Arba Minch Water Technology Institute (AWTI)

Faculty of Water Supply And Environmental Engineering

Course title: Construction Materials

Course code: CEng - 2111

Target Group: 2nd Year WSEE

Instructor; Bedane Hailu

February,2020

Course description

Objective:

- ❖ Understand the physical and chemical property of construction materials under different conditions Know the production process of some construction materials Have basic skill how to mix and produce concrete.

Outcomes: At the end of this course students will be able to:

- ❖ Describe engineering properties of concrete,
- ❖ Assess the significance of environmental factors on the behavior and durability of concrete and other construction materials.
- ❖ Design concrete mix and grouting materials

Course Contents

I. Classification of construction materials, mechanical properties of construction materials:

II. nature and performance of materials under load

III. Cementing materials: production and use of lime, gypsum and cement.

IV. Concrete and concrete making materials: Mix design; physical and mechanical properties of dry and wet concrete.

V. Grouting materials and their design.

VI. Ferrous and non-ferrous metals. Clay and clay products. Stones, timber and timber products. Bituminous materials.

VII. Miscellaneous materials such as glass, polymers, ceramics and plastics.

Teaching & Learning Methods

- Lectures, home study and laboratory exercise

Assessment

- Continuous assessment= 50%
  - ✓ Assignments,
  - ✓ Laboratory report and
  - ✓ quiz
- Final exam= 50%

Nature and properties of construction materials

- Materials used in construction are known as *Construction Materials or Engineering Materials or Building Materials.*
  - ✓ ***Concrete and Steel*** dominate the ***building industry***;
  - ✓ ***Asphalt, Concrete and Steel*** widely used in the ***transportation industry***;
  - ✓ ***Wood and Masonry*** are widely used in the ***residential housing market***; and
  - ✓ ***Polymers, Composites, Concrete, Steel and other metals*** are the ***bulk of the piping materials.***

Classification of Construction Materials

Based on Source of Material

1. Naturally occurring:
   - Inorganic: *Clay, stone, lime gravels and etc.*
   - Organic: *Wood, bamboos and etc.*
2. Artificial /Manufactured/ Modified materials:
   - *Cement, tiles, paints, steel bars, ceramic, pipes, glass, plastic and etc.*

According to their phases

1. Gases: *Air, oxygen,* CO_2
2. Liquids: *Water, chemical admixtures*
3. Semi-solids: *Fresh pastes, mortars, asphalt*
4. Solids: *Metals, hardened concrete*

Cont'd

- **According to their internal structure & chemical composition**

1. Metals: (formed by metallic bonds)
    A. Ferrous: *iron*, *cast iron*, *steel*
    B. Non-ferrous: *aluminum*, *copper*, *zinc*, *lead*
2. Polymers: (long chains having molecules of C, H, O, N. The chains are bound to eachother either by covalent bonds or Van der Waal's forces.)
    A. Natural: *rubber*, *asphalt*, *resins*, *wood*
    B. Artificial: *plastics*

cont'd

3. Ceramics: (mainly aluminosilicates formed by mixed bonding, covalent and ionic)
    A. Structural clay products: *bricks, tiles, pipes*
    B. Porcelains *(Products of fine clay)*
4. Composite Materials:
    A. Natural: *agglomerates (Mixed)*
    B. Artificial: *Portland cement, concrete*
5. Reinforced Composite Materials: (*reinforced concrete, reinforced plastics*)

Material properties

1. **Physical properties**
2. **Chemical properties**
3. **Mechanical properties**

Physical properties

- **Electrical properties**
  - **Resistivity**: The ability to ***impede*** flow of electricity
  - **Conductivity**: The ability to ***allow*** current easily
  - **Dielectric Strength**: The insulating capacity ***agains***t high voltage
  - **Superconductivity**: The ability to allow current easily at ***very low*** temperatures

Physical properties Cont'd

- **Thermal properties**
  - **Thermal conductivity** –The ability to ***allow heat flows***
  - **Specific heat** – the heat required *to raise the temperature of one gram of a substance by one degree centigrade*
  - **Thermal deformation** is the property of a substance to expand with heat and contract with cold
  - **Thermal capacity or Heat Capacity:** is ability to store heat or cold.
    - helps to even out the temperature swings in a building and also in many cases reduce energy consumption.
  - **Melting, boiling and freezing point**

Physical properties cont'd

- Temperature
  - At low temperature, where the material is ***brittle and not strong***, little energy is required to fracture the material.
  - At high temperature, where the material is more ***ductile and stronger***, greater energy is required to fracture the material.
  - The transition temperature is the boundary between ***brittle and ductile*** behavior. This is an extremely important parameter in selection of construction material.

Physical properties Cont.....

- **Optical properties** – response to light
  - **Transparent**: light passes through
  - **Translucent**: some light passes through but no distinct image
  - **Opaque**: no light passes through it
- Other, which mostly includes the following important points
  - Density
  - colour
  - Permeability
  - texture (micro, macro)
  - magnetic properties etc…

Chemical properties

How a material interacts with another material (Chemical composition, potential reaction with environment)

- **Corrosion resistance-** a material's ability to resist deterioration caused by exposure to an environment
- **Flame resistance** is the property not to flame in case of contacting with fire in the air.
- reaction with acid
- reaction with water


Mechanical properties (Static stress strain properties)

Deal directly with behavior of materials (***under equilibrium state***) under applied loads (forces, moments). These include loading under: *tension, compression, torsion, bending, repeated cyclic loading, constant loading over long time, impact, etc.*

Application of forces on solid bodies under equilibrium results in the development of internal resisting forces and the body undergoes deformations to a varying degree. ***Internal forces*** *are called* ***stresses*** *and* ***internal deformations*** *are called* ***strains****.*

- Most important mechanical properties of eng’g materials

- *Elasticity*
- *Plasticity*
- *Creep*
- *Ductility*
- *Malleability*

- *Brittleness Hardness*
- *Toughness*
- *Stiffness*
- *Resilience*
- *Fatigue*
- *strength*

Mechanical properties cont'd

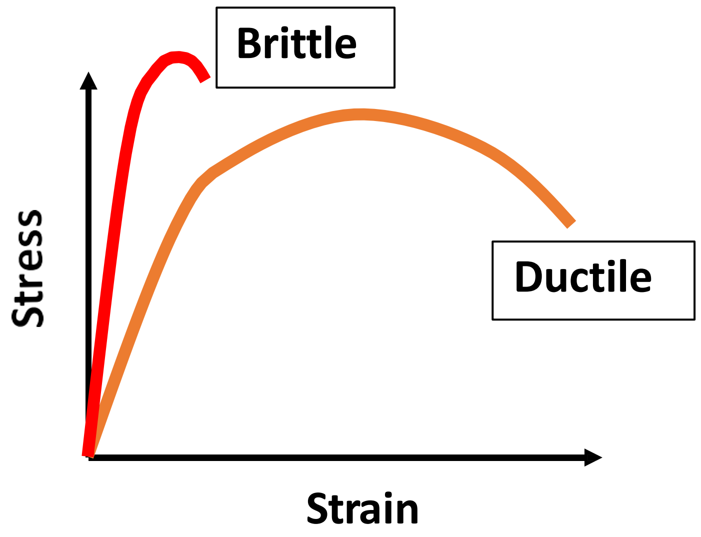
- **Elasticity:** Ability to return to ***original shape and size*** when ***unloaded***
- **Plasticity:** Retains ***new shape*** after being deformed by ***stress***
  - *Most engineering materials* are ***in part elastic*** and ***in part plastic***.
- **Stiffness:** *Deformation resistance* under load while ***in elastic state.***
  - Usually ***measured by*** the Modulus of Elasticity (E)
  - The ***bigger E*** is, the ***more difficultly*** the material ***deformed.***
- **Resilience:** The *work done* to ***deform a material up to elastic limit***
- **Toughness**: ***Materials ability*** to *absorb energy* in the ***plastic range***. It comprises both *strength and ductility.*
- **Creep:** Slow permanent /***plastic deformation*** under a *constant load* over a ***long period of time.***

Cont'd

- **Fatigue** is the *fracture/failure of a material* that is subjected to ***repeating cyclical loading, or cyclic stresses.***
- **Malleability**: The ability to *permanently extend* in ***all directions*** when *hammered*.
- **Hardness:** The ability to resist ***abrasion, penetration, scratching*** and ***indentation*** by *hard material*
- **Brittleness:** *The tendency to break/shatter* ***suddenly*** when subjected to stress ***but has a little tendency to deform*** *before* rupture.
  - characterized by ***poor capacity*** to resist ***impact*** and ***vibration*** of load, ***high compressive strength, and low tensile strength.***
- When a brittle material fails, the structure can collapse in a catastrophic manner.

Cont'd

- **Ductility**: Ability to *elongate permanently* under ***tensile forces.***
  - Generally, ***ductile materials*** are *preferred* for construction.
  - Distortions of the structure will not necessarily collapse
  - Provides *sufficient time to the occupants* for taking preventive measures



- **Viscoelasticity:** is the property of materials that exhibit both *viscous and elastic* characteristics when ***undergoing deformation.***
  - Viscoelastic materials have a ***delayed response*** to load application.
  - ***asphalt and plastics.***

Cont'd

- **Strength** is ability to *withstand load* (*self weight and any applied loads*) without *failure or plastic deformation or distortion*

Materials used for building structures are said to be strong if they are capable of safely supporting their own weight and any applied loads without distortion.

  - According to different forms of external forces, the strength ***includes*** *tensile strength, compressive strength, bend strength, shear strength, fatigue strength and others.*
  - It *varies* with the ***rate*** and ***frequency*** of loading and, *in non- homogeneous* materials, with the ***direction of load*** and ***moisture*** **content (in timber), temperature (in plastic)**

- **Specific strength** is a ***ratio*** of *material strength* to *apparent density.*

  - The ***higher*** specific strength is, the ***higher*** strength and ***lighter*** weight the material is……

Cont'd

- **Durability**: Ability to ***maintain*** their *original properties* in the process of usage (*subjected to physical, chemical, biological and other natural factors besides various kinds of stress*).

  - Physical actions cause ***expansion*** and ***contraction*** of materials.
    - *wet-and-dry,*
    - *temperature, and*
    - *freeze-and-thaw changes,*
  - Chemical actions which can ***change the compositions*** of materials
    - such as the chemical *erosion* of *cement* and the *corrosion* of *steel*.
  - Biological action which can molder or rot materials,
    - such as the decomposition of wood and plant fiber

Mechanical Tests

- With reference to the <u>*rate*</u> and <u>*duration*</u> of the load application.

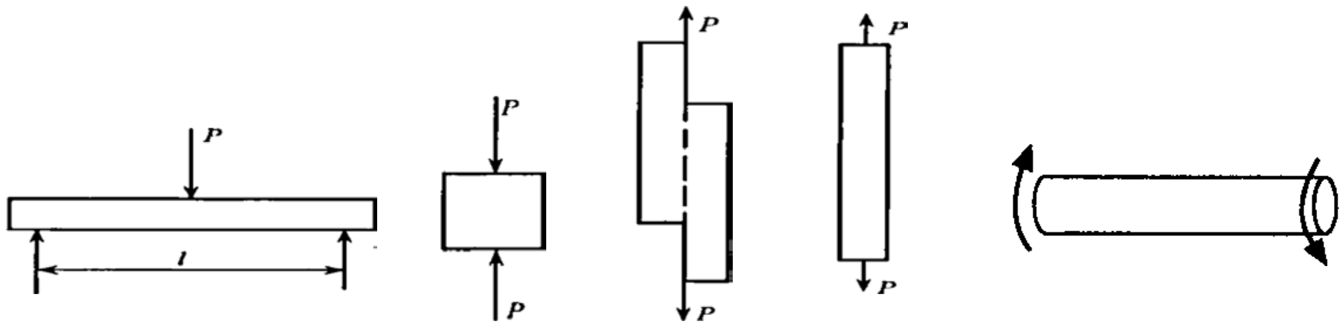
1. ***Wear tests***: made to determine ***resistance to abrasion and impact.***
2. ***Dynamic tests***: made with ***suddenly applied loads*** (generate a shock or vibration in the structure).
3. ***Fatigue tests***: made with ***fluctuating stresses repeated*** a large number of times.
4. ***Static tests***: made with ***gradually increasing load.***
5. ***Long-time tests***: made with ***loads applied for a long period of time.***

- With reference to the <u>*effect*</u> of the <u>*test*</u> on the <u>*specimen*</u>.

1. ***Destructive tests:*** tests on specimens .
2. ***Non-destructive tests:*** tests on existing structure.

Cont'd

- With reference to the ***arrangement and direction of external forces***, the following classification may be made:
  1. *Bending test*
  2. *Compressive test*
  3. *Shear test*
  4. *Tension test*
  5. *Torsion test*



- The tension and compression tests are generally used *to provide basic design information on the strength of materials and as an acceptance test for the specification of materials.*
- When a specimen is subjected to a ***gradually increasing axial tensile force***, it is ***assumed*** that the *stress is distributed uniformly on the cross section (perpendicular to the line of action of the force)*: $\sigma = \frac{P}{A_o}$ *Where, σ is tensile strength*

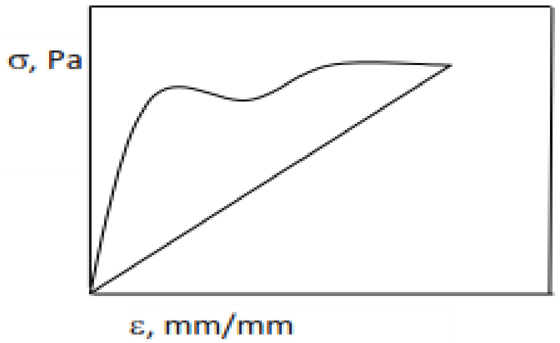
P is Applied load

A_o *is area of the section perpendicular to the line of action of the applied force*

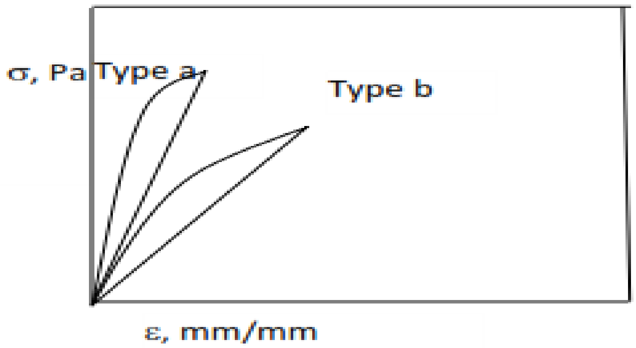
Cont’d

- The stress σ and strain ξ are called the ***nominal stress and strain*** since they ***don’t*** include ***changes*** due to ***increase in length and reduction in area of the specimen***.

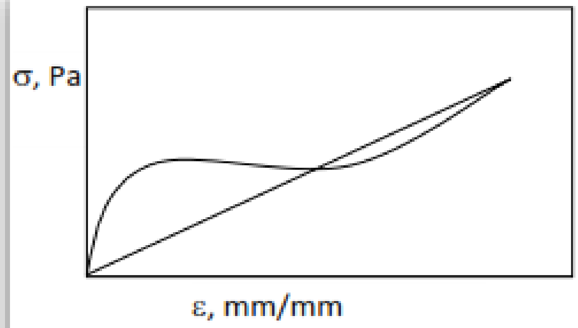
✓ ***Common types of nominal stress-strain diagrams are as follows:***



a) Ductile materials



(b) Brittle material



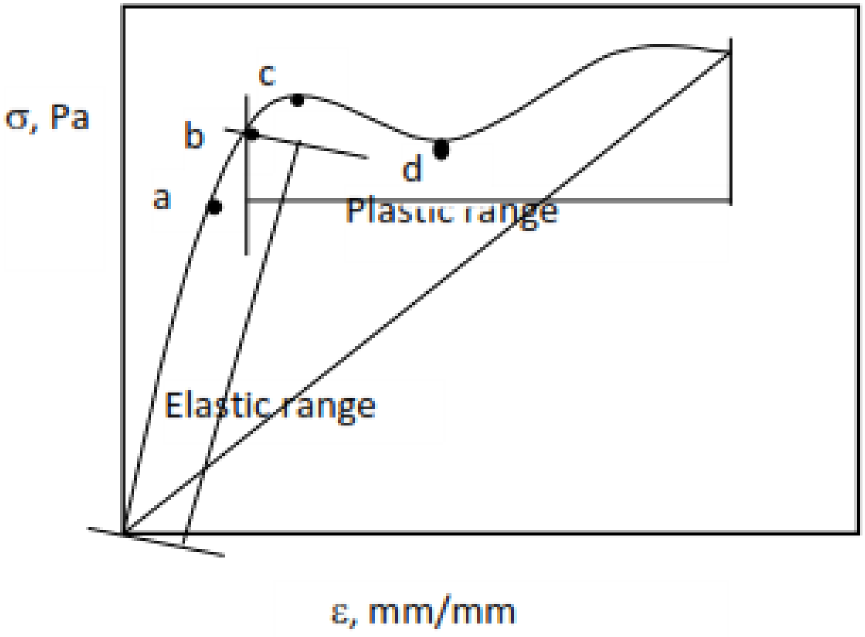
(c) Non-metallic elastic materials (soft rubber)

A ductile material will exhibit a large deformation before complete failure whereas a brittle material will fail without showing much deformation. For practical engineering purposes and many engineering materials, the initial stress strain relations may be assumed to be linear. E, the slope of the straight line, is called the modulus of elasticity.

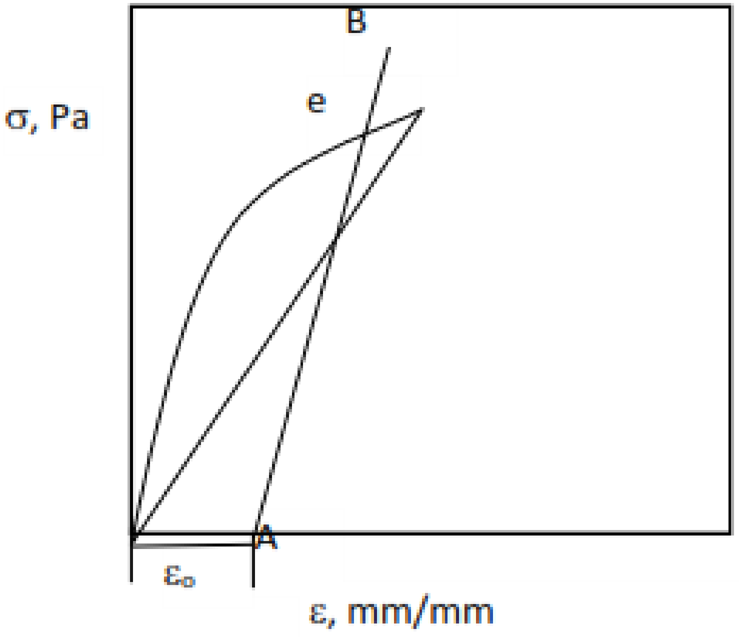
Cont'd

- The stress-strain relation is referred to as Hook's law.

$$\sigma_t = E\xi \quad \text{or} \quad E = \frac{\sigma_t}{\varepsilon} = \frac{(p/A_0)}{(\Delta l/L_0)} = \frac{PL_0}{A_0 \Delta l}$$



Elastic and Plastic strains for ductile material



Determination of yield strength for brittle materials

Properties for the elastic range

- ✓ Proportional limit: the greatest stress which the material is capable of withstanding without a deviation from the law of proportionality of stress to strain. **(point a)**
- ✓ Elastic limit: the greatest stress which a material is capable of withstanding without a permanent deformation remaining upon release of stress. **(Point b)**
- ✓ Elastic strength - measured by the stress which represents the transition from the elastic range to the plastic range **(a to d,** are on the boundary between the elastic and plastic ranges)
- ✓ Yield point: stress at which there occurs a marked increase in strain without an increase in stress (only for ductile materials). It indicates transition from the elastic to the plastic range.
  - c - Upper yield point.
  - d - Lower yield point.
- ✓ Yield strength: the stress at which yielding occurs. Stress-strain relations of most materials do not show specific yield points. To determine this stress, an offset strain **OA** = ξ_0 is measured from the **original O** (as shown in the second figure) and a line AB is drawn through the point A, ***parallel*** to the straight line portion of the stress-strain curve. The stress, at the intersection **point e,** is called the yield stress and is a measure of the yield strength based on the offset method. A. S. T. M. Commonly used values are $\xi_0 = 0.002$ and $\xi_0 = 0.0035$.

Cont'd...

- ✓ Modulus of Elasticity (young's modulus): the slope of the initial linear portion of the stress-strain curve. Three different methods are employed for materials with curved stress-strain diagrams.

a) Initial tangent modulus: the slope at the origin of the curve.

$$E_1 = \tan\theta_1$$

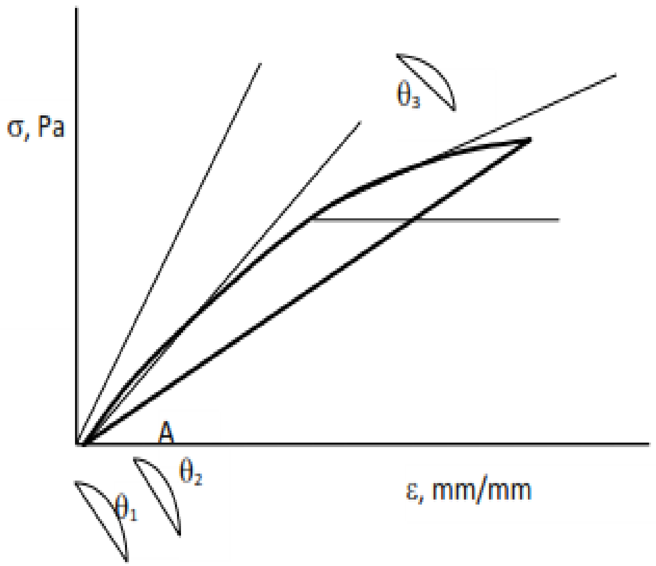
b) Secant modulus: the slope of the line joining the origin and a selected point A on the curve.

$$E_2 = \tan\theta_2$$

c) Tangent modulus: the slope of the tangent to the curve at a selected point B.

$$E_3 = \tan\theta_3$$

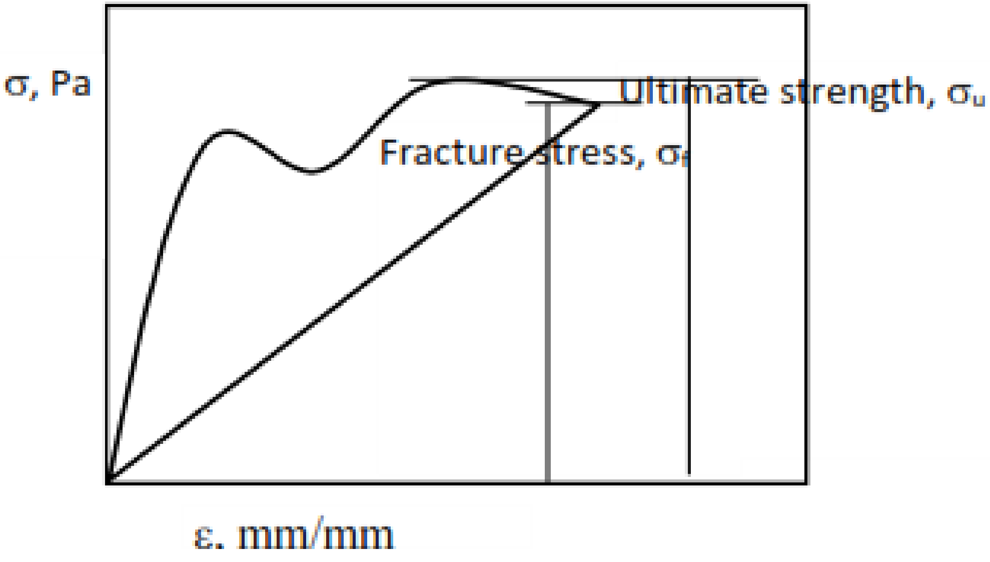
d) Stiffness: measured by its modulus of elasticity. A stiffer material exhibits a relatively small deformation in the elastic range.



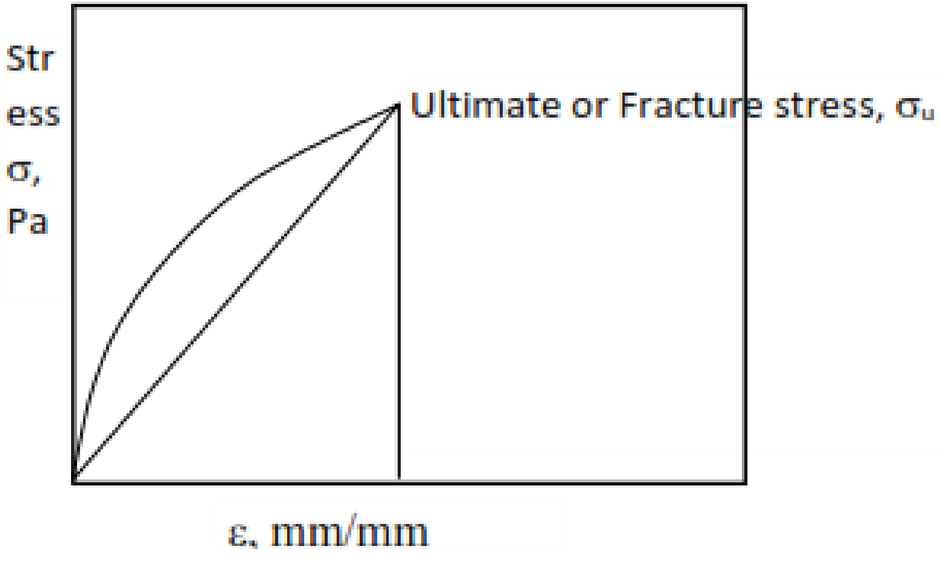
Properties for plastic range

In the plastic range a permanent deformation remains in the stressed body after complete removal of the load.

