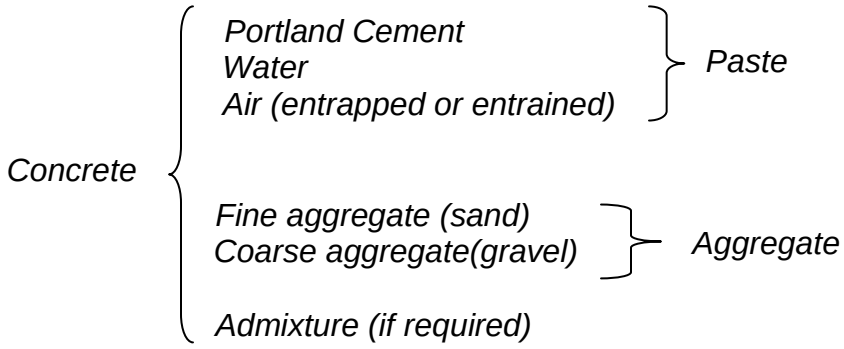
1. CONCRETE TECHNOLOGY

Concrete is a composite material made up of inert materials of varying sizes, which are bound together by a binding medium. Concrete contains coarse aggregate in addition to cement, water, air and fine aggregate. The cement, water, and air combine to from a paste that binds the aggregates together. Thus, the strength of concrete is dependent on the strength of the aggregate matrix bond.



The entire mass of the concrete is deposited or placed in a plastic state and almost immediately begins to develop strength (harden), a process which, under proper curing conditions, may continue for years. Because concrete is initially in a plastic state, it lends itself to all kinds of construction, regardless of size or shape.

TYPES AND USES OF CONCRETE

Concrete is a very versatile material and can be made to satisfy a large variety of requirements, whether it is used for foundations, floor slabs, monolithic walls cast in situ, or for prefabricating concrete blocks.

1. Plain mass concrete, with graded or predominantly small sized aggregate, for foundations, floors, paving, monolithic walls (in some cases), bricks, tiles, hollow blocks, pipes.

2. No-fines concrete, a lightweight concrete with only single size coarse aggregate (dense or lightweight) leaving voids between them, suitable for load bearing and non-load bearing walls, in-fill walls in framed structures or base coarse for floor slabs. No-fines concrete provides an excellent key for rendering, good thermal insulation (due to air gaps), and low drying shrinkage. The large voids also prevent capillary action.

3. Lightweight aggregate concrete, using expanded clay, foamed blast furnace slag, sintered fly ash, pumice, or other light aggregate, for thermal insulating walls and components, and for lightweight building blocks.

4. Aerated concrete, made by introducing air or gas into a cement-sand mix (without coarse aggregate), for thermal insulating, non-structural uses and lightweight building blocks. Disadvantages are low resistance to abrasion, excessive shrinkage and permeability. However, it is easy to handle and can be cut with a saw and nailed like timber.

5. Reinforced concrete, also known as RCC (reinforced cement concrete), which incorporates steel bars in sections of the concrete which are in tension (to supplement the low tensile strength of mass concrete and control thermal and shrinkage cracking), for floor slabs, beams, lintels, columns, stairways, frame structures, long-span elements, angular or curved shell structures, etc., all these cast in situ or precast. The high strength to weight ratio of steel, coupled with the fortunate coincidence of its coefficient of thermal expansion being about the same as concrete, make it the ideal material for reinforcement. Where deformed bars (which have ribs to inhibit longitudinal movement after casting) are available, they should be given preference, as they are far more effective than plain bars, so that up to 30 % of steel can be saved.

6. Prestressed concrete, which is reinforced concrete with the steel reinforcement held under tension during production, to achieve stiffness, crack resistance and lighter constructions of components, such as beams, slabs, trusses, stairways and other large-span units. By prestressing, less steel is needed and the concrete is held under compression, enabling it to carry much higher loads before this compression is overcome. Prestressing is

achieved either by pre-tensioning (in which the steel is stressed before the concrete is cast) or by post-tensioning (after the concrete has reached an adequate strength, allowing the steel to be passed through straight or curved ducts, which are filled with grout after the reinforcement has been tensioned and anchored). This is essentially a factory operation, requiring expensive, special equipment (jacks, anchorages, prestressing beds, etc.), not suitable for low-cost housing.

PROPERTIES OFCONCRETE

Concrete has many properties that make it a popular construction material. The correct proportion of ingredients, placement, and curing are needed in order for these properties to be optimal.

Good-quality concrete has many advantages that add to its popularity.

- It is economical when ingredients are readily available
- Concrete's long life and relatively low maintenance requirements increase its economic benefits
- Concrete is not as likely to rot, corrode, or decay as other building materials.
- Concrete has the ability to be molded or cast into almost any desired shape.
- Concrete is a non-combustible material which makes it fire-safe and able withstand high temperatures
- It is resistant to wind, water, rodents, and insects. Hence, concrete is often used for storm shelters.
- Building of the molds and casting can occur on the work-site which reduces costs.
- High compressive strength, resistance to weathering, impact and abrasion
- Low tensile strength (but can be overcome with steel reinforcement)

DISADVANTAGES OFCONCRETE

Some of disadvantages of concrete are:

- High cost of cement, steel and formwork (in developing countries)
- Difficult quality control on building sites, with the risk of cracking and gradual deterioration, if wrongly mixed, placed and insufficiently cured with water.
- In moist climates or coastal regions, corrosion of reinforcement (if insufficiently protected), leading to expansion cracks.
- Demolishing concrete is difficult.

INGREDIENTS OF CONCRETE

1. CEMENT

Usually, Portland cement is specified for general concrete construction work and should confirm to standard specifications. Various types of Portland cement as well as physical & chemical requirements were discussed in the previous course.

2. WATER

Water serves two purposes in making concrete. First of all, it triggers the hydration of cement and secondly, it makes the mix fluid and workable. Clean water is important for the same reasons as is clean aggregate; any impurities present will affect bond strength between the paste and aggregate.

Almost any water that is drinkable may be used to make concrete. Drinking water with a noticeable taste or odor should not be used until it is tasted for organic impurities.

Impurities in mixing water may cause any one or all of the following:

1. Abnormal setting time
2. Decreased strength
3. Volume changes
4. Efflorescence
5. Corrosion of reinforcement

Some of the impurities in mixing water that cause these undesirable effects in the final concrete are:

1. Dissolved Chemicals
2. Seawater

3. Sugar
4. Algae

Dissolved chemicals may either accelerate or retard the set and can substantially reduce the concrete strength. Further, such dissolved chemicals can actively attack the cement-sand bond, leading to early disintegration of the concrete.

Seawater containing less than three percent salt is generally acceptable for plain concrete but not for reinforced concrete. The presence of salt can lead to corrosion of the reinforcing bars and a decrease in concrete strength by some 10-15%.

If *sugar* is present in even small amounts, it can cause rapid setting and reduced concrete strength.

Algae can cause a reduction in the strength of concrete by increasing the amount of air captured in the paste and reducing the bond strength between the paste and the aggregate.

Although water is an essential ingredient, too much water added during mixing results in a weak concrete. Very little water is necessary to cause the hydration process. Therefore, as a general rule, no more water should be added than necessary to make the mix workable.

3. AGGREGATES

Aggregates are the filler materials which make up a large portion (roughly 70-75%) of the concrete volume. Considerable care should be taken to provide the best aggregates available.

Aggregate can be obtained from various sources; natural or manufactured. Natural aggregates are taken from natural deposits without change in their nature during production, with the exception of crushing, sizing grading, or during production.

In this group, crushed stone, gravel, and sand are the most common. Manufactured aggregates include blast furnace slag and lightweight aggregates.

AGGREGATE TERMS AND TYPES

The terms used to describe aggregates are many and varied. These descriptive terms are based on source, size, shape, type, use and other properties.

Some typical terms used in describing aggregates are:

1. ***Fine aggregate***- aggregate particles passing the No. 4 (4.75mm) sieve and retained on the No. 200 (75-μm) sieve.

2. ***Coarse aggregate***- aggregate predominantly retained on the No.4 (4.75mm) sieve.

3.***Crushed gravel (gravel and sand)-*** that has been put through a crusher either to break many of the rounded gravel particles to a smaller size or to produce rough surfaces.

4. ***Crushed rock***- aggregate from the crushing of rock. All particles are angular, not rounded as in gravel.

5. ***Screenings***- the chips and dust or powder that are produced in the crushing of rock for aggregates.

6. ***All-in-aggregate***- aggregate composed of both fine and coarse aggregate.

7. ***Concrete sand***- sand that has been washed (usually) to remove dust & fines.

8. ***Fines-*** silty-clay or dust particles smaller than 75 μm (No. 200 sieve) usually undesirable impurities in aggregates.

PROPERTIES OF AGGREGATES

Important properties of aggregates include:

- Gradation (grain size distribution)
- Shape and surface texture
- Bulk unit weight
- Specific gravity (relative density)

- Absorption
- Hardness (resistance to abrasion or wear)
- Durability (resistance to weathering)
- Crushing strength
- Cleanliness (deleterious substances)
- Chemical stability

1.Gradation

The gradation, or grain size distribution of the aggregate influences:

- the amount of paste required
- the workability of the concrete
- the strength and
- water tightness of the finished product.

In general, it is desirable that the size increase uniformly from fine sand to the maximum allowed for a given job.

Most specifications for concrete require a grain size distribution that will provide a dense, strong mixture.

Aggregates may be dense, gap-graded, uniform, well graded, or open-graded. The terms "dense" and "well-graded" are essentially the same, as are "gap", "uniform" and "open-graded"

The use of well graded mixture of aggregates results in improved workability of the concrete and economy of the cement since such aggregate has a decreased amount of voids between the particles and consequently requires less cement paste. For a given consistence & cement content, a well-grades aggregate produces a stronger concrete than a poorly graded one because less water required to give suitable workability.

SIEVE ANALYSIS

The grading or particle size distribution of aggregate is determined by sieve analysis.
The table below gives standard series of sieves of square openings, which are used in the sieve analysis of fine & coarse aggregates.

Standard size and square openings

Sieve Designation

Traditional	**Metric**
3″	75mm
2″	50mm
1 ½″	37.5mm
1″	25mm
¾″	19mm
½″	12.5mm
3/8″	9.5mm
No.4	4.75mm
No.8	2.36mm
No. 16	1.18mm
No. 30	600 μm
No. 50	300 μm
No. 100	150 μm
No. 200	75 μm

For sieve analysis, a sample of aggregate is first surface dried and then sieved though the series, staring with the largest. The weight retained on each sieve is recorded and the percentage computed. The summation of the cumulative percentage of the material retained on the sieves (not including the intermediate sieves) divided by 100 is called **fineness modulus (FM).**

Fineness modulus is used an index to the fineness or coarseness and uniformity of aggregate supplied, but it is not an indication of grading since there could be an infinite number of gratings which will produce a given fineness modulus.
Six sieves are used in the determination of fineness modulus of sand (Nos. 4,8,16,30,50 & 100). The smaller the value of the fineness modulus, the finer the sand.

The finesse modulus for good sand should range between 2.25 -3.25.
Very fine sand and very coarse sand are objectionable ,fine sand is uneconomical and coarse sand give harsh unworkable mixes .Fineness modulus of sand varies as under:

- Fine sand: 2.25 to 2.6
- Medium sand: 2.6 to 2.9

- Coarse sand: 2.9 to3.25

***Note**:* 2”**,** 1” ½” sieves are called “Intermediate” are not included for the fineness modulus calculations.

Maximum Size of Aggregate

It is not necessary that 100% of the particles of an aggregate be within the specified size range for construction purposes. A small amount, unusually 5% or 10% is allowed to be either larger or smaller than the specified size, as it would be economically impossible to ensure that 100% of the particles are within any specified range. Therefore, if 19mm (3/4”) is the maximum size of aggregate desired for concrete mix, specifications will indicate that the nominal maximum size is 19mm. In this case, 90% of the sample must be smaller than 19mm and 100% smaller than the next higher standard size, 25mm(1”).

Fine aggregate has a nominal maximum size of 4.75 (No.4 sieve) Therefore specifications will require that 100% of the aggregate pass the 9.5mm (3/6”) sieve, and 90 (or 95%) pass 4.75mm.

With a given sectional dimension of a concrete structural member and spacing of reinforcements, it is in general recommended to select the maximum possible size of aggregate.

The maximum size and grading are important because they affect:

1.The relative volume occupied by the aggregate, hence the economy in producing concrete

2.The surface area of the aggregate which determines the amount of water necessary to wet all the solids

3.The workability of the mixture

4.The tendency of segregation

5.The porosity & shrinkage

2. Shape and Surface Texture

The particle shape and the surface texture of aggregates influence the properties of fresh concrete more than those of hardened concrete. Sharp, angular, and rough aggregate particles require more paste to make good concrete than do rounded ones. Flat, slivery pieces make concrete more difficult to finish and should be limited to not more than 15 percent of the total. This requirement is particularly important for crushed fine aggregate, since material made in this way contains more flat and elongated particles.

3. Bulk Unit Weight

The bulk unit weight of an aggregate is the weight of the aggregate divided by the total volume occupied by it. The total volume includes the volume of aggregate particles and the volume of voids. In other words it is the amount of material which can be placed in a container of unit volume. The amount may vary, depending on the method used to fill the container, grading and shape of aggregates. The normal range of bulk unit weight for aggregates for normal-weight concrete is from 1200 to 1760 kg/m^3.

The range of aggregates that could be used in concrete is as follows: -

Heavyweight, Lightweight, Normal Weight

The highest volume of material in concrete is the aggregate and as consequence the properties of the aggregate can have a major influence on the performance and appearance of the concrete.

The majority of concrete that is placed uses normal weight aggregate, however heavyweight can be used for specialist nuclear shielding purposes and lightweight concrete applications include reduced weight and fire resistance.

4. Specific Gravity

The specific gravity of an aggregate is another characteristic of the material which needs to be determined. It is not a measure of aggregate quality but is used in making calculations related to mix design. The specific gravity of most normal weight aggregates will range from 2.4 to 2.9

5. Absorption:

Over a 24-hr period light weight aggregates may absorb water in the amount of 5 to 20 percent of their own dry weight ,depending on the type of aggregate and its pore structure .A tendency of this sort must be taken into account when concrete is made with light weight aggregate. To make light weight mixtures as uniform as possible, how ever, aggregates should be prewetted , but not saturated ,24 hr before they are to be used.

6. Moisture Content

Two types of moisture are recognized in aggregates: *absorbed moisture* and *surface moisture*. Absorbed moisture is that which is taken in by the voids in aggregate particles and may not be apparent on the surface, while surface moisture is that which clings to the surface of the particle.

The absorption and surface moisture of aggregate is need to be determined in order to control the net water content of a concrete mix and to make adjustments in batch weights of the materials. The moisture conditions of aggregates are designated as follows:

- ***Oven-Dry***: In this condition they are fully absorbent.
- ***Air-Dry***: Particles are dry at the surface but contain some interior moisture. They are therefore somewhat absorbent.
- ***Saturated Surface-Dry***: In this condition there is no water on the surface, but the particle contains all the interior moisture it will hold. It will neither absorb moisture from nor contribute moisture to the mix.
- ***Damp or Wet***: The particles contain an excess of moisture on the surface and will contribute moisture to a mix.

Surface moisture in fine aggregate is the cause of a phenomenon known as ***bulking of sand***. Surface moisture holds the particles apart, causing an increase in volume over the same amount of sand in a surface-dry condition. The amount of bulking will depend on the fineness of the sand.

The moisture present in the aggregate affects the total water needed for the mix. The ideal moisture is "saturated surface dry" wherein all pores of the material are filled with water but no free moisture exists on the surface. Most problems occur with the use of very wet or very dry fine aggregate.

Allowance must be made for the amount of water added under such conditions.

7. Crushing Strength and Durability

One measure of the strength of an aggregate is its resistance to freeze-thaw. This resistance is an important characteristic in concrete which is exposed to severe weather. The freeze-thaw resistance of an aggregate is related to its porosity, absorption, and pore structure. If a particle of the aggregate absorbs so much water that there is not enough pore space available, it will not accommodate the expansion which takes place when the water freezes and the particle will fail. Freeze-thaw tests on aggregates are commonly carried out on specimens of concrete made with the aggregate.

Another test of the strength of aggregates is their ability to withstand compressive stresses. This test is made by subjecting hardened concrete specimens made with the aggregate in question to compression testing.

Soluble, weak, or friable material must be avoided. As a rough guide, aggregates which have been tumbled down streams for sufficient distances to be well rounded and unbroken are strong and durable enough for concrete use. Strength can also be tested by cracking with a hammer.

8. Cleanliness (Deleterious Substances)

The cleanliness of the aggregate affects the bond between the paste and the aggregate surface, and therefore, affects the strength and water tightness of the concrete. Coarse aggregates may be checked visually.

Deleterious (harmful substances) have the following effects on concrete:

- Weaken bondage between cement paste and aggregates
- Interfere with hydration
- Reduce of strength and durability
- Affect water tightness of the concrete
- Modify setting action and
- Cause efflorescence

Examples: - Iron pyrites, coal, silt and clay, mica, chemical salts.

Iron pyrites affect concrete surfaces: staining and disruption of concrete paste. Coal affects appearance and strength of concrete. Dirt, silt and clay form coating on aggregates. If they are much in quantity, they affect strength and durability of aggregates and water demand for mixing. Mica is responsible for weak strength and durability. Chemical salts resulting in efflorescence.

Remedial measures:

- Washing to remove deleterious materials
- Avoiding aggregates with reactive tendency or using them with cement with low alkali.

SILT TEST

Fine aggregates can be checked by placing the material in a glass jar, which is then filled three-fourths full with clean 5 cm water and sealed. Turn the jar on its side and shake vigorously for one minute. Set the jar upright, level the sand by shaking sideways, and let it stand for about three hours. Any silt present will be suspended by the shaking and will settle back on the sand surface when allowed to stand. If more than (3mm) of silt skim is formed, then the sand is too dirty to form strong concrete. In the field, a simple test may be performed by rubbing a moist sample of sand between the palms. Suitable sand will leave the hands only slightly dirty.

A *colorimetric (organic impurity) test* determines whether fine aggregate contains injurious amounts of organic matter.

9. Hardness

The hardness of aggregates is expressed in terms of their resistance to abrasion. This characteristic is important if the aggregate is used in concrete intended for such purposes as heavy-duty floors. A common method of making this test is *the Loss Angeles abrasion test* and consists of placing a

specified quantity of the aggregate to be tested in a revolving steel drum. The percentage of material worn away during the test is then determined.

