surfaces of wood, iron, (etc.,) i to protect them from the injurious effects of the atmosphere and other agencies and to preserve them from decay or oxidation and corrosion respectively, and ii to improve their appearance. Paints are also used for internal decoration purposes.

### PAINTS

**Ingredients:**

1. **A Base:** which is the material upon which the character and durability of the paint depends. It gives body to the paint, reinforces the film of paint after it has dried, and minimises shrinkage cracks usually formed in drying. It should freely combine with the vehicle during application and drying, and should neutralize any acid in the ingredients added. The bases are: i. **White lead:** \(2 \text{ Pb CO}_2, \text{ Pb (OH)}_4\): It is cheap, durable, has good covering properties and density, combines freely with the vehicle; has great tenacity and offers a range of coloured paints to be built up. White lead paint is the best protective covering that can be applied to the surface of wood. It is water-
proof and has a good body. It gives an elastic film which expands and contracts as the temperature rises and falls, so that it adjusts itself to changes in the area of the surface on which it is used and cracking is thereby reduced to a minimum. Where it is exposed, however, to the fumes of sulphur acids and gases such as \( \text{H}_2\text{S} \), such as are evolved from decaying animal matter in laboratories, and in some manufacturing towns, it soon becomes darkened by the formation of black PbS. It has also the disadvantage or defect of producing numbness and painters' colic in those who use it, as Pb compounds are poisonous. It is also smelly. Pb paints have a corrosive action on iron articles, when applied directly to the surface of the iron article. ii Lead oxide: (Litharge PbO and red lead Pb\(_2\)O\(_4\)); It is anticcorsive and very penetrative on wood. Owing to its great weight, it solidifies at the bottom of containers having a paint with lead oxide as base. Hence it should be freshly mixed for use and well stirred before application. Red lead paint is used for the first or the priming coat on wood; the subsequent coats being with white lead paints. iii Zinc oxide: (Zinc white ZnO); It does not combine with oil so readily as white lead. Its covering properties are therefore inferior and it takes a long time to harden. It is acted upon by the CO\(_2\) in rain water which dissolves the oxide, and it therefore weathers badly. HCl, Cu, and Cu compounds also act on it. The acids in unseasoned wood have a great effect upon it. It is transparent, smooth, has no smell, and amalgamates readily with the binding oil during oxidizing and drying. ZnO paint retains its colour well and stands washing for several years without losing any of its freshness. When dry, it becomes very hard and takes a fine polish. It is largely used for interior decoration. It may be used without fear of painters' paralysis. It is suitable in large manufacturing towns where it is subjected to vапours containing \( \text{S} \) or in places where foul air is emanated from decaying animal matter. It is not blackened by exposure to \( \text{H}_2\text{S} \). It should not be mixed with patent or other driers which contain Pb compounds when used in areas containing \( \text{H}_2\text{S} \). The best driers to be used with it are MnSO\(_4\) and ZnSO\(_4\). iv Iron oxide: It alloys itself freely with the vehicle and when applied to iron work forms a rust preventing coating. Iron oxide paint is cheap, durable, and permanent, if properly applied. It is used for the priming coat on ironwork. v Titanium dioxide (Titanium white TiO\(_2\)): Associated with iron oxide it occurs as ilmenite in the beach sands of Kerala. It is very white, unaffected by heat or acids, non-poisonous, and has excellent body and density. It is inert and dries off with a soft film which is inclined to chalk on exposure. Titanium paint keeps the colour in industrial areas. It is used as an undercoat and with
other ingredients for internal work. vi Antimony oxide (Sb₂O₃): It is similar to TiO₂. With S it becomes yellow and again becomes white on contact with pure air. Lithopone (SnS & BaSO₄): It is dense, white, cheap, and nonpoisonous. It is used in gloss paints and many water paints. It becomes grey if exposed to open sunlight due to the formation of Zn by photo electric process. This defect is rectified by the addition of salts of V, Cr, W, etc. Lithopone paint is less satisfactory than Zn paints for exterior work and the film rapidly disintegrates. It should not be used on iron and should not be allowed to come in contact with water.

2. Inert Filler or Adulterant or Extender: is an inert material mixed with the base to make the paint lighter or heavier to the desired extent to increase the durability and lessen the cost. As components in leadless combinations prepared for internal use, inert fillers play a valuable part in preventing the settling out of other pigments, giving the paint the correct body or consistency and assisting in the build up of the dried paint film. The mineral white fillers in common use are: gypsum and chain clay for white lead, chalk and whiting for BaSO₄ and PbSO₄, and barytes, gypsum, and china clay for zinc white.

3. A Vehicle or Carrier: is added to hold the ingredients of the paint in liquid suspension, to allow them to be spread evenly over the surface, and subsequently to act as a binding agent of a colloidal character. Vehicles are either fixed or volatile. Fixed oils are obtained by extraction under pressure from vegetable substances. They are divided into drying and non-drying oils. Linseed oil, poppy oil, and nut-oil are drying oils and are used for mixing paints. Non-drying oils, e.g., olive, almond, and ground nut-oils, are not used as they impair the strength of the film. Volatile oils are obtained by distillation and have an odour resembling that of the plant forming the source. They are colourless first and on exposure to air and light, become darker, thicker, and finally are converted into a kind of resin. Of these, only turpentine is largely used in painting work.

Linseed Oil: (obtained from the seed of the common flax) is much used as an ingredient of oil paints and putty. It is superior to other fixed oils in drying power, tenacity and body and in working smoothly. Linseed oil of good quality will appear limpid, pale, perfectly transparent, and brilliant, is mellow and sweet, and has very little odour. It oxidises and gets thick on exposure to the air. Darkness in colour and slowness in drying are defects in inferior oil. Linseed oil is used either raw or boiled for woodwork. Raw linseed oil is pale in colour and is used for interior painting work. It is useful for delicate tints, for grinding up colours. It should not be used within six months of its extraction. Because of its
rather poor drying power, a drier should be added when a paint is mixed in raw oil, as in the case of thick white lead paste sold in the market; for without the drier, it will take several weeks to dry; but, with a drier, it will dry in one to three days according to the weather conditions, and will be fit to take the next coat. The drying power of raw oil can be improved by adding 1 lb. white lead to every gallon of oil and allowing it to settle for at least a week. Boiled linseed oil: also called drying oil, is obtained by reheating raw oil alone or mixed with certain driers. On boiling, it becomes thicker and so is not suitable for delicate or indoor painting work. It is not suitable for grinding in the colour pigment as it clogs and thickens too rapidly. Drying oil for ordinary work can be made by boiling 14 lb. of red lead in a gal. of raw linseed oil and allowing the mixture to settle. Double boiled oil is used for painting plastered or metal surfaces. Poppy oil: is used for very delicate colours. Nut oil (from walnut): is used for common or ordinary work, being cheaper. It dries more rapidly than linseed oil but is not durable. Rosin oil: is obtained by destructive distillation of resin. With lime it forms a grease used in the manufacture of rough lubricants for trolley wheels. Tung oil, dehydrated castor oil, soyabean oil, and fish oil are also used.

4. A Drier: is added in most cases to cause the vehicle to dry and harden quickly. As it assists oxidation by increasing the supply of $O_2$, it should carry a considerable proportion of $O_2$. As it affects the strength, elasticity, and other physical properties of the film it should be sparingly used in the finishing coat; otherwise the paint may peel off in scales. Driers are classified as: i Soluble driers: Driers dissolved in linseed oil; ii Paste driers: Driers mixed with inert fillers ground in linseed oil; and iii Liquid driers or terebene: Driers dissolved in linseed oil (or turps or with both), usually in the proportion of 1:16. The driers are: i Litharge: is commonly used. As it tends to discolor the paint, it should not be used for the finishing coat. ii Red lead: is used when its colour does not interfere with the desired tint of the paint. Its drying action is slower than that of litharge. iii Lead acetate or sugar of lead: ground in oil, is used as a drier for lighter tints in the same proportion as for litharge. iv Zinc sulphate: (for light tints), and MnSO$_4$: (for deep tints): are used as driers for Zn paints as Pb drier tends to discoloration. MnSO$_4$ should first be mixed with a small quantity of the paint and then added to the bulk with care lest the work should be spotted. v Manganese oxalate and MnO$_2$: are quick in their effects but can only be used for deep tints as they are dark.

Points to be noted in using driers: i They should not be used with pigments which dry well in oil; ii They should not be used in excess as, in
that case, oxidation which accompanies drying may be carried to excess and
the film may crack; iii They should be added to paints just before appli-
cation; and iv More than one drier should not be used with the same paint.

5. A Solvent or Thinner: is added to serve as a solvent, to
make the paint thinner and flow freely under the brush, to facilitate
spreading the paint evenly over the surface, and to help penetration of
porous surfaces like metal or plaster. The solvent, largely used, is spirit
of turpentine (or turps) produced by distilling the resinous exudation of
some kinds of pine trees. A portion of this volatilises while the remainder
aids the oxygenation of the oil and aids in fixing the colours. If turpentine
is used in excess, the colour will be flattened, that is to say there will be
no gloss, and will also not be durable as the turpentine evaporates, leaving
an excess of colour, unmixed with the oil. Pure turpentine should have
no residue on evaporation. The quantity of the oil to be added in mixing
paint may be diminished to the extent of the turpentine added. Turpen-
tine diminishes the tendency of the paint to turn yellow, especially in
rooms kept closed for sometime. Turpentine should not be added except
sparingly, in exposed out-door works, as its tendency, is to impair the
firmness of the paint. Oil paints will naturally present a glossy or shiny
appearance, provided no more turpentine has been used for thinning than
the oil. But, when a dull or dead appearance is desired only turpentine
is used, and no oil, to the paint for the last or the finishing coat. The last
cost, in this case, is called the flattening coat.

6. Colouring pigments: When the desired final colour of the
paints is different from that of the base used, the desired tint is obtained
by adding a colouring pigment to the mixed paint. The pigments are
classified as: Natural earth colours: e.g., umbers, ochres, siennas, etc.
These are beautiful and durable pigments, which readily intermix with
other paint compositions. ii Calcinied colours: e.g., Indian red, carbon
black, ultramarine, etc. In general, these are durable. iii Precipitates:
e.g., Prussian blue, chrome green, etc. iv Lakes: are obtained by precipi-
titating some organic colouring matter (usually a coal-tar dye) upon some
suitable mineral base, like barytes. These are usually fairly permanent
in respect to weather and give beautiful effects. v Metal powders: e.g.,
Al, Zn, Pb, bronze, etc. These require a minimum of vehicle for suitable
dispersion and yield films that are largely composed of the metal. The
colouring pigments in use are: i Lamp black, vegetable black, and ivory
black for black; ii Prussian blue, cobalt blue, phthalocyanine blue, and
ultramarine blue for blue: iii Pruce’s mineral, umber, and Vandyke
brown for brown; iv Chrome green, and Paris green for green; v Chrome
yellow, zine chrome, and yellow ochre for yellow; and vi Red lead, Venetian red, and Indian red for red.

Proportioning of Ingredients in Mixed Paints: The exact proportions vary according to circumstances as they are governed by the following factors: i Nature of material to be painted. Thus, the paints for protecting wood and iron respectively differ considerably; ii The kind of surface to be covered. A porous surface requires more oil than one that is impervious; iii The nature and appearance of the work to be done. Delicate tints require colourless oil. A flattened surface must be painted without oil. If the painted surface is to be varnished, the paint should contain a minimum of oil; iv The climate and the degree of exposure to which the work will be subjected. For outside work, boiled linseed oil is used as it weathers better than raw oil. Turps is avoided as far as possible because it evaporates and does not last. If however the surface is to be exposed to the sun, turps are necessary to prevent the surface from blistering; v The skill of the painter. A good workman can lay on even coats with a smaller quantity of oil and turps than a man who is unskilful. Extra turps are often added to save labour; vi The quantity of the ingredients of the paint. Thus more oil and turps will combine with pure than with impure white lead. Thick oil will require to be used in greater quantity than thin oil. When paint is purchased ready-ground in oil, a soft paste will require less turps and oil for thinning than a thick paste; and vii The different coats of paint vary in their composition. The first coat on new work requires a good deal of oil to soak into the material, on old work, the first coat requires turps to make it adhere. The intermediate coats contain a proportion of turps to make them work smoothly and to the final coat, the colouring pigment is added, the remainder of the ingredients being varied according as the surface is to be glossy or flatted.

Mixing Lead Paint: Dry white lead is ground by machinery in oil for general paints. But, for hard colours and filling up compositions, it is ground in turps with a portion of 'Japan gold size' or varnish added to bind it. The paste is softened and made smooth by adding a small quantity of oil and turps and working it well with a palette knife. The colouring pigments, if any, are then added and the paint is brought to the consistency of cream by adding more oil and turps. It is then cleaned by passing it through a canvas or thin strainer. When about to be used, the paint is thinned to the consistency necessary to enable it to work freely, by adding more oil and turps, and the driers also are added. As the paint becomes thicker during use, or when put by for some time, it will require further thinning, and perhaps repeated straining to clear
from skin or dust. To prevent mixed paints from skinning over or drying up, they should be kept constantly covered with water or a thin film of linseed oil.

The grinding and mixing of the colouring pigment with the paint is done as follows:—The pigment should be ground on a flat stone or in a colour mill until thoroughly mixed and then rendered fluid with oil or turps. It is then mixed with paint. When a colour mill is not available, the grindstone and Muller can be used. The grindstone is a smooth flat slab of granite, about 2' square, and the muller is a hard conical stone whose flat end has a dia. of 4 to 6". The colour pigment should first be pounded, sifted, and mixed with a little oil. Successive small lumps of the size of an egg are then placed on the stone and thoroughly ground with the muller. After so grinding, the white lead paste and the colour paste are rendered fluid by the addition of linseed oil or turpentine or both to the consistency of cream.

White lead is available in the market either dry or ground in raw linseed oil by a mill to the consistency of a thick paste. The method of preparing or mixing paint with the dry white lead has been described, above. The paste is sold in kegs of 28, 56, and 112 lb. each. To prepare the paint for actual use from such paste, merely requires the addition of more linseed oil, say 3 to 4 pints to 10 lb. of keg paint, for thinning it sufficiently to flow readily under the brush. When, as is usual, raw linseed oil is used for thinning and also because the keg paint is mixed in raw oil, driers should be used. Patent paints are also available in the market ready mixed, that is to say, mixed well with colouring pigments also ready for application as purchased, e.g., Shalimar paints, Carson’s paints, Hubbock’s paints, etc. These paints should be applied exactly as received in kegs. If, for any reason, the paint inside the keg should have become thick, it can be thinned by the addition of a small quantity of oil and stirring. A good test for the efficiency of a paint, whether ready mixed or mixed at the works, with ingredients is that it should flow freely from the brush when dipped in the paint and held vertically.

Characteristics of Paints: These depend upon the quality of the ingredients of the paint. Thus the qualities mentioned above under the various ingredients, if good, will give good paints. But, generally speaking, the following characteristics must be possessed by all good paints: i) It should have a good body or spreading power which depends upon the base of the paint, the nature of the coat (priming or second), and the nature of the surface over which it is applied (wood, metal, or plaster). ii) It should work freely and smoothly under the brush. This depends
upon the solvent. The proper consistency is indicated when the paint flows slowly and steadily in a thin stream from a brush dipped in the paint and lifted up and held vertically. If the paint is too thick, it will either drag or streak, and if too thin it will tear. iii It should be durable. Durability depends upon the vehicle used. Paint disintegration depends upon the oxidation (of the vehicle) which does not stop when the paint is hard dry, but goes on slowly until the elastic paint film becomes hard and brittle when disintegration sets in. iv The colour of the paint should not fade or change. This is particularly necessary in a white paint. This quality depends both on the base and the pigment used. v It should become surface dry in about 9 hours, and hard dry and in a condition to take another coat in about a dry.