Plastic strength: it is the maximum stress a material can possibly resist just before failure. It may correspond to the ultimate strength (ultimate stress) or to the fracture (rupture) strength



(a) Ductile material



(b) Brittle material

Cont'd….,

Ductility: it represents the material ability to deform in the plastic range.

⇒ ***It is measured by the percentage elongation.***

$$D_e = \frac{L_f - L_0}{L_0} * 100 = \varepsilon_f * 100$$

L_0 = original length.

L_f = length at rupture.

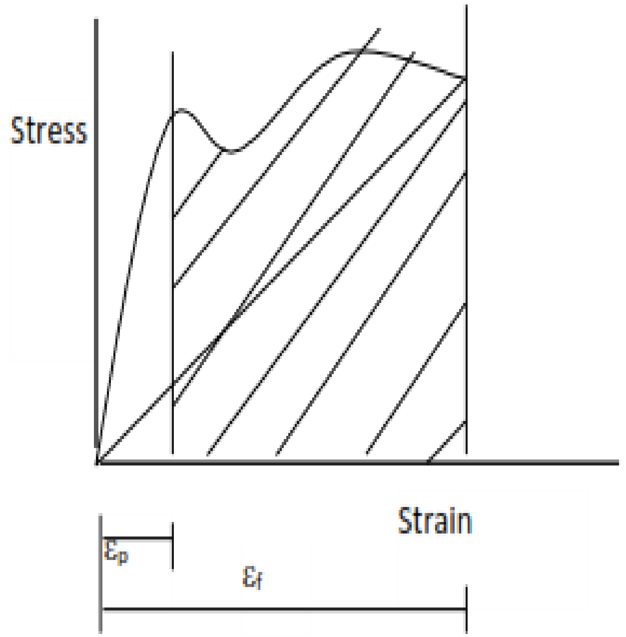
⇒ ***It is also measured by the percentage reduction in area.***

$$D_a = \frac{A_0 - A_f}{A_0} * 100$$

Toughness: materials ability to absorb energy in the plastic range.

It comprises both strength and ductility.

$$T = \int_{\varepsilon_p}^{\varepsilon_f} \sigma d\varepsilon$$



Factors Determining the Choice of Proper Material for a Structure

- ***Mechanical and non-mechanical*** properties of the building materials
- ***Construction consideration*** such as the *applicability of material to occupancy and size of building, including durability, structural, and fire protection requirements*
- ***Material compatibility** with climatic (environment), aesthetic conditions and cultural conditions*
- ***Economy***: considering *Availability*, *Initial cost*, *Useful life*, *Frequency* and *Cost* of *maintenance*, *Salvage value…*

choice of material affects all aspects of a product from cost, function (during its expected life), aesthetics, size, shape, manufacturability etc.

What is Cement?

- A **finely ground inorganic material** which has **cohesive & adhesive properties**; able to bind two or more materials together into a solid mass.

- Cohesion is the tendency of a material to maintain its integrity without separating or rupturing within itself when subject to external forces.

- Adhesion is the tendency of a material to bond to another material.

- Cement when mixed with water form a paste which sets and harden by means of **hydration reactions,** and which after hardening retain its strength and stability even under water.

CEMENTING MATERIALS

- Cementing materials are *materials with adhesive and cohesive properties*, which make them capable of of solid matter into a compact whole. ***uniting or bonding together fragments or particles***

- For engineering purposes the meaning is ***limited to those materials when mixed with water form a paste***, which is *temporarily plastic* and later on a rigid mass after setting and hardening.

- Cements of this are known as calcareous cements whose principal constituents are compounds *of lime*.

Uses of cement

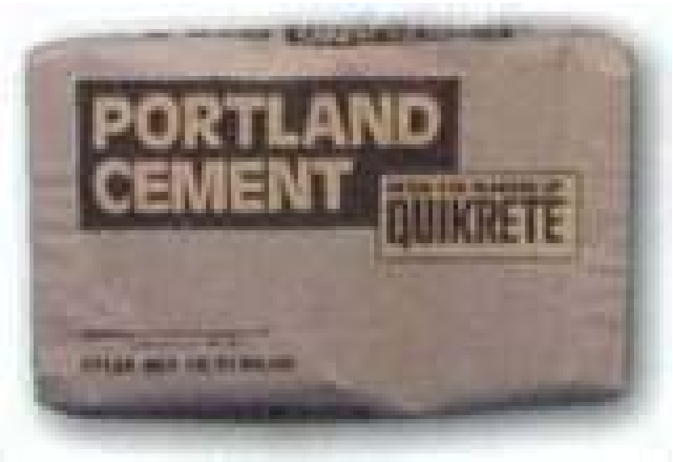
- Concrete
- Mortar
- Cement Modified Soil (CMS or soil cement)
- Asbestos cement
- Glass fiber reinforced cement

Groups of cement

Hydraulic cement

Able to set and harden in water

e.g. Portland Cement



Non-hydraulic cement

Unable   to set and harden in water but require air to harden

e.g. lime, gypsum

Raw materials of cement

- CaO (Calcium oxide) - from limestone
- SiO_2 (Silica)
- Al_2O_3 (Alumina)

- from clay

Primary material

- Fe_2O_3 (Iron oxide) - Secondary material
- MgO (Magnesium Oxide) - minor compound
- $CaSO_4$ (Gypsum) - added to cement during manufacturing

Typical composition of some raw materials

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
Limestone	2.68	0.62	0.46	51.85	1.94	0.03	0.05	0.02
Sandy clay	81.56	11.29	1.79	0.12	0.09	0.05	0.14	0.03
Clay	65.18	21.91	3.36	0.11	0.08	0.06	0.19	0.04
Iron ore	14.88	16.79	57.74	0.12	0.56	0.04	0.04	0.03
Shale	61.10	16.42	7.01	1.02	2.34	0.01	4.12	1.65
Sand	94.70	2.90	0.24	0.35	0.13	0.01	0.60	0.21
Bauxite	3.11	57.59	15.74	4.16	0.16	0.29	0.08	0.08
Gypsum	4.31	0.34	0.14	31.19	0.11	43.88	-	-
Fuel Ash	57.20	17.36	9.11	3.95	1.80	3.40	0.78	2.50

Production and Use of Lime

Calcium Carbonate

$CaCO_3$

- Carbonation Takes Place
  - Carbon Dioxide Reabsorbed
- Water Given Off

Burnt in a Kiln at 900°C

- Carbon Dioxide Given Off

Quicklime

CaO

Add to Water

Slaked Lime

$Ca(OH)_2$

- Generally <u>lime</u> is ***not found, in nature***, in free state but it is obtained by burning one of the following materials.

- ✓ Lime stone **($CaCo_3$)** found in lime stone hills:
  - consists of more than 90 percent of calcium carbonate

- ✓ Lime stone boulders found in the beds of old rivers.
- ✓ Shells of sea animals
- ✓ sometimes **dolomites** (amineralformofcalcium-magnesium carbonates, **$CaMg(CO_3)_2$**)
  - contains about 40 and 43 percent of magnesium carbonate.

Production Steps Of Lime

1. Excavation of limestone ($CaCo_3$)
2. Crushing and Grinding
3. Calcination: at 900^{o}C, ***to obtain quicklime***
   - The most commonly used kiln fuels are coal, natural gas, and occasionally oil.
   - The use of supplemental fuels such as waste solvents, scrap rubber, and petroleum coke has expanded in recent years.

4. Pulverize Quicklime (99% smaller than 0.15 mm)
5. Mixed with water under pressure: ***to obtain Slaked Lime***
6. Drying of Slaked Lime
7. Pulverizing (< 3-mm sieve) and Marketing in bags.

CALCINATION

- $CaCO_3 + \text{heat} \rightarrow CaO + CO_{2\,(g)}$ (>900°C)

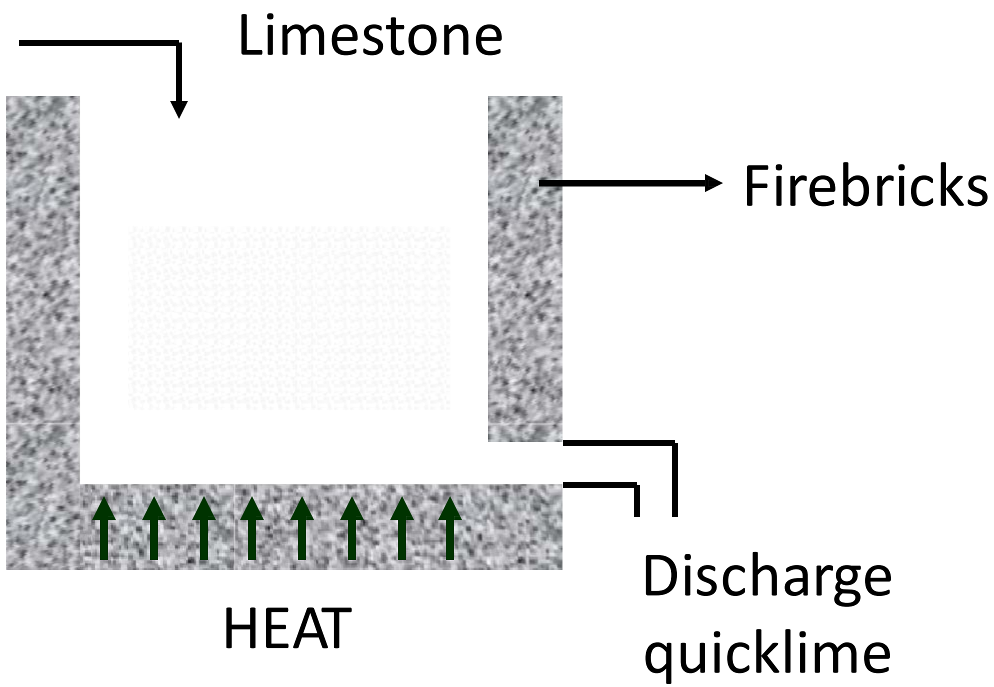
  Quick lime

- $+MgCO_3 + \text{heat} \longrightarrow +MgO + CO_2$ (>900°C)

- Calcination is carried out in kilns or furnaces
  - *Intermittent kiln (for small scale production)*
  - *Continuous kiln*
  - *Rotary kiln*
  - *Reactor kiln*

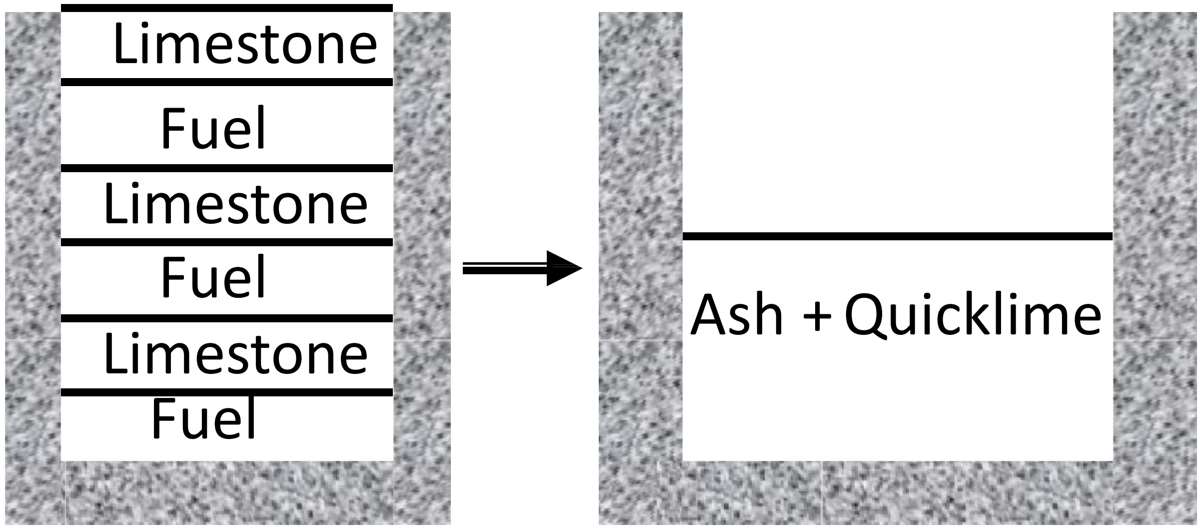
Intermittent Kiln

- It is only the flame not the fuel that comes in contact with the stones.
- It normally takes two days to burn and one day to cool the charge.
- Whenever the lime is desired intermittently or the supply of stones or fuel is not regular then the intermittent kiln is used.



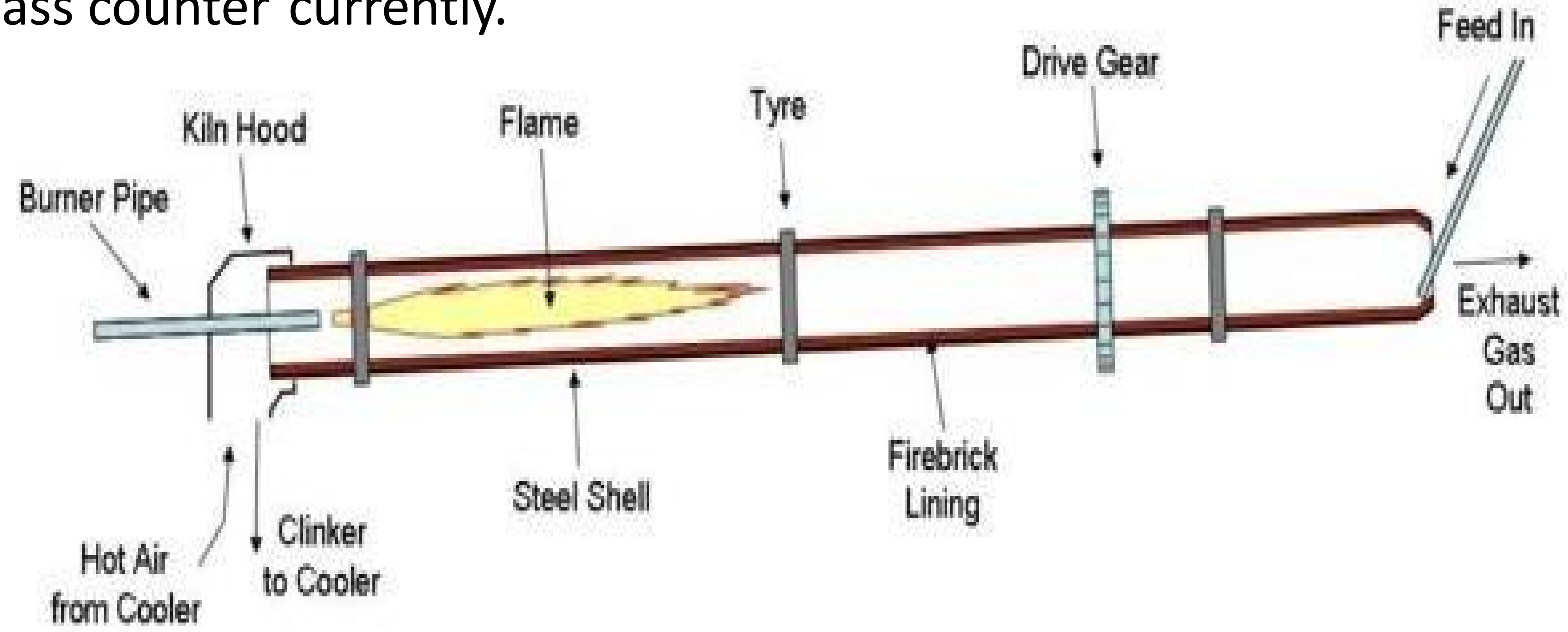
Continuous Kiln

- Burning proceeds continuously and the kiln is not allowed to cool down.
- Burnt material is drawn out daily and fresh charge of stone and fuel is added from top.



Rotary Kiln

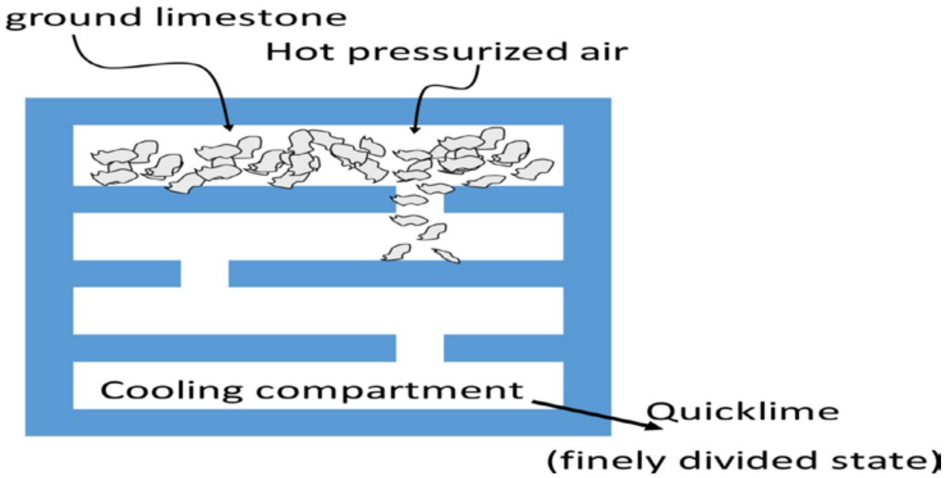
- This kiln is a long, a huge steel cylindrical, slightly inclined, refractory-lined furnace, through which the limestone and hot combustion gases pass counter currently.



Reactor Kiln

- vertical, or shaft, kiln; can be described as an upright heavy steel cylinder lined with refractory material.

- advantage over rotary kilns is higher average fuel efficiency.
- disadvantages are their relatively low production rates and the fact that coal cannot be used without degrading the quality of the lime produced.



CLASSIFICATION OF QUICKLIME

Quicklime/ Lime, is calcium oxide (CaO), a white or grayish white, finely crystalline substance that sometimes has a yellow or brown tint because of iron impurities.

1. According to Particle Size

- *Lump Lime (10-30 cm lumps)*
- *Pebble Lime (2-5 cm)*
- *Granular Lime (~0.5 cm)*
- *Crushed Lime (~5-8 mm)*
- *Ground Lime (passes #10 sieve/ 2.00 mm)*
- *Pulverized Lime (passes #100 sieve/ 0.149 mm)*

Cont‘d

2. **According to Chemical Composition**

- *High-Calcium Quicklimes, rich, fat, caustic lime* ***(CaO ≥ 90%)***
- *Calcium Quicklime* ***(75 < CaO < 90%)***
- *High magnesium/Dolomitic Quicklime* ***(at least 25% of MgO)***
- *Magnesium Quicklime* ***(at least 20% of MgO)***

3. **According to Intended Use**

- Mortar Lime (***used for stonework***)
- Plaster Lime

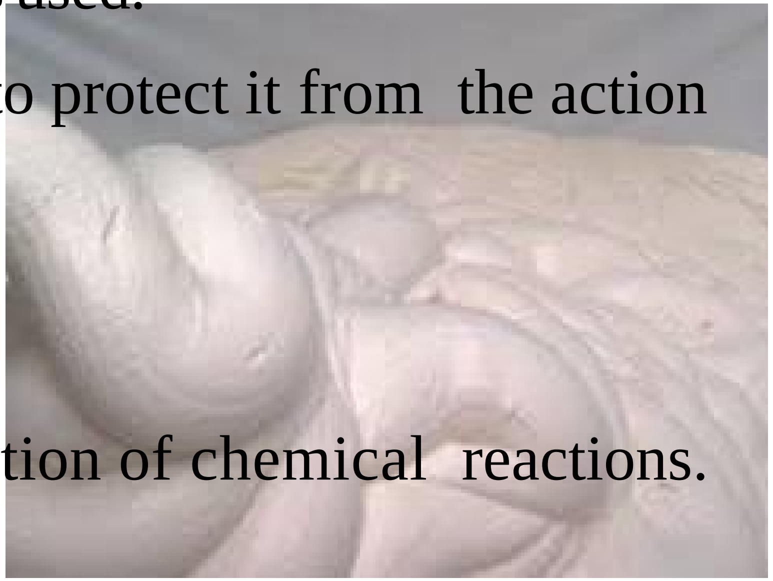
Slaking (Hydration) Of Lime

- Slaking is *adding water to Quick lime/Calcium Oxide*: $CaO + H_2O \rightarrow Ca(OH)_2$ + Heat (i.e. exothermic)
- considerable heat is generated, expansion takes place, breaking down the quicklime pieces into a fine powder, and the resulting product is calcium hydroxide, also called hydrated lime, or slaked lime.
- Magnesia limes slake more slowly and heat evolution and expansion are much less than high-calcium limes. On the other hand, they harden slowly and they are more plastic. They have less sand carrying capacity.

Cont'd

Types of slaking depending on the amount of water added are:

a) **Wet-slaking:** excess water is used.

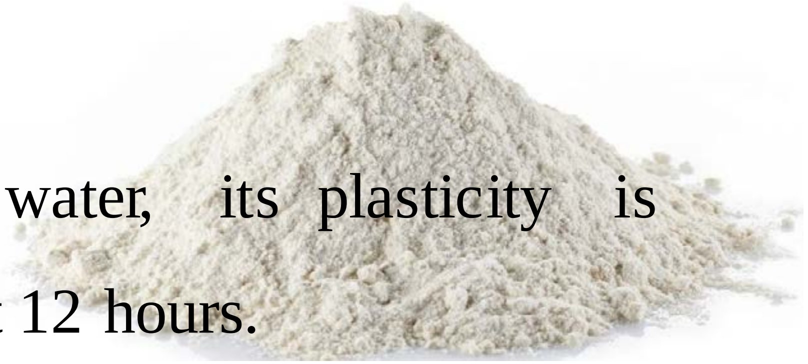


- ✓ The putty is then covered with 5-10 cm thick soil to protect it from the action of the air & left for seasoning.
  - Time of seasoning → 1 week for mortar use
    6 weeks for plaster use
- ✓ Seasoning provides a homogeneous mass & completion of chemical reactions.
- ✓ Used for plastering or limewash.
- ✓ Used for pointing masonry and even rendering.

Cont'd

b) Dry-slaking

- ✓ Just sufficient water is added (almost the theoretical quantity under carefully controlled operation),
  - The lumps break down into a dry powder
  - Can be used immediately after mixing with water, its plasticity is greatly improved by soaking overnight i.e. for at least 12 hours.



- ✓ It is usually used as an additive in cement as a plasticizer,

Hardening Of Slaked Lime

- ***Slaked lime/hydrated lime/calcium hydroxide ($Ca(OH)_2$), builders lime, or pickling lime****: is a colorless crystal or white powder*
- Slaked lime hardens or sets by gradually losing its water through evaporation and absorbing carbon dioxide from the air (carbonation), thus **reverting back** to calcium Carbonate ($CaCO_3$).

  $Ca\ (OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

- **Classification of Lime**
  1. *Fat lime,*
  2. *Hydraulic lime, and*
  3. *Poor lime.*

Cont'd

i. **Fat lime/high calcium lime/pure lime/ rich lime/ lump lime/white lime**

- ✓ Raw material is produced by fairly pure limestone, essentially calcium carbonate.
- ✓ It slakes rapidly.
  - When compared with quick lime, the volume of fat lime gets increased to about 2 - 2 ½ times during slaking. That is why it is popularly known as fat lime

The tendency of lime to expand is expressed as **soundness**.

- ✓ The color is pure white.
- ✓ It is having the high degree of plasticity.

Cont‘d

- ❖ The lime will only set by the method of carbonation
- ❖ Mixing of sand with fat lime mortar
  - forms pores for access of air which helps hardening in the interior of thick walls.
  - prevent its greater tendency to shrink and crack as it dries.
- ❖ It has greater sand carrying capacity
- ❖ does not possess much strength.
  - better for mortars, plasters and renders.

Cont’d

ii. Hydraulic Limes

- Made by burning chalk or limestone, which contain clay, silicate and producing compounds similar to those present in Portland cement.
  - The content of clay and silicate gives the hydraulic property;
- It must be thoroughly slaked by the exact amount of water required.
  - It slakes slowly.
  - Usually supplied in powder form–not usually putty like non- hydraulic.