10. Chemical Stability

Aggregates need to be chemically stable so that they will neither react chemically with cement nor be affected chemically by outside influences. In some cases aggregates with certain chemical constituents react with alkalis in cement. This reaction may cause abnormal expansion and resultant cracking of concrete.

HANDLING AND STOCKPILING OF AGGREGATES

The purpose of appropriate handling and stock piling of aggregates is to avoid segregation of aggregates.

Precautions:

- Storing on hard and dry ground or on platforms of planks, sheets, lean concrete
- Storing separately each aggregate size in compartments
- Avoiding segregation of aggregates resulting from free fall
- Damping consignments at different places.

4. ADMIXTURES (ADDITIVES)

Admixtures for use in concrete are defined as "material added during the mixing process of concrete in small quantities related to the mass of cement to modify the properties in the fresh or hardened state".

Types of concrete admixture

The following are common types of admixtures:

- water reducing/plasticizing

- high-range water reducing/super plasticizing
- water retaining (Note: this type is intended to reduce bleeding from concrete)
- water resisting (Note: this type is frequently known as waterproofing admixture)
- air entraining
- set accelerating
- hardening accelerating
- set retarding

Admixtures are frequently used to help achieve the following properties:

- compressive strength
- consistence
- density
- air content
- strength development
- retarded stiffening
- resistance to water penetration
- other special properties (e.g. accelerated stiffening, high early strength development).

Properties of Concrete Admixture

Except in special cases such as high-strength concrete, the maximum dosage of concrete admixtures is limited to 50 g/kg cement. For low dosages of less than 2 g/kg cement, the admixture has to be dispersed in part of the mixing water.

There are general performance requirements applying to all admixtures; these include:

- effect on setting time
- effect on compressive strength
- effect on air content in fresh concrete

Other types of concrete admixtures in current use are:

- corrosion inhibiting

- shrinkage reducing
- for use in underwater concrete
- for use in precast concrete

Most admixtures are supplied as liquids as these are easier to dispense and disperse in the relatively small quantities used.

The performance of admixtures is determined by using reference concrete. The test mix (with admixture) is compared with the control mix (without admixture).

FRESH CONCRETE

Fresh concrete is also known as plastic concrete. The major Properties of concrete in its plastic state are (1) workability, (2)consistency,(3) segregation, (4) bleeding and (5) Stiffening and Setting .

PROPERTIES OF FRESH CONCRETE

1. Workability: Workability is ease of placing and resistance to segregation of concrete.
Factors that affect workability are:

- Water content
- shape of aggregates
- Grading of Aggregates
- Size of Aggregates
- Surface Texture of Aggregates
- Air entraining Agents.

If water content is increased in the concrete mix particles settle and bleeding occurs. Cement slurry can escape through joints of form works.

Large sizes of aggregates consume less quantity of water and less quantity of cement, and are therefore economical. Appropriate sizes depend on handling, mixing and placing equipment, thickness of section and enforcement.

Angular shape, flakiness, and elongation of aggregates reduce workability. Nonabsorbent aggregates and optimum percentage of fine aggregate contributes to workability .

In concrete mass, air entraining agents produce numerous air bubbles that act as rollers to decrease bleeding and segregation, and as a result increase workability.

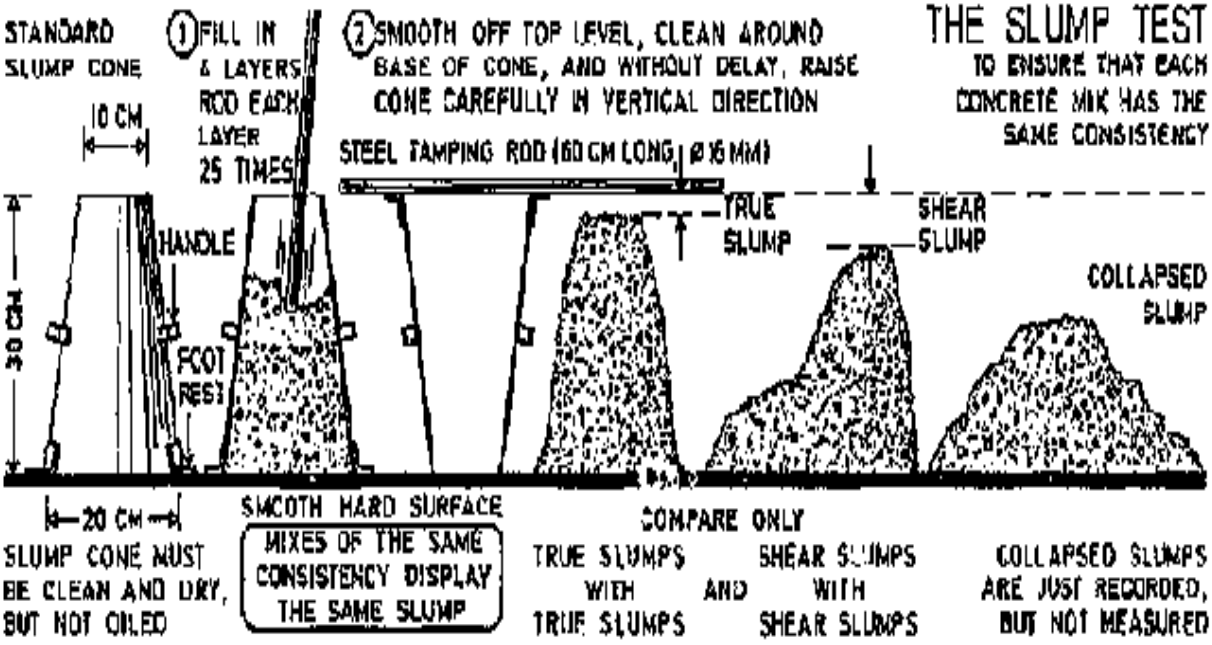
2. Consistency: refers to ease of flow of concrete and indicates wetness of concrete, and thus workability. Concrete could have dry, plastic, semi-fluid, and fluid consistency. concrete of plastic consistency can be shaped into ball, while that of semi-fluid consistency spreads out slowly and with out segregation of aggregate. Concrete of fluid consistency spreads out fast and results in segregation of aggregates, and hence unacceptable.

MEASUREMENT OF WORKABILITY

The methods *of* measuring workability, that is wetness or fluidity are slump test and compacting factor test.

Slump Test: Slump is the subsidence *of* concrete cone after mold is lifted up.
Slump test is made in laboratory and on site to measure subsidence *of* a pile *of* concrete in a mold (slump test apparatus *of* dimensions: base = 20 cm, top diameter = 10cm ,and height =30 cm.) compacted with a steel rod (16 mm long and 6Ocm long).
Types of slump (results of Slump)

- ***True Slump*** - Has even subsidence
- ***Shear Slump*** - Half *of* the cone slides, difficult to measure, and results from harsh mixes deficient in fine aggregates.
- ***Collapse Slump*** - difficult to measure, results from very wet mixes..



Permissible slumps for concrete mix are given as standard for different types of construction activities and placing conditions. The slump values shall be referred before using the concrete mix.

Slump test gives the advantage of detecting water content of successive batches of concrete of identical mix. However, there are some limitations of slump test. These are:

- Not applicable for aggregates size greater than 40 mm .
- Applicability to plastic mixes only
- Not applicable to harsh and wet mixes

Compacting Factor Test: drier mixes do not give slump. Therefore, compaction factor test should be done to determine degree of compaction (compacting factor) by falling the mix through successive hoppers with standard height using a compaction factor test apparatus.

$$\text{Compacting Factor} = \frac{\text{Weight of partially dry compacted concrete}}{\text{Weight of fully compacted concrete}}$$

Table. Permissible Values of Compacting Factor

Workability	Compacting factor
Good workability	0.95
Medium Workability	0.92
Low workability	0.85

For different placing conditions, degree of workability (extremely low, very low, medium, and high), and aggregate sizes, corresponding values of Compacting factor are given as standard to compare with.

For compacting factor values between 0.75-0.80, compacting concrete by had is not permissible. For Compacting Values less than 0.75, pressure should be exerted into concrete to vibrate.

Compacting factor test is suitable for both dry and wet mixes, since it gives constant results.

3. Segregation or separation of coarse aggregates from the mass of concrete results from:

- Uncontrolled pumping or falling
- Placing under waters
- Placing concrete in heavily reinforced members

Precautions to control segregation:

- Careful handling, pacing, and consolidation of concrete
- Placing concrete near its final position, instead of falling from greatest heights
- Applying air entraining agents

4. Bleeding: is the appearance of water on concrete surface. As a consequence of bleeding, slum layer will be formed making concrete weak and porous. Slum layer shall be removed before casting new layer.
Measures to minimize bleeding:

- Using well graded and proportioned aggregates
- Increasing amount of cement
- Applying air entering agents
- Reducing amount of water

5.<u>Stiffening and Setting</u>: Concrete is required to remain plastic for the time to be taken to transport, place, and consolidate it. Temperature influences the stiffening of concrete. That is, low temperature delays while high temperatureacce1erates.the stiffening of concrete.

VOLUME OF FRESH CONCRETE

The volume of the fresh concrete is equal to the sum of the absolute volumes of its components, including the naturally entrapped or purposely entrained air.

If V_a = Volume of the air

V_w = volume of the water

V_c= absolute volume of the cement

V_{fa} = absolute volume of the fine aggregate

V_{ca} = absolute volume of the coarse aggregate

Then the total volume of the fresh compacted concrete will be:

$$V = V_a + V_w + V_c + V_{ca} \quad \text{……(1)}$$

From the point of view of concrete technology it would be best to prescribe mix proportions by the "absolute volume" of the ingredients, because the volume of the resulting concrete and its properties are dependents on the, and not on their weight or bulk volume. But this is an impractical way to proportion materials, because the absolute volumes of the ingredients cannot be measured in the field.
However, the absolute volume can easily be calculated from the relationship of the weight and specific gravity of the material:

$$V = \frac{W}{1{,}000(G)} \qquad \text{.....(2)}$$

Where: V is the absolute volume in cu. m

W is the weight of the material in kg.

G is the specific gravity of the material.

1000 is the density or unit weight of fresh water in kg per cu. m.

The specific gravity of cement may be taken, for all practical purposes, equal to 3.15. for calculating the volumes of the aggregates we use their specific gravity (bulk, saturated surface dry basis), which is defined by " the ratio of the weight in air or the S.S.D. aggregates (i.e., including their voids) to the weight of an equal volume of water:

Substituting weight and specific gravities in equation (2) for absolute volumes in equation (1) we get the volume of concrete in cu. m as follows:

$$V = V_a + \frac{W_w}{1000} + \frac{W_c}{1000G_c} + \frac{W_{fa}}{1000G_{fa}} + \frac{W_{ca}}{1000G_{ca}} \qquad \text{.....(3)}$$

Where: V_a = as defined above, cu. M.

W_w= weight of water

W_c= weight of cement, kg.

W_{fa} = weight of fine aggregate, kg

W_{ca} = weight of coarse aggregate

If the cement, water, and air contents per cu. m. of fresh concrete are known, then the required weight of the aggregates for a cubic meter of fresh concrete can easily be calculated from Eq. (3).

If the cement and aggregates on the job are to be measured by volume, the weight proportion as obtained by the above procedure can be volumetric proportions. This is done dividing the weight of the cement and aggregates by their respective loose unit weights (in kg per cu. m) as obtained in the measuring devices on job conditions.

$$\text{Volume of Bulk Material} = \frac{Weight\ of\ \ Material, kg}{Unit\ weight, kg/cu.\ m}$$

Example:1

Given: quantities per cu. m of fresh concrete:

- Cement : 350 kg
- Water : 190 ℓ
- Air : 1% = 10ℓ
- Bulk sp. Gravity of aggregates = 2.65
- Specific gravity of cement = 3.15

Solution:

Absolute volume of air = 0.010 m^3

Absolute volume of water = $\frac{W_V}{1000} = \frac{190}{1000}$ = 0.190 m^3

Absolute volume of cement = $\frac{W_C}{1000(3.15)} = \frac{350}{1000(3.15)} = \frac{0.111}{0.311}$ m^3

Absolute volume of aggregates = 1.000 - 0.311 = 0.689 m^3
Weight of aggregates = 0.689 (2.65 x 1000) = 1825.85 kg

For convenience of calculation we can write the above in the form of the following table:

	Weight (kg)	**Absolute volume (m^3)**
Air	-	0.010
Water	190	0.190
Cement	350	0.111
Total	540	0.311
Aggregates	1826	0.689
Total	2366	1. 000

The above total weight of the concrete is the unit weight (in kg per m^3) of the fresh concrete.
If the proportion of the fine to coarse aggregate by weight is 1:2, then the quantities of aggregates will be:

Fine Aggregate (sand) : $\frac{1{,}826x1}{3} = 609\,kg$

Coarse Aggregate : $\frac{1{,}826x2}{3} = 1{,}217\,kg$

The mix quantities and proportions by weight will be

	Kgs	**Parts**
Water	190	0.543
Cement	350	1
Sand	609	1.74

C.A. 1,217 3.48

Or cement to aggregates 1:5.22

Example: 2

If the loose unit weights of the surface dry materials in example 1

Cement :1,300kg, per m^3 (under the given condition of measurement)
Sand (S. S. D) : 1, 600 kg, per m^3
C.A (S.S.D) :1,400kg

Then the total amount of dry materials in loose volume per cu. m of concrete are:

Cement 350: 1, 300 = 0.27 m^3
Sand 609 : 1, 600 = 0.38 m^3
C. A. 1,217: 1,450 = $\underline{0.84}$ m^3
Total loose volumes 1.49 m^3

The volume of loose aggregates needed for m^3. of concrete is 1.22 m^3., the mix proportions by volume are then:

$$\frac{0.190}{0.27} : \frac{0.27}{0.27} : \frac{0.38}{0.27} : \frac{0.84}{0.27}$$
$$0.703 \quad 1 \quad 1.41 \quad 3.11$$

Or cement to aggregates 1: 4.52

Example:3

If in example 1 the sand as delivered contains 3% free moisture on its surface and weights = 1, 200 kg/ m^3

When sand is delivered damp and contains free moisture on its surface. The film of water on the surface of the sand particles hold them apart and

prevent them from adjusting themselves to occupy a minimum volume. This causes a considerable increase in volume when measured loose, or a corresponding decrease in the unit weight. This phenomenon increase rapidly with increase in moisture content. The finer the sand, the more it will bulk.

The loose volume of fine aggregate needed for 1 cu. m of concrete will be:

$$609+\left(609*\frac{3}{100}\right):1{,}200=0.523 cu.m (instead of\ 0.38 cu.m)$$

When using damp sand the weight has to be increased by the percentage of free water in the sand. The amount of water added to the mix decreases accordingly:

Water = 190 - $190-\left(609*\frac{3}{100}\right):172\ell = 0.172\ cu.m$

The total volume of aggregates needed will be

0.84 + 0.523 = 1.363 cu. m

The mix proportions by volume (with damp sand)

0.172	0.27	0.523	0.84
0.27	0.27	0.27	0.27
0.638	1	1.94	3.11

Or cement to aggregates : 1: 5. 05

Failure to allow for the building of sand when batching volumetrically with reduce yield of concrete and result in an under sanded and harsh mix, which is difficult to place as may be seen from the following calculation:
If only 0.38 cu. m. sand is taken then the actual weight of sand in the mix will be:

(0.38 x 1200) - 3% (0.38x1200) = 456 - 14 = 442 kg

Its absolute volume: $\frac{442}{1000*2.65} = 0.167\, cu.\, m.$

and the volume of produced concrete will be:

	Weight	**Absolute volume**
Air	-	0.010
Water: (190-14)	176	0.176
Cement	350	0.111
Sand	442	0.167
C.A	1,217	0.460
Total	2,185 kg	0.924 m^3

The amount of cement per cu. m. $\frac{350}{0.924} = 380\, kg\ instead\ of$ 350 kg

As can be concluded from the above calculations, weight batching is much preferable to volume batching, because it is almost impossible to make exactly the correct allowance for bulking all the time. There are more factors involved like the shape the size of the measuring device and the person who fills it.

From the above results it is possible to calculate the cement factor (CF) and the yield (y) of the concrete. The cement factor for a concrete mix is the cement content expressed in terms of sacks of cement per cubic meter of concrete. In example 5.1 350 kg of cement is used to produced 1 cu. m of concrete; taking 50 kg as the weight of one sack of cement we have

$$CF = \frac{350}{50} = 7 sacks/cu.m.$$

The yield of concrete is the amount of fresh concrete in cu. m. Produced per sack of cement.

$$y = \frac{1}{7} = 0.143\, cu.m/sack$$

Exercises:

1 a) Determine a mix proportion for 120 liters of concrete with the following data.

Water = 175 kg/m^3
Cement = 300 kg/m^3
Specific gravity of cement = 3.15
Specific gravity of aggregates = 2.65
Moisture content of the fine aggregate = 2.4% by Wight
Use ratio of fine aggregate to coarse aggregate = 1:1.8 by wight
Assume air content to be at 1.6% by volume

b) Calculate the yield & the cement factor of the above mix proportion.

2) A concrete mix is designed using a proportion of 1:2.5.3.5 by weight and using a w/c ratio of 0.65:

Determine

a) The materials per meter cube of concrete
b) The yield
c) The cement factor

Use a specific gravity of cement as 3:15 and that of coarse and fine aggregate as 2.55.

MIX DESIGN

The purpose of a concrete mix design is to have economical mix proportions for the available concreting materials which complies with the contract specification in all respects and has adequate workability to be placed in it's final position on site.

Every combination of concreting materials will have it's own mix design and changes in sources of aggregates, binders and admixtures will have a significant effect on the performance and cost of a concrete. Concrete mix designs should not be used in other geographical areas with dissimilar properties of concrete materials.

Basic Relationship

Concrete proportions must be selected to provide workability, consistency, density, strength, and durability, for the particular application.

• ***Workability***: The property of the concrete that determines its capacity to be placed and consolidated properly and be finished without harmful segregation.

• ***Consistency***: It is the relative mobility of the concrete mixture, and measured in terms of the slump; the greater the slump value the more mobile the mixture.

• ***Strength***: The capacity of the concrete to resist compression at the age of 28 days.

• ***Water-cement (w/c) ratio***: Defined as the ratio of weight of water to the weight of cement this ratio is used in mix design and considerably controls concrete strength.

• ***Durability***: Concrete must be able to endure severe weather conditions such as freezing and thawing, wetting and drying, heating and cooling, chemicals, deicing agents, and the like. An increase of concrete durability will enhance concrete resistance to severe weather conditions.