Putty: Putty is a mixture for stopping nail holes, cracks, depressions in the wood, etc., previous to applying the paint, as well as for glazing which means fixing glass panes to doors, windows, etc. Putty consists of ground whiting (powdered chalk) mixed with as much raw linseed oil as will make a stiff paste. The paste is well kneaded and left for 12 hours, then it is worked up till quite soft and smooth. If the putty becomes dry, it can be restored by heating and working. The whiting should be perfectly dry and should pass through a sieve of 45 meshes to the inch. The putty can be coloured to the tint required, when coloured putty is desired.

Applying paint: Painting new woodwork: New woodwork usually requires 4 coats of paint. In best class of work, 5 or 6 coats may be required for exterior work and 2 to 3 coats for interior work. The operations for painting on wood are:

1. Preparation: The wood article to be painted should have been thoroughly seasoned and absolutely dry. All dust, dirt, etc., should be cleaned off and the surface to be painted rendered smooth.

2. All nails should be punched into ¼" below the surface.

3. "Knots," if any should be killed, if small, or cut out if large and filled tightly with a correctly fitting wooden piece. "Killing the knot," which is called "knotting," consists in covering the knots with a substance through which the resin from the knots cannot exude. Knotting is done in any one of the following ways.—i Ordinary or size knotting: To be applied in two coats over the knot. The first coat is applied with red lead ground in water, adding to it strong glue size and applying it hot. This coat dries in 10 min. The second coat consists of red lead, ground in oil and thinned with boiled oil and turpentine. ii Lime knotting: In
this, the knot is covered with hot lime and left on for 24 hours. Then it is scraped off and the surface is coated with size knotting as explained above. If this does not kill the knot, it may be coated with red and white lead ground in linseed oil and when quite dry, rubbed with pumice stone or after the application of lime it may be hot ironed and then painted smooth. In superior work, the knots may be cut to a slight depth and the holes filled up with putty made of white lead, Japan, and turps. iii Patent knotting: consists of two coats of a varnish made by dissolving shellac in methylated spirits. This is applied to stained ceilings to cover the stains and over tarred surfaces to be painted.

4. After knotting, the priming or first coat of paint is applied to the whole surface of the wooden article to be painted. It forms a hard and opaque covering, filling the pores of the wood. The paint for the priming coat consists of the following ingredients:

   **For inside work:**
   - ½ lb. red lead, 8 lb. white lead,
   - 2 pints boiled linseed oil,
   - 1 pint raw linseed oil, and
   - 1½ oz. litharge or patent drier,

   The priming coat is applied, preferably, before the woodwork is fixed in position.

5. **Stopping:** Next, the dried primed surface is well rubbed down with pumice stone or glass paper, then nail holes and other holes, if any, dents and cracks if any, are filled with putty. When the putty hardens, it should be rubbed with pumice stone. If the putty is applied before the priming, it will be liable to fall off, because the wood would absorb the oil in the putty and the putty would shrink. So “stopping” the holes, dents and cracks should be done only after priming.

6. The second and the succeeding coats of paint are then applied, one after the other. Each coat should have thoroughly dried before the next coat is applied. The paint should be laid on with a good brush, the brush being held, at right angles to the face of the work, which is being painted, so that the ends of the hairs only touch it. All successive coats of paint, except the last, should be gently and slightly rubbed down with fine glass paper after the coat has dried. No hair mark from the brush should be left on the work. The coats of paint should be spread as smoothly and evenly as possible. For this purpose, as soon as the whole or a convenient area of the surface is covered, the brush should be passed over it in a direction contrary to that in which it is finally to be laid on. This is
called "crossing." After, crossing, the paint should be laid on in a direction contrary to the crossing, but (in the case of woodwork) with the grain of the wood, taking care that the crossing brush marks are not left visible.

Painting new iron and steel work: The iron or steel work should, before painting, be freed of all mill scale, loose rust and grease. Hot rolled steelwork is cleaned by a bath of hot acid, sometimes aided by electrolytic action. The acid and loosened scale are removed by a jet of hot water, followed sometimes by a bath of hydrated lime which, after drying, leaves a loose coating of hydrated lime or CaCO₃, which tends to prevent corrosion during the interval before paint is applied. Cold-rolled steelwork is first freed from scale before the final forming operations and then coated with grease to facilitate the slipping of metal of the dies. The grease is removed by petroleum solvent or by a shower of hot alkaline cleaning solution containing Na₂CO₃, Na₂(PO₄) or NaOH. The cleaned metal is finally treated with phosphoric acid, which forms an adherent film protecting the surface from rust and giving a surface to which paint will adhere better. Then, a priming coat of oil paint (using boiled linseed oil) should be applied with lead chromate, zinc chromate, red lead, barytes or iron oxide as the base. After this has dried, the outer or the 2nd coat is to be applied. The paint used for this outer coat should be of an elastic and durable character. Bituminous paints are naturally of elastic character and adhere well to the metal and are therefore the best; though graphite paint can also be used as being durable and whose elastic nature could be improved upon by the addition of a suitable gum in the oil with which the paint is mixed. Bituminous paints, graphite paints, and anticorrosive paints (which also are used for painting iron or steel work) present a black appearance. If the painting should be desired to show either white or any other colour, either white lead paint or zinc oxide paint mixed with varnish and linseed oil, and a sufficient proportion of liquid driers may be used as a finishing coat to which the desired colouring pigment has also been added. This lead or zinc paint should not be applied directly to the iron or steel as it encourages galvanic action which destroys the paint.

Painting on Plaster: The success of painting on plaster surfaces depends on: i) Suction: When plaster is very dry, it sucks up the paint and leaves it inert. To avoid this, soak the surface with a pore-filling solution which will also dry off with an impervious surface. A hot or cold wash of 2 lb. size, 1 lb. soft soap, and 2 gal. creamy limewash or a cold wash of clearcole (1 lb. size, 2 gal. creamy limewash, and a trace of alum) is recommended. ii) Condensation: On hard impervious surfaces, condensation, which destroys tenacity, is prevalent. In order to correct this and give
the surface 'bite' and texture, a solution of a dilute acid or a solution of 5 parts turpentine, 1 part linseed oil with a little pigment is applied as many times as found necessary. This acts as a priming coat preventing suction which the broken surface is likely to develop. iii Exudation: The plaster may exude moisture or dissolved salts and affect the paint. Allow the plaster sufficient time to dry out and mature and then wash as above or apply any proprietary insulating primer.

Painting on cement rendering: The surface must be left for a considerable time to weather and become inert. If, however, a new surface has to be painted, use a paint with an oil vehicle, like synthesized tung oil, which will remain immune to the action of the alkaline matter and not saponify. Finish the surface rough to allow of quick evaporation. Use paint of nongloss finish with a minimum of oil content. Apply cold two coats of 2 lb. FeSO₄ in a gal. of boiling water to draw out any salt crystals, iron oxide rust or any other extraneous matter. Then apply two coats of 4 lb. ZnSO₄ in 1 gal. of water to clean the surface and thus leave an inert surface fit to receive the paint.

Repainting old painted surfaces: A. Woodwork: i Before repainting, the surface must be thoroughly cleaned with soap and water or, if greasy, with lime and water and rubbed down with pumice; ii All cracks and holes should be filled up with putty, that is, stopping should be done. Being an old painted surface, no priming coat is necessary before stopping as the first painting having been done, there will be no likelihood of the wood absorbing the oil from the putty; iii If the old painted surface has blistered, it must be rubbed down and scraped; iv The surface is then brought forward with 3 or 4 touchings with paint, before the painting of the general surface is begun; and v Then 2 or 3 coats of paint are applied as in the case of painting new surfaces.

B. Iron or steel work: All rust, if, any, should be cleaned and removed completely. Grease should be removed with lime and water. Then the surface should be brought forward with 3 or 4 touchings with paint. Then one or two coats of painting should be done to the general surface as in the case of painting new iron or steel work.

C. Removal of old paint: can be done in one of the following two ways: i burning the paint, preferably with a blow lamp, and scraping. This is suitable for iron or steel work but risky for woodwork; applying any of the following paint solvents: (a) Mix 1 part of soap and 1 part of potash. To this mixture 1 part of quick lime is afterwards added. The mixture is applied hot and kept on for 24 hours, after which, washing
with hot water will remove the paint; (b) 2 lb. of washing soda (Na₂CO₃), 2 lb. of quick lime mixed to the consistency of cream, spread on the painted surface and kept on for an hour. The paint can then be washed off; (c) Stipsco: is a quick paint-remover which can be used without injuring wood or metal. It is simply painted on the surface, allowed to stand for a short time and then washed off with clean cold water; and (d) organic solvents like blends of acetone, tetralin, butyl alcohol or trichloethylen, soluble waxes being used to thicken the liquids.

ICI Pretreatment Processes: For derusting steel and removing grease, handmarks, etc., from steel, Al, Pb, etc., before painting, deoxidine is applied by brush or cold dip or hot dip. Alocrom applied by power spray improves corrosion resistance and paint adhesion properties of Al, Granodine applied as warm or hot dip to steel and Zn gives a corrosion resisting phosphate coating. Lithoform applied cold with brush to galvanised iron improves paint adhesion.

Different kinds of paints:

1. Gloss paint: is made by thinning down previously prepared paste paints with 4 parts of a suitable vehicle and 1 part of a drier. It is used for both interior and exterior work.

2. Flat paint: is similar to gloss paint, but the proportions of vehicle and drier are reversed so as to keep the minimum of oil to bind the pigment. It has great penetrating power, good flow, and gives a smooth mat finish. It is used for base coats and flat wall finishes. As surface condensation and internal reaction due to efflorescence have an adverse effect upon this paint, the wall surface or plaster should be perfectly dry and cleared of any chemical efflorescence. Calcamine, casein paints and oil paints with aluminium stearate or diatomaceous silicas as a flattening agent are used.

3. Priming paint: contains an excess of oil and a pigment of pronounced drying action like red lead.

4. Inodorous paint: is mixed without any turpentine. The paint is thinned with methylated spirit in which shellac has been dissolved together with a small quantity of linseed and castor oil. The methylated spirit evaporates rapidly, leaving behind shellac which acts the part of the film of varnish left by the oil and turpentine in the ordinary method. This paint dries quickly and three coat work can be finished in a day. But the rapid drying makes it difficult to paint a large uninterrupted surface uniformly. Where rapidity in execution is desired, this paint may be advantageous. But this is not so durable as oil and turps mixed paint,
5. **Luminous paint:** This is a preparation of CaS made up with varnish. This paint is so called because it presents a luminous surface for hours or even days, after the source of light has been cut off. Oil destroys its properties, and it should be applied only to perfectly clean surfaces free from lead paint or corrosion. The luminosity of this paint is due to CaS—a phosphorescent substance.

6. **Cement paint:** is a water-dilutable paint in which the cement acts as the principal binder. Limeproof pigments, fillers, accelerators and water repellants are also added and integrally mixed with the cement during manufacture. It is applied on brick and cement surfaces. It resists the penetration of moisture.

7. **Bituminous paints:** are made from vegetable bitumen, asphalt, and mineral pitches dissolved in paraffin, petroleum or naphtha, various oils, etc. They are also made from the products of coal and other mineral oils. They are best suited for painting of iron water mains, and other iron work fixed under water.

8. **Stucco paint:** made from bitumen emulsion and suitable pigments is used for stucco, pebble dash, and similar surfaces.

9. **Coal tar paint:** Coal tar is heated to boiling point, and thinned by the addition of \( \frac{1}{4} \) pint of common country spirit to each gal. of tar to neutralise the free acids in the tar and to prevent its running. The mixture is applied hot to the surface.

10. **Ordinary tarring:** consists in boiling 6 gal. of coal tar with 1 lb. resin, and 1 lb. pitch, and applying hot.

11. **Titanic paint:** is made by powdering a black iron ore, which contains oxide of Fe and oxide of Ti in nearly equal proportions, mixed with other ores. It is said to harden without the aid of a drier, and to be peculiarly well adapted to withstand heat. The ilmenite sand available on the sea coast from Quilon to Chavara, is a mineral consisting of oxide of Fe and oxide of Ti.

12. **Anti-corrosive paint:** is a name given to different compositions which consist chiefly of oil, some strong driers, and a pigment such as red lead or lead or Zn chromes or chromium oxide or graphite mixed with very fine sand. It lasts longer than white lead, costs less, and is chiefly used for preservation of iron and steel.

13. **Marine paint:** It is a quick drying paint applied over a priming coat of an anti-corrosive paint for ships below water line. It contains copper and mercuric oxides to kill the marine growth. It is
designed to erode slowly, thus continuously freeing the surface. Zn and Fe oxides ordinarily constitute the body pigments.

14. **Enamel paint**: consists of a metallic oxide, such as ZnO or PbO, ground with a small quantity of oil, and mixed with petroleum spirit, holding resinous matter in solution. It can be made in any tint, however delicate; requires no oil, turpentine, driers, grinding or mixing, as it is sent out ready for use. It combines the functions of paint and varnish. It dries slowly and produces a brilliant, tough, elastic film which is smooth and durable. Enamel painted surfaces are washable and are not affected by steam, acids, alkalies or fumes of gas.

15. **Synthetic enamel paint**: is made from a synthetic resin instead of the fossil gum. It is superior to the ordinary enamel paint in all respects. It dries quickly, leaves no smell, and gives a durable film. *Dulux*: is the trade name for a high gloss synthetic resin-based finish given to road, rail, and commercial transport. It is suitable for application on steel, wood, and Al, and is designed for interior as well as exterior exposure.

16. **Barn paint**: is used in agricultural districts for painting barns and similar buildings. It is made by suspending the cheaper mineral earth and synthetic iron oxides in linseed or mixed oils and diluting with a petroleum thinner. Gloss oil driers made from rosin heated with litharge are sometimes added to hasten drying.

17. **Silicate paint**: has for its base a very pure silica obtained from a natural deposit found in the West of England. This is levigated, calcined, and mixed with poisonous substances. This paint has no chemical action on metals, adheres well to brickwork, considerably reduces water penetration, stands a high heat without blistering, sets quickly and dries with a hard surface, is indestructible, immune from alkali attack, and weight for weight, covers double the surface as compared with lead paint. It should be used with special silicate ‘driers’.

18. **Floor paint**: is made by suspending the pigments, and barytes or silica in linseed oil. This paste is then mixed with a durable mixing varnish. The inerts and varnish produce paint films which withstand considerable abrasion.

19. **Graphite paint**: is the best for iron and steel work in contact with sulphur gases, ammonia, chlorine, etc., and lasts 7 to 10 years especially in underground railways, mines, vicinity of large towns, etc.

20. **Bronze metallic paint**: is made by adding Al, Zn, Pb, or
bronze powders to hardened resin or ester gum in white spirit for internal work and to elastic oil varnish mixed with free lime for external work. It has great opacity, reflects light very well and forms a durable film. But storage impairs the quality since the metallic powder settles down.

21. **Cellulose paint**: is made from nitro-cotton, celluloid sheets, photographic films, etc. This hardens by the evaporation of the ingredient used for thinning, and thus, dries quickly. This can be easily washed, cleaned, possesses greater hardness, smoothness, and flexibility, and stands extremes of temperature. Cellulose acetate is non-inflammable and shrinks on drying so that it is largely used as aeroplane dope. Nitro-cellulose is inflammable, but dries very quickly. *Duco*: is the trade name for this type of finish given by spraying to modern cars for durability, beauty, and lustre. It is also applied with brush to cycles, instruments, and such other small scale paintings.