Cont'd

- Its colour is not perfect white. It varies with percentage of clay.
- It has the capacity to set and harden ***even under water***.
  - *harden by an internal reaction and the method of carbonation*
- They are strong but less fat or plastic than non-hydraulic limes.
- Hydraulic lime was found to be very useful in:
  - *damp conditions, and*
  - *the construction of dams, bridges, quays, thick walls etc.*
  - *situations where extra strength is important*

Cont'd

Based on clay percentage, hydraulic lime is divided into three types

a. **Feebly hydraulic Lime** (5 to 10% clay content)
   - used for internal work and external work on soft porous bricks and also in covered areas.

b. **Moderately Hydraulic Lime**(11 to 20% clay content)
   - used for external work in most areas.

c. **Eminently Hydraulic Lime** (21 to 30% clay content)
   - used for external work in exposed areas, such as chimneys and floor slabs/underpinning, and in damp places

- the more clay it contains, the harder it sets and the more it behaves like cement, but makes slaking difficult

Cont'd

iii. Poor lime/ impure lime or lean lime

- Is a lime with clay content more than 30%.
- It slakes very slowly.
- Its colour is muddy.
- It never gets dissolved with water and gets frequently changed.
- It has poor binding property.
- The mortar made with such lime is used for inferior works.

LIME POPS

- If quicklime is ***not mixed completely with water***, some CaO will be carried to construction stage. In its final stage it will ***absorb water & CO_2 from air and will expand upto 2.5-3 times.***
  - This will cause cracking & pop-ups in the structure.

Precautions to be taken in Handling Lime

- Workers should be provided with goggles and respirators as the lime dust causes irritation, skin burns particularly in the presence of moisture.
- Worker should be instructed to wash their skin properly after work.
- Application of oil avoids skin burns.
- Quicklime must be kept in dry storage and carefully protected from dampness until used.
- Quicklime will corrosively attack equipment.
- Slaking of lime generates immense heat. Hence, proper precautions should be taken to avoid any fire hazards.

PROPERTIES OF LIME MORTARS

- lime mortar is obtained ***By adding sand to lime***.
  - **Sand contributions**: *decreases strength and shrinkage effects*
    - *Adjusts plasticity – otherwise too sticky*
    - *Gaining economy*
  - **lime contributions:**
    - *High water retentivity (hardens slowly)*
    - *Improved bond strength*
    - *A lighter color mortar*
- compressive strength of lime mortar varies from 5 kgf/cm^2 to 20 kgf/cm^2 (less than that of cement-and gypsum-mortars)
- Its tensile strength is less about 3 to 5 kgf/cm^2.
- Portland cement used to improve mechanical properties of lime-mortar.

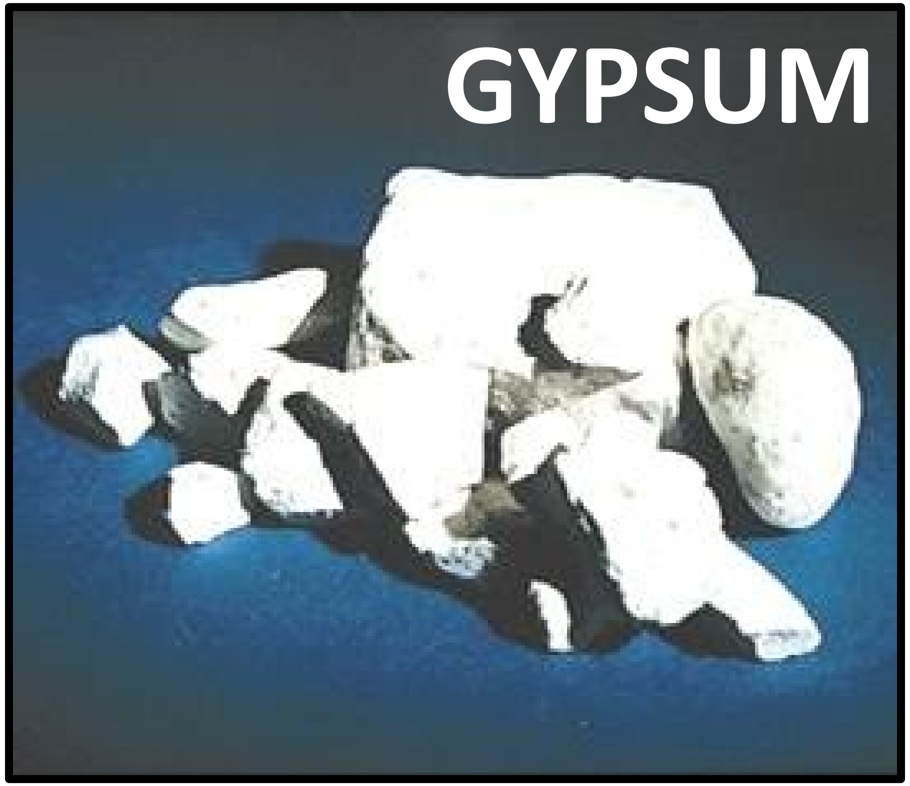
Uses of Lime

- ***Plaster mortars*** – sets slower than gypsum
- lime concrete for make ***water proof structures***.
- ***Stabilization of road surfaces*** bases and sub-bases. The use depends upon the
  - reaction of lime with particular constituent materials of the soil to give a cementing effect.
  - Climates (Slow & ineffective in cooler climates).
- It is used in the ***manufacture of glass, paints, bricks, blocks, tiles etc***.
- used as an *ingredient of cement*.
- Lime for *treatment of water and waste water.*

Production and Use of GYPSUM

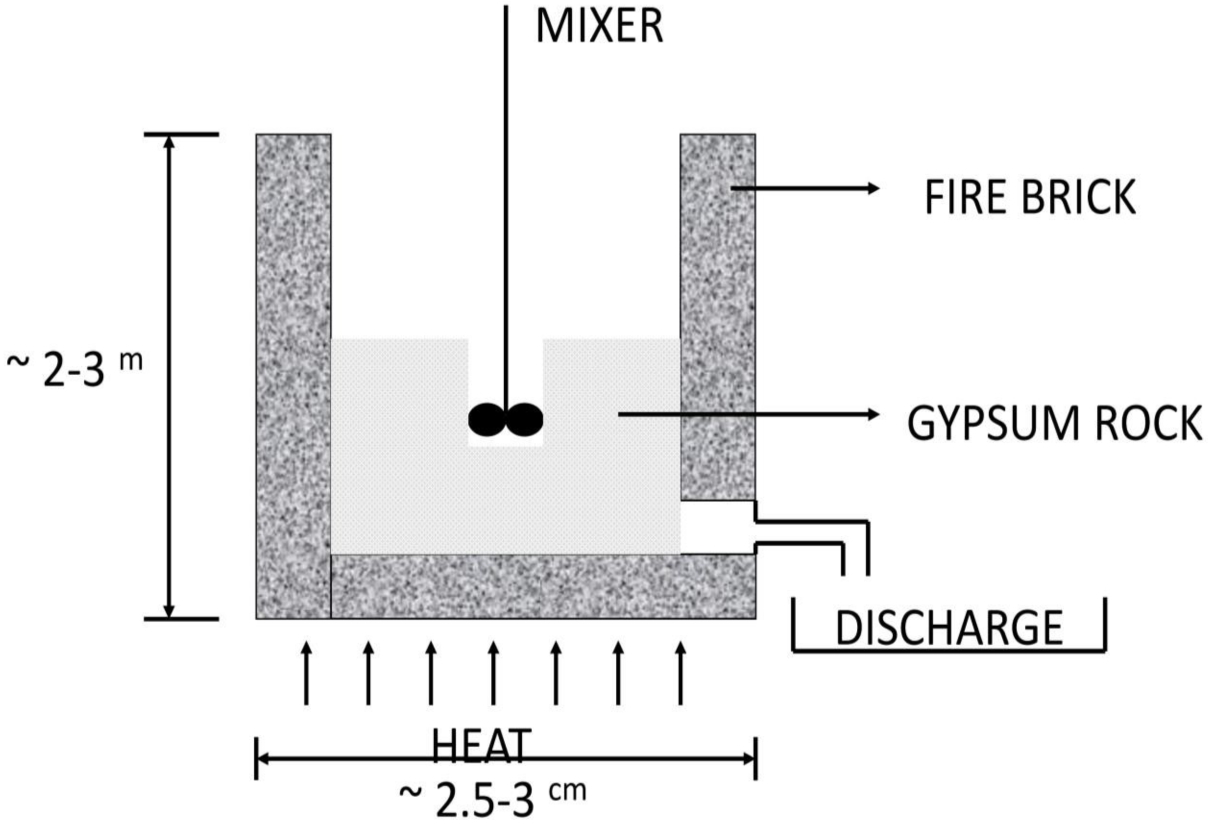
Calcium Sulphate Dihydrate /Gypsum:

- Gypsum is a hydrated calcium sulphate of non - hydraulic cementing material.
- In nature: Gypsum Rock
  - Pure gypsum rock : $CaSO_4.2H_2O$
  - Impurities : MgO, Al_2O_3, Fe_2O_3, SiO_2, $CaCO_3$, $MgCO_3$...
- It is rarely found in the pure form.



PRODUCTION STEPS

- Excavating: from open-cast mines, or underground mines using pillar and stall mining methods,
- Crushing (~25 mm diameter)
- Grinding
- Heating (calcining)
  - carried out in two types of kilns.
    - Kettle Kilns
    - Rotary Kilns
- Cooling and Pulverizing
- Marketing in Bags



Heating (calcining)

- **Incomplete calcınatıon**: is low burning process ***(150-190^{0}C)***.

  $CaSO_4.2H_2O + heat \rightarrow \quad CaSO_4.{}^1{}_2H_2O + {}^3{}_2H_2O$

  Plaster of Paris

- **Complete calcınatıon**: is high-burning process ***(above 190°C)***.

  $CaSO_4.2H_2O + heat \rightarrow CaSO_4 + 2H_2O$

  gypsum anhydrite all water is removed

- Both of these products form gypsum rock by recombining with water.

  $CaSO_4.\ {}^1{}_2H_2O + {}^3{}_2H_2O \rightarrow CaSO_4.2H_2O$

  $CaSO_4 + 2H_2O \rightarrow CaSO_4.2H_2O$

GYPSUM PLASTERS

- Obtained by Incomplete Calcination ($CaSO_4.½H_2O$)
  1. Plaster of Paris/hemihydrate /stucco: No admixtures are found.
  2. Hard Wall Plaster

     Plaster of Paris + Admixtures (Glue, Sand...)

- Obtained by Complete Calcination ($CaSO_4$)
  1. Flooring Plaster ($CaSO_4$ with no impurities)
  2. Hard Finish Plaster

     ($CaSO_4 + Al_2(SO_4)_3$)

     ($CaSO_4 + Na_2B_4O_7$)

PROPERTIES & USES OF GYPSUM PLASTERS

- Plaster of Paris (POP)/hemihydrates
  - fine, white colored powder.
  - Setting time ~5-20 min.
  - soft after setting, and can be easily manipulated with metal tools or even sandpaper.
- Used for
  - ornamental work: designs can be made in the walls and ceilings
  - Sculpturing (because of its easy occurrence and speed),
  - small repair work: seals thin cracks in the plastered surfa .
  - Finishing/ chalk plaster
  - plaster molds for casting metal to make boat keels

Cont'd

- Hard Wall Plaster
  - Setting time ~1 hr
  - Compressive strength 7 MPa
  - Admixtures result in increased plasticity & setting time & reduced shrinkage
  - Can be used for
    - plastering walls, and
    - Production of prefabricated structural units,
    - masonry bricks & blocks

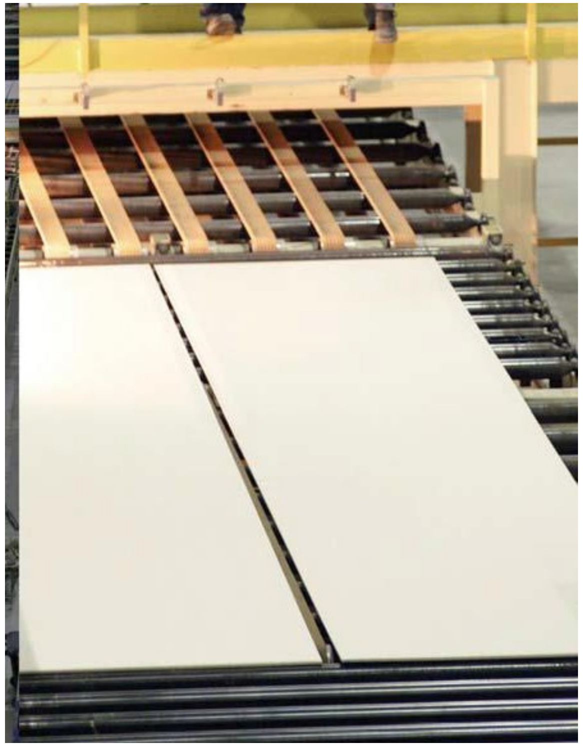
Cont'd

- Flooring, Hard Finish Plaster
  - Setting time ~1-16 hrs
  - Compressive strength > 7 MPa
  - used for producing:
    - prefabricated units,
    - masonry bricks & blocks &
    - flooring & pavement bricks & tiles.

Properties and Uses

- It is light in weight.
- It is practically unaffected by bacteria.
- It shows negligible shrinkage upon drying. So molds of actual dimensions can be used for castings.
- it is slightly soluble in water (non-hydraulıc).
    - It should not be used for exterior work & for moist interiors.
- used for sound-absorbing constructions as in acoustical plaster, plasters boards, partition tile, roof tile and reinforced plaster decking.

cont.



- Gypsum often serves as a fire and heat proofing material. It forms a powder covering the surface which acts as an effective insulator.
  - prolonged exposure to extreme heat, after the water of hydration is driven off, destroys strength.
- Plaster ingredient.
- **Gypsum board/ plaster boards/** Drywall - a layer of plaster sandwiched between two sheets of cardboard.
- Uncalcined gypsum is an effective, economical retarder in cement.
- A component of Portland cement used to prevent flash setting of concrete.

cont.

- The ultimate strength of gypsum has been found to vary from 5 kgf/cm^2 to 200 kgf/cm^2, depending upon
  - the temperature used in calcining the gypsum rock.
  - the amount of foreign materials mixed with the gypsum to retard or accelerate its rate of setting and
  - the amount of H_2O used in mixing the gypsum paste,
    - use least possible amount of water for highest strength
      - 33-38% water makes plastic or workable sufficiently.
  - completeness of drying out of H_2O after the gypsum paste has set,
    - water removed either by simply leaving the plaster to dry by evaporation or by heating it to up to 250^oC for up to 60 minutes.

cont.

- Plaster too slow in setting action , so a wide variety of setting accelerators and retardants (retarders) are used in the technology of gypsum.
  - Accelerations include such substances as potassium alum and calcium.
  - Commonly used retarders are keratin, sodium silicate, glycerol, bentonite, glue, sawdust etc.
- It should not be handled with bare hands.
  - Large amounts of Plaster of Paris placed directly onto the skin can cause serious burns because of the heat produced
  - Rubber glows and goggles should be used.

Production & Use of cements

Portland Cement

- Portland cement is a cementing material which is obtained by thoroughly mixing together **calcareous** or other lime bearing material with **argillaceous** and/or other silica, alumina or iron oxide bearing materials, burning them at a clinkering temperature and grinding the resulting clinker.
- 1824, Joseph Aspdin from Leeds city - England, produced a powder made from the calcined mixture of limestone and clay.
- He called it "Portland Cement", because when it hardened it produced a material similar to stones from the quarries near Portland Island in UK.

TYPES OF PORTLAND CEMENT

Different concrete applications require cement with different properties.

Different types of cement are achieved by changing the

- composition of cement - ratios of the four main compounds
- degree of grinding - fineness
- adding admixtures / additives

Types of Portland Cement

TYPES	ASTM	BS	MS	PROPERTIES	USES
Ordinary Portland Cement (Most common)	Type I	BS 12: 1978	522	⌗ Ordinary. ⌗ 70 % of total cement consumption. ⌗ Moderate rate of hardening. ⌗ Minimum fineness: 225 m^2/kg	⌗ General construction e.g. floors, pavements, reinforced concrete structures (Special properties not required). ⌗ Small structures (no exposure to sulfate)

Types of Portland Cement

TYPES	ASTM	BS	MS	PROPERTIES	USES
Modified Portland Cement (Moderate sulfate resistance)	Type II			▪ Moderate heat of hydration. ▪ Moderate resistance to sulfate attack.	For structures where a moderately low heat generation is desirable or moderate sulfate attack may occur either in soil or sea water e.g. large pier, retaining wall

Types of Portland Cement

TYPES	ASTM	BS	MS	PROPERTIES	USES
Rapid Hardening Portland Cement	Type III		522	⌗ Rapid strength. ⌗ High C_3S content (70 %). ⌗ High rate of heat development. ⌗ Minimum fineness: 325 m^2/kg. ⌗ 3 days strength = 14 days strength of OPC.	⌗ Urgent / fast track construction (formwork to be removed early). ⌗ High early strength is required. ⌗ Construction at low temperature.

Types of Portland Cement

TYPES	ASTM	BS	MS	PROPERTIES	USES
Low Heat Portland Cement	Type IV			⌗ Low heat of hydration. ⌗ High C_2S and C_4AF. ⌗ Low content of C_3S and C_3A resulting in low early strength but ultimate strength is unaffected.	⌗ Mass concrete structures e.g. large gravity dams. ⌗ Prevent thermal and shrinkage cracks.

Types of Portland Cement

TYPES	ASTM	BS	MS	PROPERTIES	USES
Sulfate Resisting Portland Cement	Type V		1037	⌗ Low in C_3A. (3.5%) to avoid sulfate attack. ⌗ High chemical resistance. Low heat content.	⌗ Protection from severe sulfate exposure e.g. underground water/ marine structures
White Portland Cement			888	⌗ Iron oxide < 0.4 % to ensure whiteness	⌗ Building, arts

Type IP (Portland Pozzolana cement/PPC)

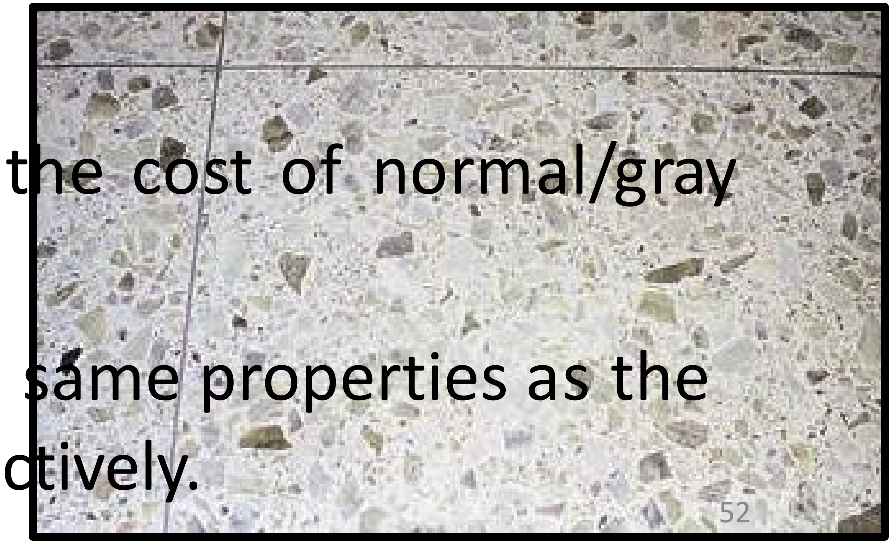
- Produced when pozollanic materials, to a maximum percentage of 35, is blended with Ordinary Portland Cement and gypsum.
- offers greater resistance to the attack of aggressive waters than OPC.
- Most pozzolans do not contribute to the strength at early ages, so strength gain of these cements is slow.
    - Therefore they require larger curing period, but the ultimate strength is the same as OPC.
- Less heat of hydration liberated during the process, which causes thermal strain resulting cracking.
- destructive expansion from alkali-aggregate reaction is less.

cont.

- The PPC is ideally suited for general construction which does not required high early strength.
- **pozzolana** is siliceous and aluminous material which in itself possesses ***little, or no cementitious properties*** but will in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.
  - Fly ash, slag (blast-furnace), silica fume are artificial pozzolans.
  - Volcanic ash, tuffs , diatomaceous earth, opaline cherts and shales are natural pozzolan.

WHITE PORTLAND CEMENT

- Used for architectural /aesthetic reasons,
  - for terrazzo flooring, stucco, and architectural concrete.
- China clay (Kaolin) is generally used together with chalk or limestone free from specified impurities (iron oxide, manganese oxide).
  - This complicates the manufacturing process and increases the energy cost
    - To avoid contamination by coal ash, oil is used as fuel in the kiln
    - The cost of grinding is higher
- Consequently, the cost approximately twice the cost of normal/gray portland cement.
- produced as Type I or Type III. Which have the same properties as the gray Type I and Type III portland cement, respectively.



Sources of Raw Materials Used in Manufacture of Portland Cement

Calcium	**Silica**	**Alumina**	**Iron**	**Sulfate**
Alkali waste	Calcium silicate	Aluminum-ore refuse	Blast-furnace	Anhydrite
Clay	Clay	Clay	Clay	Calcium sulfate
Cement rock	Cement rock	Cement rock	flue dust	Gypsum
Aragonite	Loess	Loess	Iron ore	
Fuller's earth	Fuller's earth	Fuller's earth	Mill scale	
Calcite	Fly ash	Fly ash	Pyrite cinders	
Cement-kiln dust	Ore washings	Ore washings	Ore washings	
Chalk	Sand	Copper slag	Shale	
Limestone	Limestone	Limestone		
Marble	Quartzite	Granodiorite		
Marl	Rice-hull ash	Bauxite		
Seashells	Marl	Staurolite		
Shale	Shale	Shale		
Slag	Slag	Slag		
	Sandstone			
	Trap rock			

Source: PCA, 2003

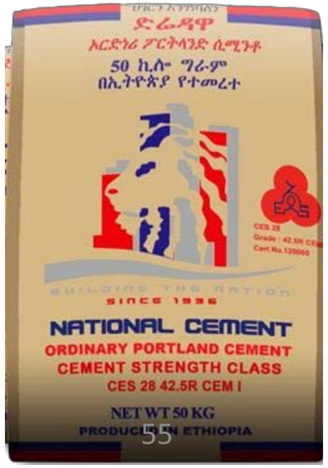
Shale = soft finely stratified sedimentary rock

chemical compounds of Portland Cement

Compound	Abbreviation	Chemical formula	Typical concentration
Tricalcium silicate / alite	C_3S	$(CaO)_3 \cdot SiO_2$	50-70%
Dicalcium silicate / belite	C_2S	$(CaO)_2 \cdot SiO_2$	15-30%
Tricalcium Aluminate / celite	C_3A	$(CaO)_3 \cdot Al_2O_3$	5-10 **%**
Tetracalcium alumino-ferrate / iron	C_4AF	$(CaO)_4 \cdot Al_2O_3 \cdot Fe_2O_3$	5-15%cont.
Calcium Oxide		CaO	2%
Magnesium Oxide		MgO	4%
Gypsum		$CaSO_4 \cdot 2\,H_2O$	2–10%

Typical Compound Composition and Fineness of Portland Cements

Type of cement	Designation ASTM	Compound comp.%				Fineness* (cm^2/g)
		C_3S	C_2S	C_3A	C_4AF	
Ordinary	Type I	50	24	11	8	1800
Modified	Type II	42	33	5	13	1800
Rapid Hardening	Type III	60	13	9	8	2600
Low Heat	Type IV	26	50	5	12	1900
Sulphate Resisting	Type V	40	40	4	9	1900



* Fineness as determined by Wagner turbidimeter test.

Steps in Manufacturing Process Of Portland Cement

- Grinding & mixing of raw materials
- Burning in rotary kiln (clinker is produced)
- Cooling, grinding of clinker & sieving
- Storing, packing & distributing

Types of Processes

- The wet process
- The semi-dry process
- The dry process

Production Steps of Ordinary Portland Cement /OPC

- raw materials acquisition and stored separately.
- Crushing and stockpiling the raw materials
- Calculating the proportions of raw materials depending upon their purity and composition
- Raw materials are blended and mixed to produce uniform chemical composition containing calcium carbonate, silica, alumina, iron oxide etc.
- ground until more than 85% of the material is less than 90µm in diameter.

cont.

- the powder goes into a or rotary kiln.
- Clinker is cooled to a temperature of about 60-150^{o}C and stockpiled.
  - Rate of cooling significantly affects the reactivity of the final cement
- Either gypsum or natural anhydrite, both of which are forms of calcium sulfate, is introduced to the process during the finish grinding of Clinker
  - to control the setting time of the finished cement.
- The finished cement is stored in silos for a relatively short time before being sent to the customer in bags or in bulks.

TESTING OF CEMENT

Testing are done to

- ensure the quality of cement.
- determine the chemical and physical properties of cement.

Tests should be conducted according to the relevant standard:

- MS 522 Part 1, 2, 3 – OPC
- BS 12: 1978 – OPC and RHPC
- BS 4550: Part 1: 1978 – Methods of testing cement.