• ***Density***: For certain applications concrete may be used primarily for its weight characteristics. Examples are counterweights, weights for sinking pipelines under water, shielding from radiation, and insulation from sound.

• ***Generation of heat***: If the temperature rise of the concrete mass is not held to a minimum and the heat is allowed to dissipate at a reasonable rate, or if the concrete is subjected to severe differential or thermal gradient, cracking is likely to occur."

Background Data

To the extent possible, selection of concrete proportions should be based on test data or experience with the materials actually to be used. The following information for available materials will be useful:

• Sieve analyses of fine and coarse aggregates.

• Unit weight of coarse aggregate.

• Bulk specific gravities and absorption of aggregates.

• Mixing-water requirements of concrete developed from experience with available aggregates.

• Relationship between strength and water-cement ratio or ratio of water-to-cement plus other cementitious materials.

• Specific gravity of Portland cement and other cementitious materials, if used.

• Optimum combination of coarse aggregates to meet the maximum density grading for mass concrete.

• Estimate of proportions of mix for preliminary design.

Table:1 Recommended slumps for various types of construction

Types of construction	Maximum Slump (mm)	Minimum Slump (mm)
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

Table:2 Mixing water and air content

NON-AIR-ENTRAINED CONCRETE								
Approximate mixing water (kg/m³) for indicated nominal maximum sizes of aggregate								
Slump (mm)	**9.5 mm**	**12.5 mm**	**19 mm**	**25 mm**	**37.5 mm**	**50 mm**	**75 mm**	**150 mm**
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	-
More than 175	-	-	-	-	-	-	-	-
Approximate amount of entrapped air in non-air-entrained concrete (%)								
Slump (mm)	**9.5 mm**	**12.5 mm**	**19 mm**	**25 mm**	**37.5 mm**	**50 mm**	**75 mm**	**150 mm**
All	3.0	2.5	2.0	1.5	1.0	0.5	0.3	0.2

Table:3 Water cement ratio

Relationship between water-cement or water-cementitious materials ratio and compressive strength of concrete	
Compressive strength at 28 days (MPa)	**Water-cement ratio by weight (Non-air-entrained concrete)**
40	0.42
35	0.47
30	0.54
25	0.61
20	0.69
15	0.79

Important! **Check the maximum permissible water-cement ratio from the Table below and revise the water-cement ratio entered in the box above accordingly.**

Table:4 Maximum permissible water-cement

Maximum permissible water-cement ratios for concrete in severe exposure		
Type of Structure	**Structure wet continuously and exposed to frequent freezing and thawing**	**Structure exposed to sea water or sulfates**
Thin section (railings, curbs, sills, ledges, ornamental work) and sections with less than 25 mm cover over steel	0.45	0.40
All other structures	0.50	0.45

Table:5 Coarse Aggregate Per Unit volume Of Concrete

Volume of oven-dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate				
Nominal maximum size of aggregate (mm)	**2.40**	**2.60**	**2.80**	**3.00**
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Mix Design Example:

Concrete is required for a portion of a structure that will be below a ground level in a location where it will not be exposed to severe weathering or sulfate attack. Structural considerations require it to have an average 28-day compressive strength of 24 MPa with slump of 75 to 100 mm. The coarse aggregate has a nominal maximum size of 37.5 dry-rodded mass of 1600 kg/m^3. Ordinary Portland cement will be used and its specific gravity is assumed to be 3.15. the coarse aggregate has a bulk specific gravity of 2.64 and an absorption of 0.5 percent. The fine aggregate has a bulk specific gravity of 2.64, an absorption of 0.7% and a fineness modulus of 2.8.

Solution:

Step 1 : The slump is required to be 75 to 100 mm.

Step 2 : The aggregate to be used has a nominal max size of 37.5mm

Step 3 : The concrete will be non-air entrained since the structure is not exposed to severe weathering. From table 2 the estimated mixing water for a slump of 75 to 100 mm in non air entrained concrete made with 37.5 aggregate is found to be 181 kg/m^3.

Step 4: The water-cement ratio for non-air entrained concrete with a strength of 24 MPa is found from table 3 to be 0.62.

Step 5 : From the information developed in step 3 and 4. the required cement content is found to be 181/0.62 = 292 kg/m^3.

Step 6 : The quantity of coarse aggregate is estimated from 5. For a fine aggregate having a finesse modulus of 2.8 and 37.5 mm nominal maximum

size coarse aggregate, the table indicated that 0.71 m^3 of coarse aggregate, on a dry-rodded basis, may be used in each cubic meter of concrete.
The required dry mass is therefore, 0.71*1600 = 1136 kg.

Step 7 : With the quantities of water, cement, and coarse aggregate established, the remaining material comprising the cubic meter of concrete must consist of fine aggregate and whatever air will be entrapped. The required fine aggregate may be determine on the basis of either mass or absolute volume as shown below.

Step 7.1 Mass basis: The mass of a cubic meter of non-air-entrained concrete made with aggregate having a nominal maximum size of 37.5 mm is estimated to be 2410kg.
Mass already known are:

Water (net mixing)	181 kg
Cement	292 kg
Coarse aggregate	1136 kg
Total	1609 kg

The mass of fine aggregate, therefore, is estimated to be 2410-1609 = 801 kg.

Step 7.2 Absolute volume basis: with the quantities of cement, water and coarse aggregate established, and the approximate entrapped air content (as opposed to purposely entrained air) of 1 percent determined from table 2 the sand content can be calculated as follows:

$$Volume\ of\ water = \frac{181}{1000} = 0.181 m^3$$

$$Solid\ volume\ of\ cement = \frac{292}{3.15*1000} = 0.093 m^3$$

$$Solid\ volume\ of\ coarse\ aggregate = \frac{1136}{2.68*1000} = 0.424 m^3$$

Volume of entrapped air = 0.01 * 1 = 0.010 m^3

Total solid volume of ingredients except fine aggregate 0.708 m^3

Solid volume of the aggregate required = 1- 0.708 = 0.292 m^3

Required weight of dry fine aggregate = 0.292*2.64*1000=771 kg

Step 7.3 Both masses per cubic meter of concrete calculated on the two bases are compared below:

	Based On Estimated Concrete Mass, Kg	**Based On Absolute Volume Of Ingredients, Kg**
Water (net mixing)	181	181
Cement	292	292
Coarse aggregate (dry)	1136	1136
Sand (dry)	801	771

Step 8 : Tests indicate total moister of 2% in the coarse aggregate and 6% in the fine aggregate. If the trial batch proportions based on assumed concrete mass are used, the adjusted aggregate masses become

Coarse aggregate (wet) = 1136 (1.02) = 1159 kg
Fine aggregate (wet) = 801 (1.06) = 849 kg

Absorbed water must does not become part of the mixing water and must be excluded from the adjustment in added water. Thus, surface water contributed by the coarse aggregate amounts to 2-05 = 1.5 percent; by the fine aggregate 6-0.7 = 5.3 percent

The estimated requirement for added water, therefore, becomes

181 - 1136 (0.015) - 801 (0.053) = 122 kg

The estimated batch masses for a cubic meter of concrete are:

Water (to be added)	122 kg
Cement	292 kg
Coarse aggregate (wet)	1159 kg
Sand (wet)	849 kg
Total	2422 kg

BATCHING

Batching is the process of measuring ingredients of concrete (cement, fine aggregates, coarse aggregate, and water).
There are two methods of hatching: Volumetric batching and Weight batching.

Volumetric Batching: One bag of cement bas a weight of 50 kg, and a volume of 35 Liters (O.O35m^3). It is not common to do cement batching by weight for a reason that the weight of one bag of cement can vary with the manner of filling the bag (loosely or compactly).

Depending on the proportion of mixing gauge box of varying sizes can be arranged. Generally, the capacity of one gauge is equal to the volume of one bag of cement (35liters or O.O3Sm^3)

In the volume batching, the gauge box should be filled by the aggregates and struck of level with straight edge.

Example:

For a concrete mix of 1 :2:4 (cement: sand: aggregates) by volume
Water cement ratio=0.6 by weight

Moisture content in fine aggregate=6%
Bulking of fine aggregate=20%by volume
Moisture content of coarse aggregate= 1. 5%

Find out quantities of different materials by volume to be mixed with one bag of cement

Solution:

Weigh Batching: is a method of measuring ingredients of concrete by weight Weigh batching is applicable for the production of high quality concrete. Weight batching is accurate compared to volumetric hatching.

In weigh batching there is no need of correction to allow for bulking of fine sand, but only correction to allow for the weight of water contained in wet aggregates.

Care should be taken to clean buckets to be used for weighing before filling ingredients. weighing machine should be leveled before weighing. Correction should be allowed for weights of aggregates and water in case of prevalence of surface water in aggregates.

Example:

Given,
Concrete mix=1 :2:3 by weight
water cement ratio=O.6% by weight
Moisture content in fine aggregates=6%
Bulking of fine aggregates=20%

Moisture content in coarse aggregate=1.5% by weight

Find out quantities of different materials by weight to be mixed with one bag of cement

Solution:

MIXING CONCRETE

The purpose of concrete mixing is to provide a uniformity blended product of cement, water, and aggregates. Concrete can be mixed using hand tools or

in power equipment of various sizes. Regardless of the type of process used, however, the principles are the same.

There should be an organized system for supplying cement, sand, aggregate, and water to the mixers. The actual mixing and pouring of concrete should be done in a continuous operation, without long delays between steps. Once the ingredients are mixed with water, the concrete should be used within 30 minutes.

For ***power mixing***, ingredients should be added as uniformly as possible. For example, some water would be followed by some cement, then sand, then aggregate, then the whole process is repeated until all the ingredients are mixed (everything must be in the right proportions, of course). Mixing should continue only until ingredients are thoroughly mixed, which usually takes about five minutes.

For ***hand mixing***, a proper mixing place should be set up with a mixing pad. This pad can be made the day (or two) before out of lean concrete, wood, or metal. It should be large enough to accommodate the largest amount of concrete that will be mixed at any one time and have raised edges around all sides.

When mixing, start with sand and cement in correct proportions. Mix them together thoroughly until a uniform color is reached. Next, the correct amount of water is added slowly, a small quantity at a time, and the mix is turned over numerous times until a smooth, consistent paste is formed. Lastly, the coarse aggregate is added and the entire mix turned over until the desired consistency is reached. For general use, the mix should be workable, of even consistency, and mushy rather than soupy.

An alternative hand mixing method is as follows: mix sand and cement together thoroughly on the mixing pad. Spread the mix out evenly and add the coarse aggregate. Mix thoroughly again, and form into a pile. Hollow out the top portion of the pile and slowly add small amounts of water while mixing all ingredients together. Continue mixing and adding water until the desired consistency is attained.

There is a natural tendency to over-wet hand mixed concrete, but this tendency can be avoided by measuring both the cement and water to maintain the desired water/cement ratio. Then, if the mix is too dry, add both water and cement in the proper ratio. If too wet, add sand and gravel

in proper proportions. If too stiff, add a small amount of sand, and if too sandy, add a small amount of cement.

Concrete could be produced:

- On site concrete plant operated by a readymixed concrete company
- Off –site concrete plant operated by a readymixed concrete company
- On site concrete plant operated by a contractor
- Off –site concrete plant operated by a precast concrete company
- On site concrete plant dedicated to supplying paving operations or other dedicated operations.

TRANSPORTING FRESH CONCRETE

Common methods of transporting concrete are

- Manual transport in iron pans, in wheelbarrows,
- Skip cars, trucks
- Conveyer, concrete pumps, etc,

While transporting, concrete must be protected from rain and snow. When transported to a long distant place, the concrete mix thickens due to cement hydration, absorption of water by the aggregate and evaporation.

Depending on the temperature of water-based concrete mixes when disposed from mixers, transporting time must not exceed 45 min.
Concrete handled by automobile trucks must be rigid or of low plasticity, because plastic mixes easily segregate when transported in drum trucks, and this results in a reduction in the strength of hardened concrete.

It is more convenient to transport plastic concrete in truck mixers. Readymixed concrete must be placed immediately on delivery without adding water to the mix.

FORMWORK

Formwork, which can be reused many times, is usually made of timber boards or steel panels, with joints sufficiently tight to withstand the pressure of compacted concrete, and without having any gaps through which the cement paste can leak.

The texture of the hardened concrete surface can be predetermined by the type of formwork. If smooth surfaces are needed, concrete remnants from previous castings should be scraped off the forms.

In order to facilitate removal, the inner surfaces of the formwork should be oiled with a brush or spray.

If reinforcement is required, it is placed in the formwork after oiling, and spacers (pieces of stone or broken concrete) are placed between the steel and the oiled surface, such that the formwork and steel do not come into contact with each other. This is needed to prevent the steel from remaining exposed on the concrete surface, where it can easily rust.

The choice of formwork must take into account ease of assembly and removal. In some cases, the formwork can be designed to remain in place (permanent shuttering); for example, where an insulating layer or special facing is needed, these can constitute the formwork (or part of it).

PLACING CONCRETE

The techniques used in placing concrete are another important consideration in the strength, water tightness, and appearance of the final product. The principal concern is to maximize the density of the concrete as it is placed, while not allowing one layer to dry before the next layer is placed. To maximize density, concrete should be mixed to the driest workable mix, using proper proportions of water, cement, and aggregates.

Care must be taken to prevent the segregation of the concrete ingredients. Segregation occurs when the majority of the coarse aggregate sinks to the bottom and excess water rises to the surface. This segregation can severely weaken the finished concrete and cause leaks in otherwise water tight structures. To avoid segregation, the concrete should be mixed as close as possible to its final location. It should never be dumped from a height. In deep forms, concrete should be laid vertically into place and not thrown against forms or piled in one location for spreading. Any throwing of

concrete is likely to produce segregation, and the higher the throwing force, the greater the segregation.

A general rule of pouring concrete is to minimize the unfinished surface area. This is the contact area between successive pours. For slabs, this means starting at one end and working outward, bringing each pour to finished elevation before expanding the work area. The concrete should be laid across the form in approximately 12 inch strips. Fresh layers of concrete should be placed down on the previous layer before that layer has had time to set (usually about 30 minutes).

For wall construction, the most desired strength characteristics are obtained from keeping the top of each pour horizontal. Therefore, for small structures each layer should be kept thin and work should progress continuously around the structure. The time for making a complete circuit should be kept to less than 30 minutes to prevent setting of previous layers.

When concrete is to be brought to finished elevation, it should be slightly overfilled, then struck off with a straight board screen, moved along the forms with a seesaw-like motion. This should be done as the work progresses so that the struck-off concrete can be incorporated in the structure.

In order to submerse all aggregate and provide a smooth finish, the concrete should be smoothed with a wood float 15 to 20 minutes after the concrete is struck off. Only a minimum of such work should be done at this time, because excess working will bring water to the surface and weaken the top layer. The excess water, known as bleeding, is commonly formed by the consolidation of concrete. If bleeding occurs, final work should be stopped until the excess water evaporates. Dry cement or sand should not be added to the surface to control the water. If heavy bleeding occurs, the water may be removed by light scraping or absorption into burlap.

Once the concrete has set so that heavy pressure exerted by a finger is required to make a small depression, the surface should be trowel to the desired smoothness using a steel trowel and heavy pressure to compact the concrete.

For sidewalks and other heavily traveled surfaces, a broomed or rough finish may be desired. After the concrete has been struck off and floated, a broom or brush is used to provide a textured finish. However, when sanitary

protection is desired, such as on a latrine slab, the surface should be as smooth as possible to facilitate cleaning.

CURING CONCRETE

Concrete gains strength by hydration, and hydration can continue only if sufficient moisture is present. To develop maximum strength, concrete must be cured, rather than being allowed to dry. The principle of curing is quite simple; moisture required for hydration must be kept in the concrete rather than being allowed to evaporate.

Curing means preventing evaporation by keeping the exposed surface of the concrete moist for a period of at least seven days. Curing of concrete is necessary to prevent surface evaporation of water during the setting and hardening stage. Curing concrete enables the concrete to reach its designed compressive strength, making the material more durable.

To cure correctly, concrete requires sufficient moisture content, a favorable temperature between 10 to 20 degrees centigrade, and time to reach its specified strength (a minimum of 7 days to reach 70%).

Studies show that hydration and consequent strength gain continue as long as moisture is present, even for a period of years. If hydration is stopped, strength gain is stopped. Freshly poured concrete should never be exposed to intensive sunlight.

Methods of curing

- Sprinkling or fog spraying. Keeping the surface continuously damp. (Alternate wetting and drying can cause cracking).
- Covering the concrete with wet straw, sawdust or sand. (Avoid materials that may cause discolor in the concrete).
- Covering the concrete with plastic sheeting. (White in hot weather, black in cold weather).
- Use curing compounds. (avoid using if the surface is to be painted or any other surface cover).

PROPERTIES OF HARDENED CONCRETE

The compressive strength of concrete is usually at least ten times its tensile strength, and five to six times its flexural strength. The principal factors governing compressive strength are given below:

- Water-cement ratio is by far the most important factor.
- The age of the cured concrete is also important. Concrete gradually builds strength after mixing due to the chemical interaction between the cement and the water. It is normally tested for its 28 day strength, but the strength of the concrete may continue to increase for a year after mixing.
- Character of the cement, curing conditions, moisture, and temperature. The greater the period of moist storage (100% humidity) and the higher the temperature, the greater the strength at any given age.
- Air entrainment, the introduction of very small air voids into the concrete mix, serves to greatly increase the final product's resistance to cracking from freezing-thawing cycles. Most outdoor structures today employ this technique.

The final strength of the finished concrete depends on:

1. The proportions of the components (i.e. whether the correct quantities of gravel, sand, cement and water have been used)
2. The quality of the components
3. The distribution of the grain sizes of the gravel and sand
4. The way the components are mixed
5. The way the mixture is transported, placed, compacted and cured

2.METALS

*In general, metals can be classified into two major groups: **ferrous** and **nonferrous**. A ferrous metal is one in which the principal element is iron, as in cast iron, wrought iron, and steel. A nonferrous metal is one in which the principal element is not iron, as in copper, tin, lead, nickel, aluminum, and refractory metals.*

Metals are not generally considered appropriate materials for low-cost constructions in developing countries as they are usually expensive, in most cases imported, and very often require special tools and equipment. However, only a very small percentage of buildings are constructed without the use of metals, either as nails, hinges, roofing sheets or reinforcement in concrete components.