22. **Plastic paint**: is widely used for theatre decoration. This liquefies when agitated and reverts to a rigid jelly when allowed to come to rest. It is applied with a brush or by spraying when it forms a tough and plastic film.

23. **Asbestos oil paint**: is recommended for places exposed to steam and acid gases and general painting.

24. **Colloidal paint**: has no filler. It settles very slowly over long periods of time and penetrates the surface of the materials to which it is applied. It is used both for exterior and interior work.

25. **Aluminium paint**: is made by holding in suspension Al powder and binding it by either quick drying spirit and slow-drying oil or varnish. Other colloidal ingredients are added to produce hard, permanent adhesion. *Dulux Al paint* 27.22, which is pleasing in effect, durable, heat resistant, and heat reflecting is supplied in a dual pack (i.e., with paste and medium in separate containers) to ensure storage without deterioration. To prepare the paint for use, three parts of medium and one part of paste are taken. A small amount of vehicle is added to the paste and worked to a thick creamy consistency. This mixture is then added to the rest of the vehicle, and thoroughly stirred. It is used for painting petrol storage tanks, withering sheds, and other tea garden installations, sugar-mill chimneys, ventilating shafts, steam pipes and machinery subject to heat, roofs of passenger vehicles and coaches, and general structural and maintenance painting. It is also used as a primer to resinous woods like teak, but should not be used on bitumen-covered or creosoted wood.

**Some Common Paint Troubles**: 1. *Chalking*: or rubbing off the clothes. This is probably due to not sufficient oil having been used in
the priming coat and the wood having absorbed all of it, not leaving enough on the surface to oxidise and form a film to hold the white lead in place. Avoid too much oil. Measure and weigh all materials as per formulae. ii Slow drying: may be caused by painting during unfavourable weather conditions; but usually this is due to the use of inferior oils or old oils that have become thick and syrupy. Oil from the bottom of the tank containing sediment called fots will also be slow in drying. Damp surfaces tend to slow up the drying of paint. iii Runs and sags: are caused by applying paint too thickly or by using a slow drying paint or by using excess drier or by changes of temperature and excessive humidity during the drying period. Painting over a glossy surface also results in runs. Kill the gloss by sanding it lightly and then dusting it off. iv Loss of gloss: is due to the ageing of the paint or use of excess drier. Spotting: is loss of gloss, fading, and chalking in small areas due to painting over surfaces that are more porous than the adjoining ones. It occurs in two-coat work on new work or one-coat work on old work or plastered walls over cracks that have been filled with plaster of Paris. v Yellowing of white paint indoors: Linseed oil, which is yellow, will not bleach unless exposed to sunlight, so that a minimum amount of oil is used for indoor painting and if a gloss is desired it is best gained by using white enamel paints. vi Cracking: often extends right down to the wood. It is often accompanied by scaling and is often observed where too many coats resulting in an excessive thickness have been applied. Want of proper seasoning and use of excess drier are also causes. vii Crazing and crocodiling: denote hair cracks on top coat of paint due to softness of the undercoat caused by the use of too much oil, use of impure oil, and insufficient drying. When these cracks enclose small areas, the effect is known as crazing and when the areas are large, it is termed crocodiling. viii Washing off: occurs when pigments soluble in water are present in the paint. After the application of such a paint, the dissolved material collects at the lower edges of the painted surfaces and forms streaks. ix Blistering and peeling: caused by moisture or heat may be found on both wood and metal surfaces. Strong sun shining on paints, rich in oil, causes blisters. Oil or grease left on the surface to be painted also causes blistering. Generally, painting when moisture is present on the surface or in the pores of the wood, results in peeling. x Chemical attack by alkali: NaOH and KOH attack linseed oil, soften the oil in the paint, and liquefy the paint by forming compounds soluble in water. Ca (OH)₂, is less severe in its effect and forms a compound which is insoluble in water and protects the surface. Tung oil is less readily attacked. Certain combinations of drying oils and resins are resistant to alkali attack.
VARNISHES

General: They consist of resins and either drying or non-drying oils. They are unpigmented and range from almost clear white to a deep gold. The important varnishes are: i those composed of resins dispersed in an oil; and ii those composed of oil-modified alkyds. In all varnishes, the volatile solvents evaporate first and then the oil dries by oxidation and/or polymerization. In the oil-modified alkyds, the resin combines chemically with oil. They are applied: i to give brilliancy to the painted surfaces and to protect them from atmospheric action or slight friction; and ii to intensify and brighten the ornamental appearance of the grains of wood on unpainted wood surface. Painted surfaces are rarely varnished. All varnishes must: i dry quickly; ii form a hard, tough, and durable film; iii retain colour and give good gloss; iv possess resistance to weathering; and v be uniform and pleasing when dry.

Ingredients: 1. Resins: a. Natural: are amorphous substances that exude from plants due to the oxidation of volatile oils secreted by the plants. The soft resins, mouldable by the hand — some are viscous and semi-fluid balsams (turpentine, canada balsam, etc.,) — are not used. The hard resins are solid and brittle at ordinary temperatures, can be easily pulverised, and contain no essential oil. Resins like common resin or rosin (obtained from the exudation of certain varieties of pine trees), lac or shellac (made from the exudation of insects which grow on some kinds of trees in India), and copal (hard, lustrous, sometime colourless and transparent but often of a bright, yellowish, brown colour found embedded in earth in places where forests of trees of pine variety existed) are generally used. The resin is first run i.e., rendered soluble by being heated in warm air well below the temperature at which the resin melts. Prolonged and strong heating darkens it and reduces its value for varnish purposes.

b. Synthetic: built up, by the union of simpler compounds (Refer Ch. v) are superior to natural resins.

2. Solvents: The solvent used must be suitable to the resin it has to dissolve. They are: i Boiled linseed oil: for amber or copal; ii Turpentine: for common resin, mastic, and dammer; iii Methylated spirit: for lac; and iv Wood naptha: for cheap varnishes. It is less brilliant and has no offensive smell.

3. Driers: Litharge, sugar of lead, white copperas (ZnSO₄), etc.

Different kinds: Varnishes are classified according to the solvent used. They are:

1. Oil varnishes: made of hard resins dissolved in linseed oil with
turps as volatile solvent, require some time to dry, but are the hardest and the most durable of oil varnishes. They are specially adapted for exposed works or those which require polishing or frequent cleaning. They are used for coaches, japan work, for the best joinery and fittings of houses and for all outside work. A few recipes for oil varnishes are given below:

1. *Glossy Brunswick jet black quick drying varnish*: is used for gates, stoves, and general iron work. Run about 45 lb. asphalt for 6 hours in a set pot. Boil 6 gal. linseed oil with 6 lb. litharge until it strings well. Mix the two, and boil until it sets hard between the fingers. On cooling, thin it with 25 gal. of turps. For harder, though paler, varnish, Chinese wood-oil instead of linseed may be used. ii *Carriage varnish (copal anime)*: Run, boil, and mix best copal 16 lb., linseed oil 5 gal., litharge ½ lb., coppers ½ lb., turps 11 gal. Also run, boil, and mix anime 16 lb., linseed oil 4 gal., turps 7 gal., and add the former hot to this. This varnish will dry in 5 hours with good gloss. iii *Hard glossy black Japan varnish (mineral pitch)*: Run 25 lb. asphalt, 4 lb. anime separately and add boiled linseed oil 5 gal. to the first and 1 gal. to the second and pour into a set pot, then run and mix. Add 5 lb. amber and 1 gal. linseed oil to the set-pot, boil for 3 hours, then add red lead 3½ lb., litharge 3½ lb., coppers 1½ lb., boil until it sets on cooling and then mix with it 15 gal. turps. iv *Black enamel (for cycles)*: Mix boiled linseed oil 2 pints, turps 8 pints, and 4 lb. asphalt in small pieces, set aside in a warm place for 7 days, shaking now and then, and then decant the clear fluid. v *Varnishes that wear well*: (a) Mix mastic 2 parts, sandarac 2, linseed oil 3, alcohol 3, and boil over slow fire. Add turps in sufficient quantity. (b) Mix dammer (sal resin) 4 part, linseed oil 32 parts, and proceed as in (a). vi *Japan varnish*: Mix 90 parts oil of turpentine with 120 parts oil of lavender and dehydrate by digestion with CaCl₂. Add camphor 1 part and tender copal 90 parts. Put the vessel on hot ashes and shake frequently till copal is dissolved. Set aside for a day and filter.

*Varnish for iron work*: Dissolve in about 2 lb. of tar oil, ½ lb. of asphaltum and an equal quantity (½ lb.) of powdered resin, mix hot in an iron kettle, taking care to prevent contact with flame. When cold, use.

2. *Turpentine varnishes*: are made from soft resin (mastic, dammar, common resin), dissolved in the best turpentine. They are cheaper, more flexible, dry quicker, and are lighter in colour than oil varnishes, but are not so tough or durable.

3. *Spirit varnishes*: are made by dissolving shellsac in alcohol to form a colloidal solution which hardens rapidly through solution of the
volatile solvent. If an oil varnish is applied to an untreated board, it will soak in and be lost. If the board had first been given a coat of shellac, the particles of shellac would have filled the surface pores, and the oil varnish would remain on the surface and give a lustrous film. They dry quicker and become harder and more brilliant than turpentine varnishes, but are apt to crack and scale off and do not stand weathering. The following are some spirit varnishes:


French polish: is used for fine furniture. Dissolve in 3 gal. methylated spirit: 3 lb. black shellac, ½ lb. olibanum, ½ lb. gamboge, 1 lb. copal or sandarac and ½ lb. gum benzoin. The gums are crushed small and added to the spirit and agitated until the gums are dissolved. A warm bath aids the operation.

4. Water varnishes: consist of shellac dissolved in hot water mixed with just so much ammonia, borax, potash, or soda, as will dissolve the lac. The solution makes a varnish which will just bear washing. This is used for delicate internal work, and as a covering of wall paper.

Incombustible varnish for wood: An application of equal parts of alum and isinglass to the place exposed to the flame prevents ignition, but not transmission of heat. By coating wooden vessels with this varnish, fluids may be boiled in them over an ordinary fire.

Application: The surface to be varnished must be made perfectly smooth with sand paper, with knotting and stopping as described under paints. Stopping (with hot glue size—one lb. of glue making about one gal. of size) is necessary, so as to close up the pores. Two coats of size are to be applied at sufficient intervals of time. When the size dries up, the surface should again be sand papered. Everything should be quite clean and the work protected from dust and smoke. Varnish should be applied uniformly in very thin coats, and sparingly at angles or corners. The second coat should be applied only after the first had become hard. Varnish applied to painted surfaces will be liable to crack (owing to unequal drying of paint and varnish, and therefore to unequal contraction), if the paint contains inferior or too much oil.
Some common troubles: i Cracking: is caused by use of excess driers, use of elastic base coat under a hard-drying varnish, use of non-elastic base coat for elastic varnish, and insufficient drying of the base coat. ii Wrinkling: is caused by irregular application of varnish. iii Webbing or crocodiling: is a network of wrinkles caused by the presence of china wood oil in the varnish. iv Pinholing: is due to a greasy surface or sweaty base coat. v Blooming: is formation of a lustreless film caused by varnishing when the humidity is high. vi Blistering: is due to moisture in the material below the varnish.

Lacquers: formerly meant spirit lacquer (lac resin dissolved in alcohol). Nowadays they are called after the chief film forming ingredient, e.g., cellulose acetate, cellulose, vinyl, and nitrocellulose. All lacquers dry hard and dust free in a few minutes by evaporation of the solvents or thinners in which the vehicle is dissolved. Synthetic resins and plasticizers are added to give the lacquers more body, improve gloss and adhesion, impart rubbing and polishing properties and give elasticity and flexibility to the coatings. Spray application or dipping is the usual procedure in lacquer work. Lacquers are resistant to water, alcohol, mild acids and alkalies, and vegetable, animal, and mineral oils. As they are inflammable, care is necessary during storage and application. They are used for automobile finishing, dopes, nail polish, coating radios, toys, and other articles, etc.

Enamels: are an intimate dispersion of pigments in a varnish (medium to short oil glyceryl phthalate) or a resin (urea, melamine or urea-melamine) vehicle, or in a combination of both. They are available in all colours and shades. They are hard and tough and offer good wear and abrasion resistance. They are used for household appliances, railway, office, and industrial equipment, toys, etc. They dry by both oxidation and polymerization at room or elevated temperatures. Hence they are of the air drying or baking (150 to 180°) type.

Baking Japans: Hard asphalts are melted, cooked with one of the drying oils and thinned to make an asphalt varnish. Formerly steel fenders of automobiles were dipped in this varnish and then passed through a baking oven at 205 to 250°, when a glossy black coating was obtained. The thinner evaporated quickly, the asphalt melted, and the drying oil oxidized while the fender was passing through the oven so that after it emerged from the oven and had cooled, it was covered with a hard, glossy surface which gave good protection. Formerly because the resins could not stand the heat of the oven, this was possible only with
asphalts; but the introduction of synthetic resins has permitted a baked finish to be produced in colours.

**Distempers**: They form a cheap, durable, and easily applied interior finish on surfaces except wood and metal, whose moisture and thermal movements are likely to cause flaking. Suitable qualities may be used externally on cement or brick surfaces.

**Types**: 1. **Older Types**: a. *Washable oil-bounded distempers*: consist of an emulsion of drying oil or varnish often dispersed by glue, with pigments like lithopone. These are fast to rubbing and fairly washable. b. *Washable oil free distempers*: are similar to a but have casein instead of oil as binder. These are a little more difficult to apply, but are resistant to alkalies provided that only lime fast pigments have been used. c. *Soft or non-washable distempers*: made from size and whiting, are used on ceilings. These are moderately fast to rubbing but not to washing.

2. **Emulsion paints**: have superior durability and washability. The types are: a. *Paints based upon alkyds* (a combination of certain synthetic resins and drying oils): These give a finish similar to flat paints. b. *Paints based upon polyvinyl compounds*: These give a glossy finish and are used in place of tiling.

*Glue size* is used either as a solution or as ‘clearcole’ to satisfy the suction of surfaces before applying size-bound non-washable distemper. *A petrifying liquid* (emulsion of oil or varnish of an oil-bound distemper with or without a little pigment) is added to satisfy the high suction of surfaces or as a thinner for oil-bound distemper to be used on such surfaces. It increases durability.

*To prepare distemper*: Take 6 lb. of best whiting and soak it in soft water sufficient to cover it for several hours. Pour off the water, stir the whiting into a smooth paste, strain the material, and add one quart of size in the state of weak jelly. Mix carefully not breaking the lumps of jelly, then strain through muslin before using; leave in a cold place and the material will become a jelly, which is diluted with water when required for use. Colouring pigments are then added as required.

**Properties**: i These allow any water in the wall to pass through them and thus are less likely to blister than a gloss paint if applied on an imperfectly dry wall. But the moisture in backing can stimulate alkali attack or mould growth or cause efflorescence or drying. ii The older types shrink on drying and thus crack and flake if the surface is friable. Flaking occurs if the surface is non-washable distemper, old limewash, flaking oil-bound distemper, or thick coats of fire-retardant silicate paints.
Cracking occurs if the surface is not strong enough to restrain drying shrinkage e.g., old gloss paints or bituminous compounds. iii The adhesion of distempers to a surface is weakened on wetting and restored on drying. Alternate wetting and drying cause flaking and peeling. Condensation on the distempered surface, as in bath rooms, kitchens, etc., gives room for a serious risk of failure. The emulsion paints are not so readily wetted as the older types.