Types of Testing

- **Chemical composition**

  - To determine the amount of C_3S, C_2S, C_3A & C_4AF

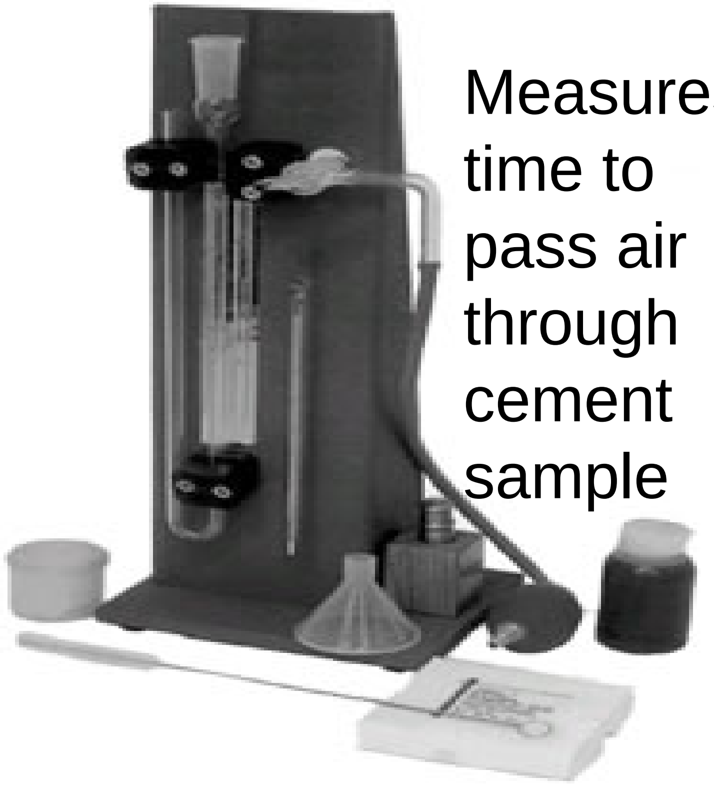
- **Fineness of cement**

  - Fineness influences:

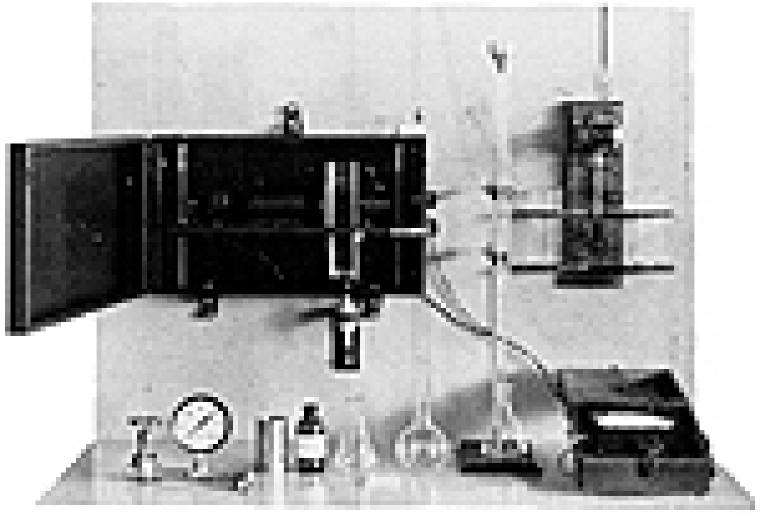
  Rate of hydration, rate of heat released and rate of strength development

  - Fineness is determined through *specific surface* (m^2/kg)

Fineness Test



Measures time to pass air through cement sample



Wagner Turbidimeter

Blaine Air Permeability

➢ Setting time

Time taken for cement paste to change from fluid to a rigid state.

Vicat test

Gilmore test

Setting time

- **Initial set** – Time from moment water is added until the paste ceases to be fluid and plastic.

  Vicat test – time when penetration of 25 mm is obtained

- **Final set** – Time from moment water is added until the paste acquire a certain degree of hardness.

  Vicat test – time when the needle does not penetrate visibly into the paste.

  For OPC and RHPC: Initial set time > 45 minutes.
  Final setting time – < 10 hours.

Setting time

- **False set**

  Occurs within a few minutes of mixing with water. No heat is evolved. The concrete can be remixed without adding water.

- **Flash set**

  In the absence of gypsum, immediate stiffening of the cement paste occur due to the rapid reaction between C_3A with water. The concrete can't be restored.

➢ Soundness

- Ability of hardened paste to retain volume after setting.
- Cements exhibiting expansions are classified as unsound.
- Expansion may occur due to reactions of free lime (CaO), magnesia (MgO) and calcium sulphate.
- Calcium sulphate – cause expansion through the formation of calcium monosulphoaluminate from excess gypsum (not used up by C_3A during setting).
- For OPC, expansion not more than 10 mm.

Soundness Test

Autoclave test

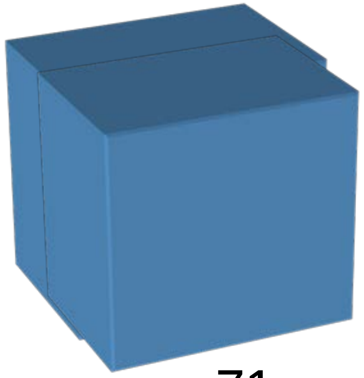
(for testing unsoundness due to magnesia.)

(detecting unsoundness due to free lime only)

Le Chattelier's apparatus

➢ Compressive Strength

Compressive strength tests are made on mortar and concrete cubes.



71 mm

Mortar Cube Test

Mortar = Cement + Sand + Water

1 : 3

(standard sand, one size and spherical shape)

(10% of the mass of dry materials)

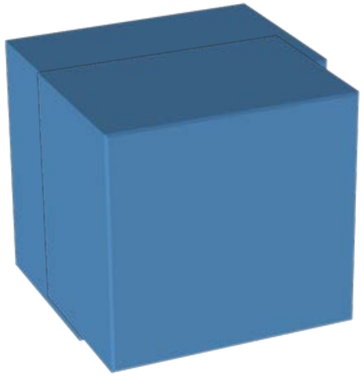
Compressive strength test

• > 24 hours, demould mortar cubes.
• Cure in water.
• Get the average compressive strength for three cubes.

According to MS 522: Part 1
• OPC – 23 MPa at 3 days, 41 MPa at 28 days
• RHPC–29 MPa at 3 days, 46 MPa at 28 days

Compressive strength test

Concrete Cube Test



100 mm

Concrete = Cement + Aggregate + Water

1 : 6 (Water / cement: 0.6, 0.55, 0.45)

- OPC – 11.5 MPa at 3 days; 26 MPa at 28 days
- RHPC – 18 MPa at 3 days; 33 MPa at 28 days

CHAPTER 3: Mix Design Process

1. Introduction

- The proportioning of concrete mixtures, more commonly referred to as mix design, is a process that consists of two interrelated steps:
    1. ***selection of the suitable ingredients*** (cement, aggregate, water and admixtures) of concrete and
    2. ***determining their relative quantities*** ("proportioning")
- to produce, as ***economically as possible***, concrete of the appropriate ***workability***, ***strength*** and ***durability***.

A. Economy

- the cost of concrete is made up of the costs of materials, labor, and equipment.
- However, except for some special concretes, the costs of labor and equipment are largely independent of the type and quality of concrete produced.

1. Introduction

A. Economy

- It is therefore the material costs that are most important in determining the relative costs of different mix designs.
- Since cement is much more expensive than aggregate, it is clear that minimizing the cement content is the most important single factor in reducing concrete costs.
- This can, in general, be done
  - by using the ***lowest slump that will permit adequate placement***,
  - by using the ***largest practical maximum size of aggregate***,
  - by using the ***optimum ratio of coarse to fine aggregates***,
  - where necessary, by ***using appropriate admixtures***.

1. Introduction

B. Workability

- a properly designed mix must be capable of being placed and compacted properly with the equipment available.
- Finishability must be adequate, and segregation and bleeding should be minimized.
- As a general rule, the concrete should be supplied at the minimum workability that will permit adequate placement.
- For concrete without mineral admixtures, the water requirement for workability depends mostly on the characteristics of the aggregate rather than those of the cement.

1. Introduction

C. Strength and Durability

- In general, concrete specification will require a minimum compressive strength.
- They may also impose limitations on the permissible w/c ratio and minimum cement contents.
- It is important to ensure that these requirements are not mutually incompatible.
- Specifications may also require that the concrete meet certain durability requirements, such as resistance to freezing and thawing or chemical attack.

1. Introduction

Limiting Values

- It is obvious to encounter limiting values in many specifications. The limiting values may cover a range of properties; the more usual ones are:
  - ***Minimum compressive strength*** necessary from structural considerations;
  - ***Maximum water/cement ratio*** and/or ***minimum cement content*** and, in certain conditions of exposure, a minimum content of entrained air to give adequate durability;
  - ***Maximum cement content*** to avoid cracking due to the temperature cycle in mass concrete;
  - ***Maximum cement content*** to avoid shrinkage cracking under conditions of exposure to a low humidity; and
  - ***Minimum density*** for gravity dams and similar structures.

1. Introduction

Specifying Concrete

- Generally concrete can be specified in one of the four ways:
  - ***Designed mix*:** is specified by the designer principally in terms of strength, cement content, and water/cement ratio; compliance relies on strength testing.
  - ***Prescribed mix*:** is specified by the designer in terms of the nature and proportions of mix ingredients; the concrete producer simply makes the concrete 'to order'.
  - ***Standard mix*:** is based on ingredients and proportions fully listed in the specific standards. This type of mix most of the time are used only in minor construction.
  - ***Designated mix*:** In this case the concrete producer selects the water/cement ratio and the minimum cement content using a table of structural applications coupled with standard mixes.

1. Introduction

Mix Design Methods

- Some of the prevalent concrete mix design methods are:
  - ***ACI***: American Concrete Institute Mix Design Method,
  - ***DOE***: Department of Environment Mix design practice (British),
  - ***DIN*** Mix design Method (German)
  - ***IS***: Indian Standard Mix Design Method

2. ACI MIX DESIGN PROCESS

Back Ground 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 absorptions of aggregates.
  - Specific gravities of Portland cement and other cementitious materials, if used.
  - Optimum combination of coarse aggregates to meet the maximum density gradings

2. ACI MIX DESIGN PROCESS

Procedure

Step-1: Choice of slump

- If slump is not specified, a value appropriate for the work can be selected from Table-1

Types of construction	Slump, mm	
	Maximum*	Minimum
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-1: Recommended slumps for various types of construction

2. ACI MIX DESIGN PROCESS

Procedure

Step-2: Choice of maximum size of aggregate

- Large nominal maximum sizes of well graded aggregates have less voids than smaller sizes.
- Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete.
- Generally, the nominal maximum size of aggregate should be the largest that is economically available and consistent with dimensions of the structure.

2. ACI MIX DESIGN PROCESS

Procedure

Step-3: Estimation of mixing water and air content

- The quantity of water per unit volume of concrete required to produce a given slump is dependent on:
  - the nominal maximum size,
  - particle shape, and
  - grading of the aggregates;
  - the concrete temperature;
  - the amount of entrained air; and
  - use of chemical admixtures.
- Table-2 provides estimates of required mixing water for concrete made with various maximum sizes of aggregate, with and without air entrainment.

2. ACI MIX DESIGN PROCESS

Procedure

Step-3: Estimation of mixing water and air content

Table-2: Approximate mixing water and air content requirements

Slump, mm	Water, Kg/m³ of concrete for indicated nominal maximum sizes of aggregate							
	9.5*	12.5*	19*	25*	37.5*	50†*	75†‡	150†‡
Non-air-entrained concrete								
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	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25 to 50	181	175	168	160	150	142	122	107
75 to 100	202	193	184	175	165	157	133	119
150 to 175	216	205	197	184	174	166	154	—
Recommended average§ total air content, percent for level of exposure:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5**††	1.0**††
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5**††	3.0**††
Extreme exposure‡‡	7.5	7.0	6.0	6.0	5.5	5.0	4.5**††	4.0**††

2. ACI MIX DESIGN PROCESS

Procedure

Step-4: Selection of water-cement or water-cementitious materials ratio

- Approximate and relatively conservative values for concrete containing Type I Portland cement can be taken from Table-3a.

Table-3a: Relationships between water-cement ratio and compressive strength of concrete

Compressive strength at 28 days, MPa*	Water-cement ratio, by mass: Non-air-entrained concrete	Water-cement ratio, by mass: Air-entrained concrete
40	0.42	—
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

2. ACI MIX DESIGN PROCESS

Procedure

Step-4: Selection of water-cement or water-cementitious materials ratio

- For severe conditions of exposure, the w/c or $w/(c + p)$ ratio should be kept low even though strength requirements may be met with a higher value. Table-3b gives limiting values.

Table-3b: Maximum permissible water-cement ratios for concrete in severe exposure

Type of structure	Structure wet continuously or frequently and exposed to freezing and thawing†	Structure exposed to sea water or sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 5 mm cover over stee	0.45	0.40‡
All other structures	0.50	0.45‡

2. ACI MIX DESIGN PROCESS

Procedure

Step-5: Calculation of cement content

- The amount of cement per unit volume of concrete is fixed by the determinations made in Steps 3 and 4 above.
- The required cement is equal to the estimated mixing-water content (Step 3) divided by the water-cement ratio (Step 4).
- If, however, the specification includes a separate minimum limit on cement in addition to requirements for strength and durability, the mixture must be based on whichever criterion leads to the larger amount of cement.

2. ACI MIX DESIGN PROCESS

Procedure

Step-6: Estimation of coarse aggregate content

- Appropriate values for this aggregate volume are given in Table-4.

Table-4: Volume of coarse aggregate per unit volume of concrete

Nominal maximum size of aggregate, mm	Volume of dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli† of fine aggregate			
	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

2. ACI MIX DESIGN PROCESS

Procedure

Step-7: Estimation of fine aggregate content

- At completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity is determined by difference. Either of two procedures may be employed:
  - the weight method or
  - the absolute volume method.

The weight method

- If the weight of the concrete per unit volume is assumed or can be estimated from experience, the required weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of the other ingredients.
- First estimate of weight of fresh concrete can be determined from Table- 5.

2. ACI MIX DESIGN PROCESS

Procedure

Step-7: Estimation of fine aggregate content The weight method

Table-5: First estimate of weight of fresh concrete

Nominal maximum size of aggregate, mm	First estimate of concrete unit mass, kg/m^{3*}	
	Non-air-entrained concrete	Air-entrained concrete
9.5	2280	2200
12.5	2310	2230
19	2345	2275
25	2380	2290
37.5	2410	2350
50	2445	2345
75	2490	2405
150	2530	2435

2. ACI MIX DESIGN PROCESS

Procedure

Step-7: Estimation of fine aggregate content The weight method

- If a theoretically exact calculation of fresh concrete weight per m^3 is desired, the following formula can be used

$$U_M = 10G_a(100 - A) + C_M(1 - G_a/G_c) - W_M(G_a - 1)$$

where

U_M = unit mass of fresh concrete, **kg/m³**

G_a = weighted average specific gravity of combined fine and coarse aggregate, bulk, SSD

G_c = specific gravity of cement (generally 3.15)

A = air content, percent

W_M = mixing water requirement, **kg/m³**

C_M = cement requirement, **kg/m³**

2. ACI MIX DESIGN PROCESS

Procedure

Step-8: Adjustment for moisture aggregate

- The aggregate quantities actually to be weighed out for the concrete must allow for moisture in the aggregates.
- Generally, the aggregates will be moist and their dry weights should be increased by the percentage of water they contain, both absorbed and surface.
- The mixing water added to the batch must be reduced by an amount equal to the free moisture contributed by the aggregate -- i.e., total moisture minus absorption.

2. ACI MIX DESIGN PROCESS

Procedure

Step-9: Trial batch adjustments

- The calculated mixture proportions should be checked by means of trial batches prepared and tested in accordance with ASTM C 192

2. ACI MIX DESIGN PROCESS

Example-1

Concrete is required for a portion of a structure that will be below 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 (cylindrical)***. It is determined that under the conditions of placement to be employed, a ***slump of 75-100 mm*** should be used. and the ***coarse aggregate*** has a ***nominal maximum size of 37.5 mm*** and ***dry-rodded mass of 1600 kg/m***^{3}.

- Other properties of the ingredients are: ***cement*** -Type I with specific gravity of 3.15; ***coarse aggregate*** - bulk specific gravity 2.68 and absorption 0.5 percent; ***fine aggregate*** - bulk specific gravity 2.64, absorption 0.7 percent, and fineness modulus 2.8.
- Calculate the weights of all materials that you would use for the first trial mix on a concrete mix.

2. ACI MIX DESIGN PROCESS

Example-1 Solution

- ***Step 1:*** The slump is required to be 75 to 100 mm.
- ***Step 2***: The aggregate to be used has a nominal maximum size of 37.5 mm.
- ***Step 3***: The concrete will be non-airentrained 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 mm aggregate is found to be ***181 kg/m³***.
- ***Step 4:*** The water-cement ratio for non-airentrained concrete with a strength of 24 MPa is found from ***Table-3a*** to be ***0.62***.
- ***Step-5***: From the information developed in Steps 3 and 4, the required cement content is found to be 181/0.62 = ***292 kg/m³***.

2. ACI MIX DESIGN PROCESS

Example-1 Solution

- ***Step 6***: The quantity of coarse aggregate is estimated from ***Table-4***. For a fine aggregate having a fineness modulus of 2.8 and a 37.5 mm nominal maximum size of coarse aggregate, the table indicates 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 x 1600 = ***1136 kg***.
- ***Step 7***: The required fine aggregate may be determined on the basis of either mass or absolute volume as shown below:

2. ACI MIX DESIGN PROCESS

Example-1 Solution

- ***Step 7*: *Mass basis***
  - From Table-5, 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 ***2410 kg***. Masses already known are:

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

- The mass of fine aggregate is therefore estimated to be

$$2410 – 1609 = 801 \text{Kg}$$

2. ACI MIX DESIGN PROCESS

Example-1 Solution

- ***Step 7***: ***Absolute volume basis***
  - With the quantities of cement, water, and coarse aggregate established, and the approximate ***entrapped air content*** of ***1 percent*** determined from Table-2 , the sand content can be calculated as follows:

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

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

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

2. ACI MIX DESIGN PROCESS

Example-1 Solution

- *Step 7*: *Absolute volume basis*

Volume of entrapped air	=	0.01 x 1.000	0.010 m^3
Total solid volume of ingredients except fine aggregate			0.708 m^3
Solid volume of fine aggregate required	=	1.000 - 0.705	0.292 m^3
Required weight of dry fiie aggregate	=	0.292 x 2.64 x 1000	771 kg

2. ACI MIX DESIGN PROCESS

Example-1 Solution

- *Step 7*:
  - Batch 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

Example-1 Solution

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

$$\text{Coarse aggregate (wet)} = 1136(1.02) = 1159 \text{ kg}$$
$$\text{Fine aggregates (wet)} = 801(1.06) = 849 \text{kg}$$

- Ab… d must be exc… ace water contributed by the ***coarse aggregate amounts to 2 - 0.5 = 1.5%***; by the ***fine aggregate 6 - 0.7 = 5.3%***. The estimated requirement for added water, therefore, becomes

$$181 - 1136(0.015) - 801(0.053) = 122 \text{ kg}$$

2. ACI MIX DESIGN PROCESS

Example-1 Solution

- ***Step 8***:
  - 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
Fine aggregate (wet)	849 kg
Total	2422 kg

- ***Step 9***: For th le the masses down to produce 0.02 m^3 of concrete.

2. ACI MIX DESIGN PROCESS

Exercise-1

- Calculate the weights of all materials that you would use for the first trial mix on a concrete mix required to achieve Characteristic compressive strength of 25 N/mm^2 at 28 days (cubic strength). The following information on material properties and plant performance is available to you.

Cement Type, specific gravity respectively	O.P.C, 3.15
Max. Aggregate size, rodded bulk density of aggregate	19mm,1600kg/m^3
Rel. Density (S.G) of combined aggregate (SSD)	2.75
Required Slump	25mm
Maximum Cement Content	500 Kg/m^3
Max free water/cementratio	0.5
Fineness modulus	2.97
Air content	1%
Freemoisturecontentofsandandcoarseaggregaterespectively	8%, 1%
Bulk specific gravity of coarse and fine aggregate respectively	2.7, 2.6
Absorption of coarse and fine aggregate respectively	0.3%, 0.8%

2. ACI MIX DESIGN PROCESS

Exercise-2

- Calculate the weights of all materials that you would use for the first trial mix on a concrete mix required to achieve Characteristic compressive strength of 40 N/mm^2 at 28 days (cubic strength). The following information on material properties and plant performance is available to you.

Cement Type, specific gravity respectively	O.P.C, 3.15
Max. Aggregate size, rodded bulk density of aggregate	12.5mm,1700 kg/m^3
Rel. Density (S.G) of combined aggregate (SSD)	2.7
Required Slump	50mm
Min. Cement Content	320 Kg/m^3
Max free water/cementratio	0.7
Fineness modulus	2.93
Air content	1%
Free moisture content of sand and coarse aggregate respectively	8%, 1%
Bulk specific gravity of coarse and fine aggregate respectively	2.7, 2.6
Absorption of coarse and fine aggregate respectively	0.3%, 0.8%

Common terms

- **Paste:** is a mixture of water and cement
  - Hydration, chemical reaction between water and cement which begins as soon as they meets, results a hardened cement paste (cement stone).

Mortar

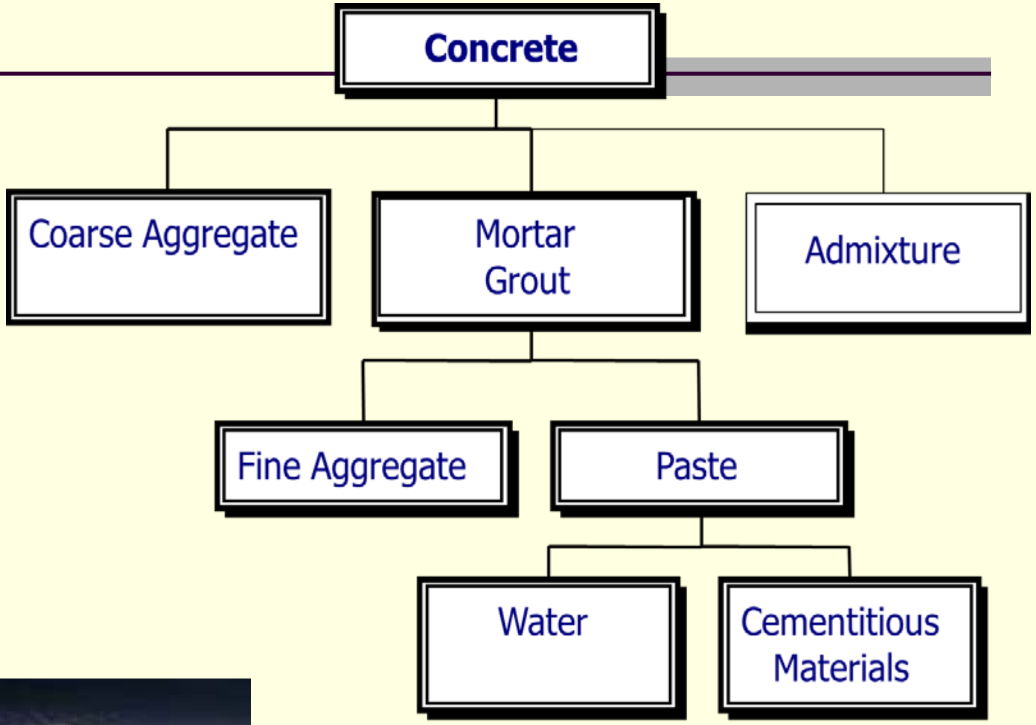
- **Mortar/cement plaster:** mixture of ***paste and fine aggregate***
  - Depending on the desired strength, cement to the sand ratio varies from 1:2 to 1:6.
    - *(1:2 cement to sand ratio means 1 part cement and 2 part sand)*
- **Lime mortar** = water+ lime (fat lime or hydraulic lime) + sand
  - The lime to the sand proportion is kept 1:2.

Common terms

- **Gauged mortar** = water + cement + lime + sand .
  - cement to lime proportion varies from 1:6 to 1:9.
  - economical than cement concrete and stronger than lime mortar.
- mortar are used
  - as a render on masonry
  - as a bedding agent in brickwork, ceramic tiles, roof tiles
  - as a finishing material /plaster to provide weather resistance

Concrete

- **Concrete:** mixture of mortar & larger aggregate or cement paste & aggregates (fine and coarse aggregate)
  - the cement paste: 25 - 35 percent of concrete volume
  - aggregate: 60 - 75 percent of concrete volume.
    - fine aggregate content usually 35% to 45% of total aggregate
  - contains air, which varies from 2-8% by volume
  - admixtures: unlike cement, aggregate and water are not an essential component, but they are increasingly widespread.



AGGREGATE

- Rocklike material of random shapes and contains mineral such as sand, gravel, shale or slag.
- Aggregate is a collective term for sand, gravel and crushed stone.

Uses

- Underlying material (base course) for foundations and roads Add stability & provide drainage layer.
- Base materials for roads
- Ballast for railroads
- Asphalt concrete
- Protection of bank or shore from erosion – riprap

Uses

- As a bedding or backfill material for underground pipes.