SOURSES OF METALS

In general, over 45 metals of industrial importance are found within the earth's crust. With the exception of aluminum, iron, magnesium, and titanium, which occur in appreciable percentages within the earth's crust, all other metals comprise less than one percent of the earth's crust. Thus, most metals occur in the form of ore, in which the metal has to be extracted. An ore is usually referred to as a mineral, which is a chemical compound or mechanical mixture. The material associated with the ore which has no commercial use is referred to as gangue.
Basically, six classifications of ore exist:

1. Native metals
2. Oxides
3. Sulfides
4. Carbonates
5. Chlorides
6. Silicates

The native metals consist of copper and precious metals. Oxides are the most important ore source, in that iron, aluminum, and copper can be extracted from them. Sulfides include ores of copper, lead, zinc, and nickel. Carbonates include ores of iron, copper, and zinc. The chlorides include ores

of magnesium, and the silicates include ores of copper, zinc, and beryllium.

PRODUCTION OF METALS

Four operations are required for the production of most metals:

1. Mining the ore
2. Preparing the ore
3. Extracting the metal from the ore
4. Refining the metal

In the mining operation, the methods of open-pit borrowing and underground mining are both utilized.
In the preparation process the ore is crushed and large quantities of gangue are removed by a heavy-media-separation method. In some cases, the preparation of the ore may involve roasting or calcining. In roasting, the ore of sulfide is heated to remove the sulfur and in calcining the carbonate ores are heated to remove carbon dioxide and water.
The extraction of the metal from the ore is accomplished through chemical processes. These chemical processes reduce the compounds, such as oxides, by releasing the oxygen from chemical combinations and thus freeing the metal.
Basically, three types of processes of extraction are used:

1. Pyrometallurgy
2. Electrometallurgy
3. Hydrometallurgy

In the pyrometallurgy process (generally referred to as *smelting)* the ore is heated in a furnace producing a molten solution, from which the metal can be obtained by chemical separation. The blast furnace or reverberatory furnace is used in this process.

In the electrometallurgy process metals are obtained from ores by electrical processes utilizing an electric furnace or an electrolytic process.

Hydrometallurgy or *leaching* involves subjecting the ore to an aqueous solution from which the metal is dissolved and recovered. As a result of the extraction process, the metals will contain impurities, which must be removed by a refining process. If the metal was extracted by the pyrometallurgy process, the most common method of refining is by oxidizing the impurities in a furnace: (steel from pig iron). However, other methods

are utilized, such as liquidation (tin), distillation (zinc), electrolysis (copper), and the addition of a chemical reagent (manganese to molten steel).

FERROUS METALS

Ferrous metals comprise three general classes of materials of construction:

1. Cast iron
2. Wrought iron
3. Steel

All of these classes are produced by the reduction of iron ores to pig iron and the subsequent treatment of the pig iron to various metallurgical processes. Both cast iron and wrought iron have fallen in production with the advent of steel, as steel tends to exhibit better engineering properties than do cast and wrought iron. The application of steel and steel alloys is so widespread it has been estimated that there are over a million uses.

In construction, steel has three principal uses:

1. Structural steel.
2. Reinforcing steel.
3. Forms and pans.

CLASSIFICATION OF IRON AND STEEL

Iron products may be grouped under six headings:

1. Pig iron
2. Cast iron
3. Malleable cast iron
4. Wrought iron
5. Ingot iron
6. Steel

Pig iron*:* is obtained by reducing the iron ore in a blast furnace. This is accomplished by charging alternate layers of iron, ore, coke, and limestone in a continuously operating blast furnace*.* Blasts of hot air are forced up through the charge to accelerate the combustion of coke while raising the temperature sufficiently to reduce the iron ore to molten iron. The limestone is a flux which unites with impurities in the iron ore to form slag.

The blast furnace accomplishes three functions:

1. Reduction of iron ore
2. Absorption of carbon
3. Separation of impurities

The amount of carbon present in pig iron is usually greater than 2.5 percent but less than 4.5 percent. The iron may be cast into bars, referred to as *pigs.*

Cast iron: is pig iron re-melted after being cast into pigs or about to be cast in final form. It does not differ from pig iron in composition and it is not in a malleable form.

Malleable cast iron: is cast iron that has undergone special annealing treatment after casting and has been made malleable or semi malleable.

Wrought iron: is a form of iron that contains slag, is initially malleable but normally possesses little to no carbon, and will harden quickly when rapidly cooled.

Ingot iron: is a form of iron (or a low-carbon steel) that has been cast from a molten condition.

Steel: is an iron-carbon alloy which is cast from a molten mass whose composition is such that it is malleable in some temperature range. Carbon steel is steel that has a carbon content of less than 2 percent and generally of less than 1.5 percent; its properties are dependent on the amount of carbon it contains.

MANUFACTURE OF STEEL

As previously stated, the first process in the manufacture of steel is the reduction of iron ore to pig iron by use of a blast furnace. This is followed by the removal of impurities, and four principal methods are used to refine the pig iron and scrap metal:

1. Open-hearth furnace
2. Bessemer furnace

3. Electric furnace
4. Basic oxygen furnace

STRUCTURE OF IRON AND STEEL

Carbon Steel: is an alloy of iron and carbon. The carbon atoms actually replace or enter into solution among the lattice structure of the iron atoms and limit the slip planes in the lattice structure. The amount of carbon within the lattice determines the properties of the steel.

- ***Cast irons*** are alloys of iron, carbon (in excess of 2 %), silicon, manganese and phosphorus. They have relatively low melting points, good fluidity and dimensional stability.
- ***Wrought iron*** is pure iron with only 0.02 to 0.03 % carbon content, is tough, ductile and more resistant to corrosion than steel, but is expensive and unsuitable for welding, so that it has almost completely been replaced by mild steel.
- ***Steels*** are all alloys of iron with carbon contents between 0.05 and 2 %, and with additions of manganese, silicon, chromium, nickel and other ingredients, depending on the required quality and use. These steel products, including structural steel and reinforcing steel, can be rolled and molded into a shape. However, as the carbon content goes above 2.0 percent, the material becomes increasingly hard and brittle.

    - ***Low carbon steels***, with less than 0.15% carbon, are soft and used for wire and thin sheet for tin plate.
    - ***Mild steels***, with 0.15 to 0.25 % carbon, are the most widely used and versatile of all metals. They are strong, ductile and suitable for rolling and welding, but not for casting.
    - ***Medium carbon steels***, with up to 0.5 % carbon, are specialist steels used in engineering.
    - ***High carbon steels***, with up to 1.5 % carbon, have high wear resistance, are suitable for casting, but difficult to weld. They can be hardened for use as files and cutting tools.
    - ***Structural Steel***

      It is obvious that the steel must have strength, toughness, and, above all, durability. The requirements for structural steel are many. In most cases the maximum percent of carbon is less than 0.27, but most structural steels average 0.2 percent.

- ***Reinforcing Steel***

  As was explained in part one concrete exhibits great compressive strength but little tensile or flexural strength. Thus, deformed bars of structural steel are embedded in the concrete to take up the tensile or flexural forces. These deformed bars have been developed in such a way as to force the concrete between the deformations such that failure in shear will occur before slippage.

IMPURITIES IN STEEL

The principal impurities in steel are silicon, phosphorus, sulfur, and manganese. The amount of silicon in structural steel is less than 1 percent and forms a solid solution with iron. This small amount of silicon increases both the ultimate strength and the elastic limit of steel with no appreciable change in its ductility. Silicon may further prevent the solution of carbon in iron.

The phosphorus in steel is in the form of iron phosphide (Fe_3P). For low-grade structural steel the amount of phosphorus is about 0.1 percent and decreasing to 0.05 percent for high-grade structural steel. Tool steel is approximately 0.02 percent phosphorus.
Sulfur in steel combines with the iron to form iron sulfate (FeS). This compound has a low melting point and segregation may take place.
Manganese has an affinity for sulfur and combines with such as well as with other impurities to form slag. In other words, manganese acts like a cleanser. Manganese is used to harden steels.

HEAT TREATMENTS

Hardening or Quenching

Whenever a solid solution, such as steel, decomposes due to a falling temperature into the eutectoid, the decomposition may be more or less completed, depending on the cooling rate. This process is utilized in the hardening of steel. If the steel is cooled slowly, the changes just discussed will take place; however, if the steel is cooled too quickly, decomposition into the eutectoid will be prevented and a structure called martensite is produced rather than steel. Martensite is a hard structure with little ductility (a necessary property in steels).

The successful hardening of steel may be achieved by the application of three general principles:

1. Steel should always be annealed before hardening, to remove forging or cooling stains
2. Heating for hardening should be slow.
3. Steel should be quenched on a rising, not on a falling temperature.

Quenching media vary, but are basically of three types:

1. Brine for maximum hardness.
2. Water for rapid cooling of the common steels.
3. Oils (light, medium, or heavy) for use with common steel parts of irregular shapes or for alloy steels.

All hardened steel is in a state of strain, and steel pieces with sharp angles or grooves sometimes crack immediately after hardening. For this reason, tempering must follow the quenching operation as soon as possible.

Tempering

Tempering of steel is defined as the process of reheating a hardened steel to a definite temperature below the critical temperature, holding it at that point for a time, and cooling it, usually by quenching for the purpose of obtaining toughness and ductility in the steel.

Annealing

Annealing has basically the opposite objective of hardening. Annealing has the process of heating a metal above the critical temperature range, holding it at that temperature for the proper period of time, and then slowly cooling. During the cooling process, pearlite, ferrite, and/or cementite form.
The objectives of annealing are:

1. To refine the grain.
2. To soften the steel to meet definite specifications.
3. To remove internal stresses caused by quenching, forging, and cold working.
4. To change ductility, toughness, electrical, and magnetic properties.
5. To remove gases.

PHYSICAL PROPERTIES OF STEELS

In general, and as previously mentioned, three principal factors influence the strength, ductility, and elastic properties of steel:

1. The carbon content.
2. The percentages of silicon, sulfur, phosphorus, manganese, and other alloying elements.
3. The heat treatment and mechanical working.

1. Carbon content

The various properties of different grades of steel are due more to variations in the Carbon content of the steel than to any other single factor. Carbon acts as both a hardener and a strengthener, but at the same time it reduces the ductility.

2. Percentage of Silicon, Sulfur, Phosphorus, and Manganese

The effect of silicon on strength and ductility in ordinary proportions (less than 0.2 percent) is very slight. If the silicon content is increased to 0.3 or 0.4 percent, the elastic" limit and ultimate strength of the steel are raised without reducing the ductility. This is i a procedure used for steel castings.

Sulfur within ordinary limits (0.02 to 0.10 percent) has no appreciable effect upon the strength or ductility of steels. It does, however, have a very injurious effect upon the properties of the hot metal, lessening its malleability and weldability, thus causing difficulty in rolling, called "red-shortness."

Phosphorus is the most undesirable impurity found in steels. It is detrimental to toughness and shock-resistance properties, and often detrimental to ductility under static load.

Manganese improves the strength of plain carbon steels. If the manganese content is less than 0.3 percent, the steel will be impregnated with oxides that are injurious to the steel. With a manganese content of between 0.3 and 1.0 percent, the beneficial effect depends upon the amount of carbon content. As the manganese content rises above 1.5 percent, the metal becomes brittle and worthless.

3. Effect of Heat Treatment upon Physical Properties

The effects of various heat treatments upon the mechanical properties of wrought or rolled carbon steels of various compositions are discussed in the previous section

ALLOY STEELS

Alloy steels are steels that owe their distinctive properties to elements other than carbon. Common alloys include chromium, nickel, manganese, molybdenum, silicon, copper, vanadium, and tungsten.

These alloys can be classified into two groups: those which combine with the carbon to form carbides, such as nickel, silicon, and copper, and those which do not combine with carbon to form carbides, such as manganese, chromium, tungsten, molybdenum, and vanadium.

Alloys are added to steel for three principal reasons:

1. To increase hardness.
2. To increase the strength.
3. To add special properties, such as
   a. Toughness.
   b. Improved magnetic and electrical properties.
   c. Corrosion resistance.
   d. Machinability.

Chromium

Chromium is primarily a hardening agent and is generally added to steel in amounts of 0.70 to 1.20 percent, with a variation in carbon content of 0.17 to 0.55 percent. Its value is due principally to its property of combining intense hardness after quenching with very high strength and elastic limit. Thus, it is well suited to withstand abrasion, cutting, or shock. It does lack ductility, but this is unimportant in view of its high elastic limit. Chromium steels corrode less rapidly than do carbon steels.

Nickel-Chromium

Nickel-chromium steels, when properly heat-treated, have a very high

tensile strength and elastic limit, with considerable toughness and ductility. The nickel content is usually 3.5 percent, with a carbon content ranging from 0.15 to 0.50 percent.
One very important property of nickel-chromium steels is that by adding aluminum, cobalt, copper, manganese, silicon, silver, or tungsten, stainless steel results.

Manganese

As previously indicated, manganese is present in all steels as a result of the manufacturing process. When the manganese is 1.0 percent or greater in solution with steel, it is considered an alloy. Manganese will add hardness to steel if used within the proper range.

Molybdenum

Molybdenum provides strength and hardness in steel. It inhibits grain growth on heating as a result of its slow solubility of austenite. When in solution in the austenite, it decreases the cooling rate and, therefore, increases the depth of hardening.

Silicon

Silicon is added to carbon steel for the purpose of deoxidizing. For this reason, silicon may be added in amounts of up to 0.25 percent. Silicon does not form carbides but does dissolve in the ferrite up to about 15 percent.

Vanadium

Vanadium is a powerful element for alloying in steel. It forms stable carbides and improves the hardenability of steels. Vanadium promotes a fine-grained structure and promotes hardness at high temperatures. The amount of vanadium present is 0.10 to 0.30 percent when used.

Copper

Copper increases the yield strength, tensile strength, and hardness of steel. However, ductility may be decreased by about 2 percent. The most important use of copper is to increase the resistance of steel to atmospheric corrosion.

Tungsten

Tungsten increases the strength, hardness, and toughness of steel. After moderately rapid cooling from high temperatures, tungsten steel exhibits remarkable hardness, which is still retained upon heating to temperatures considerably above the ordinary tempering. heats of carbon steels. It is this property of tungsten that makes it a valuable alloy, in conjunction with chromium or manganese, for the production of high-speed tool steel.

NONFERROUS METALS

In this section, various nonferrous metals will be listed with only a brief statement; specific details will be omitted. Basically, three groups of nonferrous metals exist. In the first group, those of greatest industrial importance, are aluminum, copper, lead, magnesium, nickel, tin, and zinc. The second group includes antimony, bismuth, cadmium, mercury, and titanium. The third and final group, important in that they are used to form alloy steels, includes chromium, cobalt, molybdenum, tungsten, and vanadium.

- ***Aluminum***, the most common element, but difficult to recover as a metal (produced with very high energy input and high costs), is the lightest metal, has good strength, high corrosion resistance, high thermal and electrical conductivity, and good heat and light reflectivity. Aluminum and its alloys have numerous applications in building construction, but their high costs and limited availability in most developing countries makes them less appropriate building materials.
- ***Copper*** is an important non-ferrous metal, available in its pure form, or as alloys, such as brass, bronze, etc., and suitable for a large number of special uses, but with few applications in low-cost constructions.
- ***Lead,*** mainly used in its pure form, is the densest metal, but also the softest, and thus weakest metal. Its good corrosion resistance makes it useful for external applications, eg in roofing (flashings, gutters, etc.), but rarely in low-cost constructions. Its high toxicity makes it a less recommended material, especially where alternatives are available, as for pipes and paint pigments.

- ***Cadmium, chromium, nickel, tin, zinc*** and a few other metals are mainly used as constituents of alloys to suit a variety of requirements, or as coatings on less resistant metals to improve their durability, a common example being galvanization (zinc coating) of corrugated iron sheets (gci). The nonferrous alloys of the greatest importance are alloys of copper with tin (***bronzes***), alloys of copper with zinc (***brasses***), and alloys of aluminum, magnesium, nickel, and titanium.

CORROSION AND WEAR

Most metals associated with construction materials come in contact with water which contains dissolved oxygen or with moist air and enter into solution readily. The rate of solution is usually retarded by a film of hydrogen forming on the metal or by coating the metal with a protective coating. However, oxygen will combine with the hydrogen and over a period of time will strip it away from the metal, and thus further corrosion will result.

Metals under stress, especially those beyond their elastic strength, corrode more rapidly than do unstressed metals.

In nearly all cases the failure of materials by mechanical wear under abrasion occurs gradually, the progress of wear is evident, and the failure is not a definitely defined event but one whose occurrence is a matter of judgment on. the part of the user of the material. Failure by wear rarely leads to disaster, and usually involves repair or replacement of a part.

Five classifications of corrosion for metals exist:

1. Atmospheric.
2. Water immersion.
3. Soil.
4. Chemicals other than water.
5. Electrolytic.

In atmospheric corrosion a large excess of oxygen is available and the rate of corrosion is largely determined by the quantity of moisture in the air and the length of time in contact with the metal.

When metals are immersed in water, the amount of oxygen dissolved in the

water is an important factor. If the water does not contain any dissolved oxygen, the metal will not corrode. If the water is acidic, the corrosion rate is increased, whereas water that is alkaline has very little corrosion activity unless the solution is highly concentrated.

In soil corrosion and in corrosion by chemicals other than water, the most important item is the ingredient coming in contact with the iron or steel.
Corrosion by electrolysis due to stray currents from power circuits may be disastrous, but in nearly all cases it can be prevented by suitable electrical precautions.

PREVENTING CORRSION

The most common protective coating against corrosion for iron and steel is paint. The paint coating is usually mechanically weak and it cracks and wears out. Thus, to do a satisfactory job, the paint must be renewed every 2 or 3 years. Before the structure is painted, it should first be cleaned and the rust removed.
If the structure is to be immersed in water or if it comes in contact with water, paint provides little protection. Thus, the portion that is in contact with water might require a coating of asphalt or coal tar to protect it.
Another excellent method of preventing corrosion is to encase the iron or steel in concrete. Although concrete is porous, it will provide adequate protection for years. However, if the concrete becomes cracked, it loses most of its protecting ability and should be replaced if possible, or patched.

APLICATIONS OF METALS

- Structural steel components (columns, beams, joists, hollow sections, etc.) for complete framed structures, or individual elements, such as lintels, trusses, space frames and the like.
- Sheets, usually corrugated for stability, for roofs (mainly galvanized corrugated iron, less commonly corrugated aluminum sheets), walls (infill panels or cladding), sun-shades, fencing, etc.
- Plates, strips or foil for flashings (e.g. steel, copper, lead), fastenings (as in timber trusses) and facing (for protection against physical damage or for heat reflection).
- Steel rods, mats, wire mesh for reinforcement in concrete. The use of deformed bars (twisted or ribbed) gives higher mechanical bond between steel and concrete, reducing construction costs by up to 10

%. Mild steel wires of 6.5 to 8 mm, drawn through a die at normal temperatures, producing 3,4 or 5 mm wires, have twice their original tensile strength and low plasticity, and are used in making prestressed concrete components, saving 30 to 50 % of the steel.