**Application:** These should be applied boldly and rapidly, in parallel lines with broad stiff brushes in dry weather, after the surface is dried and dusted. The edges must be kept "alive," otherwise the finished surface will be marred by marks, known as "laps." For local made distempers, use a priming coat of milk. For ready mixed distempers, the priming coat should be as recommended by the manufactures. i On new surface: a. For alkaline surface (cement or lime): The risk of attack of distempers by alkalies is much less than with oil paints. Porous polyvinyl emulsion paints are the best. Use lime-fast pigments. If the surface is rough, a base coat of Spanish white or chalk mixed with a solution of glue is applied. b. For smooth polished surfaces: Use a base coat of sharp colour of warm glue. c. For surfaces of high or variable suction (hot surfaces): Apply the distemper as a thin coat. With size-bound distempers, apply a thin coat of clearaco or size. d. Efflorescence on the surface: if slight, may be dusted down or wiped off with a damp rag; if severe, wiping should be repeated until no appreciable growth occurs, and then a coat of sharp colour applied. ii On old surfaces: Remove non-washable distempers. Wash or sponge washable distemper surfaces and then distemper. More than 4 or 5 coats cause flaking. In such cases stripping is the best. If this is not possible, apply a thin coat of sharp colour before distempering to bond the old coats and make them waterproof.

**Some common troubles:** i Peeling, flaking, and blistering: is due to alternate wetting and drying. To remedy, strip, dry, and redistemper. ii Bleaching: is due to attack by lime-activated by salts and moisture. To remedy, strip, dry, and redistemper or use a washable oil-free distemper or a porous polyvinyl paint with lime-fast pigments. iii Spots of various colours: are due to mould formation by persistently damp conditions. To remedy, strip, treat with Santobrite or Shirlan N. A. or zinc silicofluoride in water, allow to dry and redistemper. iv Green slimes over surface: is due to algae growing under damp conditions. To remedy, apply a wash of CuCO₃, 1 oz., NH₃ solution (0.88 sp. gr.) 10 oz., and water 10 gal. v Cracking: is due to inability of base to restrain the drying shrinkage of the distemper. To remedy, rub down the old finish, apply a coat of sharp
colour, and then distemper. If it is due to cracking of the background, wait till cracking is complete, fill cracks with a paste distemper, and then redistemper. vi Bleeding: of soluble colours from old finish through the distemper is due to moisture. To remedy, strip old finish or seal back with knotting (mixed with a little pumice).

Wax Polishing: Wax polish consists of beeswax dissolved in turpentine. The polish is applied by means of a pad, and rubbed until the required finish is obtained. Usually, three applications will be required. Before waxing a floor, clean off all dirty spots with a soft cloth, soaked with benzine. It may not be necessary to touch up more than a few spots but it saves the polishing cloth from becoming excessively dirty. The whole floor should be dusted with a dust mop before attempting to apply the wax. Place a lump of the floor wax in a thickness of cheese cloth and as you rub this over the floor a thin layer of wax is left on the wood. Allow this to remain for 15 min. If polished much before this time, a lot of wax will be removed; if left for a long time without polishing, the job will be more difficult. A clean soft piece of flannel-like cloth may be used for polishing. A brisk rubbing will result in a bright surface being produced. To prevent worn spots appearing on the floors, a protecting coat of wax on the places that are frequently used must be applied about once a week. As water, if allowed to remain, spots the finish, it should be wiped off a waxed surface at once.

Wood Oiling: is sometimes done as a substitute for painting on woodwork not exposed to weather. It consists of linseed oil with a small quantity of gum dammar or red ochre, boiled up in it. Other recipes for wood oil are: Linseed oiling: 3 parts by wt. of double boiled linseed oil and 1 part of beeswax, are heated over a slow fire until the wax has melted. After the mixture has cooled, one part of turpentine is added to it and applied in two coats. Sweet oiling: Equal parts of common Vinegar, country sweet oil, and turpentine are mixed and used. This gives a darker effect than above.

Coal Tarring: The wood or iron work must first be thoroughly cleaned. The coal tar is heated to nearly boiling, thinned by adding half a pint of country spirit to each gal. of tar and while still hot, is applied to the surface with a brush and sometimes covered with coal dust or sand. If the iron work can be removed from its position, it should first be heated, short of redness, before being brushed over with coal tar. Iron work, which cannot be removed for being heated, will be painted with hot tar and spirit as in the case of woodwork. 10 lb. of tar are required per 100 sq. for good and satisfactory work. In using coal tar, 2 lb. of unslaked lime
should be mixed with one gal. of tar to prevent its running.

**Glazing:** is the work of fixing panes of glass in window, door, or other shutter frames. When glass panes of required size are not procurable from the merchant, they can be cut to size at the works spot with a glazier’s diamond. Window glass is generally \( \frac{1}{16} \)" thick, weighing 21 oz. / \( \square \) known in the trade as “Seconds.” The glass panes are usually fixed to the sashes in glazier’s putty which has already been described under ‘Paints’. The sashes should be primed and prepared as for painting before the panes are fixed; as otherwise, the wood will absorb the oil in the putty and the putty will shrink and fall out. Sometimes the glass pane is fixed to the sash with small brad nails before the putty is put in. All glass should be properly bedded to the sash frame with putty, that is, there should be putty on both the sides of the glass. If the weight of a glass pane is much, small pieces of lead or wood are inserted at the bottom of the pane to prevent it setting while the putty is soft. Sometimes, instead of filling the triangular space between the glass pane and the sash with putty, wooden fillets are screwed with brass screws. A thin film of putty is however provided between the glass and the space of the triangular fillet which is in contact with the glass. *Canada balsam,* which dissolves in alcohol, and sets firm on exposure to air, is an excellent adhesive for glass.

**To soften putty to remove glass panes:** To 3 lb. of quick lime, slaked in water, one lb. of pearl ash is added and the mixture is made of the consistency of paint. It is applied to both sides of the glass and allowed to remain for 12 hours when the putty will be softened. Then the glass may be taken out.

**CHAPTER VII**

**REINFORCED CONCRETE**

**General:** R. C. is formed by the employment of concrete and steel in combination, each material being applied so that its distinctive properties are utilised to the best advantage. It may be defined as that construction in which concrete and steel are combined, these materials being so disposed that the concrete resists the compressional stresses, and the steel the tensional stresses. In R. C., the steel “reinforces” or strengthens the concrete, concrete being very poor in resisting tension while steel is very strong in this respect. By reinforcing the concrete, the power of the concrete, taken by itself, alone, to extend without showing signs of cracking or other failure is increased considerably. R. C., though
it is a composite mass, has for this reason become to be treated as a new and single material.

In structural members of R. C., the concrete is the only material visible, the steel rods and stirrups reinforcing the concrete being embedded in the concrete sufficiently to protect them from fire and corrosion and therefore not visible. The steel is placed with special regard to the distribution of the stresses to which the concrete offers little or no practical resistance. The steel should, in properly designed and constructed R. C., be held firmly in place by the surrounding concrete by adequate adhesion; and when this is the case the steel units in the R. C. become valuable and effective details of the structural member, for considered separately, the collection of the steel units constituting the reinforcing system does not form a structural member; the reinf. being otherwise nothing but a number of loose bars and stirrups.

It will thus be seen that R. C. is something essentially different from a steel beam, steel column, or a steel frame embedded or encased in concrete. This is however not to say that large sections of steel, such as T and I sections, are not to be used to constitute, in conjunction with concrete, genuine R. C. On the other hand, some designers do use such large sections as real reinf. Though, generally speaking, large steel sections are less advantageous than thin steel bars from the theoretical standpoint, there may be cases where the employment of large sections as reinf. is attended with practical advantages.

**Uses:** R. C. has been and is largely employed for almost all structural purposes for which stone or brick masonry or steelwork were and are being used; as for instance, buildings, bridges, retaining walls, dams, and other engineering works. It is also used in constructing a frame comprising columns, beams, floors, stairs and sometimes roof, the whole enclosed by brick and stone walls carried by small lintels and columns forming part of the frame. In bridge work, it is used for platforms of the beam and slab type, arch ribs, pile or well foundations and the like with R. C. or masonry abutments and piers. Strong rooms of treasuries are often built entirely of R. C. Some more important structures are foundation rafts, footings, column bases, water tanks, and chimneys. After designing the individual members, provision should be made for their proper connections in the most secure and rigid manner possible by filling up angles, by extending the heads of columns, adding haunches, and applying suitable reinforcements to the connection formed.

*Properties and its advantages and disadvantages over other types:*
Among the chief properties and advantages are: Rigidity; lightness with great strength; great durability; resistance when exposed to fire, water, white ants or an acid-laden atmosphere; adaptability to curved, moulded or irregular shapes in work; saving in space; economy of cost; rapidity of erection; perfect sanitary properties, hardly any subsequent outlay for maintenance and no appreciable depreciation of strength with age; impermeability; protection of metal from rust; hardness and impenetrability; neat appearance; monolithic nature; resistance to shock (and small period of vibration and therefore liability to fatigue of material) and consequent greater suitability to withstand earthquake shocks—the material gives notice of approach of failure, if failures at all occur; evenness of temperature inside R. C. buildings owing to the low conductivity of the material and deadening of sound in R. C. buildings.

The main disadvantages are: i It is not foolproof as skill, care, and experience are very necessary in the designer and builder. ii Being hard and impenetrable it will not be possible to drive nails and the like, nor will it be easy to cut out portions later if and when it should be desired to introduce new door or window opening and the like. So wooden plugs to drive nails into to hang pictures, and all door, window, and other openings required at the time of construction or in the immediate future should be well thought out and provided for. iii As R. C. is air tight and light proof, there will be no ventilation in a building built entirely of R. C. if all the doors and windows should be shut, unless ventilating cowl had been introduced at the time of construction.

**Points to be borne in mind during construction:** On the careful observance of these depends the satisfactoriness of the quality of the R. C. work. i Good and sound materials and good workmanship under skilled supervision with regard to the quality, proportioning, and mixing of materials, including the quantity of water and securing proper consistency. ii The sizes and exact positions of the reinforcement, i.e., steel; iii The construction and removal of the formwork or boxing and of the supporting staging or centering; iv Avoidance of delay between mixing the concrete and laying it in its place; and v Thorough punning or consolidation of the concrete to obtain solidity and freedom from voids or hollows.

**Methods of Erection:** i The parts of the R. C. structure may be moulded in advance either out of doors or in sheds and be placed in position on the structure e.g., precast slabs for culverts, cantilever steps of a staircase, arch ribs of bridges, etc. ii The whole or part of the structure may be moulded in situ on timber falsework or formwork which may be struck when the concrete has hardened sufficiently for this to be
elected with safety; and iii The reinf. may be erected or partially erected
first, and serve as an aid in support of the moulds. This refers generally
to buildings built entirely of R. C.

Material used in R. C. C.: i Cement which is called the matrix;
ii Good graded sand, which is called the fine aggregate; iii Broken stone
which is called the coarse aggregate, generally \( \frac{1}{2} \), \( \frac{3}{4} \), or 1; iv Water;
v M. S. reinforcements; and vi Timber, steel, etc., for the formwork.

I. Matrix (Cement): shall pass the tests given in Ch. III
(Pa. 95 to 106).

II. Fine Aggregate: means an aggregate mainly passing IS
Sieve 480. It is divided into two classes 'A' and 'B' so that when
material of class 'A' is not available, the slightly lower class 'B' material
may be specified. Natural sand: denotes the fine aggregate produced by
the natural disintegration of rock. Crushed stone sand and crushed gravel
sand: denote fine aggregates produced by artificial crushing of hard stone
and natural gravel respectively. It shall pass the tests given in Ch. III
(Pa. 104 to 106).

III. Coarse Aggregate: means an aggregate mainly retained
on IS Sieve 480. It is described as natural gravel, crushed gravel,
and crushed stone as appropriate. It shall be inert in water and shall
have a crushing strength at least equal to that of the hardened cement
paste. It shall pass the tests given in Ch. III (Pa. 110 & 111). Excess of fine
material in an aggregate tends to cause weak concrete. All-in aggregate
means an aggregate containing a proportion of material of all sizes from
the pit, river, bed, foreshore, quarry, or crushing plant.

Grading of aggregates: results in a dense concrete and also in the
required workability being obtained with a minimum of water. The lower
the water content, the smaller is the cement content as well
and therefore grading gives the most economical concrete
of the required strength. It also results in uniformity in the
quality of the concrete and re-
duced shrinkage cracks. A large quantity of coarse aggregate gives an economic mix and reduces volume change and heat of hydration while an increased quantity of fine aggregate gives a more workable mix. A workable range is given approximately by the fineness modulus of mixed aggregate (see later) and accurately by grading curves. Fig. 158 shows the general form of grading curves for $\frac{3}{4}$", $\frac{1}{2}$", and $\frac{1}{4}$" aggregates. If an actual grading curve lies largely below this curve a harsh concrete results, and if it lies above a workable concrete with reduced strength and density results. Excess of middle size causes harshness and honey-combing and lack of these causes segregation. Excess of fines requires excess water and results in a reduction of density and strength.

IV. Water: used to mix the concrete should be clean, and free from oil, alkali, and acid. Generally speaking, water that is fit to drink is good for concrete. Sea water, which contains sulphates in fairly strong concentration, will decompose the cement and disintegrate the concrete unless it is made thoroughly dense and impervious by proper proportioning and special treatment. In concrete structures, whether plain or reinforced, not made with special care but exposed to sea water, disintegration is greatest and most rapid in those portions of them which are in the range of the tides.

Proportioning of Ingredients: i A large proportion of cement will be required when the concrete has to be impermeable or water tight as in the case of R. C. tanks and reservoirs holding water. ii The less the proportion of cement, the less will be the liability to change of volume, the expansion and contraction being due entirely to the cement. Therefore, except in special cases as in i, it is advisable to use somewhat less proportion of cement for parts of a structure under tensile or bending stresses than for those under compressive stresses. iii For thin slabs (1 to $\frac{1}{4}$" thick), sand and cement alone are used. For thicker work, broken stone is added. Concrete proportioning should be based on the results of mechanical analysis. The quantity of cement will be sufficient to fill the voids in the graded sand and the quantity of such cement and sand mixture will be sufficient to fill the voids in the broken stone.

Water Cement Ratio: is the ratio of the weight of water to the weight of cement in the mix. This water determines the strength, durability, resistance to exposure, and watertightness of the concrete so long as the mix is of workable plasticity. The above weight of water denotes the water required for the hardening of the cement and should allow for the water present as surface moisture in the aggregates,
Some jobs require stronger concrete than others e.g., a water tank must be much stronger and more water-tight than a base for an oil engine. Therefore, first the quality of concrete needed and secondly the correct proportion of water to cement to obtain concrete of the required quality for any work must be determined. There is a definite quantity of water which will chemically combine with a given quantity of cement. If more water were added in mixing the concrete, the excess will be left over. While a good portion of this excess will be brought to the surface in the process of ramming the concrete, some of the excess will yet remain in the mass of the concrete. When this water evaporates in course of time, the space occupied by it will remain as voids in the concrete rendering it porous and weak. It has been found by experiments that a w/c ratio of 0.33 gives the maximum strength for a normal cement. The strength falls off if the ratio is either increased or decreased. Normally a ratio of 0.5 is required for workability. By the use of vibrators, workability can be ensured with a ratio of about 0.4. Also if the ratio is more than 0.6, permeability increases greatly.

Fig. 159 shows the strength of concrete with any w/c ratio for both normal and rapid hardening cement. The curves can be used to find the effect on strength of a change in the w/c ratio of any given mix or to find the w/c ratio necessary to give any special strength.