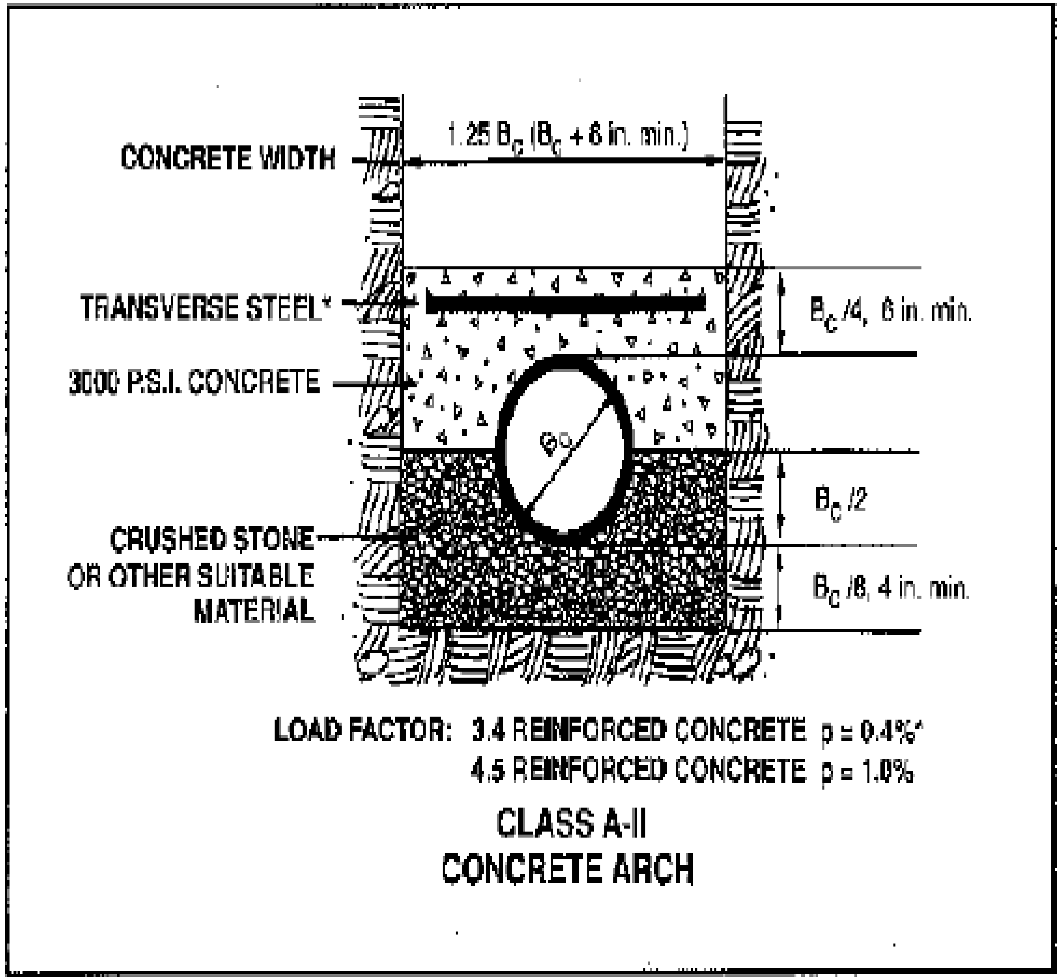
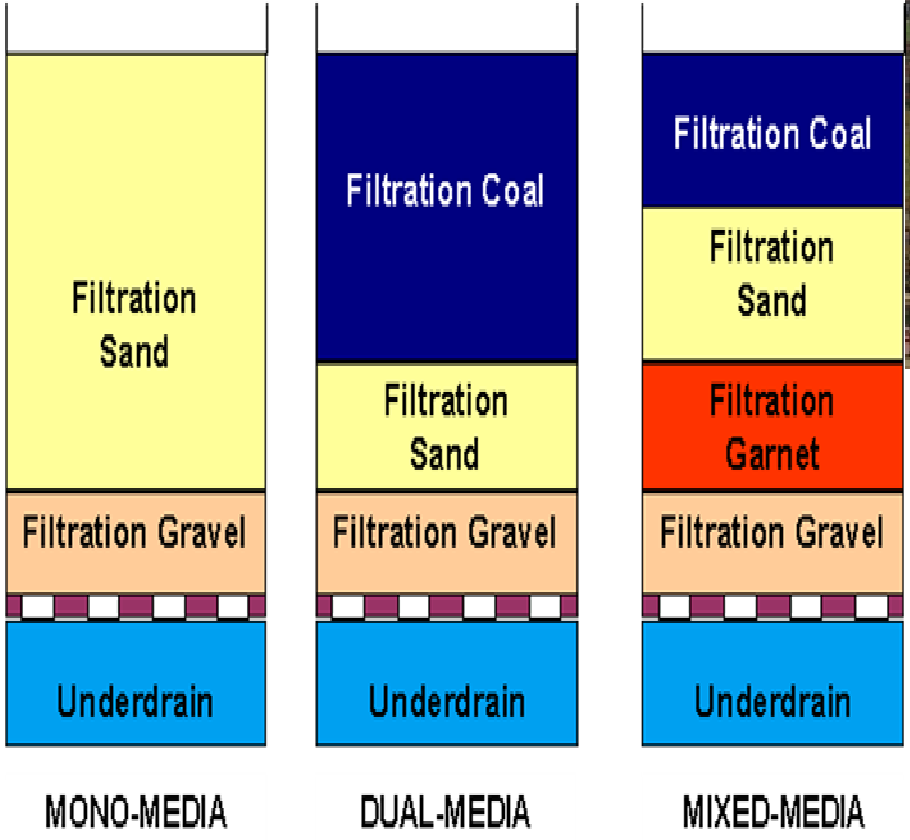


FIG. 16

Uses

❖ Stone retaining walls
(held in place by wire baskets – *gabions*)
❖ Water filter



Sources

- Natural – Mined from natural deposits (land or underwater).
- Manufactured – e.g. Blast furnace slag, fly ash (industrial by products)
- Recycled Aggregate – e.g. crushed concrete, clay bricks

Sizes of Aggregate

- Fine aggregate < 5 mm
- Coarse aggregate > 5 mm (10 mm, 20 mm, 40mm)

Conditions

- Crushed

From quarry - sharp, angular particles, rough surface, good bond strength, low workability

- Uncrushed

From river - round shapes, smooth surface, low bonding properties, high workability

Processing

Mining

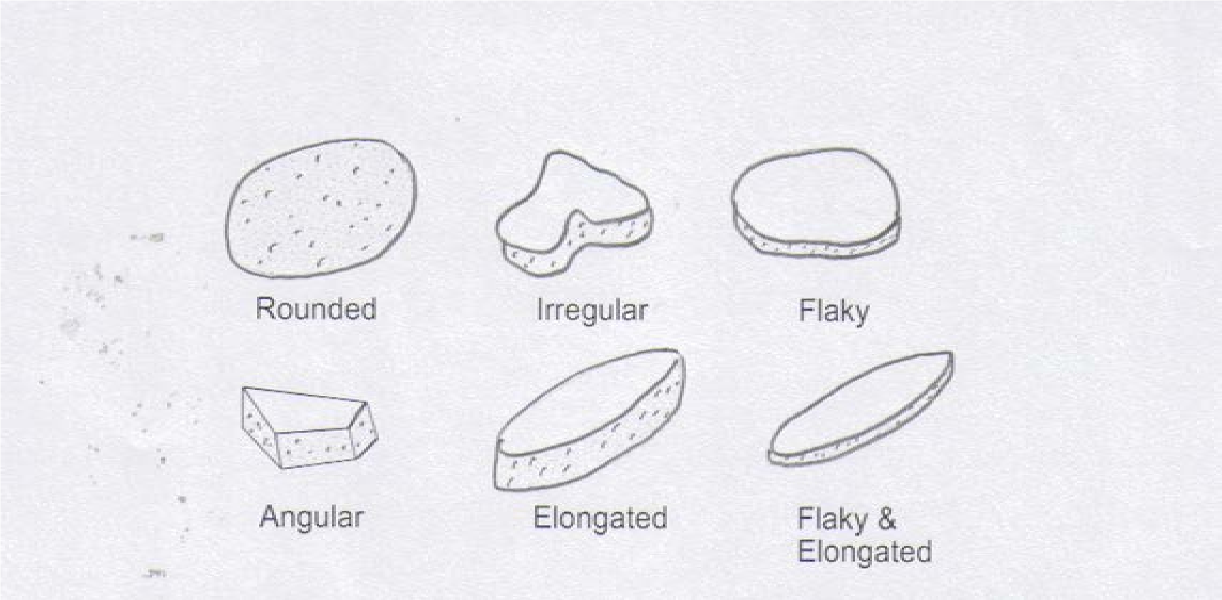
Crushing –

Primary &

Secondary

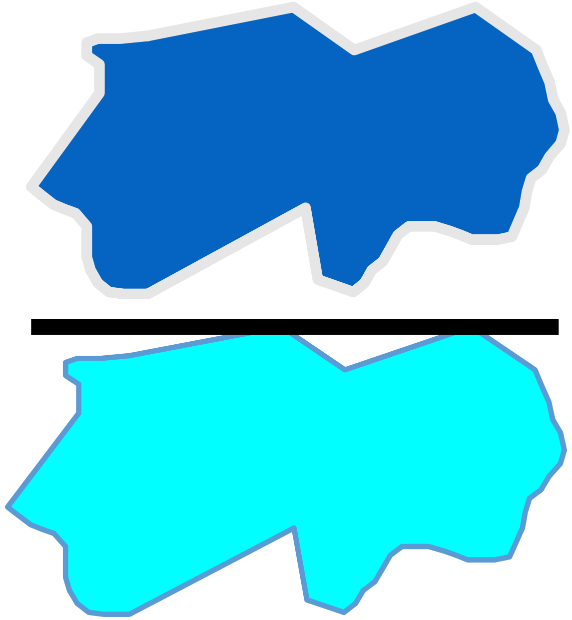
Aggregate properties

- Particle shape & texture
- Specific gravity
- Moisture content & absorption
- Voids
- Bulk density
- Porosity
- Modulus of elasticity
- Compressive strength
- Gradation & fineness modulus
- Shrinkage
- Chemical reactivity



Specific Gravity

- Ratio of the weight (mass) of an object to the weight of an equal volume of water (at std. temp. & pressure)



e.g.

1 m^3 of sand weighs 2600 kg

1 m^3 of water weighs 1000 kg @ 4 ^oC

Specific gravity = 2600/1000

= 2.6

Cont’d

- **Specific gravity (s.g.) or relative density (rl.dn.)**

$$G = \frac{\rho_a}{\rho_w} = \frac{\gamma_a}{\gamma_w} = \frac{m_a}{m_w}$$

- Where - ρ_a and ρ_w density of aggregate and water
  - γ_a and γ_w unit weight of aggregate and water
  - m_a and m_w mass of aggregate and water in equal volume.
  - affects density of concrete.
- The main use of specific gravity in concrete mix design
  - weight-volume conversions
  - to calculate void ratios for a given aggregate.
  - to calculate the yield of concrete for a given proportion

Aggregates Properties effecting concrete

- **Toughness**
- **Hardness**

important for concrete used in road pavements.

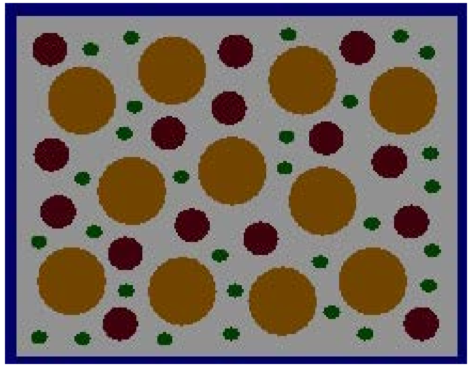
- **size** (use maximum possible size).
- larger the maximum size of aggregate,
  - smaller is the paste requirement
  - Higher is the workability of concrete.
- N.B. Maximum size of aggregate should **not** be larger than
  - 1/5th of minimum dimension of section
  - 1/3rd of slabs thickness
  - 3/4th of minimum clear spacing between reinforcing bars and between rebars and the form.

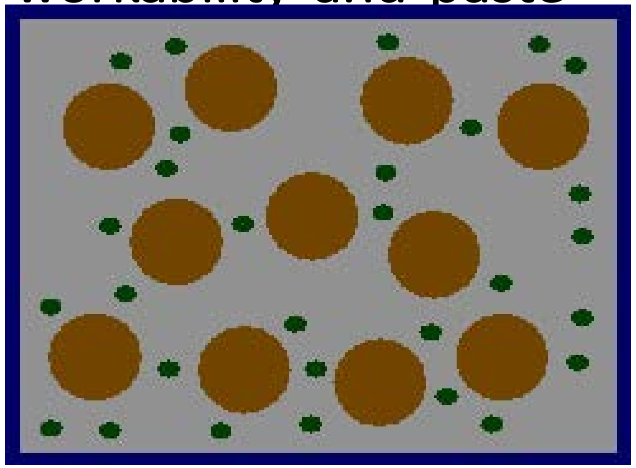
Cont’d

- **Bulking of Sand**
- Because of their small size and weight, sand particles are easily pushed and held apart by surface water there by increasing the total volume per given weight of sand. This phenomenon is known as bulking (%).
  - *The finer the sand the higher will be the bulking effect*.
  - Sand which is completely submerged or “inundated” shows no bulking.
  - In coarse aggregate the bulking due to moisture is negligible.

Cont'd

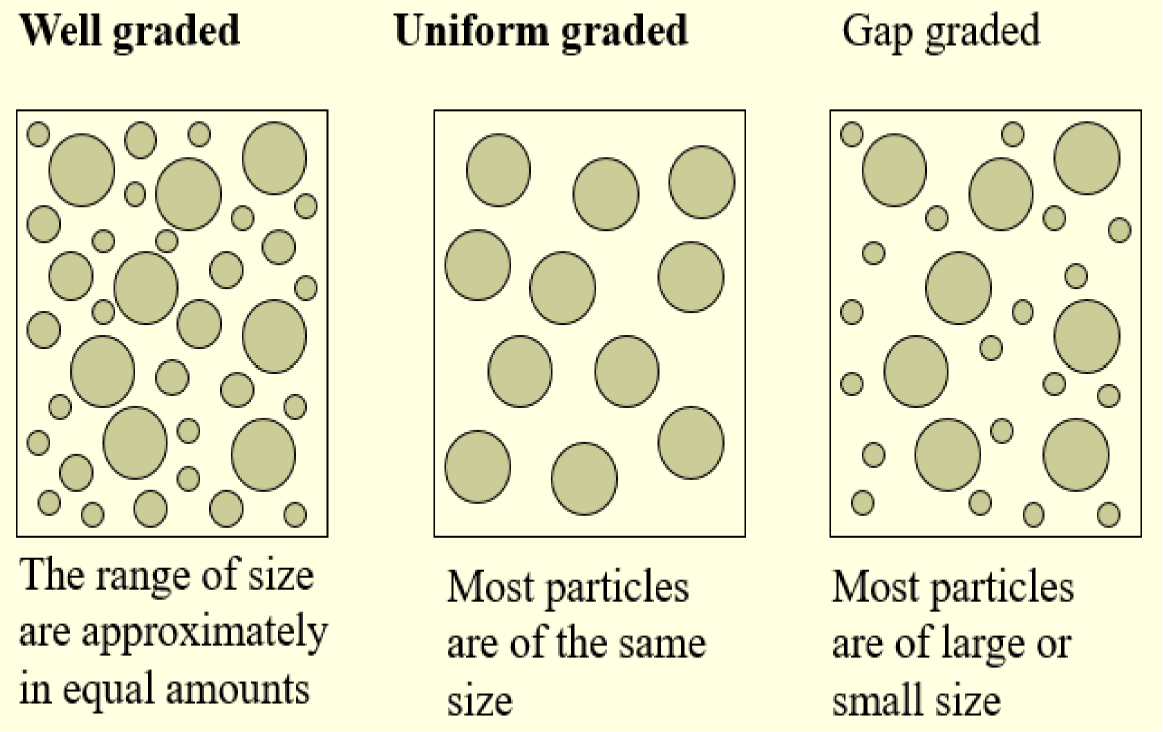
- **gradation:** is the particle-size distribution of an aggregate
- Well graded in order to minimize paste,
- hence cement requirement.
- **Combined gradation:** fine and coarse aggregates are combined
  - good interlocking, few voids, economical.
  - course aggregates **gradation plays an important role in workability and paste requirements**
  - fine aggregates **gradation affects the workability and finishing characteristics of concrete**





Grading of aggregates

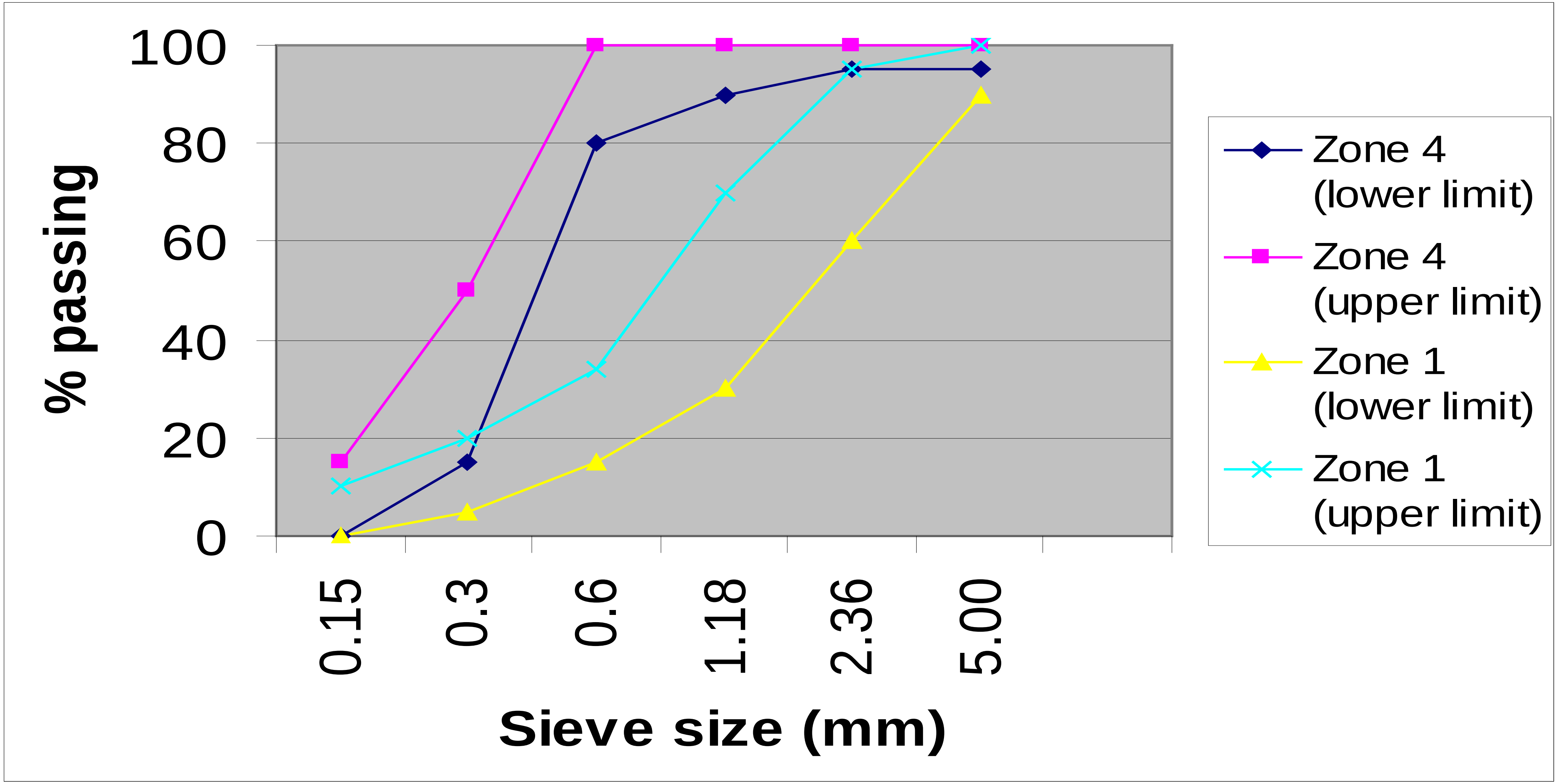
Grading refers to the process that determines the particle size distribution of a sample of aggregate.



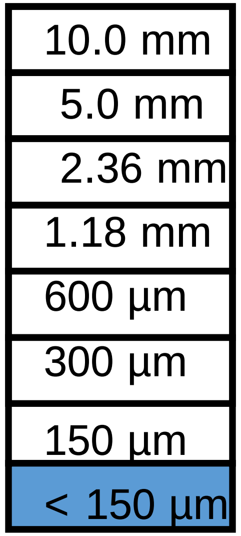
Standard Sieve Size and Square Openings

For Fine Aggregate			For Coarse Aggregate		
ES series	ASTM series		**ES series**	ASTM series	
Sieve size & clear opening	Sieve size	Clear opening	**Sieve size & clear opening**	Sieve size	Clear opening
9.5mm	3/8 in	0.375in	**75mm**	3in	3.00in
4.75mm	No.4	0.187in	**63mm**	(2in)*	2.00in
2.36mm	No.8	0.0937in	**37.5mm**	1 ½ in	1.50in
-	-	-	**-**	(1in)*	1.00in
1.18mm	No.16	0.0469in	**19mm**	¾ in	0.75in
600μm	No.30	0.0232in	**13.2mm**	(½ in)*	0.50in
300μm	No.50	0.0117in	**9.5mm**	3/8 in	0.375in
150μm	No.100	0.0059in	**4.75mm**	No.4	0.187in

Grading limits for fine aggregate
(from MS 7.4)



A typical example of calculation for aggregate grading (Fine aggregate)



Sieve size	Weight of aggregate retained (g)	Percentage retained (%)	Cumulative percentage retained (%)	Cumulative percentage passed (%)
10.0 mm	0	0	0	100
5.0 mm	6	2	2	98
2.36 mm	31	10	12	88
1.18 mm	30	10	22	78
600 µm	59	19	41	59
300 µm	107	35	76	24
150 µm	53	17	93	7
< 150 µm	21	7	100	0
Total	**307**		**326**	

Fineness modulus = 326/100 = 3.26

Cont'd

- **fineness modulus, FM:** is a weighted ***average size of a sieve*** on which the material is retained.
- It is an index to the relative fineness or coarseness and uniformity of aggregate supplied, but it is ***not an indication of grading*** since there could be an infinite number of grading which will produce a given fineness modulus.

$$FM = \sum \frac{\text{cumulative percentage of a sample aggregate retained on the sieves (by mass)}}{100}$$

- ***Sum doesn't include intermediate sieves and pan.***

…con't

- FM of fine aggregate is useful in estimating proportions of fine and coarse aggregate in concrete mixtures.
- Note: The higher the FM, the coarser the aggregate.
  - Fine aggregate: 2.3-3.1
    - from 2.3 to 2.6 indicate a fine sand,
    - from 2.61 to 2.9 medium sand and
    - from 2.91 to 3.1 coarse sand.
  - Coarse aggregate: 5.5-8
  - Combined aggregate: 4-7
- Limits are usually specified for percentage of material passing each sieve
- In general, aggregates which conform to the grading limits produce the most satisfactory limits.

Example of sieve analysis of fine aggregate suppose that a 500 gram sample yielded the following amounts on each sieve after screening.

Sieve size	Weight retained (gr)	% retained	Cumulative % retained	Cumulative % passing
9.5mm	0	0	0	100
4.75mm	30	6	6	94
2.36mm	40	8	14	86
1.18mm	80	16	30	70
600µm	160	32	62	38
300µm	140	28	90	10
150µm	40	8	98	2
Passing 150µm	10	2	100	0
Total	500	100	300	

- Fineness modulus = $\frac{300}{100} = 3$

Types of concrete

- **Reinforced concrete :** Plain concrete & steel reinforcement
- **Pre stressed concrete:** Pre tensioned concrete and Posttensioned concrete

- **Precast concrete:** Concrete that is cast in some other location (factory or job site). Reduce construction time.

- **Fiber reinforced concrete:** Concrete being reinforced with fibers e.g. steel, polypropylene, nylon, glass. Produce tougher & more durable concrete.

- **Lightweight concrete** (< 1850 kg/m3) Made with lightweight aggregates. Low density, thus, reduce loads on foundation.

- **High strength concrete** (> 41.4 MPa) High cement content, low w/c ratio, admixtures (chemical or mineral), smaller maximum size aggregates (10 –12 mm).

Concrete Quality

- Achieve the required strength / grade
- Workable
- Enough time for placing before setting
- Free from defects after formwork is removed (Uniform appearance of hardened concrete)
- Durable

The quality of concrete is governed by

- Chemical composition of Portland cement
- Hydration
- Aggregate characteristics
- Amount of water
- Admixtures

- Methods of mixing
- Transporting
- Placing
- Compaction
- Curing

Factors affecting concrete strength

- **Type & Amount of cement**

  - Higher cement content increases strength and the heat generated. Finer cement causes faster hydration rate, more heat and faster strength development.