- Wire of various types and thicknesses, e.g. steel wire for tying steel reinforcements or other building components together, copper wire for electrical installations and thick galvanized steel, aluminum or copper wire for lightning conductors.
- Galvanized steel wire mesh or expanded metal (made by slotting a metal sheet and widening the slots to a diamond shape) as a base for plaster or for protection of openings.
- Nails, screws, bolts, nuts, etc., usually galvanized steel, for connections of all kinds of construction components, formwork, scaffolding and building equipment.
- Rolled steel sections or extruded aluminum sections of various profiles for door and window frames, shading devices, fixed or collapsible grilles.
- Ironmongery of all kinds, e.g. hinges, handles, locks, hooks, various security devices, handrails, etc.
- Pipes, channels, troughs for sanitary, electrical, gas installation.
- Construction tools and equipment.

- Miscellaneous metal components for tanks, furniture, outdoor facilities.

ADVANTAGES OF METALS

- Most metals have high strength and flexibility, can take any shape, are impermeable and durable.
- Prefabricated framed construction systems of steel or aluminum are assembled extremely quickly. With strong connections, such systems can be very resistant to earthquake and hurricane destruction.
- Roofing sheets are easy to transport without damage, easy to install, require minimum supporting structure, permit large spans, are relatively light, are wind- and waterproof, and resistant to all biological hazards. In most developing countries they have a high prestige value.
- Many concrete constructions are only possible with steel reinforcements.
- Similarly, there are often no alternatives to certain uses of metals, e.g. electrical installations; screws, bolts, etc.; tools; security devices

DISADVANTAGES OF METALS

- High costs and limited availability of good quality metal products in most developing countries. As a result, inferior quality products are supplied, e.g. extremely thin roofing sheets, insufficiently galvanized components.
- With regard to roofing sheets: lack of thermal insulation (causing intolerable indoor temperatures, especially with extreme diurnal temperature fluctuations); condensation problems on the underside of roofs (causing discomfort, unhealthy conditions and moisture related problems, such as corrosion and fungal growth); extreme noise during rainfall; tendency of thin sheets to be torn off at nailed or bolted points (particularly those without or with only small washers) under strong wind forces; havoc caused by whirling sheets that have been ripped off in hurricanes.
- Poor fire resistance of most metals: although they are non-combustible and do not contribute fuel to a fire or assist in the spread of flames, they lose strength at high temperatures and may finally collapse.
- Corrosion of most metals: corrosion of ferrous metals in the presence of moisture and some sulfates and chlorides; corrosion of aluminum in alkaline environments; corrosion of copper by mineral acids and ammonia; corrosion of various metals by washings from copper; corrosion by electrolytic action due to contact of dissimilar metals.
- Toxicity of some metals: lead poisoning through lead water pipes or paints containing lead; toxicity caused by fumes emitted when welding metals coated with or based on copper, zinc, lead or cadmium.

Remedies

- Cost reduction by limited use of metals and design modifications which permit the use of cheaper alternative materials.
- To counteract heat and condensation: avoidance of sheet metal roofs in areas of intense solar radiation and large temperature fluctuations; double layer roofs with ventilated air space and absorptive lower layer; reflective outer surface.
- To prevent corrosion: avoidance of use in moist conditions; periodic renewal of protective coating; in case of dissimilar metals, prevention of contact with non-metallic washers; avoidance of contacts between aluminum and cement products (mortar or concrete).

- For noise reduction: shorter spans and coating of bitumen on underside of roofing sheet; also careful detailing of suspension points, and application of insulating layers or suspended ceiling.
- For resistance to uplift: thicker gauged sheets and stronger connections.
- To reduce toxicity: avoidance of lead or lead compounds where they may come into contact with food or drinking water; good ventilation of rooms in which toxic fumes are produced.

TESTING AND EVALUATION OF METALS

Tests are conducted on materials of construction in order to determine their quality and their suitability for specific uses in machines and structures. It is necessary for the producer, consumer, and the general public to have tests for the determination of quantitative properties of materials such that the material may be properly selected, specified, and designed. Tests are further needed to duplicate materials and to check upon the uniformity of different shipments.
Testing and evaluation of the many various metals and alloys requires hundreds of tests and specifications.

TIMBER

Timber is not only one of the oldest building materials, along with stone, earth and various vegetable materials, but has remained until today the

most versatile and, in terms of indoor comfort and health aspects, most acceptable material.

However, timber is an extremely complex material, available in a great variety of species and forms, suitable for all kinds of applications. This diversity of timber products and applications requires a good knowledge of the respective properties and limitations as well as skill and experience in order to derive maximum benefits from timber usage.

Although only a small proportion of the timber harvested is used for building, the universal concern about the rapid depletion of forests, especially the excessive felling of large old trees (which take hundreds of years to replace) and the great environmental, climatic and economic disasters that follow deforestation, has led to a great deal of research into alternative materials and rationalized utilization. Since timber cannot be completely replaced by other materials, it shall long remain one of the most important building materials, and hence great efforts are required to maintain and renew timber resources with continuous, large scale re-afforestation programs.

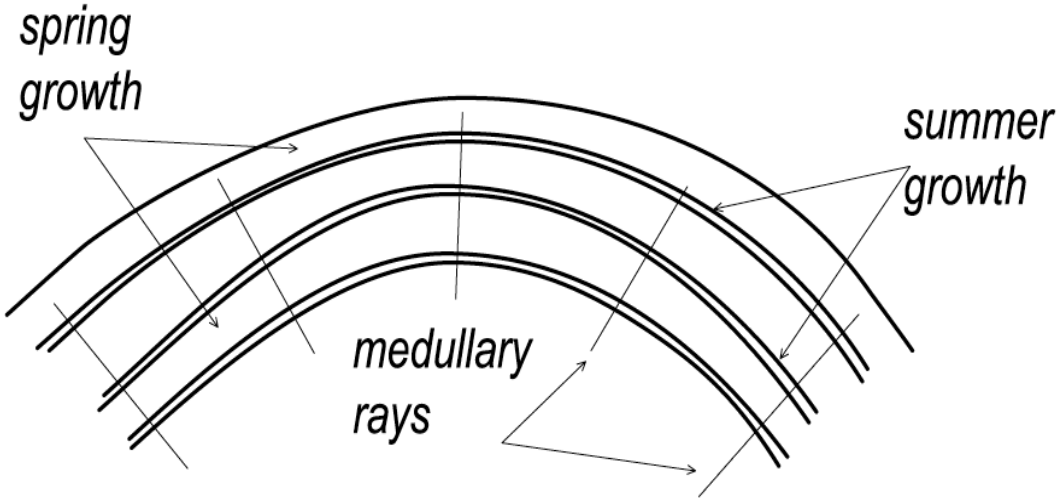
CLASSIFICATION OF TREES

There are two main groups of timber producing trees used commercially; softwoods and hardwoods. These terms immediately create contention because they do not accurately describe the timber correctly.

Softwoods

Softwoods are coniferous trees and the timber is not necessarily 'soft'. They are 'evergreen'. Their general characteristics are: Straight, round but slender, tapering trunk. The crown is narrow and rises to a point. It has needle like or scale-like shaped leaves and it's fruit, i.e. it's seeds are carried

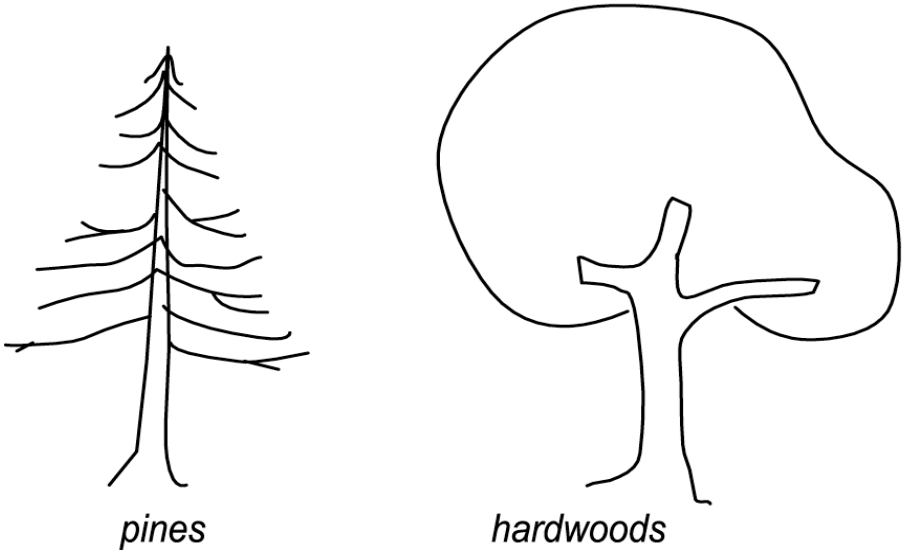
in cones. The bark is course and thick and softwoods are evergreen and as such do not shed their leaves in autumn.



Enlarged softwood section showing annual growth

Hardwoods

Hardwood trees are broadleaf and generally deciduous. Their timber is not necessarily hard. for instance, balsa (the timber used for making model planes) is a hardwood. The general characteristics are: Stout base that scarcely tapers but divides into branches to form a wide, round crown. The leaves are broad and may have single or multi lobes. The bark may be smooth or course and varies in thickness and colors. Its fruit may be: nuts, winged fruits, pods, berries, or fleshy fruits.



General characteristics

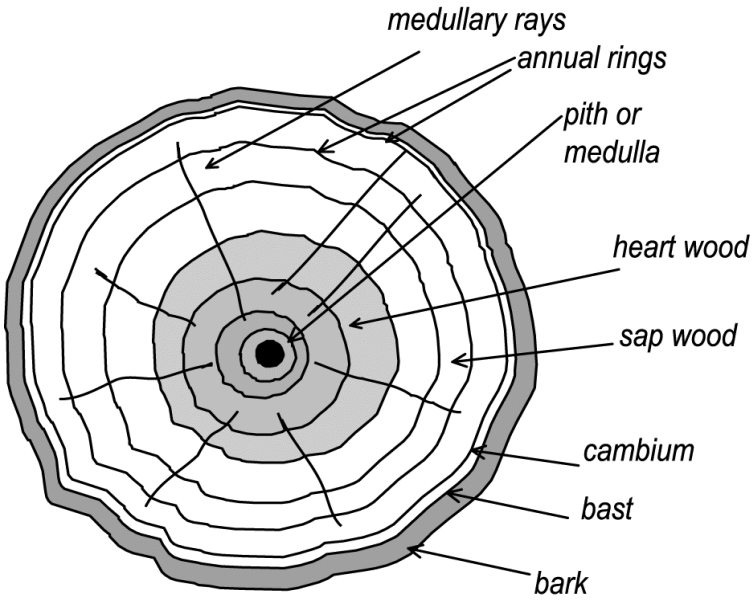
Timber for building construction is divided into two categories: primary and secondary timber species.

Primary timbers are generally slow-grown, aesthetically appealing hardwoods which have considerable natural resistance to biological attack, moisture movement and distortion. As a result, they are expensive and in short supply.

Secondary timbers are mainly fast-grown species with low natural durability, however, with appropriate seasoning and preservative treatment, their physical properties and durability can be greatly improved. With the rising costs and diminishing supplies of primary timbers, the importance of using secondary species is rapidly increasing.

TIMBER GROWTH

***Annual or growth rings*:** in temperate climates there are two distinctive growth seasons, spring and summer ~ the spring growth is rapid and is shown as a broad band whereas the hotter, dryer summer growth shows up narrow. In tropical countries the growth rings are more even and difficult to distinguish.



The tree trunk showing growth rings

***Bark*:** the outer layer, corklike and provides protection to the tree from knocks and other damage.

Bast: the inner bark, carries enriched sap from the leaves to the cells where growth takes place.

***Cambium*:** layer of living cells between the bast and the sapwood.

Crown: the branches and leaves that provides its typical summer shape.

Heartwood: mature timber, no longer carries sap, the heart of the tree, provides the strength of the tree. Usually a distinctive darker color than the sapwood.

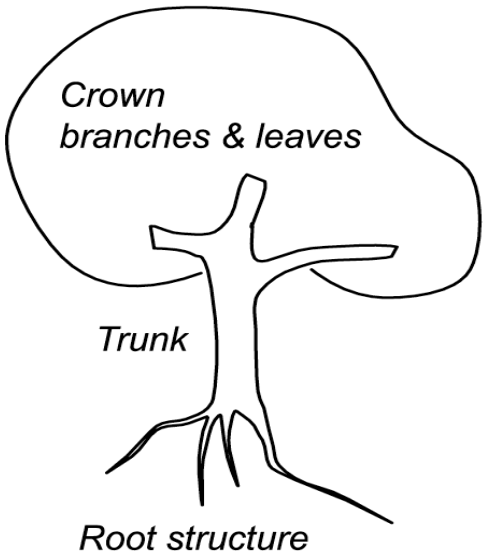
Medullaray rays: food storage cells radiating from the medulla ~ provides a decorative feature found in quarter cut timber.

Pith or medulla: the centre of the tree, soft and pithy especially in the branches.

Sapwood: new growth, carries the raw sap up to the leaves. Usually lighter in color than the heartwood, especially in softwoods.

Trunk: main structure of the tree, produces the commercial timber.

Root structure: Absorbs water and minerals from the soil. It is the anchor of the tree.



SEASIONING OF TIMBER

Seasoning is the process by which the moisture content of timber is reduced to its equilibrium moisture content (MC) (between 8 and 20 % by weight, depending on the timber species and climatic conditions). This process, which takes a few weeks to several months (depending on timber species and age, time of harvesting, climate, method of seasoning, etc.),

Seasoning makes the timber suitable for the environment and intended use. We need to reduce the MC of timber for the following reasons:

- Makes the timber more resistant to biological decay, increases its strength, stiffness and dimensional stability, and reduces its weight (and consequently transportation costs).
- Seasoned timber show fewer tendencies to warp, split or shake.
- Seasoned timber although lighter will be stronger and more reliable.
- The sap in timber is a food for fungi and wood parasites. Remove the sap and the wood will be less attractive to these dangers.
- For construction grade timber the timber must be below 20% MC to reduce the chances of Dry Rot and other fungi infestations.
- Dry and well seasoned timber is stronger.
- Dry and well seasoned timber is easier to work with and consequently safer especially machine working.
- Timber with higher moisture content is difficult to finish i.e. paint, varnish, etc.

There are two main ways of seasoning timber, Natural (Air) and Artificial (Kiln) drying. Both methods require the timber be stacked and separated to allow the full circulation flow of air, etc. around the stack.

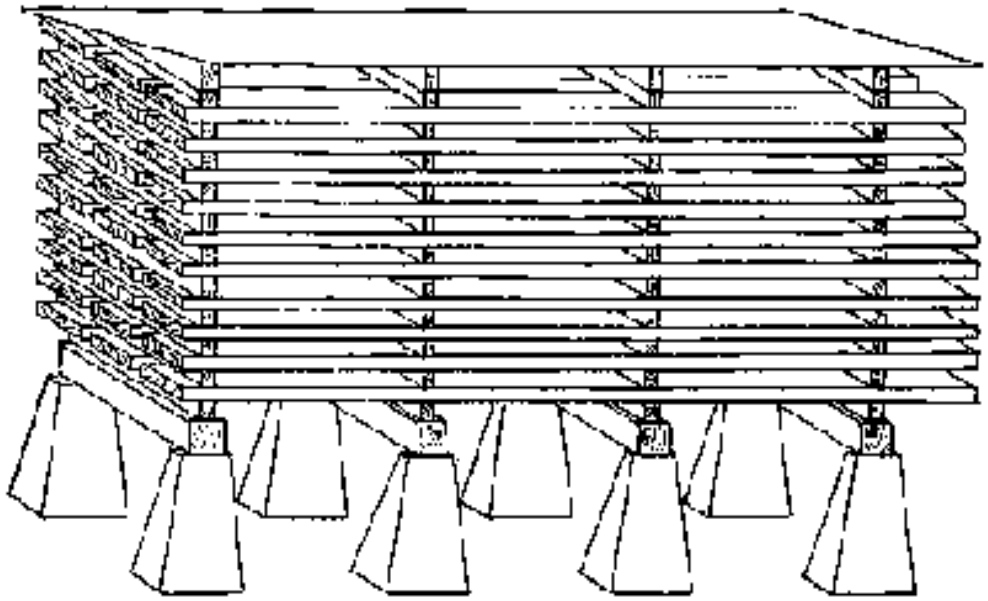
Air Seasoning

Air seasoning is done by stacking timber such that air can pass around every piece. Protection from rain and avoidance of contact with the ground are essential.

Forced air drying is principally the same as air seasoning, but controls the rate of drying by stacking in an enclosed shed and using fans. Seasoning time is greatly reduced if the timber is harvested in the dry or winter season, when the moisture content of the tree is low.

Air seasoning requires the following:

- Stacked stable and safely with horizontal spacing of at least 25 mm.
- Vertical spacing achieved by using timber battens (piling sticks) of the same or neutral species. Today some timber yards are using plastics. The piling sticks should be vertically aligned and spaced close enough to prevent bowing say 600 to 1200 mm max centers.
- Ends of boards sealed by using a suitable sealer or cover to prevent too rapid drying out via the end grain.
- The stack raised well clear of the ground, vegetation, etc to provide good air circulation and free from rising damp, frost, etc.
- Over head cover from effects of direct sunlight and driving weather.