Consistency: denotes a wide range of the fluid condition of concrete. It depends on more factors than the w/c ratio e.g., a low w/c ratio does not necessarily result in a dry consistency.
Field tests for water-cement ratio: i Consistency should not change if the mortar be gauged for an additional 3 min. after an initial 5 min.; ii If a small quantity of mortar be dropped from a trowel, the trowel ought to be left perfectly clean (i.e., without any mortar sticking to the trowel); iii A little mortar worked gently in the hands should be easily moulded into a ball, on the surface of which water should appear; and iv When the above ball is dropped from a height of 20" on to a hard surface, it must retain its rounded shape without cracking.

For making these tests, it is best to mix the mortar with a minimum of water at the commencement, and add further water until the desired consistency is obtained, from which the amount required for a unit of cement is easily found. This amount is adopted in the hand-mixing or in machine mixing in concrete mixers.

The consistency of freely mixed concrete can be specified by:

i Dry mixture: This denotes concrete of the consistency of damp earth, from which the water rises to the surface only after prolonged ramming, and then simply in a glistening film. This may be employed in dry location for mass concrete in foundations which must withstand severe compressive strain within one month after laying, provided it is carefully laid in layers of not over 6" thick and is thoroughly rammed. This is not suitable for R. C. II Medium or quaking mixture: This means a tenacious, jelly-like consistency, which shakes on ramming. It is adopted for ordinary mass concrete and also by some engineers for R. C.; iii Very wet or mushy mixture: This will not support the weight of a man and an ordinary rammer (of iron) will sink into this mixture by its own weight; it will run off a shovel unless shovelled very quickly, and will spread out and settle to a level surface after wheeling for about 25, in a wheel barrow. This consistency is suitable for R. C. and will enable the mass to flow sluggishly around the steel to thoroughly embed it.

Workability: means that a well-proportioned mix should be of such a degree of stiffness or wetness (called plasticity or consistency) that it can be placed in the form readily and with due care, will result in dense concrete with free surfaces free from rough spots called "honeycombing." If a concrete mixture is too wet, stones sink to the bottom of the mass and the resulting concrete is weak or porous because it is not of uniform composition throughout. If it is too dry, it is stiff and hard to handle and place in the form and consolidate. Both conditions are corrected by changing slightly the amounts of sand and stone but never the amount of mixing water. If the mixture is too wet and sloppy so that water collects on the top or around the edges, sand and broken stones are
added in small amounts; and mixed until the right degree of workability is obtained. If the mixture is too dry, and appears crumbly, the batch may be made workable again by mixing up a small amount of water-cement paste in the same proportions as originally used and adding it slowly until the mix is workable. Succeeding mixes should be made according to the adjusted proportions.

The workability depends on: i Water: The wetter the mix, the more workable it is. ii Cement: If water is kept constant, greater workability is obtained with less cement. Fine cements (specific surface >1,600 sq. cm. per gm.) increase strength, and water tightness but decrease durability. iii Entrained air: 2 to 6% of air entrainment obtained by adding an air-entering agent (Vinsol Resin, Darex AEA) to the mix improves the workability with no loss of slump. iv Use of admixtures: Addition of pozzolanas, diatomite earths, wetting and foaming agents, dispersing agents (Lissapol N), and protective colloids increases the workability. v Mixing: Increasing the time of mixing increases the workability. vi Silt and dust content: should be < 5%. vii Size, nature, and grading of aggregates: The size should be between 3" and $\frac{3}{4}$" depending on the work. The aggregates should be rounded. Importance of grinding is small for rich mixes but increases both with a reduction in cement and a demand for higher workability. Coarse grading is necessary with a high cement content or when low workability is required. The grading becomes progressively finer with decrease of cement or increase of workability.

Tests: 1. Slump Test: This is the most useful test generally employed to test the uniformity of production of a well designed mix. The test is conducted by placing a conical tube, 12" high, lower dia. 8", and upper dia. 4", upright and filling with the test concrete (Fig. 160). The filling is effected in 3 stages, the layer formed in each stage being lightly tamped 25 times with an iron rod, 24" long, $\frac{3}{4}$" in dia. and bullet pointed at the lower end. Immediately afterwards, the tube is lifted off and the slump or settlement is measured. Note, as a rough guide that a. Mixes of 0 to 1" slump are of low workability and are suitable for heavy mass concrete or precast vibrated work; b. Mixes of 1 to 3" slump are of medium workability and are suitable for R. C. work with small amount of reinf. and for pavements; c. Mixes of 3 to 6" slump are of
high workability and are suitable for medium to heavily reinforced R. C. work and for work in thin or intricate sections; and $d$. Mixes of over 6" slump are very seldom required while a high workability vide $c.$ above cannot be obtained with a lean mix without sacrifice in strength. When high frequency vibrators are used, the values given for slump should be reduced by $\frac{1}{4}$. Fig. 161 & 162 show the relation between slump and temperature and slump and $w/c$ ratio. The slump test measures only consistency or fluidity.

2. 15. **Compacting factor test:** It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are used when concrete is to be compacted by vibration and may consistently fail to slump. The apparatus consists of two conical hoppers (A and B) mounted above a cylindrical mould (C) as in Fig. 163. The lower ends of the hoppers shall be closed with tightly fitting hinged trap-doors having quick release catches. The concrete to be tested is gently placed, level with the brim of the upper hopper. The
trap door shall then be opened so that the concrete falls into the lower hopper. The cylinder shall then be uncovered, the trap door of the lower hopper opened, and the concrete allowed to fall into the cylinder. The concrete in the cylinder shall then be levelled off with a trowel and its weight, called 'weight of partially compacted concrete' determined. The cylinder shall then be refilled with concrete from the same sample in 5 cm deep layers, the layers being heavily rammed or preferably vibrated so as to obtain full compaction. The top of the concrete shall be levelled off and the weight of this compacted concrete determined. The compacting factor equals the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete.

**3. IS. Flow of concrete test by the use of flow table:** This test determines the fluidity of concrete. The metal mould (base 25.4 cm diameter, top 17.14 cm diameter, and 12.7 cm high) with top open and at right angles to the axis shall be centred on the flow table (Fig. 164), firmly held in place and filled in two layers, each approximately half the volume of the mould. Each layer shall be rodded as in the slump test. The top shall be levelled off and the mould removed from the concrete by a steady upward pull. The table shall then be raised and dropped 1.27 cm, 15 times in about 15 sec. The diameter d cm of the spread concrete shall be measured. Then

\[
\text{Flow of concrete} = \frac{100(d - 35.4)}{25.4}\%
\]

**4. Consistency of concrete by Vee-Bee Consistometer:** (Fig. 165). This test gives the time required for transforming, by vibration, a concrete specimen in the shape of the slump cone into a cylinder. A vibrator table, supported on rubber shock absorbers, is mounted on a cushion base and is equipped with an electrically operated vibrometer mounted under it. A sheet metal cone open at both ends is placed in a cylindrical metal
pot which is fixed on to the vibrator table by means of two wing-nuts. A swivel arm holder is fixed to the base and into this is telescoped a swivel arm with a funnel and a guide-sleeve. The swivel arm can be readily detached from the vibrating table. A vertical rod (2 cm diameter and 50 cm long) passes through the guide-sleeve in the swivel arm, and is graduated to record the slump and the volume of concrete after vibration of the cone in the pot. A slump test is made in the pot. The glass disc attached to the vertical rod is moved and is placed just on the top of the slump cone in the pot and before the cone is lifted up the position of the concrete cone is noted by adjusting the glass disc attached to the rod. The cone is then lifted up and the slump noted on the rod by lowering the disc on to the top of the concrete cone. The electrical vibrator is then switched on and the concrete is allowed to spread out in the pot. The vibration is continued until the top concrete surface uniformly adheres to the disc and the time taken for this in seconds gives the consistency of concrete in VB degrees. Fig. 166 gives the relationship between slump in cm and consistency in VB degrees. The consistency scale is given as: i. Moist earth- VB 40 to 20 - Particles of coarse aggregate in concrete are adhesive, but concrete does not clot. Risk of segregation. ii. Very dry - VB 20 to 10 - Concrete has consistency of very stiff porridge, forms a stiff mound when dumped, and barely tends to shake or roll itself to form an almost horizontal surface when conveyed for a long time in, say, a wheelbarrow. iii. Dry- VB 10 to 5 — Concrete has consistency of stiff porridge, forms a mound when dumped and shakes or rolls itself to form a horizontal surface when conveyed as inji. iv. Plastic- VB 5 to 3 — Concrete can be formed into a ball between the palms.
of the hands. Adheres to the skin. v Semi fluid—VB 3 to 1—Concrete cannot be rolled into a ball as in iv, but it spreads out even though slowly and segregation does not occur. vi Fluid—VB < 1—Concrete spreads out rapidly, and segregation occurs.

5. Heap Test: A mass of concrete is allowed to fall from a conical hopper on to a flat surface and after setting, it is photographed. The most workable concrete forms a heap of approximately semi-spherical shape, neither very flat nor irregular in outline. Heaps of a flat shape are generally formed by harsh or segregating concrete while the irregular type is due to cohesiveness.

6. Slab Test: records the tendency of concrete to produce honeycombing. The concrete is deposited by allowing it to fall from a hopper above in a mould $18^\circ \times 3^\circ \times 18^\circ$ long. No tamping or ramming is used, and the top surface is finished by floats. The mould is removed when the concrete is set and the surface is photographed.

V. Reinforcements: 1. Bars: a. Process of manufacture: The rods of mild steel shall be manufactured from steel made by the Acid or Basic Open Hearth, Electric, Duplex or Acid Bessemer process and shall not contain more than 0.06% S or 0.06% P. The rods of high tensile steel shall be manufactured from steel made by the Acid or Basic Open Hearth process and shall contain >0.3% C, 0.2% Si, 0.05% S, 0.06% P, and <0.25% Cu. b. Tensile tests: One test for each cast of 25 T, and for each diameter of rod ordered shall be performed. The values shall be as given below:

<table>
<thead>
<tr>
<th>Details</th>
<th>Mild Steel</th>
<th>High Tensile Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile stress</td>
<td>tsi</td>
<td>27-34</td>
</tr>
<tr>
<td>Elongation (Min.)</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Gauge length 8D: Length between grips &lt; 9D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For bars under $\frac{3}{4}$&quot; diameter</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>For bars $\frac{3}{8}$&quot; &amp; under 1&quot; diameter</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Gauge length 4D: Length between grips &lt; 4'5D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For bars 1&quot; &amp; over in diameter</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>Yield stress (Min.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For bars up to $\frac{3}{4}$&quot; diameter</td>
<td>tsi</td>
<td>15</td>
</tr>
<tr>
<td>For bars over $\frac{3}{4}$&quot; diameter</td>
<td>14.5</td>
<td></td>
</tr>
<tr>
<td>For bars up to 1&quot; diameter</td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>For bars over 1&quot; &amp; up to 1½&quot; diameter</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>For bars over 1½&quot; &amp; up to 2½&quot; diameter</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>For bars over 2½&quot; &amp; up to 2¾&quot; diameter</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>For bars over 2¾&quot; diameter</td>
<td></td>
<td>19</td>
</tr>
</tbody>
</table>

c. Cold bend test: The bar shall withstand without fracture being doubled over either by pressure or hammering until the two sides of it are
parallel, and in the case of bars above 1" in diameter the internal radius is $\geq 1\frac{1}{2}$ times the diameter or thickness of the bar and in the case of bars 1" and under in diameter, the internal radius is $\geq$ the diameter or thickness of the bar. One test shall be made for each lot of 5 T, or part thereof over the first 5 T, or part of 5 T. (where one additional test shall be made for each size of bar).

2. **Hard-drawn steel wire**: 
   a. **Process of manufacture**: All wire shall be cold-drawn from steel made by the Acid Open Hearth, Duplex or Electric process, and shall not contain more than 0.06% S and 0.065% P.
   b. **Tensile tests**: The tensile strength of all wire shall be between 37 and 42 tai with an elongation of $\leq 7\frac{1}{2}$" on test piece with gauge length 8D. One such test shall be made from every 10 or part of 10 coils or bundles.
   c. **Cold bend test**: The wire shall withstand, without showing signs of fracture, the following treatment: One end of the wire shall be firmly gripped in a vice and the free end shall be bent round a radius equal to the diameter of the wire through 90°, and then bent back in the opposite direction round the same radius through 180°, thereafter being bent back again to the original position. One such test shall be made from every 10 or part of coils or bundles.

**Percentage of reinforcement**: The steel should be correctly located and adequate in quantity. If the area of the steel is too large, the beam will fail by compression in concrete, but if too small, failure will occur as soon as the reinf. has reached its yield point. The area of the steel, $A_s$ (in rectangular beams and slabs) varies from $\frac{1}{3}$ to $\frac{1}{4}$% of the area of cross section above the steel. This $A_s$ should be determined from the character of the member and the strength and elasticity of the concrete and the steel. The % of steel should be economical. This depends on: i Considerations of the strength and elasticity of the concrete and steel; and ii Comparative costs of the concrete and steel.

Item i for concrete depends on its ingredients and mixture proportions. Those of steel are constant. For each mix, the relation between the E for steel and that for concrete called *modular ratio* is constant. The prices of concrete and steel being normal, $A_s$ will be economical, when the tensile stress induced in it by bending or transverse load approaches the safe working stress of steel in tension, and the compressive stress induced in the concrete at the same time approaches the safe working stress in compression for the particular mix. The total compression in the concrete will be equal to the tension in the steel; the moment of this internal couple, called the moment of resistance being equal to the external bending moment. If concrete is costly, steel will be introduced on the compression
side to reduce the area of the concrete. If steel is costly, it will be economical to increase the concrete by making the beam deeper (thereby increasing the lever arm) and reducing the A.<

The ends of all tension rods should be bent into 'U' form (dia. = 4d where d is the dia. of the rod) or otherwise anchored. The bending should be done cold in a bar bending machine. The bars, hooked as above, should be so placed that there will be a backing of concrete of a thickness equal to 4d to prevent the hook kicking back before the elastic limit of steel is reached. All reinf. used should be clean and free from mill scale, rust, paint, oil, dust, etc. Reinf. subject to tensile and shearing stresses should not be welded; if unavoidable, the weld should be designed carefully in the light of the stress at the point. Rods should be bound together with braces, distance pieces, and transverse rods, with pliable iron or thoroughly annealed M. S. wire so that they may not be displaced while laying the concrete. The min. clear distance between parallel bars should be \(1\frac{1}{2}d\), or \(1\frac{1}{8}\) times the max. size of the coarse aggregate used, whichever is the larger. The bars should have a cover at the faces of the R. C. structure at least equal to \(d\). Where rods have to be spliced, the splices should not be at points of max. stress and should have an overlap of at least 50 \(d\). Adjacent bars should not be spliced at the same point of the structure.

**Arrangement of reinforcement:**

*a.* For columns: consists of longitudinal vertical bars held together at intervals by \(\frac{1}{4}\)" stirrups or laterals. Instead of laterals, a spirally wound hooping, round the longitudinal bars, to prevent the concrete from swelling laterally, enables the column to take a higher load.

*b.* In beams and slabs: Usually concrete takes the entire compression and steel is provided only to resist the tensile stresses. But,
where the size will become unwieldy if all the compressive stress is to be resisted by the concrete, the concrete is assisted by providing reinfl. in the

compressive zone to take a portion of the compression and thereby reduce the size of the structure to reasonable or aesthetic proportions. c. In arches: Under a uniformly distributed moving load, tension occurs at the intrados at the crown and at the haunches. Due to temperature variation, tension occurs at the extrados. So reinfl. is placed near the intrados and extrados.

Fig. 167 to 170 show details of reinfl. of a rectangular beam, a continuous slab, a laterally reinforced column, and a spirally reinforced column, the designs of which are given in the book on 'R. C. C. Designs' by the author.