- **Water / Cement ratio**

  - Water not used in the hydration process contributes to increased porosity.
  - Reduced water content increased compressive strength & resistance to weathering, lower permeability and reduces shrinkage and cracking.

- **Aggregates**

- **Size**

  Too large or too fine aggregate decrease strength

- **Shape and Texture**

  Crushed or rough surface provides better early strength and similar long term strength as smooth aggregate

- **Types**

  Limestone is generally stronger than sandstone.

- **Gradation**

Factors affecting concrete strength

- **Air Voids**

  - Air voids lower the durability, permeability and the strength of concrete.

- **Curing**

  - Time of curing: 7 days of moist curing is very effective.

  - Without moist curing, potential strength may reduce by 50%

  - Concrete continues to gain strength as long as water and cement are available.

Properties of Concrete

- **Water Cement ratio (w/c ratio)**

  = weight of water in the mix

  weight of cement the mix

- Water-cement ratio affects

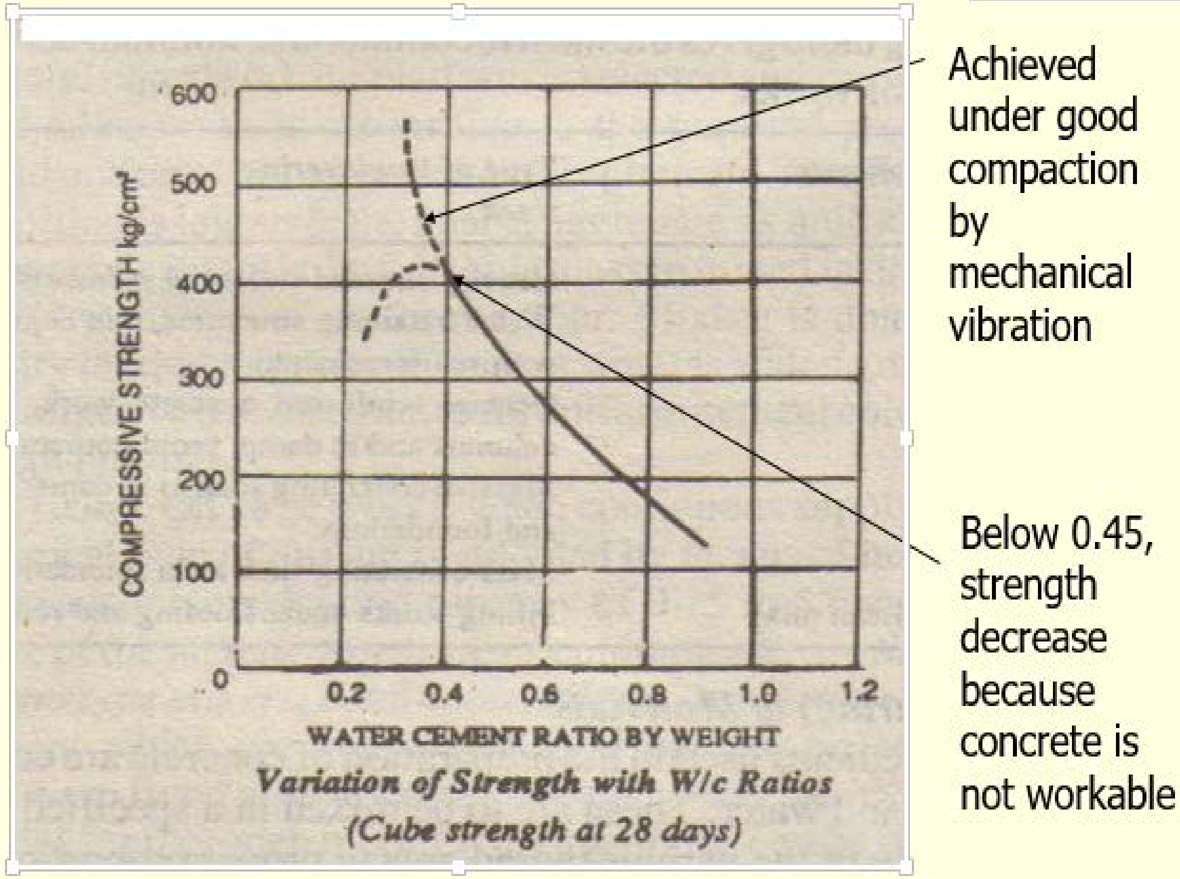
  - strength and durability of concrete

  - workability of concrete

- Water-cement ratio for

  (a) Normal strength concrete – 0.45 to 0.65

  (b) High strength concrete – < 0.45



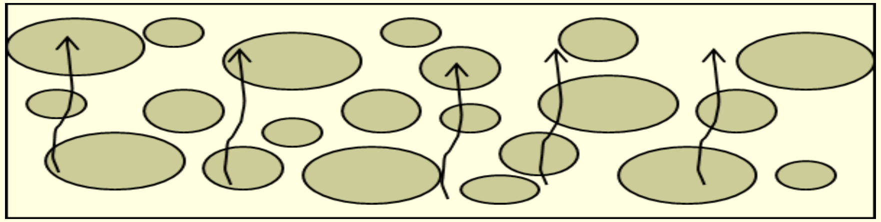
Variation of Strength with W/C ratio
(Cube strength at 28 days)

Properties of Fresh Concrete

Workability

The ease with which concrete can be mixed, handled and placed without segregation.

Bleeding: Tendency for water to rise to the surface.



Caused by: Excess water, insufficient fines (cement, sand) in mix.

Problem: Cause weakness on concrete surface or develop line of weakness between pours.

Can be avoided by using finer cement, high C_3A content, less water content & richer mix.

Consistency

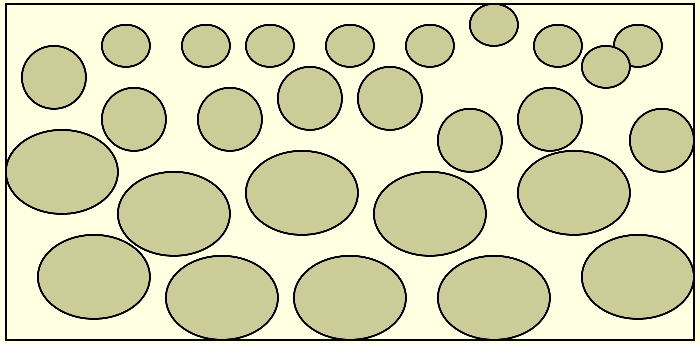
The degree of plasticity of fresh concrete or mortar. (Ability of concrete to flow). The normal measure of consistency is slump for concrete and flow for mortar

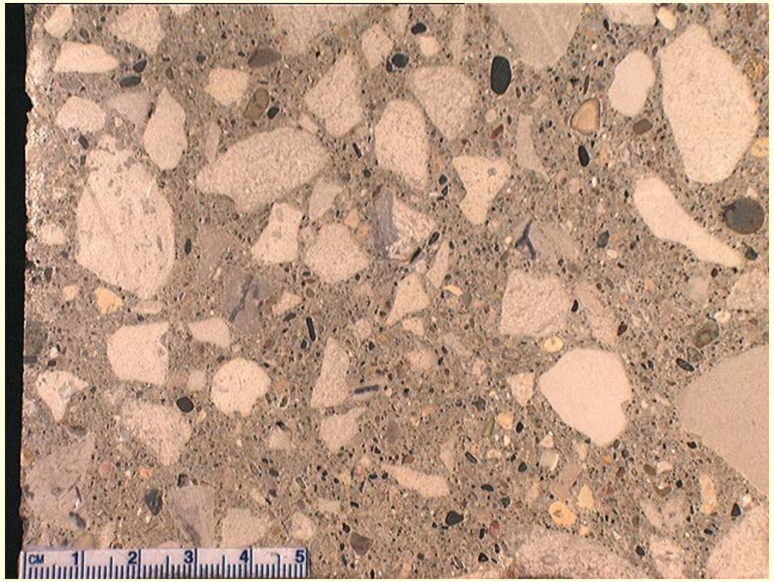
Segregation

The tendency for

(i) sand-cement mortar to separate from coarse aggregate

(ii) cement paste to separate from fine aggregate.





Caused by:

- Excessive or inadequate vibration
- Dropping fresh concrete from a height
- High workability (excess water content) or poor grading (excess coarse aggregate).

Problem: Reduction in strength

Water

- Good water is essential for quality concrete.
  - It should be good enough to drink
    - free of trash, organic matter and excessive chemicals and/or minerals
    - pH of 6-8 works best
- Water of doubtful quality should be submitted for laboratory analysis and tests.
- The possibility for increased alkali-aggregate reactivity should be considered before using the alkaline water as mixing water.
- Use of acid waters with pH values less than 3.0 should be avoided.

In the production of concrete, water is used for:

(i) chemical reaction with cement
(ii) workability of concrete
(iii) washing aggregate
(iv) curing process of concrete

Cont’d

- Excessive impurities in mixing water affect setting time and concrete strength and also cause
  - efflorescence (unsightly white salts deposits on the surface of the concrete),
  - staining,
  - corrosion of reinforcement,
  - volume changes, and
  - reduced durability

…con’t

- Water used:
  - to lubricate all other materials and make the concrete workable.
  - to react chemically with the cement
- The total amount of water for good concrete depends on:
  - The desired consistency of the concrete
  - The surface texture, particle shape, maximum size and grading of the aggregate.
  - Water reducing or air entraining admixtures.
- The water required to achieve ascertained workability cannot be related to any single measurable characteristics & is generally ascertained by trial & error.

Cont’d

- **Water/Cement Ratio:** is the relationship between the total ***free*** water and the cement, usually expressed in mass
- Water to cement ratio should be kept as low as possible to have
  - the less voids and more strength,
  - Lower permeability, thus increased water-tightness and lower absorption.
  - Increased resistance to weathering.
  - less drying shrinkage and more durability,
  - Better bond between successive layers and between concrete and reinforcement.

ADMIXTURES

- Admixtures: are a material added to the batch of concrete before or during mixing
- There are two main groups of admixtures.
  - Chemical admixtures: are water soluble compounds (Accelerators, retarders, water-reducing and air-entraining)
    - quantities no larger than 5% by mass of cement
    - Most admixtures are supplied in ready-to-use liquid form.
  - Mineral admixtures: are finely divided solids to improve workability, durability, or provide additional cementing properties. (i.e. slags, silica fume, fly ash, and pozzolans).
      - About 40% of ready-mix producers use fly ash.

Benefits of Admixtures

- they are capable of imparting considerable physical and economic benefits with respect to concrete.
  - ensure the quality of concrete during mixing, transporting, placing, finishing and curing under difficult circumstances
  - makes possible the use of a wider range of ingredients in the concrete mix.
- ***It should be stressed that they are no remedy for:***
  - ***poor quality mix ingredients,***
  - ***use of incorrect mix proportions, or***
  - ***poor workmanship in transporting, placing and compaction.***

Types of Chemical Admixtures

- ASTM classification of admixtures by their function in concrete:
  - Type A – Water reducing
  - Type B – Retarding
  - Type C – Accelerating
  - Type D – Water reducing & retarding
  - Type E – Water reducing & accelerating
  - Type F – High range water reducing or super plasticizing
  - Type G – High range water reducing and retarding or super plasticizing and retarding

Air

- All concrete contains “entrapped” air, from mixing process, which are undesirable for durability & permeability
  - 0-2% by volume of concrete
  - Irregular shape, large size

Air-entraining admixtures,

- Air-entraining concrete is produced by using either an air-entraining cement, by adding an air-entraining admixture (liquid or powder) during batching, or a combination of these approaches.
- air-entraining admixture used to ***purposely introduce*** and stabilize microscopic air bubbles (spherical shape) into the concrete

…con’t

- Entrained air bubbles:
  - imparts better workability, improved homogeneity, decreased segregation and bleeding.
  - Increase durability or resistance to severe conditions of exposure, including application of deicing salts and other chemicals and freeze/thaw action by providing “escape route”
- Some of the most commonly used air-entrainment chemicals are:
  - Salts of wood resins (Vinsol resin)
  - Synthetic detergents
  - Salts of petroleum acids

…con’t

- The effectiveness of an admixture depends on several factors including:
  - Type and amount of cement,
  - Water content,
  - Mixing time,
  - Slump, and
  - Temperatures of the concrete and air.

Factors That Affect Workability and Consistence

i. **Grading, Shape and surface characteristics of aggregate particles**

- They affect the amount of paste required to fill the spaces thoroughly and surround the aggregate particles completely, and the friction between the particles as the concrete is molded.
  - Angular particles or those with rough surfaces require a greater amount of paste for the same mobility of mass than is necessary for well-rounded particles or those with smooth and slippery faces.

…con't

ii. **Plasticity of the cement paste**

- paste with less water than optimum will itself be stiff and cannot carry much aggregate without becoming so stiff as to be wholly unplaceable and decreases strength
- paste with more water than optimum may be so thin and watery that it will be unable to hold the aggregates in the cohesive mass which is the very embodiment of plasticity.
  - reduced cement bonding and strength
  - Cause segregation, shrinkage and creep
  - increases permeability → reduced density, abrasion resistance, Freeze-Thaw resistance and durability

…con't

iii. **Relative quantities of cement paste and aggregates**

- use a minimum amount of paste that will lubricate the mass while fresh and after hardening will bind the aggregate particles together and fill the space between them.
  - Any excess of paste involves: easy to place and will produce a smooth surface, greater cost, greater drying shrinkage, greater susceptibility to percolation of water and therefore attack by aggressive waters and weathering action.
  - If less than the required it will be difficult to place and produce rough, honeycombed surfaces and porous concrete.
- Aggregate is much cheaper than cement and maximum economy is obtained by using as much aggregate as possible.

Handling, placing and compacting fresh concrete

- Concrete should be handled from the place of mixing to the place of final deposit as rapidly as practical by methods which will prevent the segregation or loss of any of the ingredients.
  - If the segregation does occur during transport, the concrete should be remixed before being placed.
- Fresh concrete needs forms or moulds until it sets and hardens.
- Concrete should be uniformly spread on all the sides for better compaction.
- It should be deposited in layers of uniform depth, usually not exceeding 25cm. Each layer should be compacted before the next is placed.

- When the work has to be resumed on a surface which has hardened:
  - surface should be roughened and swept clean, thoroughly wetted and covered with a 13mm layer of mortar (to prevent formations of stone pockets and secure tight joints) composed of cement and sand in the same ratio as the cement and sand in the concrete mix.
- When the work has to be resumed on a surface which hasn’t fully hardened:
  - all lattance should be removed by scrubbing the wet surface with wire or bristle brushes, care being taken to avoid dislodgement of particles of aggregate.
  - The surface should be thoroughly wetted and all free water removed.
  - The surface should then be coated with neat cement grout.
  - The first layer of concrete to be placed on this surface should not exceed 150mm in thickness, and should be well –rammed against old work.

- Forms can be removed after 4-7 days (depends on temperature)
  - The forms are generally made of either timber or steel.
- Before placing concrete, the forms and subgrade should cleaned and moistened thoroughly specially in hot weather.
  - Where wooden forming have been exposed to the sun for some time, it may be necessary to saturate the wood to tighten the joints.
- In order to prevent concrete from adhering to the surface, forms should be thoroughly oiled.
- However comparatively more costly, steel shuttering is used for major work where every thing is mechanized.

A good form work should satisfy the following requirements:

- It should be cheap and suitable for re-use several times
- It should be practically water proof so that it doesn’t absorb water from concrete. Also, its shrinkage and swelling should be minimum
- It should be strong enough to withstand all loads coming on it,
- It should be as light as possible
- The surface of the form work should be smooth, and it should afford easy stripping
- All joints of the form works should be stiff so that lateral deformation under loads is minimum. The form work should rest on non-yielding supports.

COMPACTING

- Compaction is the removal of entrapped air to achieve maximum density which leads to higher strength and durability
  - should be done during the operation of placing.
- Compaction can be:

a) manual
   - Rodding: for thin vertical members
   - Temping: for slabs
   - hammering

b) Mechanical/vibrator: is used only when the mix is stiff.
   - Over-vibration or vibration of very wet mixes can result in bleeding.

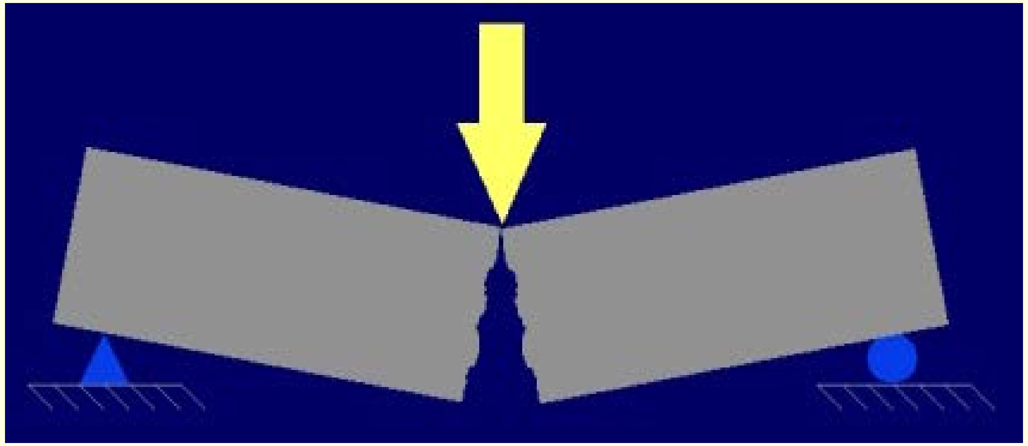
Hardened concrete

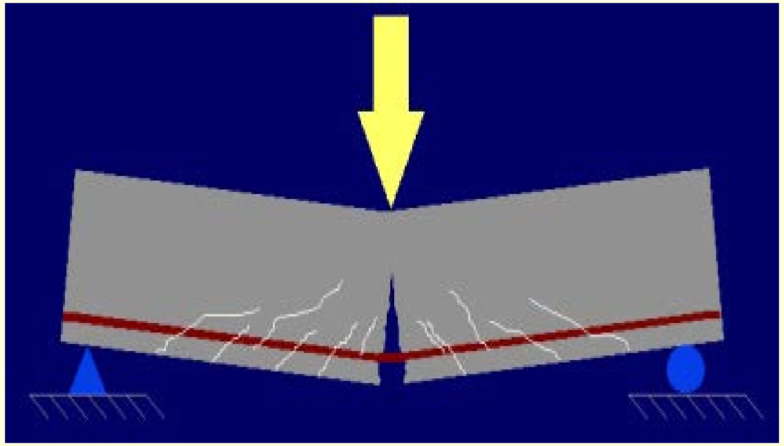
- Fresh concrete, if left undisturbed, gradually stiffens until it may be said to have “set”.
- there is no well-defined point at which concrete sets or passes from the plastic to rigid condition.
- In practice concrete, in which ordinary portland cement is used, should remain sufficiently plastic over a period of at least ½ an hour and preferably 1 hour
  - Concrete should be placed in the forms as soon as possible, in no case more than 30 minutes after mixing.
- it should harden within a reasonable time for the construction to precede.

- The requirements for a fresh and a hardened concrete may vary in wide range, dependent on the type of structure to be cast and the available equipment.
- Concrete is a plastic material when fresh
- **Workability:** The ease with which a concrete mixture can be mixed, transported, placed in the form, compacted & finished without any segregation.
- **Consistence:** is degree of wetness or fluidity of concrete.
  - classified and described as stiff, plastic, and flowing.

…con’t

- Hardened concrete properties that need great attention are:
  - **Compressive strength:** good to resist compressive stresses
  - **Shear Strength:** is about 12 to 13% of its compressive strength.
  - **Tensile Strength:** is about 10% of its compressive strength.
    - Concrete is brittle material and
      is not designed to carry tensile forces.
- Bar is used to increase tensile strength of concrete, known as reinforced concrete.





…con’t

- The strength of concrete is affected by
  - the water cement ratio
  - air content
  - the degree of compaction.
  - the component materials (cement and aggregates),
    - both on the type and quantity of cement.
    - the compressive strength of concrete decreases with the specific surface of the aggregate increases.
  - the age
    - strength of concrete increases with time or age.
  - curing condition.
    - Properly cured concrete will gain good strength.

Properties of Hardened Concrete

- **Strength**: Max. compressive stress before failure
  - For ordinary construction, compressive strength in the range 20.7 – 41.1 MPa
- **Modulus of Elasticity** = 14 to 40 GPa
- **Shrinkage** – volume reduction or contraction
  - Drying shrinkage : shrinkage due to drying of hardened concrete
  - Plastic shrinkage : reduction of volume of plastic concrete (typically during first 12 hours after placement)

- **Creep**

A very gradual change in length (deformation) which occurs over time when a material is subjected to sustained load.

The arch of Wade St Bridge, Bendigo (1901) has become almost flat in the centre. Creep in the concrete is probably the major factor.

Properties of Hardened Concrete

- **Durability**

Ability to resist deterioration from weathering action (environment) and traffic.

e.g. Able to resist high and low temperature (thermalexpansion/contraction), freezing and thawing, rain, alkali-silica reaction, sulfate attack, action by chemicals e.g. salts.

Two key factors affecting durability:
1. **compressive strength** 2. **permeability**.
- Low strength and high permeability decrease durability.

Methods for mixing concrete

❖*Methods of mixing of concrete :*

1. *Hand mixing*
2. *Machine mixing*

- *Mixing time 2 to 3 minutes*

Manually

Machine mixing

Drum mixer

Pan Mixer

Ready mixed

Methods for transporting concrete

Wheelbarrow

Concrete buggy

Chute

(Concrete transported to lower level)

Bucket

(Large & massive construction. Handled by crane)

Concrete pump

(through pipe)

Placing and Compaction

- Concrete should immediately be placed in the structure and should be compacted before placing the next layer.
- Purpose of compaction is to eliminate entrapped air from the concrete so that concrete is less permeable and good bond between reinforcement and concrete is achieved.
- 1 % entrapped air cause 5 – 6 % reduction in concrete strength.

Methods of Compaction

Internal vibration

- Rodding – for thin sections by pushing iron bar inside and outside of concrete
- Vibrators – for heavy sections
- Vibrating rod (poker)

External vibration

Vibrators are clamped to formwork and vibrated.

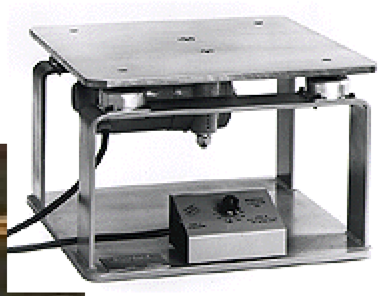
- **Surface vibration**

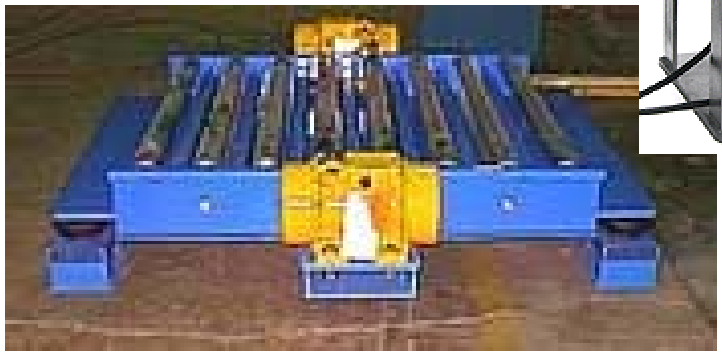
Concrete is vibrated from the surface when screeding (striking off) the concrete is carried out. (For pavements and slabs).

Surface vibrator

Screed

Table vibrator





- **Table vibration**

For precast concrete.

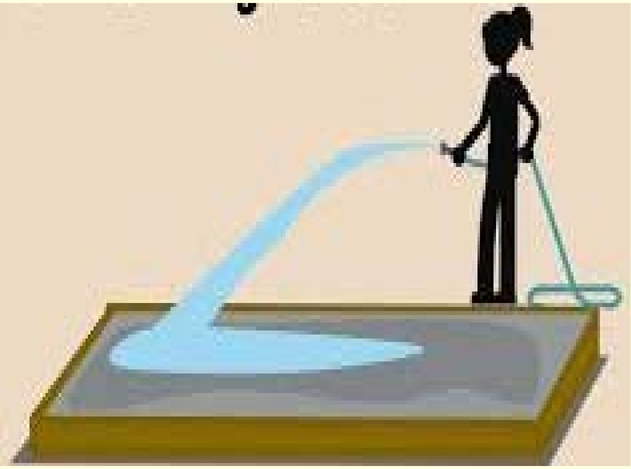
Curing Concrete

- It is a process of maintaining enough moisture and avoiding temperature extremes (above 32°C or below -12°C) in concrete to maintain the rate of hydration during its early stages
  - amount of water left in the concrete, after evaporation, may not enough for full hydration and hardening.
- Begin curing as soon as the concrete has hardened sufficiently to avoid erosion or other damage to the freshly finished surface.
  - Usually within one to two hours after placement and finishing.
- The period of curing depends upon atmospheric conditions such as temperature, humidity and wind velocity.
  - 7 days (or longer) are recommended, but not less 3 days

Commonly used concrete curing methods:

1. Keep ***water on the concrete*** during the curin
   a. **Ponding or immersion**
      - Impounding water in earthen or sandy over the flat surfaces,
      - the method is generally used only for small jobs.
      - undesirable if the concrete will be exposed to early freezing.
      - the water must be free of substances that will stain or discolour the concrete.

   b. **spraying or fogging**
      - Used when the ambient temperature is well above freezing and the humidity is low.