Figure

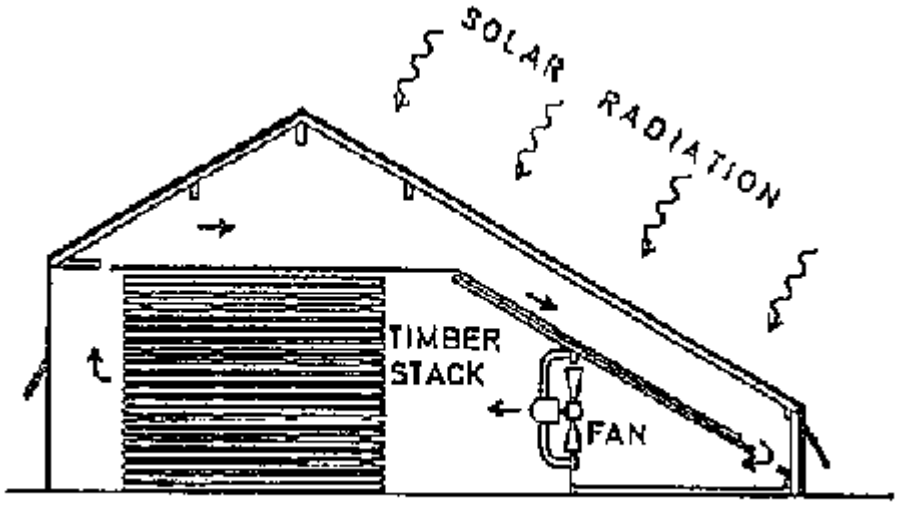
Kiln Seasoning

There are two main methods used in artificial seasoning, *compartmental*, and *progressive*. Both methods rely on the controlled environment to dry out the timber and require the following factors:

- Forced air circulation by using large fans, blowers, etc.
- Heat of some form provided by piped steam.
- Humidity control provided by steam jets.

The amount and duration of air, heat and humidity again depends on species, size, quantity, etc.

Kiln seasoning achieves accelerated seasoning in closed chambers by heating and controlling air circulation and humidity, thus reducing the time by 50 to 75 %, but incurring higher costs. An economic alternative is to use solar heated kilns.



Solar timber seasoning kiln

Compartmental kiln

A compartment kiln is a single enclosed container or building, etc. The timber is stacked as described above and the whole stack is seasoned using a program of settings until the whole stack is reduced to the MC required.

Progressive kiln

A progressive kiln has the stack on trolleys that 'progressively' travel through chambers that change the conditions as it travels through the varying atmospheres.

The advantage of this system, although much larger, has a continuous flow of seasoned timber coming off line.

PRESERVATIVE TREATMENT

Seasoning alone is not always sufficient to protect timbers secondary from fungal decay and insect attack. Protection from these biological hazards and fire is effectively achieved by preservative treatments with certain chemicals.

There are many chemicals, used singly or in combination, which preserve timber against insect and/or fungal attack. Preservative treatment does not affect the weathering of timber and for most species, some form of surface finish such as a paint, varnish or stain is needed to maintain the appearance, especially when timber is used outdoors.

Preservatives fall into two main groups:

1. Tar oils

Creosote is the most commonly used type. However, its smell, dark color and tendency to bleed out of the treated wood, make it generally only suitable for outside uses such as fence posts and transmission poles.

2. Preservative treatment

Chemicals can be applied to timber using a variety of methods including pressure impregnation, hot and cold soaking, dipping, spraying and brushing. Pressure treatment is the most effective though the pressure vessel imposes limitations on the size and shape of the components which can be treated. The degree of penetration of the chemicals into the timber depends upon the permeability of the species and the treatment regime. The sapwood is always more permeable than the heartwood.

When considering preservative treatment of timber, it should be remembered that timber is the healthiest of all building materials and it is paradoxical to "poison" it, especially when other methods can be implemented to protect it, for instance, with non-toxic preservatives and good building design (exclusion of moisture, good ventilation, accessibility for periodical checks and maintenance, avoidance of contact with soil, etc.).

TIMBER PROPERTIES

Timber, as a natural material is variable. It is its variability which provides the inherent visual attraction of the material. The disadvantages of variability are overcome by selection or grading processes and by the application of safety factors in structural calculations.

The density of timber varies between different species, between timber from different trees of the same species and even within the same tree. The cell structure of a species determines whether it is inherently light in weight or dense and heavy. The rate of growth of the tree also has an influence; fast grown timber will be less dense than slow grown material. The strength of timber is broadly related to its density.

Durability

The durability of timber is a measure of its resistance to attack by insects and fungi.

The most effective means of preventing fungal attack is to ensure that the moisture content of timber remains below 22% when there is not enough moisture for the fungus to survive. Insect attack is often associated with fungal decay.

Some woods, such as teak and European oak have greater natural durability than others. This natural protection is provided by chemical substances in the wood which are repellent or toxic to insects and fungi. However, it is primarily the heartwood which is protected. The sapwood of most species is susceptible to attack if above 22% moisture content. Resistance to attack by insects and fungi can be enhanced by the application of preservative treatments.

Permeability

Permeability is an important factor in the treatment of timber with chemicals such as preservatives and flame retardants. Permeability varies enormously between species although the sapwood of all species is more permeable than the heartwood.

Fire resistance

Fire resistance is an important consideration in using timber. Although wood is used as a fuel, large sections of timber are difficult to ignite and the charcoal produced on the surface provides protection for the wood underneath. The rate at which timber chars is predictable and is little

affected by the severity and temperature of the fire. It is affected by the density and to a lesser extent by the moisture content of the timber section. The uncharred parts of timber sections retain their integrity and mechanical properties - timber does not melt or expand.

Timber has the unique advantage amongst structural materials in that fire protection can be achieved by additional 'sacrificial' material since the structural integrity of the remaining uncharred section is not affected.

Strength

The structural strength of timber is a measure of its ability to resist outside forces, such as compression, tension and shear. The density is reliable indicator of many structural and mechanical properties. There is a particularly strong relationship between density and compressive strength, bending strength and hardness and a fairly reliable relationship between density and stiffness.

Density ranges from an average of 160 kg per cubic meter for balsa to 1040 kg per cubic meter for greenheart, with the most commonly used structural softwoods having a density between 450 and 550 kg per cubic meter. There is a marked difference in strength properties depending upon whether they are measured parallel to or perpendicular to the grain of the timber. The tensile strength of most timbers parallel to the grain is three to four times the compressive strength. The tensile strength parallel to the grain can be thirty times as high as perpendicular to it, while for compressive strength the ratio is of the order of six to one.

Factors affecting strength

The range of strengths between species varies as much as their densities. The strongest hardwood species such as greenheart is almost eight times as strong in bending and almost six times as strong in compression as the weakest, such as balsa.

The strength of a piece of timber is also affected by characteristics such as knots, direction and slope of grain (diagonal or sloping grain reduces strength, particularly bending and stiffness), moisture content (generally timber is more flexible when wet but increases in strength as it dries): distortion can occur due to stresses as the timber dries, and ruptures of the

tissue, such as splits checks and shakes can also result. Biological degrade can be caused by insect or fungal attack. Natural defects such as bark or pitch pockets, compression fractures and brittle heart can also have an effect on strength.

DEFECTS OF TIMBER

Since timber is a natural product, developed through many years of growth in the open air, exposed to continual and varying climate conditions, it is prone to many defects.

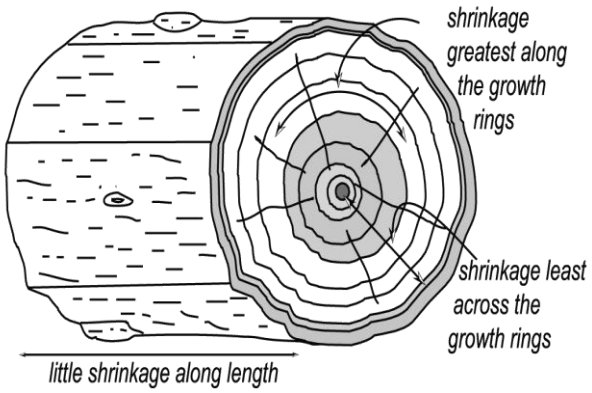
Defects cannot be corrected and therefore each individual piece must be inspected before use and judged on its own merits. Defects can be caused during growth, during drying, through insects, through fungi or during subsequent handling or machining, and each should be known, so that imperfect pieces can be detected and rejected.

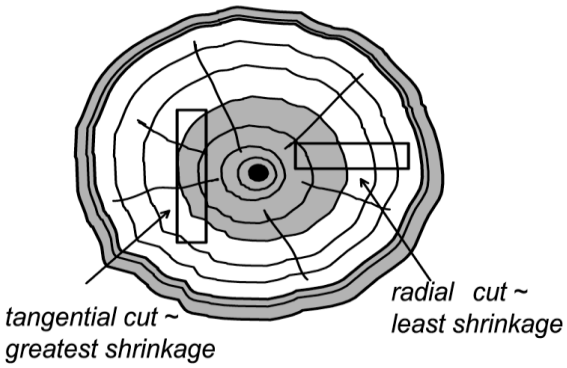
1. Shrinkage

When timber is seasoned and it's moisture content (MC) is reduced below the Fiber Saturated Point (FSP) continued drying will cause dramatic change such as increase in strength but also distortion and shrinkage.

Shrinkage is the greatest tangentially over the radial direction with little loss along the length of the board, etc.

The shrinkage of wood is a common feature and varies according to the direction of shrinkage: radial shrinkage is about 8 % from the green to the dry state; the corresponding tangential shrinkage is about 14 to 16 %; in the longitudinal direction shrinkage is negligible (0.1 to 0.2%).

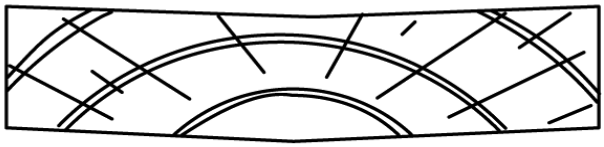




2. Cupping

Because of this varying shrinkage rates tangential boards tend to cup because of the geometry of the annual rings shown on the end grain. It can be seen that some rings are much longer than the others close to the heart. Therefore they will be more shrinkage at these parts than the others ~ cupping is the result.

In square section timber cut from the same place, diamonding is the result.



typical 'cupping' of tangential board showing the bulge of the heart and the cup towards the older wood

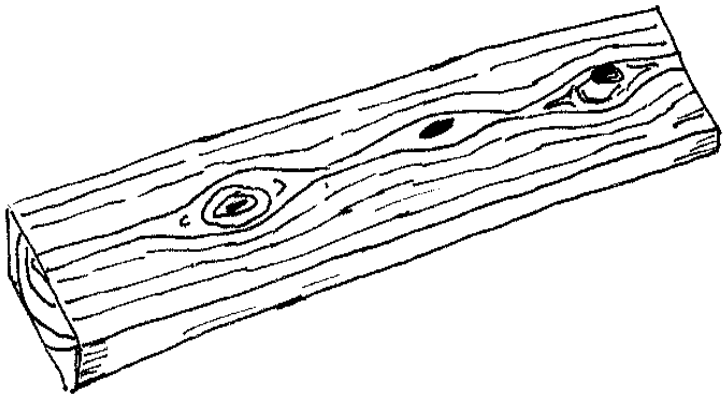
3. Knots

Knots are the result of the trees attempt to make branches in the early growth of the tree. They are the residue of a small twig, shoot, etc. that died or was broken off by man or an animal in the wood or forest. The tree subsequently continued its growth over this wood.

The knot may be live, sound, or tight or if it has become separated and is contained in residue of bark, dead.

Dead knots become loose and downgrade the appearance and stability of the board. Most grading systems uses the amount of knot area as an indication of its quality. The more knots the less the quality.

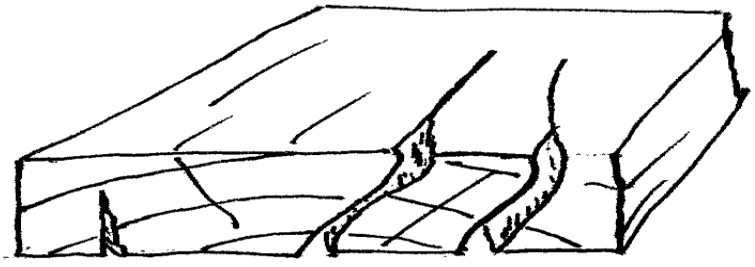
Dead loose knots are extremely dangerous to machinists. The cutters may pick these up and eject them rapidly towards the operator.



4. Splits

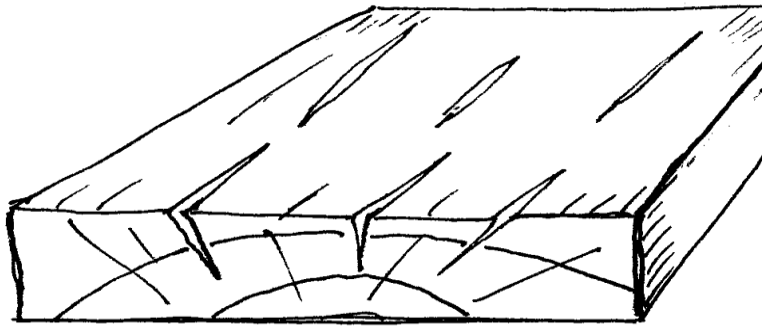
A separation of the wood fibers along the grain forming a fissure that extends through the board from one side to the other.

It is usual in end grain and is remedied by cutting away the defected area. All boards should have an allowance so that some end grain may be cut away because of possible shakes or splits.



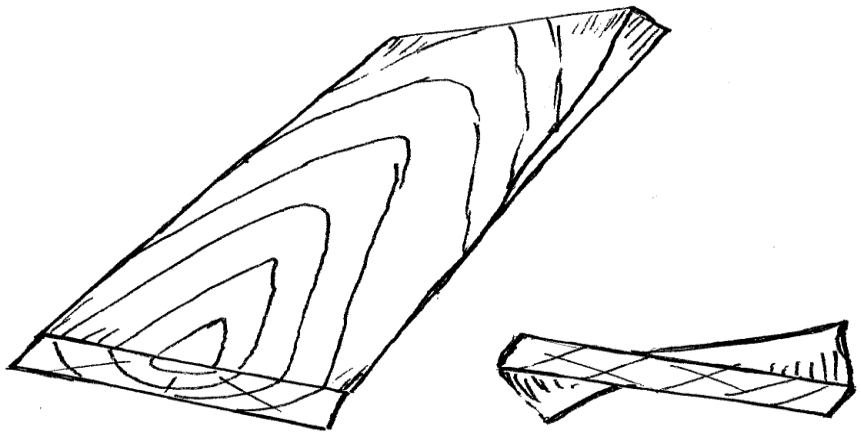
5. Checks and end checking

A separation of the fibers along the grain forming a fissure which shows up on one face or at the end grain but does not continue through to the other side.



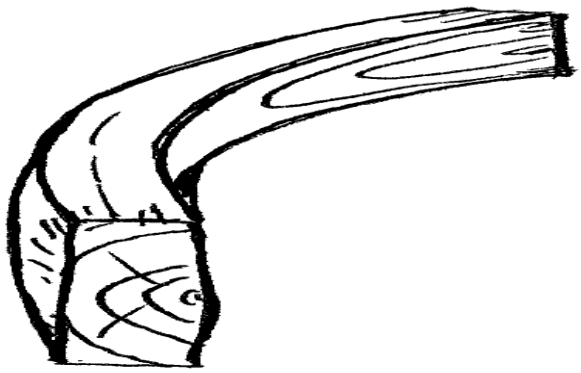
6. Wind or Twisting

Spiral or corkscrew distortion in a longitudinal direction of the board. Due to the board being cut close to the centre of the tree which has spiral grain. The board is of not much use but small cuttings may be obtained from it with careful selection.



7. Bow

Bowing is concave/convex distortion along the length of the board. It is a seasoning and or storage defect caused by the failure to support the board with stickers at sufficient intervals. The boards own weight and probably those above it bears down and the resultant bow is inevitable. This defect can and should be avoided by careful use of stickers supporting the board at the correct width.



8. Spring

Spring is concave/convex distortion along the length of the board again but this time the distortion is in the flat plane of the board.

Boards with this defect may have been cut from near the heart of the board and is the result of growth stresses being released on conversion.

Useable timber may be recovered from these boards by cutting a straight edge and re sawing. The grain direction however may not be satisfactory for aesthetics and care should be taken for placing the possible short grain figure where stability is required.

9. Shakes

Shakes are separation of the fibers along the grain developed in the standing tree, in felling or in seasoning. They are caused by the development of high internal stresses probably caused by the maturity of the tree.

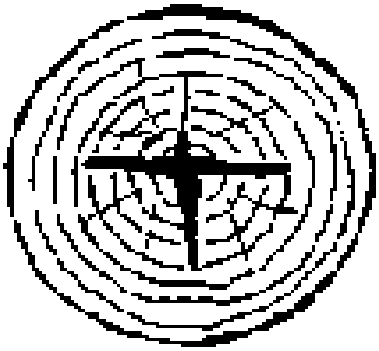
The shake is the result of stress relief and in the first place results in a single longitudinal crack from the heart and through the diameter of the tree.

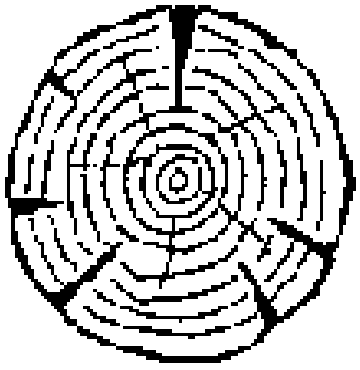
As the stress increases a second relief crack takes form at right angles to the first and is shown as a double heart shake.

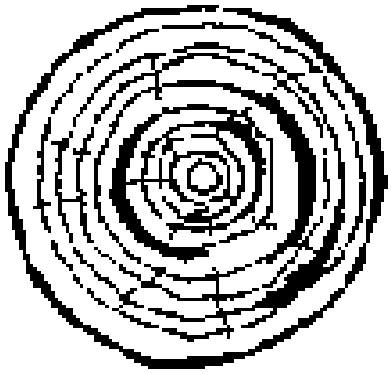
Further cracks are known as star shakes and show the familiar pattern shown.

Ring or partial cup shakes in the form of longitudinal tangential cracks occur as a result of high radial tension. It is often said that it is caused by an early frost freezing the rising sap or perhaps a heavy felling on hard ground.

External radial cracks are caused by the tree laying too long before it is converted and seasoned







a) Star shake

b) Heart shake

c) Cup shake

10. Defects through insects

Termites or white ants attack timber structures and are a serious problem. The species that causes the damage live in the ground. Precautions involve treating timber with a preservative or avoiding direct timber contact with the ground.

CONVERSION OF TIMBER

As soon as possible after felling the tree should be converted into usable timber.

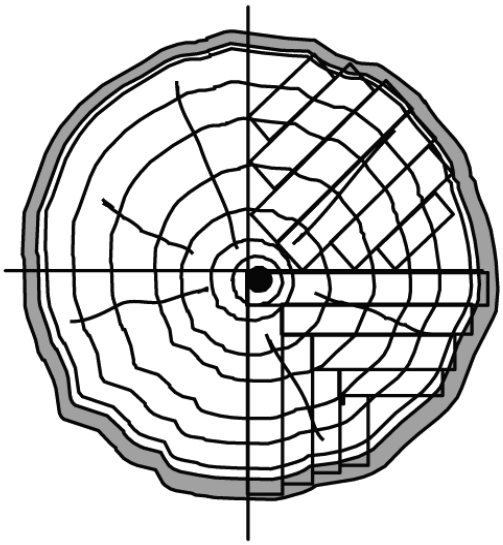
There are two main methods of converting timber:

- Through and through (or *Plain*) and
- Quarter also referred to as *rift sawn*.