Types of reinforcement: i Round and square bars of mild steel, and medium and high tensile steel. ii Patented, deformed, or indented bars are used to provide a greater bond by mechanical resistance to sliding. These become effective only after appreciable slip has occurred. As there is a danger of splitting the concrete, some form of wire binding to reinforce the surrounding concrete is necessary. iii Cold twisted square steel bars are used where a high tensile stress has to be allowed. iv Iseteg steel where two bars are twisted together to a pre-determined point beyond the yield point of the component bars. It has a high yield strength, uniform hardness, increased safety and stands increased bond stresses. v Cold drawn steel wire is used in prestressed concrete work where a high tensile stress is adopted. vi

LATERALLY REINFORCED COLUMN

Fig. 169.
Angles, joists, rails, wire ropes, etc. vii Expanded metal sheet, B. R. C. fabric, twisted steel fabric, fabric, Hy-rib (expanded metal with ribs), etc., are used in floors, road slabs, pipes, etc.

**Bending of reinforcements**: In simply supported slabs the tension rods will be entirely at the bottom. If, on the other hand, the ends of the slab are rigidly fixed at their end supports, the rods are bent up towards the ends at 45° at points distant about 1/4 span from each end, since the top fibres of the slab near its ends carry tension and the bottom portion compression, since the bending moment at and near the supports is in this case, negative. Where the slab of the floor of the first floor in a two-storied building is supported at the tops of the walls of the ground floor and the walls of the first floor are built over the ends of the slab, it is usual to consider the ends of the slab as only partially fixed to be on the safe side. In this case the bearing rods are placed alternately straight and bent up. Simple R. C. slab (without girders) may be used, provided the unsupported clear span does not exceed 8' or 10', for, for larger spans, it will be more economical to introduce girders so as to reduce the length of the unsupported span for the slab. Where slabs are laid over R. C. or R. S. beams, the slab will be continuous over the several beams and as the bending moment over the beams will be negative the tensile stress occurs in the top fibres of the slab over these beams and not in the bottom fibres, which carry compression stresses. In other words, the state of affairs is similar to that in the case where the ends of the slab are rigidly fixed at the supports. In a case like this, therefore, the alternative main reinf. or bearing rods are bent up over the beams, alternate rods running straight. To provide adequate reinf. at the top portion over the beams fully to resist the tensile stress there, a separate grill is provided, the bearing rods of which occupy midway between the bent portions of the bent rods, that is to say, exactly opposite and above the straight rods. The length of the bearing rods of this top grill will be a trifle more than 1/4 the length of the span for the slab.

**Shear reinforcements**: are necessary to resist the shearing stress, the capacity of the cement concrete to resist such stresses being very poor. These reinf. are vertical, bent in the shape of stirrups with the ends of the
rods (which will be near the top) being turned over the main reinfor., and then hooked to the latter. The shearing stress is nil at the centre of the span and increases to a max. at the supports. So the stirrups are spaced closer together near the supports, the intervals increasing towards the centre of the span. The sloping portion of a main reinfor. bent up also assists in resisting shear stresses (and diagonal tension which is brought into play near the ends, in a direction inclined at 45° to the horizontal, by the shearing stresses).

VI. Formwork, Shuttering, Centering, or Falsework: General: As R. C. structures have to be moulded to required shapes and sizes, as in the case of C. I. or other metal castings, moulds are required. These moulds, called formwork or forms are supported on a rigid formwork of props and braces, known as trestlework or staging. The forms and staging are only of temporary use as they are to be removed or struck after the concrete has hardened. The requirements of forms are: i They should be durable, rigid, and should not warp or twist. ii The joints between the various members should be watertight so that no leakage of fluid through the concrete takes place. iii The form and staging should be stiff and strong enough to support the weight of the concrete, men and materials, and the impact of ramming without bulging or vibrating. iv They should be simple and lend themselves to easy supporting so that they may be put together, taken to pieces, erected and removed with the minimum of labour. v They should be correct to line. vi The interior surfaces should be wetted or coated with inert whitewash, oil or soft soap or some form of lining such as oiled paper, canvas, etc., introduced to prevent the tendency of the concrete to adhere to the formwork.

Types: In South India, mango planks, 1" thick (and thicker whenever necessary) are used for the formwork, and bamboos, jungle-wood round saplings, or sometimes sawn scantlings are used for the staging. The planks should not be dry as to absorb water from the concrete. The posts are well braced together. The formwork should be so arranged as to permit of easying and removal without jarring the concrete. Wedges, clamps, and screws should be used whenever possible instead of ordinary wire nails. The formwork is usually chamfered on the re-entrant angles and filleted with triangular wooden fillets at the other angles so as to get a splay of at least 1\(\frac{1}{2}\)" at all corners of the concrete. Moulds or boxing of R. C. beams and allied members are designed and constructed such that the side planks may be removed without interference with the other parts of the formwork. The supporting struts or posts of the staging should be placed upon proper sole plates of wood.
or sleepers so arranged that they may be lowered gently in the striking of the formwork. For this purpose, they are provided with folding or double wedges. After the boxing is erected in position, their inside surfaces are treated with a coat of whitewash. Steel and Al forms, which are durable and economical where repetition work has to be done, are also used.

There are no standard types for the supporting staging. The arrangement to be adopted in any case is left to the ingenuity of the designer. The general formwork for a slab, beam, and wall are shown in Fig. 171 to 173. The following three methods are adopted for columns: i The formwork or boxes are brought up entirely as the work proceeds. This is most convenient. The sides are made with planks (grains horizontal) held in position by uprights at the corners; ii Three of the sides are made with vertical planks before the moulding or laying of the concrete is commenced, the fourth side being brought up as the concrete is deposited. This method is less easy than i since only one side is available for inserting the concrete and for consolidating it; and iii All the four sides are formed to the full height before concreting and all the concrete is put in from the top (Fig. 174). The method is suitable only for very short columns of large cross-sectional dimensions. The mixture of the concrete has to be sloppy and the consolidation has to be with iron rods of flat bars with which the concrete is poked. This is not a satisfactory method.
**Round columns:** Special boxes or drums in two halves are employed, using narrow battens held together with hoop iron bands. Sometimes, the two halves are hinged together, sheet iron moulds are also used instead of wooden batten moulds. Forms for arches should be stiff, easily movable, and involve minimum of material. For deep navigable rivers, trusses are used. For shallow waters, bents supported on wooden piles are used. For silos and chimneys, sliding or movable forms are used. When the formwork and the staging are to be struck, the double or the folding wedges at the feet of the props are eased gently and knocked out with a run. Where temporary bolts have to be used, the holes should be large enough for the bolts to be withdrawn easily. Where holes have to be provided, wooden plugs of the required size should be introduced and while the concreting is in progress, the plug should be gently turned round so as to prevent its getting firmly fixed in the concrete.

**Time of release:** With a temperature of \( < 21^\circ \), the following minimum intervals should be allowed between laying concrete and striking forms: i) Vert. sides of slabs, beams and columns—2 days; ii) Bottom of slabs up to 15' span—7 days; iii) Bottom of slabs above 15' span, bottom of beams up to 20' span, and arch rib bottoms up to 20' span—14 days; iv) Bottom of beams over 20' span and arch rib bottoms above 20'—span—21 days. For rapid-hardening cement, \( \frac{1}{2} \) of the above periods will be sufficient in all cases except vert. sides of slabs, beams and columns, which should be retained at least for 24 hours. Proper precautions shall be taken to allow for the decrease in the rate of hardening that occurs with all cements in the cold weather.
Design of slabs: An empirical rule gives the thickness as $\frac{1}{2}$" per foot of span plus $\frac{1}{4}$". For design purposes, standard tables giving the resistance moment, depth of neutral axis, lever arm, and area of steel $A_s$ for the different mixes and steel stresses adopted in R.C. work are available. e.g., 1:2:4 Mix Ordinary as per By-Laws: $f_c = 750$ psi, $f_s = 18,000$ psi; $m = 15$; Area of steel $A_s = 0.008 \cdot bd$; $L$ = 0.87 $d$; Depth of $N$, $A_n = 0.385 \cdot d$; and R. M. = 126 $bd^2$ where $b$ is the breadth in inches and $d$ is the effective depth in inches from the extreme fibre on the compression side to the C. G. of the reinforcement. In slab design, its length is usually considered as composed of strips 12" wide so that $b$ is usually 12". The max. bending moment $M$ is usually calculated for the span and the given loading taking $b = 12"$. Equating $M$ to $126 \times 12 \times d^2$, $d$ is found. Adding a protective cover of $\frac{1}{4}"$ (which should be 1" in beams and 1\frac{1}{2}" in columns and $<\text{ the dia. of the bar in all the cases}$) to the value of $d$, the total thickness of the slab is found. $A_s$ required in the 12" strip is given by $0.008 \times 12 \times d$. Dividing this area, by the area of a $\frac{1}{4}"$, $\frac{3}{8}"$, or $\frac{1}{2}"$ dia. rod, the number of rods required in the 12" width is found. This is usually expressed as so many rods of such and such dia, at so many inches centre to centre. The transverse rods (usually $\frac{1}{4}"$ dia. rods) or distributors shall have an area of at least 20% of the main steel. For further details with regard to the design of slabs refer to the book on 'R. C. C. Designs' by the author.

Methods of Proportioning: 1. Arbitrarily selected volumes method: This is one of the oldest methods. It was formerly taken that for workable concrete, fine aggregate should be 50% of the coarse aggregate. Subsequent experience has shown that, except in mixes rich in cement, a larger proportion of fine aggregate is necessary. Large differences in results may be obtained by this method if materials are not carefully handled and measured, especially if varying consistencies are permitted. This method is not economical. It does not give a workable or uniform concrete.

2. Minimum voids in aggregate method: The fine aggregate is taken to fill all the voids in the coarse aggregate and the cement paste to fill all the voids in the fine aggregate. The min. volume of cement paste should be from 15 to 20% in excess of the voids in the fine aggregate to ensure thorough filling of these voids. 1 c. ft. of cement paste is considered to be given by 1.2 c. ft. of dry cement. The volume of sand should exceed by 5 to 10% the volume of the voids in the coarse aggregate in order to ensure that the voids are completely filled and to allow for the probable increase in volume of voids due to the fine aggregate particles wedging between the coarse aggregate pieces. As the volume of voids in the fine
aggregate is greatly influenced by the amount of contained moisture and as the compactness of the aggregates varies with the methods of handling, this method is uncertain and is used only occasionally.

In the above arbitrary methods, failure to obtain a dense combination of mixed aggregates requires the use of a greater volume of cement paste to obtain the necessary workability. If the cement paste is increased, the cost is increased, and if more water is added, the quality is impaired. The following methods are developed on scientific lines:

3. Fuller's maximum density method: Several tests are made to determine the combination of sizes of fine and coarse aggregates which, when mixed with a given percentage of cement, gives the densest, strongest, and most impermeable concrete. The grading curve resembles a parabola and consists of a combination of the ellipse and straight line. This gives a strong concrete and a harsh working mix, but is not economical because of the cost of screening and handling.

4. Edward's surface area method: This method assumes that the strength and other properties of mortar and concrete are mainly dependent upon the amount of cementing material used in relation to the total surface area of the aggregates. It has something in common with the fineness modulus method, but is not generally adopted.

5. Talbot's mortar voids method: This method is based on the voids in mortar and concrete. The strength of concrete is dependent upon the ratio of the absolute volume of the voids to the absolute volume of the cement in a unit volume of freshly mixed concrete. The relation holds both when the voids in coarse aggregate are completely filled with mortar and when not completely filled except in the more extreme cases. This method is largely used, especially in the design of mixes for highways.

6. Trial batch method: The desired water-cement ratio is selected. A cement paste, with known weights of cement and water, is prepared. Fine and coarse aggregates of known weights are added to the cement paste until a plastic mixture of desired consistency is obtained. The quantity of concrete formed is noted and its slump determined. This trial is repeated until a mix giving the smallest volume of mixed concrete (densest mix) with as coarse grading and as stiff consistency as possible without producing harshness or stone pocketing results.

7. Abrams fineness modulus method: This method takes into account the grading of both the fine and coarse aggregate. The principle is that aggregates having the same fineness modulus require the same amount of water to produce a concrete of equal workability and strength. For each
ratio of cement to aggregate there is a fineness modulus that gives the max. strength for a given quantity of water. The modulus of aggregates is determined by passing them through a series of 9 sieves (Meshes per linear in. 100, 50, 30, 16, 8, 4, 2, 1, and ½). Take a sample of dry fine aggregate of weight (\(w_1\) lb) > 4 lb. Sieve it on the first one and weigh the quantity retained. Sieve it successively through the others until the sieve is reached that passes all the stuff. Weigh the amount retained on each sieve. Find the total weight \(w_1\) lb. of all the retained weights. Then the fineness modulus \(f_r\) of sand, which should be < 1.5, is \(w_1 \div w_1\). Similarly take < 10 lb. of the coarse aggregate and find its fineness modulus \(f_c\) which should be < 6.5. If \(f\) is the fineness modulus that gives the max. strength for a given proportion of cement, the proportion by weight of fine to total aggregate is given by \((f_r - f) \div (f - f_c)\). The values of \(f\) for various mixes, depending on the max. size of aggregate are usually known. This method is largely adopted in the U. S. A. and is essential in impermeable construction.

**Proportions of Cement to Aggregate:**  
*a. Real mix:* is the proportion of cement to a volume of combined coarse and fine aggregates (dry). The proportions of the fine and coarse aggregates can be varied but the fineness modulus of the combined aggregate must be secured.  
*b. Nominal mix:* The proportions of cement, fine aggregates, and coarse aggregates are nominally expressed by arbitrary standards, one c. ft. of cement being the unit.  
*c. Field mix:* The volumetric proportions of cement to fine aggregate and coarse aggregate, after allowing for their bulking due to presence of moisture, is expressed by a field mix.

**Laying Beams and Slabs:** Whether the floor consists of plain slab, or beams and slabs, the reinforcements are all tied completely, fixed in their correct positions and checked by the engineer in charge before the concrete is laid. The grill will be supported in its correct position on pieces of metal here and there. Beam reinforcement will be kept suspended in position by a sufficient number of \(\frac{3}{4}\) dia. vertical rods hooked to the main beam reinf. at the bottom and to short iron rods, of sufficient thickness to support the weight without bending, placed horizontally across the beam at the top. The horizontal cross rods used at the top will be removed after the beam has been almost fully filled up with concrete leaving the vertical suspending rods embedded in position. The earlier practice of using small concrete blocks or cement concrete fillets at the bottom of the beam or slab to support the reinf. and keep it in position has lately been given up and should be avoided. When concreting a large area, laying is started from one end beginning with the beams first in that position. The inside face of the formwork is well cleaned and wetted with water. A thick
coat of neat cement grout is applied to the bottom plank of the boxing, and then cement mortar (1:3) of pasty consistency is thrown in and levelled to a thickness of \(\frac{1}{4}\)" and consolidated with pokers (flat thin rammers).