…con't

c. **Saturated wet coverings**

- Fabric coverings, such as burlap, cotton mats, rugs, or other moisture-retaining fabrics, are saturated with water

d. **Steam curing**

   i. curing in live steam at atmospheric pressure (for enclosed cast in place structures and manufactured precast units)

   ii. curing in high pressure steam autoclaves (for small manufactured units)

- Steam Curing Advantages
  - early strength gain in cold weather.
  - Reduce creep

…con’t

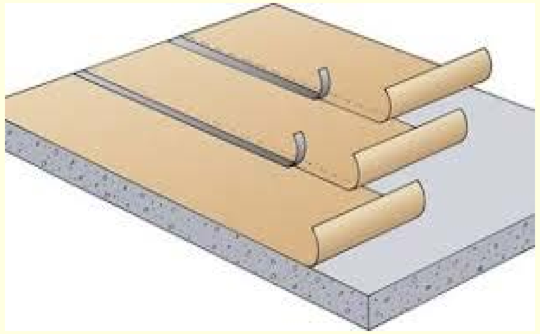
2. Prevent the loss of ***mixed water*** from concrete by sealing the surface.
    - Advantage: periodic additions of water are not required.

   a. Applying membrane-forming curing compounds.
    - Liquid membrane-forming compounds consisting of waxes, resins, chlorinated rubber, and other materials can be used.
    - It maintain the relative humidity of the concrete surface on which it sprayed above 80% for seven days.
    - Its types are:
        - clear or translucent;
        - white pigmented.

…con’t

b. **Covering the concrete with impervious paper or plastic sheets,**

i. Impervious paper (two sheets of kraft paper cemented together by bituminous adhesive with fiber reinforcements)



- The sheets must be weighted to maintain close contact with the concrete surface during the entire curing period.
- Used for horizontal surfaces and structural concrete of relatively simple shapes.

ii. Plastic sheets (such as polyethylene films 0.10 mm thick)

- easily applied to complex as well as simple shapes.
- It may also be placed over wet covering materials to eliminate the need for continuous watering of the covering.

Cont’d

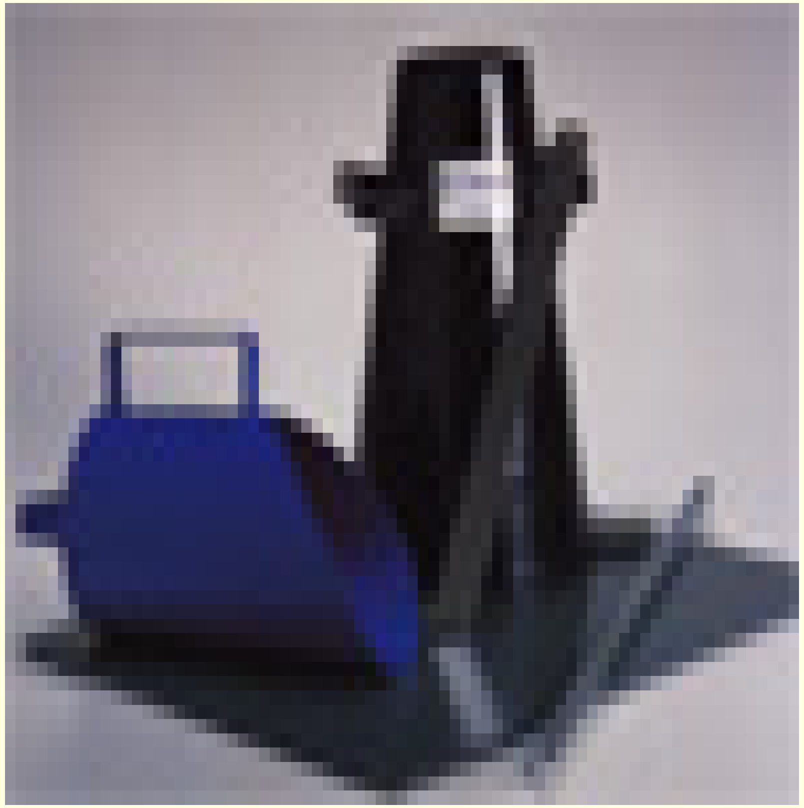
- Curing has a major influence on the properties of hardened concrete such as volume stability, water-tightness, strength, abrasion resistance, wear resistance, durability, and resistance to freezing and thawing and deicer salts.
- The best curing method depends on:
  - Cost, equipment required, materials available,
  - Method of construction,
  - Size and shape of the concrete surface,
  - the intended use of the hardened concrete.

Concrete work at construction site

- Measuring of materials
- Mixing
- Transporting
- Placing
- Compaction (Consolidation)
- Curing

Tests to Measure Workability

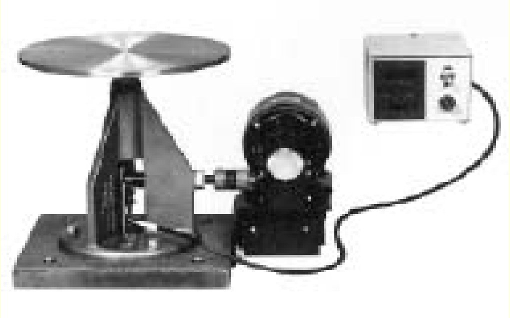
Four widely used tests



Slump Test

Compacting factor test

Vebe Time test



Flow test

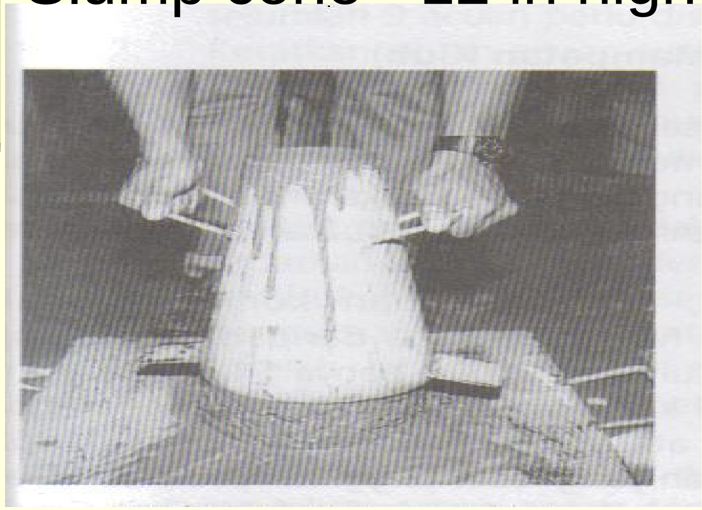
Slump Test

Most useful test at site. Useful in checking the consistency of concrete mix at site.

Method

The cone is filled in three equal layers. Each being tampered 25 times with a 5/8 in bullet nose tampering rod.

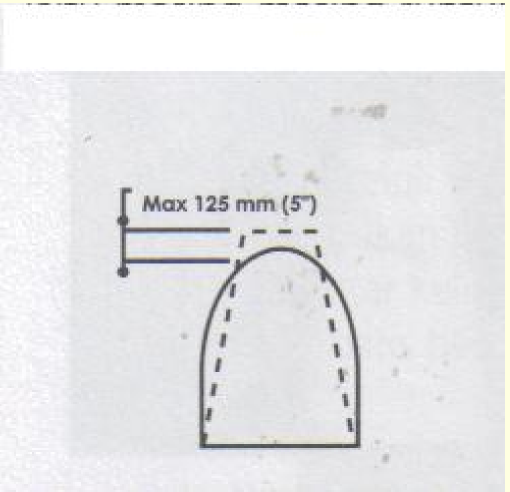
Slump cone - 12 in high 8 in at bottom.

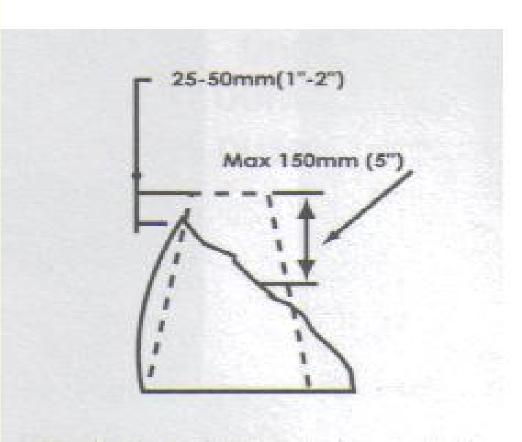


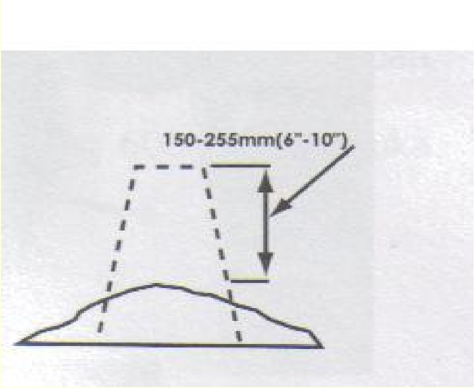
Cone is filled and level off. It is then carefully lifted.

The amount of slump is then measured.

Types of Slump







True Slump

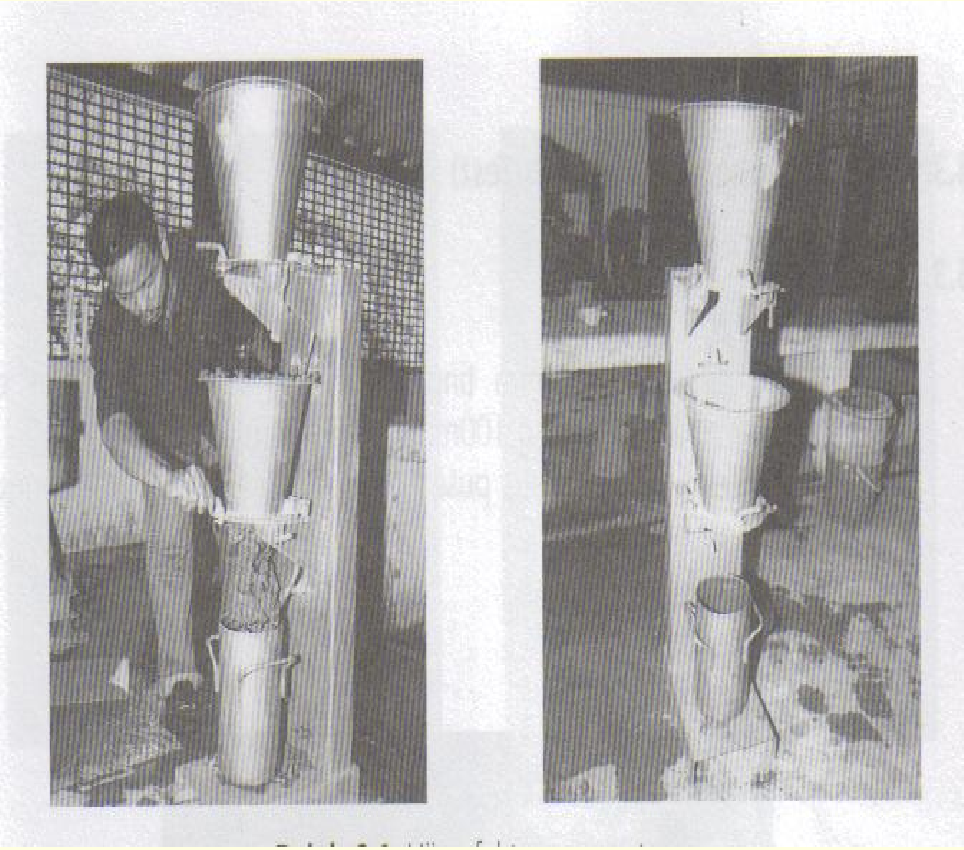
Concrete slump must be in this form. Normal slump range (12 mm – 115 mm)

Shear Slump **Collapse Slump**

Concrete lack of cohesiveness or too wet. Not allowed for structural work.

Compaction factor test

Measure the degree of compaction required for a concrete. Suitable for all mixes.



Method

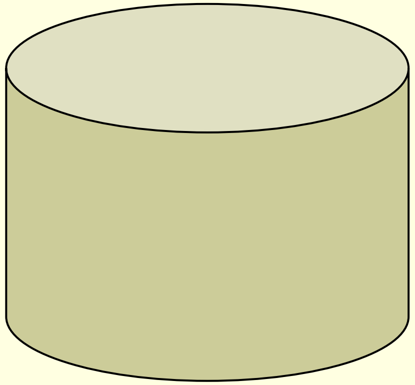
- Concrete mixture is put in top hopper
- Allowed to fall into 2nd hopper then cylinder
- Top of cylinder is struck off. Concrete is weighed.
- Compared with weight of fully compacted concrete in cylinder

Compaction factor

= weight of partially compacted concrete

weight of fully compacted concrete

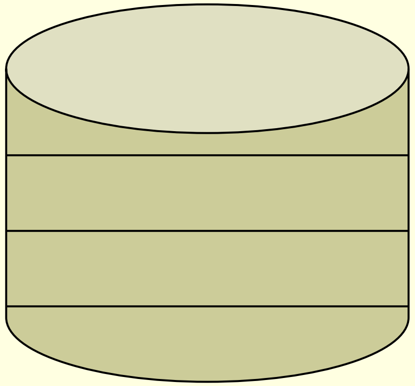
(compacted in 4 layers, 25 x tempering each layer)



e.g

weight of concrete partially compacted = 11.02 kg

weight of concrete fully compacted = 12.04 kg



Compaction factor = 11.02 kg / 12.04 kg

= 0.915

Vebe time test

- Measures the work (time) needed to compact concrete.

Method

- The concrete is packed into a cone (similar to slump test). The cone stands within a special cylinder on a platform and lifted.

- The container is vibrated and the time taken for the concrete to be compacted flat by glass plate is Vebe time.

Flow Test

Determine the flow of cement pastes and cement mortars by measuring the spread in mm (width) of a standard cone on a dropping table. This value is a measure of the plasticity of the mortar.

Degree of workability	Slump (mm)	Compaction factor	Vebe time (s)	Use for which concrete is suitable
Extremely low	0	0.70 - 0.78	20	Prestressed concrete structure compacted with heavy vibrators
Very low	0 - 25	0.78 -0.85	7 - 20	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand-operated machines.
Low	25 - 50	0.85 - 0.92	3-7	Roads vibrated by hand operated machines. Mass concrete foundations without vibration or lightly reinforced sections with vibration.
Medium	50 - 100	0.90 - 0.95	1 - 3	At the less workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration.
High	100 - 150	0.95	0 -1	For sections with congested reinforcement. Not normally suitable for vibration.

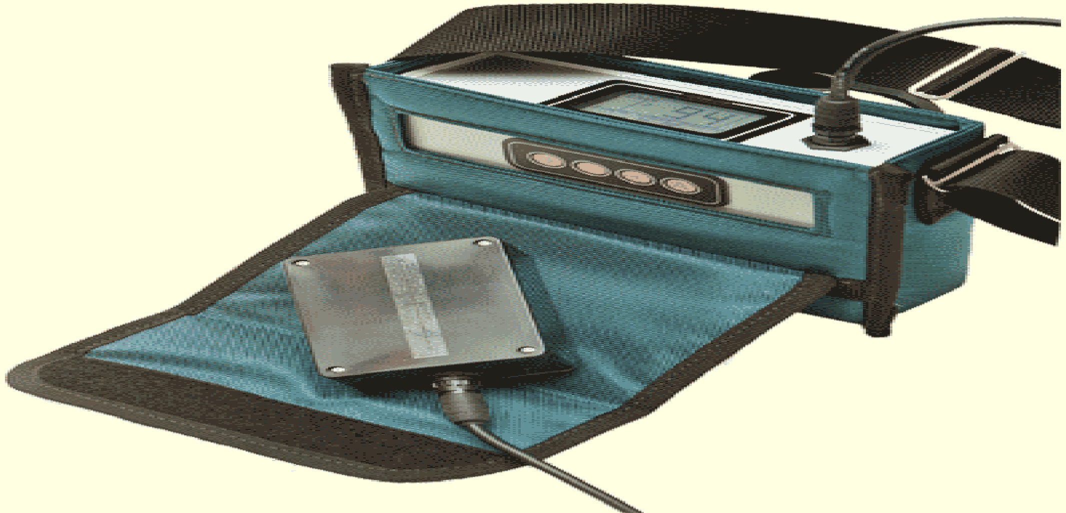
Concrete Testing

Destructive test

- Compression test
- Beam bending strength test
- Cylinder splitting test
- Concrete core test

Non destructive test

- Ultrasonic pulse velocity test
- Rebound hammer test (Schmidt hammer test)
- Cover-meter test
- Gamma-ray test



Destructive concrete test

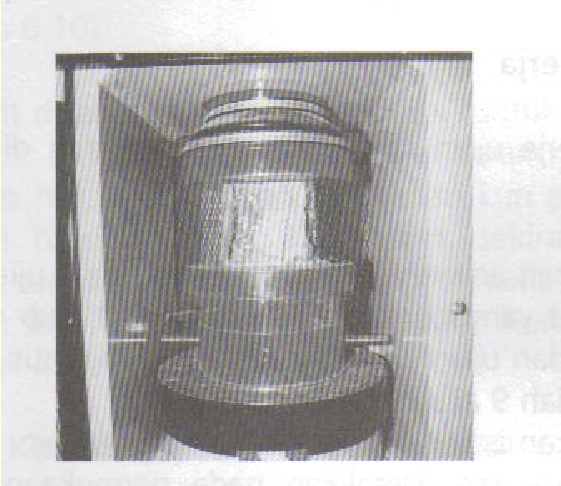
Compression test

The 7 day and 28 day strength of a standard concrete cube or cylinder specimen are tested.

Max compressive strength

$$= \frac{\text{Maximum load}}{\text{Surface area}} \quad (N/m^2)$$

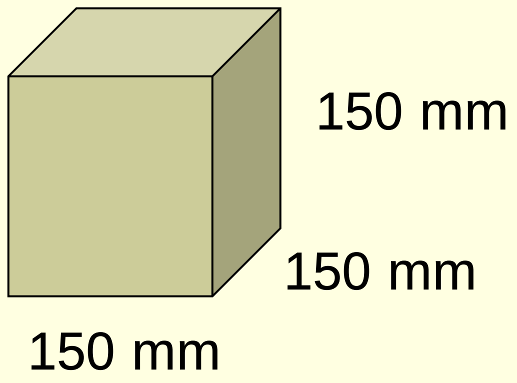
Concrete cube samples from site are tested for their actual strength and compared with design strength.

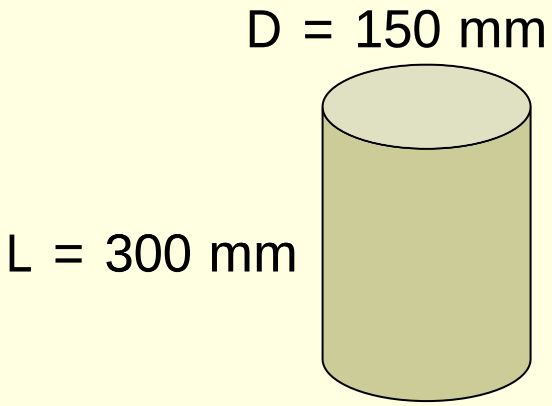


Compression machine

Normal failure mode

Method for preparing concrete samples





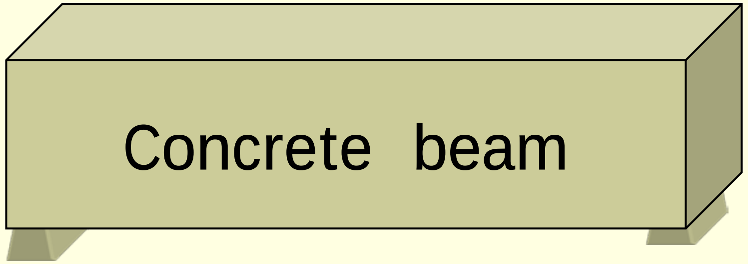
- Concrete mould is filled with concrete.

  (3 layers, 35 x tempering each layer using standard rod)

- Concrete is covered and allowed to set and harden for 24 hours.
- Remove concrete from mould and soak in water until testing of strength is carried out at 7 and 28 days.

Destructive concrete test

Beam bending strength test

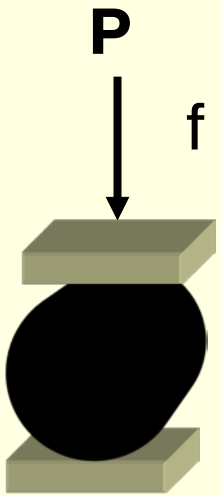


(size : 150 x 150 x 750 mm)

Measure the strength of an unreinforced concrete beam or slab to resist failure in bending

- **Cylinder splitting test**

(Measures tensile strength)

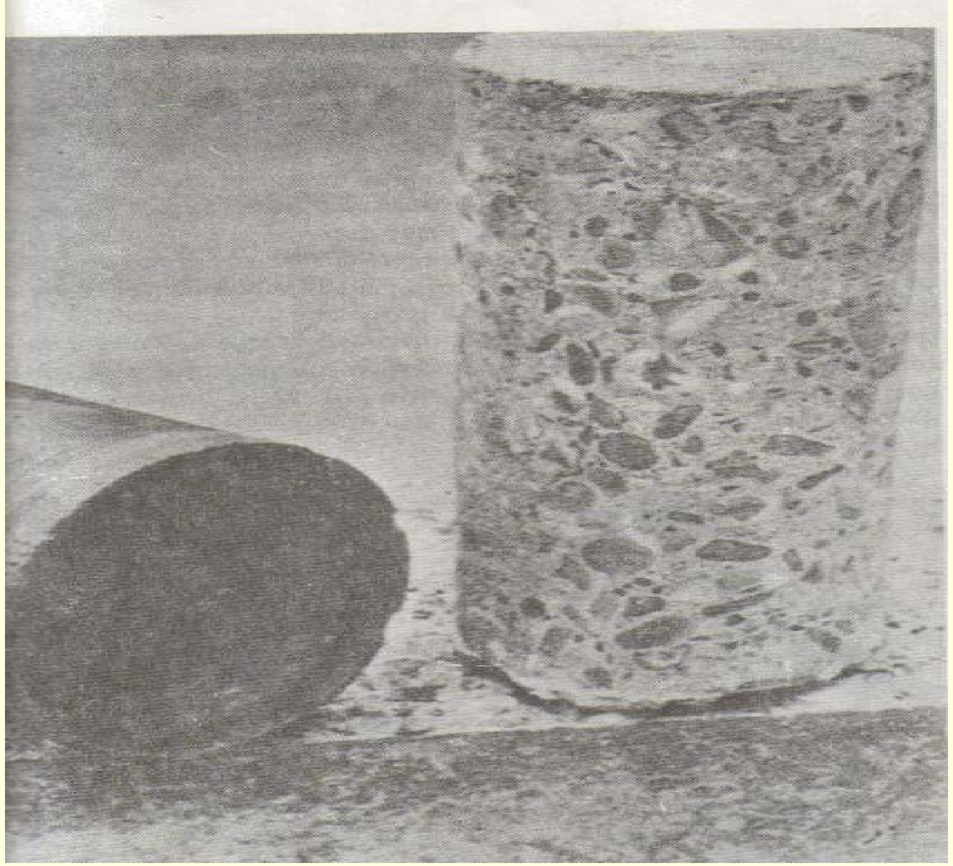


$f_{\text{tensile strength}} = 2P / \pi D L$

L = length of cylinder
D = diameter of cylinder

Destructive Concrete test

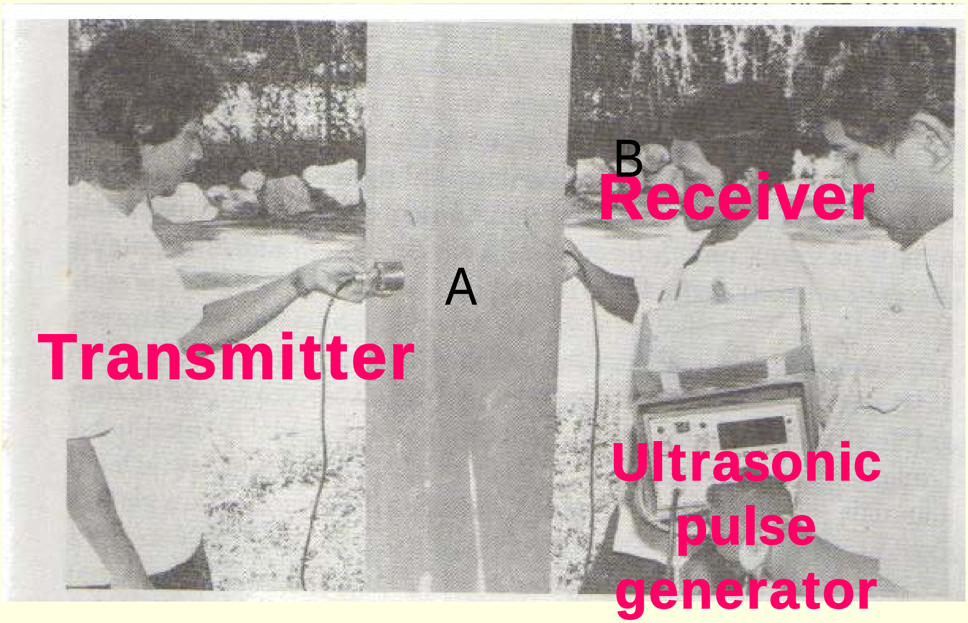
Concrete core test



- Concrete specimen is cored from actual concrete.
- Compression test is done on sample to obtain strength

Non destructive Concrete test (Ultrasonic Pulse Velocity Test)

- Measures the velocity of pulse wave passing through a solid material.
- Transmitter generate pulse, receiver receive the pulse.