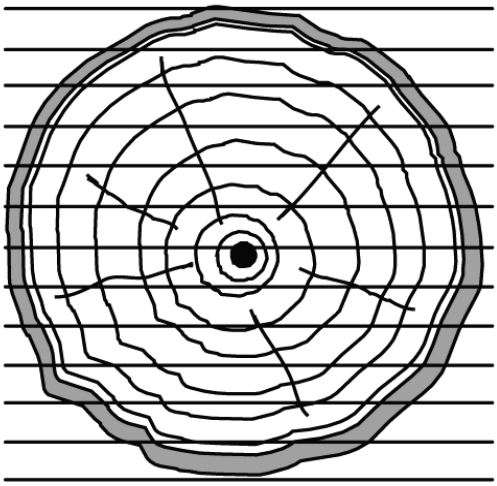
The **quarter sawn** is far more expensive because of the need to double (or more) handle the log. There is also more wastage. It is however more decorative and less prone to cup or distort. Note also there are two ways of sawing the quarter.

Through and through produces mostly tangentially sawn timber and some quarter sawn stuff. *(see diagram)* Tangential timber is prone to cupping but it is stronger when placed correctly. Because of this it is used extensively in the construction industry and especially for beams.

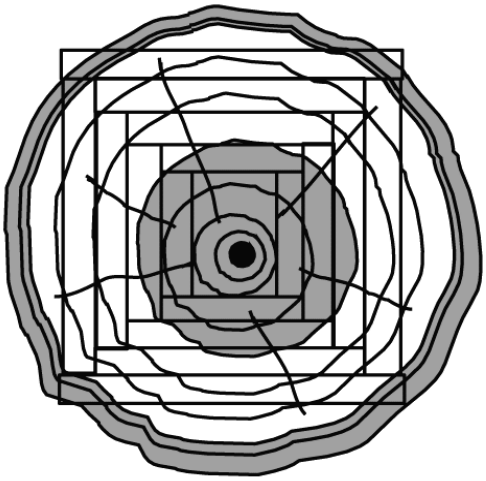
Boxed heart is the technique used when converting old timbers especially oak that has gone rotten in the middle.



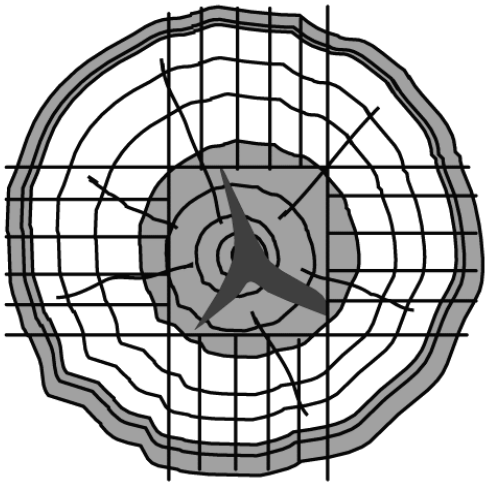
Quartered conversion, showing 2 different ways (radial boards)



Through and through conversion. (tangential and some radial boards)



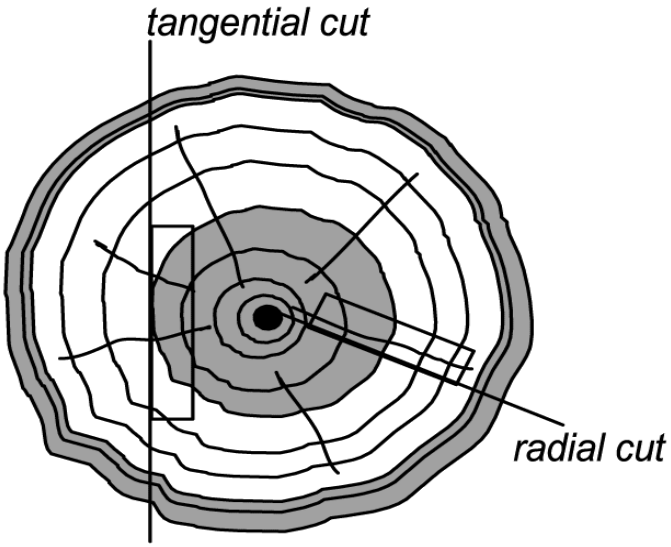
tangential cuts



boxed heart (usually old oak)

Tangential boards are the stronger boards and when placed correctly, used for beams and joists. These type of boards suffer from 'cupping' if not carefully seasoned, converted and used properly.

Radial boards are cut on 'the quarter' and produce a typical pattern of the medullary rays especially in quartered oak. Such timber is expensive due to the multiple cuts required to convert this board. Quality floor boards are also prepared from this *rift sawn* timber because it wears well and shrinks less.



TIMBER COMPOSITIES

Timber is a natural composite which can be used in its original or sawn sections. It can also be converted into particles, strands or laminates which can be combined with other materials such as glues to form timber composite products. The principal reasons for transforming timber into composite products include:

- to transcend the dimensional limitations of sawn timber
- to improve performance; structural properties, stability or flexibility
- to transform the natural material into a homogenous product
- to utilize low-grade materials, minimize waste and maximize the use of a valuable resource

Complex structural assemblies can be built up using a combination of solid timber or structural timber composites and wood-based board materials to

increase stiffness and strength. Examples include I beams, T beams, box beams and stressed skin panels.

Timber composites can be divided into three categories

Layered composites

Layered composites are used to produce both sections and sheets. The orientation of the fibers can be optimized and knots, splits and other irregularities removed or distributed within the section, to achieve enhanced and consistent structural performance. Since composites are often made from relatively small sections, efficient use of the source material can be maximized.

Layered composites can also be reinforced or interleaved with other materials, further to increase strength and dimensional stability.

Layered composites can be classified into three groups:

- Parallel laminates –glued laminated timber(glulam), laminated veneer lumber (LVL)
- Cross laminates - Plywood
- Sandwich panels

Laminated timber comprises several layers of timber sections glued together. The layers can be thick or thin and arranged so that the grain of the timber in the layers run parallel or at right angles (exceptionally at other angles) to each other.

All types of laminated sections used for structural purposes are factory-produced. This allows the moisture content to be controlled and a high level of consistency, accuracy and finish can be guaranteed. The size of finished members is limited only by the production facility and transport. Laminated beams generally are stronger and have a higher stiffness to weight ratio than solid timber.

Layered composites - Parallel laminates

Glued laminated timber

Glued laminated timber (glulam) is formed by gluing together a series of precision cut small sections of timber to form large cross section structural members of long length.

The timber members are strength graded before fabrication. The strength grade or combination of strength grades used determines the grade and strength of the laminated beam. The member can be straight or curved and can be made with a variable section according to the structural requirements.

Laminated Veneer Lumber

Laminated Veneer Lumber (LVL) is manufactured from thin sheets or laminate which are peeled from the log. The veneers are glued together to provide the required thickness and then cut into structural sized sections. A proportion of the laminates within a section may be laid with the grain at right angles to balance the movement characteristics of the section. Standard sizes of LVL range from 19 - 89 mm thick x 45 - 900 mm width.

Layered composites - Cross laminates

Plywood

The most familiar cross laminate is plywood. Modern plywood make use of a range of species in many configurations. The basic characteristics of plywood are veneers bonded together, most frequently with synthetic glues. In most plywood the grain of the wood in each veneer is laid at right angles to the adjoining one.

Plywood usually contains an uneven number of veneers so that the properties are 'balanced' about the central veneer or core. The core in some plywood may be a double veneer. One of the outer veneers may be a decorative hardwood, balanced by a cheaper wood on the back.

The quality and durability of plywood depends on both the timber species and the adhesive used to bond it. The quality of the face veneer may be of particular significance if the plywood is to be seen.

Grading systems for veneers vary between countries but are generally based on

- near perfect as peeled
- imperfect as peeled but repaired
- imperfect as peeled but not repaired.

Major sources of plywood are Canada and the USA, Finland, Russia, the Baltic States and the Far East. North American plywood is made predominantly from softwoods with pronounced variation between earlywood and latewood, some Finnish, Baltic and Russian types are more even in color and texture, using birch face veneers. Far Eastern production uses red and white hardwoods.

Plywood is dimensionally stable and can be used for large uninterrupted surfaces. It is resistant to splitting and can be nailed or screwed close to the edges of the panel. Plywood panels can, within limits, be bent without cracking to form smoothly curved surfaces. Common uses for plywood are sheathing, panelling, floors and structural diaphragms, concrete formwork, furniture and fittings. Many traditional uses of plywood are being taken over by other wood-based boards.

Layered composites - *Other types*

Other types of layered composites are produced, for example cores of timber strips produce boards by the name of battenboard, blockboard or laminboard, depending upon the width of the strips used. Sandwich panels are built up of layers of different materials. Normally the outside layers are of high strength and stiffness with a thicker core of lower strength material. There are many possible combinations, most of which are designed for specialist applications. Plywood is an ideal material for use in the outside layers and has been used with cores of insulating foam for facade panels, paper honeycomb for doors and timber spacers for stressed skin panels.

Particle Composites

Particle composites can be divided into 3 broad types:

- Particleboards - chipboard, cement-bonded particleboard
- Oriented Strand Board
- Structural particle composites - Parallel Strand Lumber

Particleboard

Chipboard is produced from dried and graded chips mixed with resin which are formed into boards by curing in a heated press. Board thicknesses range from 6 - 25 mm, although panels up to 70 mm thick can be produced.

Chipboard has a wide variety of uses in building, such as flooring and cladding. It is widely used pre-painted or faced with decorative wood veneers, melamine foils or other surface treatments. For purposes such as flooring, panels are often sold with tongued and grooved edges to facilitate interlocking and gluing where appropriate.

Fiber composites

Fiberboards

Fibers are produced from chips of wood (mainly from forest thinning) which are reduced to a pulp by mechanical or pressure heating methods. In wet process boards the pulp is mixed with water and other additives, formed on a flat surface and pressed at high temperature. In most fiberboards the basic strength and adhesion is obtained from felting together of the fibers themselves and from their own inherent adhesive properties. Board types are differentiated by the manufacturing process - whether produced by the wet or a dry process and their density

Softboards are the lowest density fiberboards with a density of less than 400 kg per cubic meter.

Thicknesses range from 9 - 25 mm. It is slightly compressed during manufacture and is mainly for insulating purposes in walls, ceilings and floors. When impregnated with bitumen it has good resistance to moisture and can be used for sarking, floor underlay and sheathing. Softboards have low structural strength.

Medium boards have densities between 400 and 900 kg per cubic meter. They are divided into low and high density types:

Low density medium boards have a density of 400 to 560 kg per cubic meter. Thicknesses range from 6 to 12 mm. Uses include paneling, wall linings, ceilings and pinboards.

High density medium boards have a density of 560 to 900 kg per cubic meter. Thicknesses range from 6 to 12 mm. Uses include paneling, ceilings, sheathings floor underlay, shopfitting and signboards.

Medium density fiberboard (MDF) is manufactured under a dry process, using a resin adhesive. Its density is greater than 600 kg per cubic meter and thicknesses range from 4 to 35 mm. The homogenous cross section and smooth faces of MDF give high quality surfaces that are ideal for painting and have made it a popular, relatively recent addition to the range of wood-based boards. It is widely used for skirting, moldings, architraves, joinery and furniture.

Hardboard is the highest density fiberboard - over 900 kg per cubic meter. Tempered hardboard is impregnated with hot oil or resin and heat cured. Thicknesses range from 2 to 12 mm.

Generally hardboard has a smooth face with a fine mesh pattern on the reverse although boards with two smooth faces are available.

Hardboard is strong and stiff, but since it is thin it has restricted spanning capabilities. It is used as floor and wall linings, for doors, paneling, joinery and furniture. Tempered hardboard can be used in structural components such as box or webbed beams. Pre-coated and surface laminated hardboards are available, as are embossed and perforated boards.

COMMERSIAL SIZES OF TIMBER

Common trade names:

a) Log - A trunk with branches off.

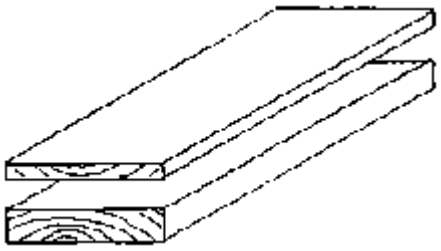
b) Plank - Pieces 38 mm to 100 mm (1½" to 4") thick and 150 mm (6") or over wide.

c) Boards - Pieces 10 mm to 38 mm (3/8" to 1½") thick and 75 mm (3") and over wide.

d) Battens - Pieces 19 mm to 38 mm (¾" to 1½") thick and from 25 mm to 75 mm (1" to 3") wide.

e) Strips - Under 19 mm (¾") thick and up to 75 mm (3") wide.

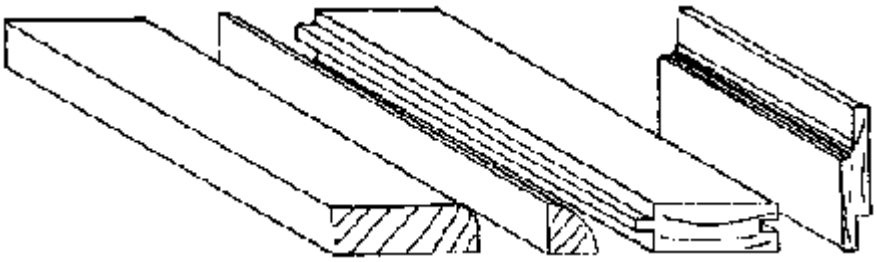
f) Molding - Shaped timber, can be plank, boards, strips etc...



Plank



Battens and Stripes



Moldings

APPLICATIONS OF TIMBER

- Complete or partial building and roof frame structures, using pole timber, sawn timber beams, or glue laminated elements.
- Structural or non-structural floors, walls and ceilings or roofs, made of pole timber (block construction), sawn timber boards, or large panels from plywood, particle board, fiber board or wood-wool slabs; in most cases, suitable for prefabricated building systems.
- Insulating layers or panels made of wood-wool slabs or softboard.
- Facing of inferior qualify timber elements with timber ply or veneer, to obtain smooth and appealing surfaces, or facing of other materials (brickwork, concrete, etc.) with boards and shingles.
- Door and window frames, door leaves, shutters, blinds, sun-screens, window sills, stairs and similar building elements, mainly from sawn timber and all kinds of boards and slabs.
- Roof constructions, including trusses, rafters, purling, lathing and wood shingles, mainly from pole or sawn timber.
- Shuttering for concrete or rammed earth constructions and scaffolding for general construction work, from low grade pole and sawn timber.

- Furniture, using any or combinations of the timber products described above.

ADVANTAGES OF TIMBER

- Timber is suitable for construction in all climatic zones, and is unmatched by any other natural or manufactured building material in terms of versatility, thermal performance and provision of comfortable and healthy living conditions.
- Timber is renewable and at least secondary species are available in all but the most arid regions, provided that re-afforestation is well planned and implemented.
- Most species have very high strength: weight ratios, making them ideal for most constructional purposes, particularly with a view to earthquake and hurricane resistance.
- Timber is compatible with traditional skills and rarely requires sophisticated equipment.
- The production and processing of timber requires less energy than most other building materials.
- Timber provides good thermal insulation and sound absorption, and thicker members perform far better than steel in fire: the charred surface protects the un-burnt timber, which retains its strength.
- The use of fast growing species helps to conserve the slow growing primary species, thus reducing the serious environmental problems caused by excessive timber harvesting.
- Using pole timber saves the cost and wastage of sawing and retains its full strength, which is greater than sawn timber of the same cross-sectional area.
- Since coco wood was previously considered a waste material with immense disposal problems, its utilization as a building material not only solves a waste problem but provides more people with a cheap, good quality material and conserves a great deal of other expensive and scarce timber resources.
- All the timber-based sheets, boards and slabs provide thin components of sizes that can never be achieved by sawn timber. Apart from requiring less material by volume (which generally consists of lower grade timber or even wastes), larger, lighter and sufficiently strong constructions are possible.
- Demolished timber structures can often be recycled as building material, or burnt as fuel wood, the ash being a useful fertilizer, or processed to produce potash (a timber preservative).

DISADVANTAGES OF TIMBER

- High costs and diminishing supplies of naturally resistant timber species, due to uncontrolled cueing and exports, coupled with serious environmental problems.
- Extreme hardness of some dried timbers making sawing difficult and requiring special saws.
- Thermal and moisture movement (perpendicular to the grain) causing distortions, shrinkage and splitting.
- Susceptibility of cheaper, more abundantly available timber species to fungal decay (by moulds and rot) and insect attack (by beetles, termites, etc.).
- Fire risk of timber members and timber products with smaller dimensions.
- High toxicity of the most effective and widely recommended chemical preservatives, which represent serious health hazards over long periods.
- Failure of joints between timber members due to shrinkage or corrosion of metal connectors.
- Discoloration and embitterment or erosion of surface due to exposure to sunlight, wind-borne abrasives or chemicals.

REMEDIES

- Conservation of forest resources by comprehensive long-term re-afforestation programs, and use of fast growing timber varieties and forestry by-products, thus also reducing costs.
- Harvesting timber in the dry or winter season, when the moisture and starch content, which attracts wood-destroying insects, is lowest.
- Sawing of hard timber species when still green, since the moisture in the fresh logs lubricates the saw.
- Reduction of moisture content to less than 20 % by seasoning, in order to prevent fungal growth. Care should be taken to control and slow the rate of drying to avoid cracking, splitting or other defects.
- Temperatures below 0° C and above 40° C also prevent fungal growth, as well as complete submersion in water.
- Chemical treatment of timber against fungi, insects and fire should only tee done with full knowledge of the constituent substances, their toxicity (especially the long-term environmental and health hazards associated with their production and use), the correct method of application and the requisite precautionary measures. Opinions from different experts should be sought, in order to determine the least hazardous option. Proposals, such as facing of particle board with wood veneer or plastic laminate, are not always acceptable, as the emission of formaldehyde fumes is not reduced but takes place over a longer period.