The concrete is then laid in layers of \(\frac{1}{4}\)" and rammed well till the girder is filled up, working thoroughly so that no hollows are left round the reinf. Sometimes, cement mortar is inserted by applying it to the (vertical) sides of the boxing before the concrete is laid for any layer. The space between the stirrups and the sides of the boxing will be narrow and the concrete in this space should therefore be consolidated with the thin wedge shaped rammers of flat iron bars. There should be no delay between mixing the concrete, laying it in the forms, and consolidating it. While laying concrete for the beam is in progress, care should be taken to see that the reinf. is not laterally displaced to one side or the other but kept in its proper position. The short cross iron rods placed at the top for supporting the beam reinforcement are then removed. Before concreting the slab, the cover, spacing of rods, etc., of the slab reinf. will have to be checked. If the reinf. has sunk down anywhere, it should be lifted up and kept at the correct height by inserting a few pieces of metal here and there between it and the plank below. If any bent rods have tilted laterally, they should be set right. Then, the surface of the staging where the concrete is to be laid is cleaned, just wetted, and a thick coat of cement grout is applied over it and a thin layer of mortar (not too wet) is laid by throwing it with force in a slanting direction so that it may mix with the grout and form a thin uniform layer of about \(\frac{1}{4}\)" thickness. By thus applying the mortar, some of it will also get under the reinf. rods which is essential. Then concrete of a mushy consistency is laid, levelled by bricklayers, and consolidated in layers, which depend on the thickness of the slab. Whatever may be the number of layers, the penultimate layer must be to the level of the top reinf. of the slab which must be visible when levelled to admit of ramming being done between rods without disturbing them. In consolidating the bottom layer, care should be taken to poke thoroughly round and near the rods with the thin wedge-shaped rammers held in a slightly slanting direction so that the concrete might well envelop the reinf. The concrete in the rectangular spaces formed by the main and the transverse rods of the grills should be well rammed. After the penultimate layer has been rammed, level templates are formed by bricklayers with concrete at regular intervals with straight edge and masons levels, the top level of these templates being such that the finished surface after ramming will be \(\frac{1}{4}\) to \(\frac{1}{2}\)" below the desired and designed final level. Then the spaces between the template levels are filled with con-
crete and properly levelled by bricklayers with their trowels, frequently applying their straight edge and testing the level with reference to the template levels, and then the concrete is rammed well.

After the final ramming is over, a thin layer of cement mortar 1:1, not more than $\frac{1}{4}$" thick is applied to the surface immediately and finished to proper level with a straight edge. The surface will now be too soft and moist to admit of any floating. After a while when the water is absorbed and the surface becomes just sufficiently hard, it should be floated hard and trowelled smooth. After the plastering as above is over, the surface is left alone for the night. From the next morning e.g., after 12 to 18 hours, the whole surface should be kept under water and cured by any of the methods explained below.

Curing: While hardening of cement in air is accompanied by progressive shrinkage, hardening in water causes an increase in bulk which is lost upon subsequent drying and then shrinkage occurs. Temporary saturation of hardening concrete decreases the rate of shrinkage and hence the tensile stresses set up in the concrete with the result that shrinkage cracks are prevented. Such a concrete attains a higher strength at any given age than a concrete that has hardened in air. The aim of curing is to maintain the immature concrete moist for a given period, usually 7 days, though a curve extending up to 28 days is certainly beneficial, and also to prevent rapid temperature changes in the concrete. The length of the period of curing depends on a large extent on the type of cement used—rapid hardening cements require a shorter period.

Methods of curing: i Moist curing: This is by far the easiest, most efficient, and extensively used method. It consists in the application of water either directly by immersion, spraying, or ponding or by means of wet coverings. a. Spraying: Water is periodically sprayed through a hose to all exposed faces of the concrete. It is done mechanically by sprinklers in the curing yards of precast concrete factories. As spraying within the first few hours after concreting may wash some cement out of the concrete surface, hessian should be used on uniformed surfaces for several hours at least. Precast products are also cured in chambers where steam is released to keep the concrete moist. b. Ponding: is adopted for horizontal surfaces like roads and floor slabs. In certain cases the surface is covered with gunny bags for a day and then little earth dams are built over the entire area to be cured forming squares which are then flooded with water to a depth of 2". c. Wet coverings: consist of earth, sand, straw, mattings, hessian, etc., which must be kept constantly saturated with water.
ii Membrane curing: Where there is difficulty in getting water, a continuous seal over the concrete surface is obtained by means of a firm impervious film of material used so as to prevent moisture in the concrete from escaping by evaporation, there being sufficient excess water in the concrete to effect proper curing. The sealing compounds (black and clear) are sprayed on to the concrete through an atomising needle either soon after finishing operations or after a period of moist curing, the former practice being generally considered insufficient. The black compounds are asphalt emulsions, asphalt cutbacks, and coal-tar pitch cutbacks. These are not used on concrete permanently exposed to view because the resulting dark surface is undesirable in appearance and causes excessive heat absorption which, in turn, increases the tendency towards crazing and cracking. These are used on the interiors of tunnels and chambers which will not be illuminated, on the interiors of culverts and syphon barrels, and on exterior surfaces which will later be backfilled. The clear coatings are marketed under different trade names e.g., Tru-cure, Aquastatic, Seal kure, etc. These are composed of 30 or more per cent of blends of non-volatiles such as paraffin, wax, resin, vegetable oil, etc., and a petroleum solvent. These absorb much less heat than the black compounds and leave the concrete with more nearly its natural appearance. Water-proof paper: is a satisfactory curing membrane for horizontal surfaces. It is used on the underside of concrete road slabs to prevent absorption of moisture from the concrete by the subgrade. Alkathene film (available in sheets up to 6' width and thickness ranging from 0.001" to 0.007") when spread over the surface of the mix, covering the edges with sand or gunny bags, stops the necessity for further watering for proper curing.

iii Calcium chloride: (a deliquescent salt) used either as a surface coating or as an admixture to the concrete has been satisfactory as a curing medium. The salt not only absorbs moisture from the atmosphere but aids in retaining a part of the mixing water. As water evaporates from it when the relative humidity of the air falls below a critical point, it is specified that it should not be used in arid or semi-arid regions, under high temperatures, and when the relative humidity is < 50% at normal temperatures. The finished concrete surface is moist cured for 12 hours, sprinkled with water, and then the CaCl₂ applied at 1.5 lb./sq. yd. by means of a squeegee or a suitable mechanical device. When used integrally (dry 1½ to 2½ lb. per bag of cement and solution 100 lb. dissolved in water to make 20 imperial gallons) as an admixture to the concrete mix, it serves as a curing agent by accelerating the setting and hardening of the cement before the concrete dries out. After final finishing, the
concrete is covered with hessian and kept wet for < 24 hours.

iv Heat treatment: hastens the curing process. The usual methods are: a. by passing an A.C. current through either the steel reinforcement or the concrete itself. This method is used in Russia, Japan, and the continent to protect the concrete from freezing during cold weather concrete. b. By passing hot saturated air over the concrete surface; and c. By curing the concrete products in high pressure saturated steam, atmospheric steam or very hot water. Curing from 1 to 4 hours at a steam pressure of 30 psi produces satisfactory strength for high grade work. To prevent undue cracking and to obtain higher strength, the rate of the initial temperature rise must be carefully controlled. Steam-cured concrete continues to gain strength with age after steaming, just like air-cured concrete. Similarly the strength of steam-cured concrete varies with water content unlike air-cured concrete. Aluminous cement is unsuitable for steam-curing as its strength decreases with increase of temperature. The ultimate shrinkage of concrete is considerably reduced by steam-curing, but, for several days after casting, steam-cured concrete actually expands. The bond strength developed between steel and concrete is reduced by steam-curing and should be supplemented by mechanical bond to obtain satisfactory results. Steam-cured concrete is white in colour, sound in appearance and possesses the same flexibility as normal air-cured concrete.

Fig. 175 shows the relation between curing and compressive strength. It can be easily seen that there is a rapid increase of strength during the first 28 days and then it continues gradually. Fig. 176 shows the relation between curing and the number of freezing and thawing cycles
required to reduce the weight of concrete by 25%. As this is a measure of durability, it is clear from Fig. that curing at least for 10 days is essential in order to secure maximum resistance to disintegration by frost. The decrease in permeability with moist curing follows a similar curve. Fig. 177, shows the relation between curing and effect of temperature during moist curing on compressive strength. The best results are obtained when concrete hardens in a warm, damp atmosphere. When the temperature is < 5°, the rate of hardening is very low; when it is > 21° and the concrete is exposed to drying winds, the water required for hydration may evaporate and prevent hardening of the concrete. Cracks may develop as the concrete is not hard enough at an early age to resist without cracking the stresses set up by contraction. Hence, when concreting during hot weather, use mat canopies (like the ones with coconuts leaves on light framework as in Kerala) to shade the concrete, concrete at night, use cold mixing water, sprinkle or cover the aggregate, avoid use of hot cement and wet all moisture-absorbing surfaces in advance of concreting.

Shrinkage: of concrete is the volume change due to drying out of the cement gel between the aggregate particles. Members exposed to low humidities or in a heated building have maximum shrinkage. After each cycle of alternate wetting and drying, there is usually a residual shrinkage. Lean mixes shrink < rich. Mixes with high water-cement ratio shrink more than dry mixes in air, but they expand less under water. Large members dry quickly at their surfaces and non-uniform shrinkage may produce unequal strains and warping. Shrinkage is reduced by curing for 28 days. Its effects are very great in mass concrete where the heat of hydration is not dissipated immediately. In such cases the shrinkage movement is reduced by circulating cold water through pipes embedded in the concrete.

Plastic flow, Creep or Time-yield: of concrete is the additional volume change under sustained stress. It may be due to: a. crystalline flow—slippage along planes within the crystal, b. seepage-flow of absorbed water from the cement gel due to applied pressure, and c. Viscous flow—movement of particles. It is largely due to seepage. Water may exist in the concrete as a. chemically combined with cement, b. absorbed by the cement gel, and c. free within the pores between the gel. It is the gain or loss of the absorbed water from the gel that appears to be the basis of the volume changes resulting from sustained pressure. The greater the applied load, the steeper the gradient with consequent increase in rate of expulsion of water. The rate of expulsion also depends on the vapour pressure outside of the mass. Release of load enables recovery to take
place which continues for a period of several weeks. Plastic flow does not seriously reduce the strength of most R. C. structures.

Damp-proofing: The materials employed for this purpose are divided into three classes: i Transparent coatings: are usually given by alternate applications of solutions of soap and alum. These materials react within the pores and form an insoluble Al soap with a distinct water repelling property. Paraffin wax may be applied either in the molten condition to the surface (carefully heated), or as a solution in petroleum naphtha. Silicafluorides of Al, Mg, and Zn, are also used; ii Opaque coatings: include paints. But paints cannot be safely applied to a cement surface, or a recently lime plastered wall since the Ca (OH)₂ that is set free during the setting of the cement or found in the wall reacts with the oil and destroys the durability of the film. To overcome this action, the surface is treated with ZnSO₄ when the stable CaSO₄ and Zn (OH)₂ which do not react with the oil are produced. Sometimes a casein paint is applied first and then oil paint or the casein-painted surface treated with formaldehyde; and iii Bituminous coatings: Tar, heated to expel moisture and treated with lime to neutralize its acidity, is either applied hot or applied as a paint after thinning with petroleum naphtha or benzol. Some special bitumens are incorporated into the wall. The bitumen is applied before the finishing coat. Then a coating of plaster, with which the bitumen bonds well, is applied over it.

Water-proofing: is secured by having the ingredients of the concrete rightly proportioned, so that the voids are eliminated. A 1:1½:3½ nominal mix laid with proper care regarding mixing, placing, and curing will be water-proof. The special methods of water-proofing are divided into two classes—the ’integral’ or rigid method, in which a water repellent material (Cico No 1) is incorporated with the concrete mass; and the ’membrane’ or bituminous shield method, in which the concrete is insulated from contact with water by the use of a continuous, water-proof, bituminous layer. In the former method suspensions of Ca and Al soaps are added in small amounts and are effective in interrupting the passage of water by capillary action because of their water-repellant action. Care should be taken in this case to see that the surface is kept damp for at least 28 days and the concrete is allowed to harden, as after drying the concrete will not absorb moisture. In the second method, as applied to roofs and cellar walls, the surface is swabbed with hot asphalt and is at once covered with overlapping sheets of felt (previously saturated with asphalt or pitch by the manufacturer). Two more layers are similarly laid and asphalt is swabbed on the top. Gravel is then spread over the whole
surface to provide a top coat resistant to cuts and scuffing of feet. Good slates, lead sheets, fibre glass sheets, and plastic sheets like 'Nevastral seal proof' are also used.

Sal-ferricite, a patented finely ground metallic compound, is mixed with cement and aggregate to give an iron-like, dustless, wear-resistant surface, impervious to water and oil. Another patented liquid is mixed with the gauging water to increase the strength, adjust the setting and hardening times, and improve the water-tightness of the concrete. Exposed surfaces are made water-tight by applying two coats of a slurry, composed of this liquid and cement. Rockite is a similar patented metallic powder and rite-sil is a waterproof cement paint used on concrete, lime, or brick surfaces. Barnseal is a type of bituminous plastic waterproofing compound obtainable in black or red colour. It gives durability and anti-corrosive protection. It is applied cold to burn roofs and buildings. It forms a tough elastic film flexible enough to take up normal roof movement. It does not flow in hot weather or become brittle under conditions of extreme cold. It can be applied to damp surfaces and used at any season for waterproofing brick, stone, concrete, or metal. It is also used for external waterproofing of water barrels, runways, troughs, gutters, and sealing deep-seated cracks in masonry.

Surface Treatments: Where chemicals, oils, and various other industrial liquids are kept in storage in R. C. tanks, it is important to know the effect, if any, of these substances on the unprotected concrete (vide 'Decay of Concrete') and to recommend suitable protective treatments. In structures which are subject to frequent wetting and drying by brine and salt solutions, it is necessary to provide impervious concrete and sufficient coverage over the steel and in addition provide some surface coating. Also in concrete used for industrial floors, cracking and crazing will have to be prevented and the surface will have to be dust-proof, non-skid, and wear-resistant. The protective treatments are:

1. Magnesium fluosilicate or zinc fluosilicate: The treatment consists of two or more applications of a solution of the salt (first coat 1\% lb. per gal. and second coat 2\% lb. per gal.), each coat being applied after the previous one has dried. The treatment hardens the surface by chemical action and makes it more impervious.

2. Sodium silicate: of about 42.5° Baume gravity diluted with about 4 times its volume of water is applied in two or more coats as in (1). Scrubbing each coat with water after it has hardened provides a better condition for application of succeeding coats. For tanks and
similar structures, progressively stronger solutions are used for the succeeding coats.

3. Drying oil: Two more coats of boiled or raw linseed oil, China wood oil, tung oil, and soya bean oil (diluted with an equal volume of turpentine for first coat) are applied as in (1). Hot application gives better penetration. Sometimes a drying oil is applied after magnesium fluorosilicate treatment.

4. Cumar: (Synthetic resin, dark brown to colourless). Two or more coats of 7 lb. of powdered Cumar dissolved in a gal. of xylol with ½ pint of boiled linseed oil give a good coating.

5. Varnishes and paints: See Ch. VI.

6. Bituminous coatings: 1. Bituminous or coal tar paints, tar and pitches: are applied in two coats—the first a thin priming coat to insure bond and the second a thicker finish coat. ii. Bituminous enamel: is a suitable protection against relatively strong acids. It does not resist abrasion at a high temperature. It is applied in two coats. When the first priming coat has dried to slightly tacky state, the enamel (bitumen with a finely powdered siliceous mineral filler) is melted and carefully heated until it is fluid enough to brush and applied quickly as it sets and hardens rapidly. iii. Bituminous mastic: is used chiefly for floors on account of the thickness of the layer which must be applied. Some mastics can be trowelled on vertical surfaces. Some are applied hot, while others are heated until fluid. The cold mastic is applied in two coats. When the thin first coat has dried to a tacky state, the second or body coat (mastic—bitumen with asbestos and finely powdered siliceous filler) is applied. The hot mastic is similar to the mixture used in sheet asphalt pavement but contains more asphaltic binder so that when heated it can be poured and trowelled into place. It is applied only in layers of 1" or more in thickness. When ready to lay, the mastic contains 15% asphaltic binder, 20% finely powdered siliceous mineral filler, and the remainder sand graded up to ½" size.

7. Vitrified bricks or tiles: which possess high resistance to attack by acids or alkalies, are laid in mortar which is also resistant against the substance to which they are to be exposed. These find a large application in the lining of many acid tanks, and petroleum and coal-tar distillate containers.

8. Glass, lead, and sheets of resin, rubber, and synthetic rubber: These are used for HCl, H₂SO₄, and HNO₃ tanks, for formalin containers, etc.

Decay of Concrete: 1. Acid waters: have a profound disinte-
grating effect. They are capable of extracting, fairly quickly, up to 14% by weight of concrete. The action is probably a combined leaching of the free lime (by CO₂) with the formation and then solution of Ca(HCO₃). Even pure water extracts the lime rapidly. The water slowly hydrolysates the silicates and aluminates and extracts the liberated Ca(OH). Treatment with bituminous paints, enamels, and mastic, Na₂SiO₃, and drying oils is recommended.

2. Alkali waters: contain MgSO₄, CaSO₄, Na₂SO₄, MgCl₂, NaCl, KCl and carbonates of Mg, Na, and K. The sulphates are most active, the chlorides are less active, and carbonates are inactive. The attack by sulphates results in the formation of insoluble compounds accompanied by considerable expansion resulting in the disintegration of the concrete. The effect is marked in the case of thin precast materials, structures subject to alternate wetting and drying, and porous concrete. The remedy lies in using dense concrete and treating with Mg or Zn fluosilicate, drying oils, varnish, and varnishes and paints.

3. Sea water: containing MgSO₄, MgCl₂, NaCl, CaSO₄, react with the constituents of cement, especially those with high free lime or alumina content. The mass swells, cracks and gradually falls; sometimes the mortar softens and gradually disintegrates; and occasionally a crust forms on the surface which later cracks off. The action is similar to that by alkali waters. R.C. is more liable to attack than plain concrete owing to the corrosion and expansion of the reinf. The deterioration is marked between high and low water levels and at construction joints. Dense concrete with well graded aggregates or an outer shell of especially dense material cast along with the inner, use of a reduced proportion of fine sands, use of cements poor in alumina and rich in silica, addition of BaCl₂ (which forms insoluble sulphates and closes the pores in the mortar), hot bitumen impregnation, and special surface renderings are adopted to resist the harmful effects of sea water.

4. Clay soils: contain gypsum, MgSO₄, Na₂SO₄, K₂SO₄, and pyrites. Pyrites on exposure, are oxidised to FeSO₄. Cements attacked by CaSO₄ or Na₂SO₄ become soft and slushy, while those attacked by MgSO₄ remain hard but much expanded and cracked. Treatment with Mg or Zn fluosilicate drying oil and varnish is recommended.

5. Fire: Flint, gravel, sandstone, and granite as coarse aggregates are not satisfactory in concrete required to be fire-resistant. Limestone, basalt, broken brick, slag, and clinker are satisfactory. Steel is a good conductor of heat and loses its strength rapidly with rise of temperature. Hence adequate cover to reinforcement, thicker in structures with greater
liability to fire hazards, will have to be provided. High alumina cement is more resistant than ordinary cement.

6. Electric current: Concrete, if old and dry, is a good insulator. Its resistance drops with increase of moisture and cement. The compressive strength of concrete is not affected by A. C. or D. C. With D. C., if the reinforcement is cathode a. if the current density is > 20 microamps/sq. cm., the bond strength is reduced if the electrolysis is continuous, and b. if excess alkalies are present (as in sea water), the concrete softens near the cathode. If the reinforcement is anode, O₂ is given off, and steel corrodes and cracks the concrete. No damage is done if the voltage is <15 for D. C. and < 240 for A. C.

8. Oil: All oils reduce the strength of fresh concrete, the effect being marked on poor porous concrete. Hardened concrete is not affected. A surface coating of silicate of magnesia renders the concrete oil-proof.

9. Frost: causes surface scaling, which increases if salt is used to remove ice or snow from the surface. It causes damage by expansion of water freezing in the pores of the concrete. Proper consolidation and low w/c ratio reduce the liability to damage by frost.

10. Efflorescence: due to CaCO₃, MgCO₃, CaSiO₄, or CaSO₄, is reduced by using a minimum of water and proper curing of concrete. It has no harmful effect and is removed by washing and rubbing with water.

Joints in Concrete: Construction joints: (Fig. 178 to 182). The methods of treating such joints so as to secure good bond and a watertight joint have been dealt with in Ch III, Pa. 114 to 118. In the case of large works where the whole concreting cannot be finished in a day, construction joints are left at the end of the day's work. They should be so arranged that the strength of the member is not affected i.e., at points of least bending moment and shear. They must be made to transmit shear between adjacent sections. In one way reinforced slabs, the joints at right angles to span are located at mid-span and those parallel to span within the middle third. In two way reinforced slabs, they are within the middle third on either span. In continuous beams, they are between 0·2 and 0·3 of the span from either support. In T beams at the junction of rib and slab (provided sufficient shear reinforcement is provided). In columns, at floor level and continued through a storey height in one operation. In water containing structures, copper strips are placed both in horizontal and vertical joints. In horizontal joints, just after the concrete has been placed to the level of the joint, one half of the strip is inserted into the fresh concrete, and the other half is left projecting above—to be embedded in the next layer. In vertical joints the strip is
crimped so that one half of it extends into the concrete and the other half is flush with the bulkheaded end the wall. After removal of forms, the exposed half of the strip is straightened out so that it will extend into the adjoining section of the concrete. The joints in exposed works, like walls, should be arranged at levels to blend with the general architectural appearance and should usually be masked by lines of tiles or grooves or projections.

**Contraction and expansion joints** (Fig. 173 to 191). The initial shrinkage of concrete is greater than any subsequent expansion due to moisture and temperature changes which may be expected in ordinary building floors. These changes produce two distinct types of undesirable conditions in concrete. Cracks are formed in restrained concrete as a result of shrinkage and insufficient tensile strength, whilst alternate expansion and contraction gradually tend to break down the structure of the cement paste and the bond between paste and aggregates, thereby leading to disintegration of the concrete. For this reason contraction
rather than expansion of the floor is important and joints should be provided accordingly. For road and floor slabs, contraction joints should be provided at 30 ft. intervals. These should be placed on column lines and intermediate ones should be used where the column spacing exceeds 30'.

Expansion joints are provided in concrete structures of 40' length or more so that they can expand freely on temperature rise without one jamming against another. Such joints mean a complete dismemberment at the place of the joint. They provide a space filled with some elastic material like asphalt, carbo-elastic, cork, etc., which yield on expansion and prevent the collection of dust, earth, etc. Where the joints should be waterproof, as in dams, a copper strip is incorporated in the concrete of the two lengths at the joint. These joints are installed at all walls and around all columns or machinery foundations primarily to permit differential settlement of the floor and the walls and foundations. Some engineers prefer using expansion joints in concrete roads only at 60' or greater lengths. In such cases to control intermediate cracks and confine them to the bottom portion of the slab, dummy joints (Fig. 192)-grooves \( \frac{1}{2}'' \) wide and 1'' deep at the top at every 15' and filled with asphalt - are provided.

Contraction joints should permit the slabs to separate when tension develops but should be capable of transmitting shear across the joint. They should form a straight line so as not to disfigure the floor. An ordinary tongue and groove construction joint will function as a contraction joint; or the tensile strength of the slab may be reduced at the joint by inserting a strip of metal, wood or premoulded joint filler in the bottom of the slab, or by making a groove. Such a strip or groove should reduce the effective thickness of the slab about \( \frac{1}{2} \) or \( \frac{1}{3} \). The break of the remaining portion of the slab will be sufficiently irregular so that shearing loads will be transmitted across the joint. If the slab is reinforced, the reinforcement should be cut at contraction joints. Such joints of about \( \frac{1}{20}'' \) width are provided to prevent uncontrolled cracking of mass concrete dams during cooling and are grouted after a major portion of the construction is over. Compristrip is claimed to be an ideal caulking strip for joints in concrete structures. It is said to be elastic, watertight up to 120 psi, acid and alkali proof, rot proof, and heat resistant up to 160'.

Cracks in Concrete: These can be classified as those which occur:

1. **Before hardening**: These are:
   a. **Consolidation movement**: due to moisture changes and insufficient compaction. It is prevented by adequate control of the subgrade. **Formwork movement**: due to inadequate design or construction and prevented by
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careful attention to both. ii Settlement shrinkage: a. Shrinkage around reinforcement or similar obstructions: due to upper surface of the concrete becoming set whilst the interior is still setting. Use dense plastic mixes with well graded aggregate, low water content, and adequate compaction and postpone the final floating until internal set is complete. b. Shrinkage around aggregate particles: due to settlement of paste around aggregates. The remedy is the same as in ii a. iii Setting shrinkage: a. Plastic shrinkage due to syneresis (When HCl is added to Na₂SiO₃ solution, silica gel is precipitated. This freshly formed gel is unstable and begins to shrink, expelling water from the mass, undergoing the process known as syneresis. During syneresis no volume change occurs in the whole system, and the process consists simply in the expulsion of free liquid enmeshed in the gel, the shrinkage of the gel reducing the available pore space and false set. Delay the finishing—pressing the plastic concrete to close the cracks. b. Drying shrinkage: Rapid stage is due to thinning of air and water films separating the particles and consequent pulling together of solids by surface tension and loss of water by flow into the subgrade. Prevention lies in covering the concrete with damp sand, hessian, jute bags or straw so as to ensure adequate moist curing and keeping the subgrade damp. Slow stage is due to shrinkage of the gel with loss of water. Reduction in the cement and water content with proper curing minimises this shrinkage.

2. After hardening: These are: i Physical: a. Drying shrinkage: cause and remedy are as in iii b ‘slow stage’ above. b. Moisture movement: is due to alternate wetting and drying and use of inferior and porous aggregates. Use sound aggregates: ii Chemical: a. Carbonation: due to excess of lime, magnesia or sulphate in the cement and its reaction with CO₂ of air when exposed. Test the cement and keep the components within the limits fixed in the specification. b. Due to reactive aggregates: like pyrites and alkalies. The remedy is to limit the KOH and NaOH in cement to 0.5 to 0.6%. c. Foreign bodies and rust: The reinforcing bars are oxidised. Provide adequate cover and impermeable concrete. iii Thermal: a. Internal temperature stresses: are due to differential temperature caused by the heat of hydration of cement as in massive dams. Keep the heights of pours small, extend the period between successive lifts, use low heat cement, and adopt refrigeration for cooling. b. Use of aggregates having different thermal properties: c. External temperature variations: due to mix and outside temperature. Provide adequate expansion joints. d. Frost and ice action: due to water getting into outer pores and freezing subsequently. Provide dense and impermeable concrete. iv Stress con-
centrations: a. **Around reinforcement**: Minute hair cracks appear when concrete is stretched up to its elastic limit, ii when deformed bars are used, and iii when bars are bent. Prestress in case i and provide sufficient depth of concrete at points where the bars are bent in case iii. b. **In structural forms**: at square openings or re-entrant angles. Place the reinforcement suitably. c. **Due to creep**: under certain conditions of design and loading. v **Foundation settlement and accidents**: are due to overloading, excess vibration, fire, storm, and earthquake.

**Repair of cracks**: The above cracks can be classified as: i **Superficial**: These are harmless and consist of numerous hairlines on the surface. These are due to reasons given in 2 ii a above. The superficial crazing, which results, can be prevented as given in Pa 42 under ‘Crazing’. ii **Constructional**: These occur at construction joints if the joints have not been carefully done. But as these joints are at places of least bending moments and shear, the cracks will not produce any harmful effects. iii **Structural**: These are the most dangerous and may be due to excessive tensile, shear, or bond stresses caused either by direct loads or restrained shrinkage and temperature movements. In structures near the sea coast, the reinforcement may get corroded either due to a porous concrete cover or to electrolysis caused by stray electric currents, expand, and cause extensive cracks in the structure. To reduce the occurrence of such cracks, low shear and bond stress and close spacing of steel will have to be adopted. Cracked surfaces are also repaired by guniting (Pa 121).

**Vibrated Concrete**: When concrete is mixed in an ordinary concrete mixer, a considerable amount of air is trapped in the concrete. Its density is therefore reduced. It will be impossible to completely eliminate the air, however thoroughly the tamping (hand compaction be done. De-aerating of concrete by mixing the dry ingredients for two min. and then mixing for five minutes with admixture of water has been tried and found to produce concrete 5% denser than the concrete produced by the ordinary method. The modern high-frequency electric or pneumatic vibrators (giving \( \leq 3,000 \) and up to \( 5,000 \) impulses per min.) enable to place economically mixes which are impracticable to place by hand. Vibration sets the particles of concrete into motion, reduces friction between them, makes the air bubbles rise to the surface, effects a temporary liquefaction of the concrete and thus enables it to settle easily into place. It enables concrete of higher strength and better quality to be made. If the workability is such that the concrete can be placed by hand spading, there is no advantage in vibrating it. The full benefit of vibration can be realised only by using stiffer and harsher mixtures,
The advantages of reducing water content are: increased compressive and flexural strengths, increased density and water tightness, lower moisture absorption, increased resistance to weathering, better bond, less volume change, less tendency for segregation and bleeding, earlier removal of forms and more rapid placing of concrete. Since over-vibration leads to segregation, vibration should be stopped just when compaction is complete i.e., when the air bubbles which come to the surface stop and when the tone of the sound is constant. The surface texture also gives an indication.

The types of vibrators are: i Internal vibrator: which is commonly used, is of two types. In one type, the driving motor is housed with the vibrating element, which is inserted into the concrete. In the other type, the vibrating element is actuated through a flexible shaft by a motor which can be moved around at will. Satisfactory results are obtained by inserting the vibrators at points 12" apart and operating them for about 5 to 10 sec. in each location. ii Surface, float or shoe vibrator: is used principally to level off the surface of mass concrete which has been placed very stiff and consolidated by means of internal vibrators. Vibratory band screeds have been developed to aid in placing concrete in city pavements, bridge decks, sidewalks, etc. iii Shutter or form vibrator: is used extensively in the manufacture of precast concrete units such as pipes, joists, building units, and cast stone. It is also used in conjunction with internal vibrators for in situ concrete to ensure smooth surfaces. iv Vibrating table: is used only for precast products.

Reinforced Brickwork: The weak point in all brickwork is the adhesion between bricks and mortar and this defect brings about its crushing much earlier than the bricks and the mortar. The bulging and splitting, which causes tension, will be resisted by providing hoop reinf. of rods, flats, or metal lathing (B. R. C., Exmet, Briector, etc.,) in the brickwork (in cement mortar,) the compression being taken by the brickwork. Floors, roofs, staircases, etc., can be constructed in this manner. The advantages of this system are: i Simplicity of construction, requiring minimum formwork and shuttering for beams and slabs, ii Good work involving low maintenance charges, iii Fire proof, iv Neat and artistic in appearance, v Cool rooms, and vi Low
cost. It is very common in Central and Northern India.

Fig. 193, 194, and 195 show a wall, slab, and column. Slabs thicker than 6" are found to be very heavy and expensive for ordinary use. They are finished with lime concrete terracing for roofs and patent stone for floors. The lime concrete terracing is done after about a month while the stone flooring is done before removal of centering of the slab. The underside is finished with lime plaster which readily adheres to the surface of the bricks. Many arch bridges, walls, slabs, columns, stairways, retaining walls, silos, and storage bins have been built of reinforced brickwork.
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