- Indoor and outdoor uses of timber should be differentiated according to durability and degree of toxicity: under ideal (dry, well-ventilated, clean) conditions, even low-durability timbers can be used indoors; treated timbers that could represent a health hazard should only be used externally, but well protected from rain, if leaching out of toxic chemicals is expected.
- Good building design using well seasoned wood, good workmanship and regular maintenance can considerably reduce the need for chemically treated timbers.
- Good design of timber constructions includes: avoidance of ground contact: protection against dampness by means of moisture barriers, flashing and ventilation; avoidance of cavities, which can act as flues spreading fire rapidly; accessibility to all critical parts for regular maintenance; provision of joints designed to accommodate thermal and moisture movement; avoidance of metal connectors in places exposed to moisture, protection of exterior components from rain, sunlight, and wind by means of wide roofs and vegetation.

ASPHALT CEMENT

Asphalt or bituminous materials (or bitumen) are hydrocarbons which are usually fairly hard at normal temperatures; when heated, they soften and flow. When mixed with aggregates in their fluid state they solidify and bind the aggregates together, forming a pavement surface.

ASPHALT AS PAVING MATERIAL

Bitumens that have been used in paving include

1. **Native asphalts**: Obtained from asphalt lakes these were used in some of the earliest pavements.

2. **Rock asphalts:** These are rock deposits containing bituminous materials which have been used for road surfaces in localities where they occur.

3. **Tars:** Tars are bituminous materials obtained from the distillation of coal.

4. **Petroleum asphalts:** These are products of the distillation of crude oil. These asphalts are by far the most common bituminous paving materials in use today.

Grades of asphalt materials and temperatures at which they are used depend to a great extent on their viscosity. The viscosity of asphalt varies greatly with temperature, ranging from a solid to a fairly thin liquid. Viscosity-temperature relationships are extremely important in the design and use of these materials.

Viscosity decreases (that is, material becomes more fluid) as temperature increases. A very viscous fluid is very "thick."

Absolute (or dynamic) viscosity is measured in Pa . s (SI units) and poises (traditional units). [1 poise = 0.1 Pa . s] Kinematic viscosity is measured in cm^2/s (SI units) and stokes or ceritistokes (traditional units) [1 stoke = 100 centistokes = 1 cm^2/s]. Since kinematic viscosity equals absolute viscosity divided by density (about 1 g/cm^3 for asphalts), the absolute viscosity and the kinematic viscosity have approximately the same numerical value when expressed in poises and stokes.

Viscosity has often been measured in the Saybolt Furol apparatus as the number of seconds it takes for a specified volume to flow.

Asphalt cements were originally graded according to *penetration value.* This is an empirical test in which the amount the needle penetrates a prepared asphalt sample in five seconds is measured in tenths of a millimeter under standard conditions. For example, if the needle penetrated 9.8 mm-or 98 tenths of a mm-the penetration value would be 98.

Plant temperatures for mixing asphalt paving materials are usually specified in terms of viscosity, for this indicates how fluid the material is and how well it will coat the aggregates without overheating. Temperature limits corresponding to viscosities of 1.5 to 3.0 cm^2/s (150 to 300 centistokes) are sometimes used.

The minimum temperature for spraying (as in pavement seal coats) is often specified as that corresponding to a viscosity of 2.0 cm^2/s (200 centistokes).

The major paving products are:

1. asphalt cements
2. liquid asphalts
3. asphalt emulsions

1. Asphalt cements are the primary asphalt products produced by the distillation of crude oil. They are produced in various viscosity grades, the most common being AC 2.5, AC 5, AC 10, AC 20, and AC 40. These roughly correspond to penetration grades 200-390, 120-150,85-100,60-70, and 40-50, respectively. The viscosity grades indicate the viscosity in hundreds of

poises ± 20% measured at 60°C. For example, AC 2.5 has a viscosity of 250 poises ± 50. AC 40 has a viscosity of 4000 poises ± 800.

2. Cutback asphalts (Liquid asphalts) are asphalt cements mixed with a solvent to reduce their viscosity and, thus, make them easier to use at ordinary temperatures. They are commonly heated (if required) and then sprayed on aggregates. Upon evaporation of the solvent, they cure or harden and cement the aggregate particles together.

Types and grades are based on the type of solvent, which governs viscosity and the rates of evaporation and curing.

1. **Rapid curing(RC)** types use gasoline as a solvent, and therefore cure rapidly.

2. **Medium Curing (MC)** types use kerosene.

3. **Slow Curing (SC)** types use diesel fuel, or they may be produced directly from the refinery during distillation. Solvent contents are commonly from 15% to 40% of the total. Grades of liquid asphalts are governed by viscosity.

3. Asphalt emulsions are mixtures of asphalt cement and water. As these components do not mix themselves, an emulsifying agent (usually a type of soap) must be added. The emulsifying unit breaks up the asphalt cement and disperses it, in the form of very fine droplets, in the water carrier. When used, the emulsion sets as the water evaporates. The emulsion usually contains 55%-75% asphalt cement and up to 3% emulsifying agent, with the balance being water.

Two general types of emulsified asphalts are produced, depending on the type of emulsifier used:

- Cationic emulsions, in which the asphalt particles have a positive charge;
- Anionic*,* in which they have a negative charge.

Anionic emulsions adhere better to aggregate particles which have positive surface charges (e.g., silica). Cationic emulsions also work better with wet aggregates and in colder weather.

Aging or hardening of asphalts is due to the evaporation and oxidation of the lighter oily constituents during mixing at high temperatures and to the oxidation of the oils to resins and resins to asphaltenes when used over a period of years. Design of asphalt mixtures must take into account these possible effects on the useful life of a pavement.

An emulsion's rate of hardening (or "breaking") depends on the amount and type of agent used. There are three grades of the two types of asphalts(C indicates cationic types):

1. Rapid setting (RS or CRS).
2. Medium setting (MS or CMS).
3. Slow setting (SS or CSS).

TESTS FOR ASPHALT

Quality control tests for asphalt materials include the following:

1. Viscosity: Many methods of measuring viscosity have been used, as indicated above in the discussion on viscosity: Absolute viscosity is measured by the vacuum capillary viscometer .Kinematic viscosity is measured by the kinematic viscometer Viscosity in seconds, Saybolt Furol is measured in the Saybolt Furol apparatus. Penetration values, measuring depth of penetration of a standard needle into asphalt cement, are obtained from the penetration apparatus.

2. Ductility: An asphalt sample is cast in a mold consisting of two jaws, then placed in a water bath. One jaw is moved from the other at a standard rate; the distance it moves before the thread between the two breaks is the ductility in centimeters.

3. Thin Film Oven Test: Asphalt paving materials in use are found as extremely thin layers joining aggregate particles together. The properties of the mix-especially durability-depend to a great extent on the properties of a thin film of asphalt. In this test, a thin sample is heated in an oven for a period of time, and the properties of the sample afterward are obtained as an indication of the rate of aging or hardening of the asphalt.

4. Solubility: With this test the purity of the asphalt can be checked.

5. Flashpoint: This test determines the temperature to which asphalt

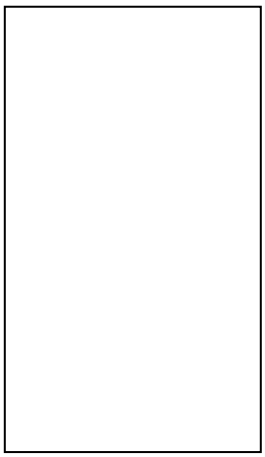
materials may safely be heated.

MASS VOLUME RELATION FOR ASPHALT CONCRETE

The mass-volume relationships for asphalt (bituminous) concrete are illustrated in the figure below.

The following relationships are usually calculated:

$$\text{Density } (p) = M / V$$
$$\text{Asphalt content (AC)} = M_B / M$$
$$\text{Asphalt absorption (Asp Abs)} = M_{BA} / M_G$$
$$\text{Air voids (A V)} = V_A / V$$
$$\text{Voids in mineral aggregate (VMA)} = (V_A + V_{BN}) / V$$



V= total volume
VA = volume of air
V_{BN} = volume of net asphalt
V_G = volume of aggregate
M_B = mass of asphalt
M_G = mass of aggregate
M_{BA} = mass of absorbed asphalt
M_{BN} = mass of net asphalt
$M_{BN} + M_{BA} = MB$ = total mass of asphalt

Fig. Mass-volume relationships for asphalt concrete.

Example 1
An asphalt concrete mix contains 2250 kg of aggregates and 150 kg of asphalt per m^3. Asphalt absorption is 1.2%. The bulk relative density of the aggregates is 2.67; relative density of the asphalt, 1.05. Find the mass volume relationships.
Solution:

Example 2

Given:

Density= 2440 kg/m3

AC = 5.8%

Asp Abs = *0.8%*

RD_B (aggregates) = 2.67

RD (asphalt) = 1.03

Find A V and VMA.

Solution

Some organizations calculate the asphalt content as a percentage of the mass of aggregates, not as a percentage of the total mass. Calculations required for this approach are illustrated in the following example.

Example 3

Given:

Density = 148.5 Ib/ft3

AC = 6.5% (as percentage *of* mass *of* aggregates)

Asp Abs = 1.1 %

Bulk relative density (aggregates) = 2.61

Relative density (asphalt cement) = 1.04

Find A V and VMA.

solution

ASPHALT CONCRETE PROPERTIES

The main asphalt paving material in use today is asphalt concrete. This is a high quality pavement surface composed of asphalt cement and aggregates, hot-mixed in an asphalt plant and then hot-laid. This is the common "black-top" or "hot mix" or "asphalt" used on most roads (except rural and secondary roads).

Asphalt concrete consists of asphalt cement, aggregates, and air. However, some of the asphalt cement seeps into voids in the aggregate particles, and therefore is not available to coat and bind aggregates together. This also leaves more air voids in the mixture than would be expected by calculating the total aggregate and asphalt volumes, shows the components of an asphalt concrete. Relative amounts of aggregate, asphalt, and air are important, as is discussed in the following section.

The amount of asphalt absorption is less than the water absorption for the same aggregates, usually by about one-half. However, it is important to include the volume of absorbed asphalt in calculations, since all volumes must be measured accurately. The amount of asphalt absorption can be found by measuring the relative density of a mixture of asphalt-coated aggregates, and comparing this with the value expected with no absorption.

FIG. 6-7. Asphalt mixture showing net or effective asphalt, absorbed asphalt, and air voids.

Asphalt concrete surfaces must provide smooth, skid-resistant riding surfaces. They must be strong enough to carry the imposed loads without rutting. They must maintain these properties for the design life. Since they distribute loads by deflecting slightly with each load application, they must be flexible. These requirements lead to the following required properties for asphalt concrete mixes:

- strength
- flexibility
- durability
- skid resistance

Most specifications for asphalt concrete take into account the necessity of meeting these four requirements.

Strength must be sufficient to carry the load without shear occurring between particles. The structure must remain intact. The main contributor to strength is friction between the grains. A dense-graded mixture is best for high friction strength with a relatively low amount of binder. If the asphalt coating around the particles is too thick, the amount of friction between particles is reduced.

Flexibility is obviously very important, as these are flexible pavements. The asphalt concrete must be able to deflect slightly under each load without cracking. For this requirement, a more open-graded aggregate mixture is better, as is a higher asphalt cement content. These conditions allow more movement without cracking.

Durability measures the pavement's resistance to wear and aging. Aggregates should be hard and cubical to ensure the minimum breakdown during manufacture and during application of loads. Aggregates should also be sound, not susceptible to disintegration from cycles of freezing and thawing. Certain aggregates have a greater affinity for water than for asphalt cement. In these cases, water may replace the asphalt film on the aggregate particles, destroying the bond between particles.

The major causes of asphalt concrete aging are evaporation and oxidation of asphalt cement. During mixing at high temperatures, some of the lighter constituents of the asphalt evaporate, leaving a harder cement. After construction, air and water circulate through the material. These lead to oxidation of the asphalt, again removing the lighter constituents and leaving a hard, brittle material. Figure 6-9 illustrates the effects of evaporation and high rates of oxidation on asphalt cements, showing how either of these may reduce the penetration value of the cement to about 30, a level at which there is evidence that cracking will occur.

Cracking leads to rapid failure of the pavement, since it loses some of its load distribution properties and allows water into the surface and base, again lowering load-carrying capacity.

To control aging and hardening of the binder materials, the following are often specified:

1. Maximum temperature during mixing, to reduce evaporation.

2. Maximum percentage of air voids to reduce permeability and movement of air and water in the mixture, and therefore to reduce the rate of oxidation.

3. Minimum percentage VMA, to ensure that sufficient space is left for asphalt cement (which helps to ensure that the binder film around each particle is thick enough to remain ductile, not brittle).

4. The softest possible grade of asphalt cement for a project, softer grades being less likely to crack in cold weather.

Skid Resistance Loss of *skid resistance* of asphalt concrete surfaces is mainly caused by *polishing* of the aggregates or *bleeding* of the cement. Surface courses usually have a lower maximum particle size in order to increase the number of small particles and therefore the number of projections at the surface for skid resistance. The aggregates should be hard and resistant to wear, and thus resistant to polishing. It has been found that limestone aggregates tend to polish in many cases. Bleeding occurs on hot days, when the cement tends to seep to the surface in mixtures with few voids. Specifications usually require a minimum air void content so that asphalt cement can be accommodated in the air void space as the pavement becomes denser under load.

Mix requirements to meet the above criteria are summarized in table 6-3.

Obviously no one mixture is best for all these properties, and a compromise must be made in 'specifications to accommodate each property to the maximum extent possible without seriously affecting other properties.

Aggregates should be:

1.***Well-graded*** *-dense,* including mineral filler (if required) for strength.

2. ***Hard*** *-for* resistance to wear and to polishing due to traffic.

3. ***Sound*** *-for* resistance to breakdown due to freezing and thawing.

4. ***Rough surfaced*** *-crushed* rough surfaces give higher friction strength and a better surface for adhesion of the asphalt cement.

5. ***Cubical*** *-thin,* elongated aggregate particles break easily.

6. ***Hydrophobic*** *(or "water hating") -some* siliceous aggregates such as quartz are hydrophilic ("water liking"), meaning that they have a greater affinity for water than for asphalt, due to their surface charges. This may lead to stripping, as asphalt coating comes away from the particle in the presence of water.

AGGREGATES FOR ASPHALT CONCRETE

Aggregates for asphalt concrete are usually classified as coarse aggregates, fine aggregates, or mineral filler. Types of coarse and fine aggregate have been discussed previously. Mineral filler is often used in asphalt concrete mixtures to supply the fines (smaller than 75 μm or No. 200 sizes). Fines are very important in producing a dense-graded, strong material. Many natural sands do not contain the amount or type of fines required. Limestone dust is the most common material used for mineral filler.

Table:

Property	**Asphalt Content**	**Aggregate Gradation**	**Air Voids**	***Aggregate Quality***
Strength	Low	Dense	Low	Rough faces; crushed
Flexibility	High	Open	High	Coarser sizes; better
Durability	High	Dense	Low	hard, cubical; resistant to freeze thaw damage; does not strip
Skid Resistance	Low	-	High	High sand content; hard; resistant to polishing

ASPHALT CONCRETE MIX DESIGN

The design of an asphalt concrete mixture includes the selection of the best blend of aggregates and the optimum asphalt content to provide a material that meets the required specifications as economically as possible.

Mix design involves the following steps:

1. Selection of aggregate proportions to meet the specification requirements.

2. Conducting trial mixes at a range of asphalt contents and measuring the resulting physical properties of the samples.

3. Analyzing the results to obtain the optimum asphalt content and to determine if the specifications can be met.

4. Repeating with additional trial mixes using different aggregate blends, until a suitable design is found.

The two most common methods for making and evaluating trial mixes are the Marshall method and the Hveem method. Marshal method is only discussed here.

Specifications for the gradation of the blended aggregates in asphalt concrete vary considerably. A number of gradation specifications for various types of asphalt materials and for different types of pavements are given in standards.

In the first step in a mix design, proportions of the proposed aggregates (including mineral filler) are chosen to produce a combined gradation close to the center of the specification limits.

MARSHALL MIX DESIGN METHOD

The Marshall Method consists of the following major steps:

1. Aggregates are blended in proportions that meet the specification requirements.

2. The mixing and compacting temperatures for the asphalt cement being used are obtained from the temperature-viscosity graph. These

temperatures are those required to produce viscosities of 1.7±0.2 cm^2/s (170 ± 20 centistokes) for mixing and 2.8± 0.3 cm^2/s (280 ± 30 centistokes) for compacting.

3. A number of briquettes, 101.6 mm (4 in) in diameter and 60-65 mm (2 in) high, are mixed using 1200 g of aggregates and asphalt cement at various percentages both above and below the expected optimum content. For surface courses with 12.5 mm (1/2-in.) aggregate, the expected optimum content may be about 6.5%. Therefore briquettes would be made at 5.5%, 6.0%, 6.5%,7.0%, and 7.5% asphalt cement.

4. Density of the briquettes is measured to allow calculation of the voids properties.

5. Briquettes are heated to 60°C (140°F). *Stability* and *flow* values are obtained in a compression test in the Marshall apparatus to measure strength and flexibility. The stability is the maximum load that the briquettes can carry. The flow is the compression (measured in units of hundredths of an inch or in millimeters) that the sample undergoes between no load and maximum load in the compression test.

Results of the Marshall test are plotted on graphs such as density, stability, flow, air voids, and VMA are plotted against asphalt content. These typical relationships can be observed:

1. Density initially increases with asphalt content, since the fluid lubricates grain movements. Eventually, however, a maximum density is reached. Then density decreases, since the lighter asphalt replaces some of the aggregate, shoving the particles apart.

2. Stability increases and decreases along with asphalt content on a curve similar to that for density, since the strength is mainly a function of friction between grains of aggregates and, therefore, of density.

3. Flow increases along with asphalt content, since friction between particles decreases with thicker asphalt films.

4. The percentage of air voids decreases as asphalt content increases, since the asphalt tends to fill all the void spaces.

5. The percentage of voids in mineral aggregate is approximately opposite to the density curve, since the mass of aggregates is the main component of the total mass of the mix.

The optimum asphalt content is one that economically and safely satisfies all specification requirements.

Example:
Results of a trial mix have been plotted in fig…..The mix is to meet the Asphalt institute's requirements for a surface course subjected to medium traffic, with12.5 mm maximum sized aggregates.

Solution:

From graphs:

Asphalt content at maximum density=6.2%
Asphalt content at maximum stability=5.8%
Asphalt content at4%air voids (the middle of the 3-5% allowed)=6.3%
Average asphalt content=6.1%

The mix meets all requirements

Stability =4000 N (900 Ib)
Flow3 mm= (12 units of 0.01 in)
AV =4.3%
VMA=16.0%