- Time taken by the pulse to travel from point A to point B in concrete sample is recorded.
  Distance = thickness of concrete
  Time = (micro second)
  Velocity = Distance / time

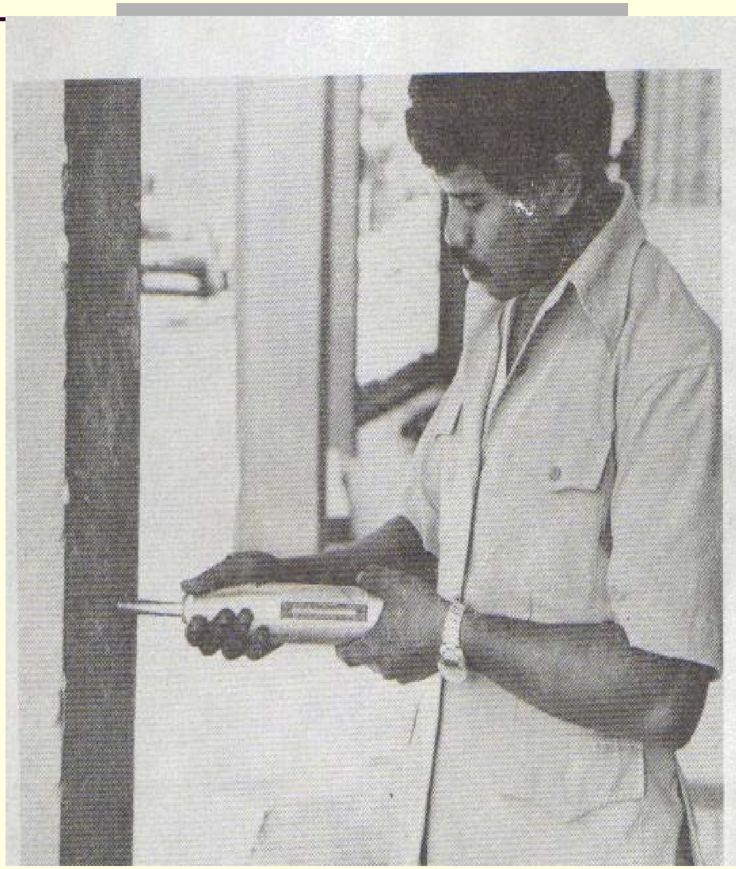
Classification of concrete quality based on pulse velocity

Pulse velocity (x 10 ^{3} m/s)	Concrete Quality
4.6	Very good
3.6 – 4.6	Good
3.0 – 3.6	Questionable
2.1 – 3.0	Bad
< 2.1	Very bad

Application

- Assess the conditions of structural members with two-sided access such as beams, columns and walls.
- Voids, honeycomb, cracks and other damage in concrete, wood, stone and masonry materials can be also located.

Rebound Hammer Test (Schmidt hammer test)



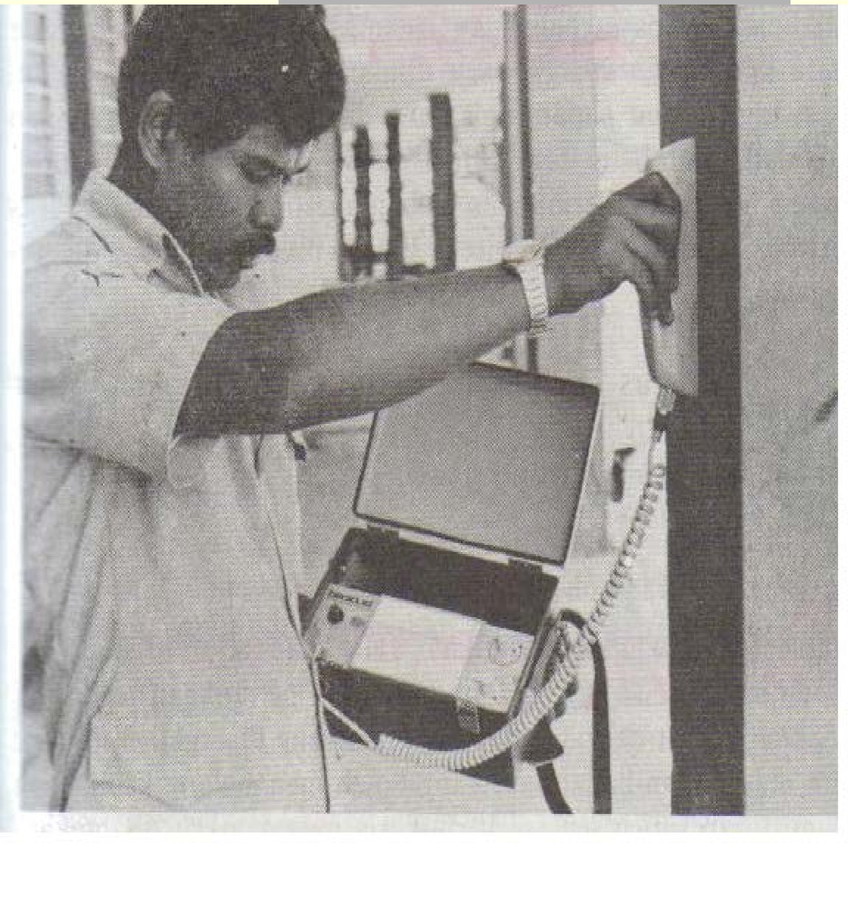
- The test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges.
- Within limits, there is a correlation between strength of concrete and the rebound number.
- Higher rebound number indicates high compressive strength.
- The test is sensitive to the presence of aggregate and of voids immediately underneath the plunger.

Cover-meter Test

- This test can be used to determine the depth of concrete cover and locating the direction and size of reinforcement.

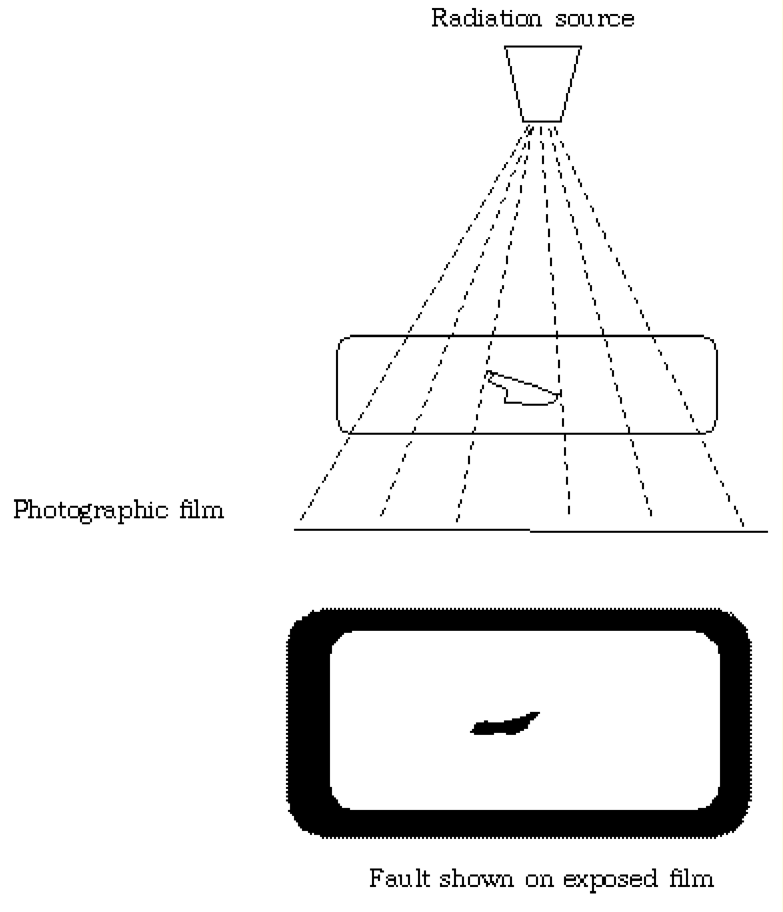
- The instruments consist of a searcher unit connected to the main unit containing the cells, circuits and indicator scale.

- Working range of up to 100 mm depth. Accuracy of ± 15%.



▪ Gamma-Ray Test

- Use gamma ray to detect the presence of voids in concrete, the location and size of reinforcement and the efficiency of the grouting of cable ducts in post-tensioned concrete.
- Special precautions are necessary to avoid contamination from the radioactive source.
- Costly



CONCRETE MIX DESIGN

- It is the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain strength and durability as economically as possible.
- The common method of expressing the proportions of a concrete mix ingredients is in terms of parts or ratios of cement, fine and coarse aggregates. For e.g., a concrete mix of proportions 1:2:4
  - The proportions are either by volume or by mass.
- **Batching:** is the measurement of materials for making concrete
- There are two methods of batching:
  - Volume batching
  - Weight batching

Volume batching

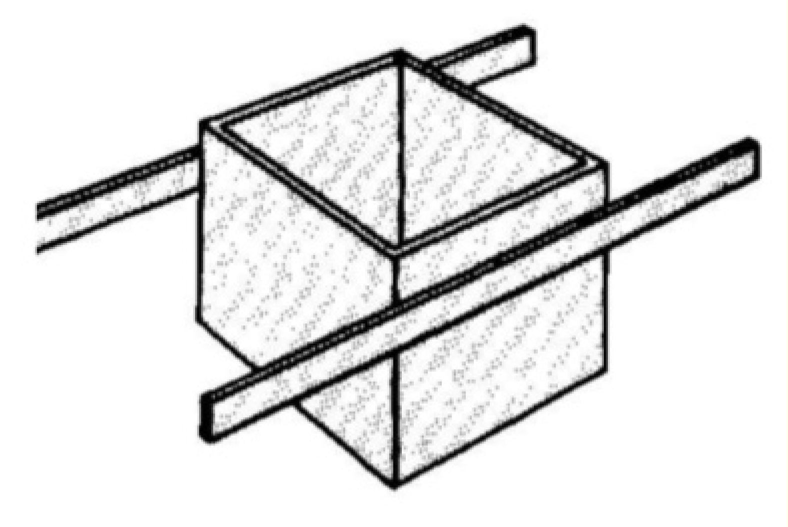
- it is convenient to use at most construction sites.
- a measuring box (40cm X 35cm X 25cm or 35 liter) is used to measure aggregate .
  - Care must be taken in the case of wet sand, which might bulk.
- Water is usually measured by volume in a calibrated tank or by means of flow type water meters.
- volume of the fresh concrete $V = V_a + V_w + V_c + V_{fa} + V_{ca}$
- If V_a = volume of air

  V_w = volume of water

  V_c = absolute volume of cement

  V_{fa} = absolute volume of fine aggregate

  V_{ca} = absolute volume of coarse aggregate



Weight batching

- preferred on important jobs.
  - Because the quantity of solid materials in a container very much depends on its degree of compaction
    - Volume batching of cement should be avoided.
      - Each cement bag is packed to contain a net weight of 50Kg, which is approximately 35 liter in volume.

Materials proportioning

- Identify mix proportion

  (amount of cement, water and aggregate)
- Mix proportion is based on strength required
- **Concrete grade**

  A number which is equivalent to the strength characteristic

Table 3	**Standard Mixes And Related Strengths**
Standard Mix	Characteristic Compressive Strength At 28"" Days Assumed Or Structural Design N/mm^2 (- MPa)
ST1	7.5
ST2	10.0
ST3	15.0
ST4	20.0
ST5	25.0

e.g.

ST5 –
Grade 25

(strength

25 N/mm^2)

For max. size aggregate of 20 mm and slump 75 mm,
Cement:
- 340 kg/m^3 of concrete

Total aggregate:
- 1830 kg/m^3 of concrete

Proportion of fine and coarse aggregate:
ST5
Grading limit M
(medium sand)
Fine aggregate/ Total aggregate = 30 - 40%

Standard Mix	Constituent	Nominal Maximum Size Of Aggregate			
		40mm		20mm	
		slump 75 mm	slump 125 mm	slump 75 mm	slum p 125 mm
ST1	Cement (kg) Total aggregate (kg)	180 2010	200 1950	210 1940	230 1890
ST2	Cement (kg) Total aggregate (kg)	210 1980	230 1920	240 1940	260 1800
ST3	Cement (kg) Total aggregate (kg)	240 1950	260 1900	270 1890	300 1820
ST4	Cement (kg) Total aggregate (kg)	280 1920	300 1860	300 1860	330 1800
ST5	Cement (kg) Total aggregate (kg)	320 1820	340 1860	340 1830	370 1770
ST1 ST2 ST3	Fine aggregate (percentage by mass of total aggregate)	30 to 45	30 to 45	35 to 50	35 to 50
ST4 ST5	Fine aggregate (percentage by mass of total aggregate) Grading limits C Grading limits M Grading limits F	 30 to 40 25 to 35 25 to 30		 35 to 45 30 to 40 25 to 35	

Variables in proportioning

In connection with specifying a concrete mix, four variable factors to be considered are

- Water-cement ratio.
- Cement content or cement-aggregate ratio.
- Gradation of the aggregates.
- Consistency.

Variables in proportioning (Cont'd)

- Usually two or three factors are specified, and the others are adjusted to give minimum workability and economy.
- Water/cement ratio expresses the dilution of the paste - cement content varies directly with the amount of paste.
- Gradation of aggregate is controlled by varying the amount of given fine and coarse aggregate.
- Consistency is established by practical requirements of placing.

Variables in proportioning (Cont'd)

- In brief, the effort in proportioning is to use a minimum amount of paste (and therefore cement) that will lubricate the mass while fresh and after hardening will bind the aggregate particles together and fill the space between them.
- Any excess of paste involves greater cost, greater drying shrinkage, greater susceptibility to percolation of water and therefore attack by aggressive waters and weathering action.
- This is achieved by minimizing the voids by good gradation.

American Method of Mix Design

- In practice the most widely used method of mix design is that of the American Concrete Institute, given in ACI Standards.
- The ACI method utilizes the fact that, for a given maximum size of aggregate, the water content in kilogram per cubic meter determines the workability of the mix, largely independently of the mix proportions.
- It is thus possible to start the mix design by selecting the water content from these two tables.
- The values given are for well-shaped angular coarse aggregates, and in practice there would be some variations due to differences in aggregate shape and texture.
- It should also be added that in mixes with a cement content in excess of about 360 or 390 kg/m3 the water requirement is greater.

American Method of Mix Design

- A further assumption is made that the optimum ratio of the bulk volume of coarse aggregate to the total volume of concrete depends only on the maximum size of aggregate and on the grading of fine aggregate.
- The shape of the coarse aggregate particles does not directly enters the relation since, for instance, a crushed aggregate has a greater bulk volume for the same weight (i.e. a lower bulk density) than a well rounded.

American Method of Mix Design (Cont'd)

The first step in mix design is to establish the design strength from the project requirement and the over design factor. The following mix design procedure is based on the ACI manual of concrete practice standard ACI 211.1-91, using metric units.

1. Choose slump from ***Table 3.1a***
2. Choose the maximum size of the aggregate. The largest size that is economically available in the area is usually chosen, subject to the following maximums:

⇒ *One-fifth of the width of the forms*

⇒ *One-third of the depth of the slabs*

⇒ *Three-fourths of the space between reinforcing bars*

American Method of Mix Design (Cont’d)

3. The Estimate the amount of mixing water and air required from ***Table 3.1b***. Admixtures, if used, are added to the water.

4. Select the W/C or W/CM ratio from ***Table 3.4*** (for design strength), and ***Table 3.5 (for exposure). (Use lowest)***.

5. Calculate the cement content from the W/C ratio and water-content values.

6. Estimate the proportion of coarse aggregate from ***Table 3.3,*** and its mass using the dry-rodded density.

7. Estimate the mass of fine aggregate using the estimated total mass ***shown in Table 3.2.***

American Method of Mix Design (Cont’d)

8. Calculate the adjustments required for aggregate moisture. Usually the aggregates are wet and therefore the mass of water that they contain, both absorbed and surface water must be added to the required mass of aggregates, and the mass of surface water subtracted from the water requirement.

9. Make trial batches. Only sufficient water should be used to produce the desired slump. Test for slump, air, and density, and cast cylinders for strength, if required. If specifications are not met, new batches should be prepared with adjusted proportions. If the mix is satisfactory, design quantities, corrected for moisture contents of the aggregates, should be recorded for use. e first step in mix design is to establish the design strength from the project requirement and the over design factor. The following mix design procedure is based on the ACI manual of concrete practice standard ACI 211.1-91, using metric units.

Example on Concrete Mix design

Example1: A trial mix is required for a **150-mm** pavement slab being constructed in an area where ***exposure to seawater is expected.*** Strength required is 20 MPa. Trial mix design strength is 28.5 MPa as previous test result are ***not available.*** *For the sand, FM = 2.80* and *absorption is 1.2%.* The absorption of the coarse aggregate is 1.6%, and its dry-rodded density is 1730 kg/m^3. ***Fine aggregate is dry*** and coarse aggregate contains 3.0% water.

Solution

1. *Slump allowed is 25-75 mm (Table 3.1a).*
2. *Maximum aggregate size is 50 mm (150/3). Size 37.5 mm is chosen, as it is economically available in the area.*
3. *Mixing water required is 150 kg/m^3 (for 25-50 mm slump). Air content required is 5.5% (Table 3.1b).*
4. *Maximum W/C is 0.47 for strength and 0.45 for exposure. Use 0.45 (Tables 3.4 and 3.5).*
5. *Cement content is 150 kg/m^3/0.45 = 333 kg/m^3.*

Solution

1. ***Volume of dry coarse aggregate per volume of concrete is 0.71 (Table 3.3).***
2. ***Materials per m³ (Estimate only as variation in aggregate densities and water absorption not considered).***

Coarse aggregate –0.71 x 1730	= 1228 kg
Water	150 kg
Cement	333 kg
Total	***1711 kg***

Solution

Estimated total mass of concrete is 2350 kg ***(Table 3.2).***

∴ Dry mass of fine aggregate is 2350 kg-1711 kg = ***639 kg***

1. Adjust for moisture contents.

Extra water required for fine aggregate is 1.2% x 639 = 7.7 kg

Surplus water on coarse is 1.4% x 1228 kg = 17.2 kg

Corrected mix proportions:

Cement = 333 kg

Water 150 + 7.7 – 17.2 = 140 kg

Solution

Fine aggregate (dry) = 639 kg

Coarse aggregate = 1228 + 3.0% x 1228 = 1265 kg

9. ***Prepare trial mixes.*** A 150 x 300 mm standard cylinder contains 0.053 m^3. For a mix making three cylinders plus enough for other tests, 0.03 m^3 (3% of 1 m^3) will be prepared.

Therefore, quantities are 3% of those required for 1m^3.

Cement	9.99 kg
Water	4.20 kg
Fine aggregate	19.2 kg
Coarse aggregate	38.0 kg

Solution

Water is added to the mix only in sufficient quantities to give the desired slump. This could be more or less than the amount prepared. If requirements have been met, corrected batch quantities must be calculated. Results of the trial mix were: water used, 4.12 kg; air content, 5.2%; and density of the mix, 2340 kg/m3.

Cement 9.99 kg

Fine aggregate (SSD): 19.2 + 1.2% x 19.2 (absorption is 1.2%) = 19.2 + 0.23 = 19.43 kg

Coarse aggregate (SSD): 38.0 – 1.4% x 38.0 [excess moisture is total (3.0) – absorbed (1.6) = 38.0 – 0.53 = 37.47 kg

Mix water; 4.12 – 0.23 + 0.53 = 4.42 kg

Total mass = 71.31 kg

Density was 2340 kg/m3.

Solution

Therefore, batch quantities per cubic meter are

Cement: 9.99 x (2340/71.31) = 9.99 x 32.814 = 328 kg/m3

Water: 4.42 x 32.814 = 145 kg/m3

Fine aggregate (SSD): 19.43 x 32.814 = 638 kg/m3

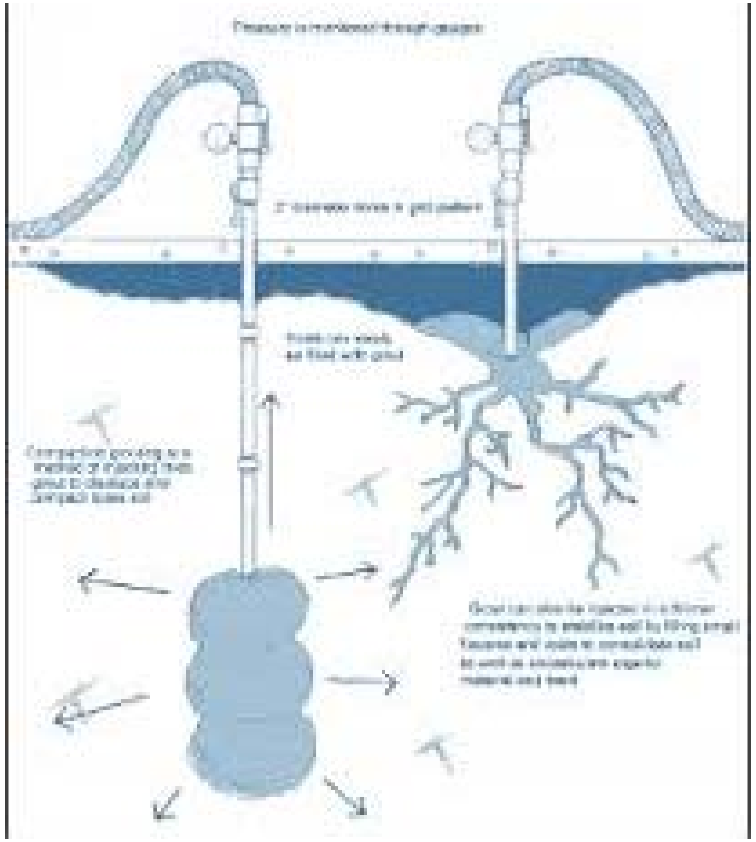
Coarse aggregate (SSD): 37.47 x 32.814 = 1230 kg/m3

Total: 2341 kg/m3

Actual W/C ratio = 145/328 = 0.44

The proportions of cementing materials can also be calculated using the volume occupied by each component. In the ACI method illustrated in Section 7-6.2, the amount of fine aggregate required is obtained using the masses of the components. An alternate method uses the absolute volumes of the components. This method is also included in the CPCA manual. The following example illustrates the calculations.

GROUTING



GROUTING

- **Grouting:** is injection of a special liquid or slurry material called grout into pores, fissures, voids joints or fractures .
- Grouts can be divided into two main groups:
  A. SUSPENSION GROUT: Cementitious grouts
  B. SOLUTION GROUT: Chemical grouts (Sodium Silicates, Acrylates, Acrylamides, Polyurethanes, MC-Silicates)

Cont'd

A. Suspension grouts:

- mixture of cement plus water and other particulate solids such as clay, fly ash, additives, lime, sand, asphalt emulsion etc.
- usually undergoes a significant filtration effect.
- According to its dry matter content, it can be:
    a. Stable grouts (i.e., have minimal bleeding)
    b. unstable grouts

Cont'd

1. **Pure cement grout**

- It is an unstable grout.
- Its water cement ratio is between 0.4 to 1 (if less than 0.67 bleeding can be avoided).
- Very high mechanical strength can be attained.

2. **Cement-based Grouts**:

- Its properties and characteristics are varied with the mix proportions (water cement ratio and Total dry matter to Water weight ratio)
- Relatively low cost mixes
- used in both water stopping and strengthening treatment.

cont’d

3. Bentonite cement grout

- It is a stable grout.
- bentonite improves the penetration (in compact type soils)
  - In water stopping, grout will include a lot of bentonite and little cement
  - In consolidation works, grout will contain a lot of cement and little bentonite.

4. Grouts with fillers

- low cost
- The most commonly used fillers are the natural sands and fly ash.
  - Mortar is grouts with high sand content.

B. Liquid grout or solution grout

- It consists of chemical products in a solution or an emulsion form and their reagents.
- These are intimate one-phase system retaining an originally designed chemical balance until completion of the relevant reactions.
- The most frequently used products are sodium silicate and certain resins.

Cont'd

i. **Silicate based grouts**

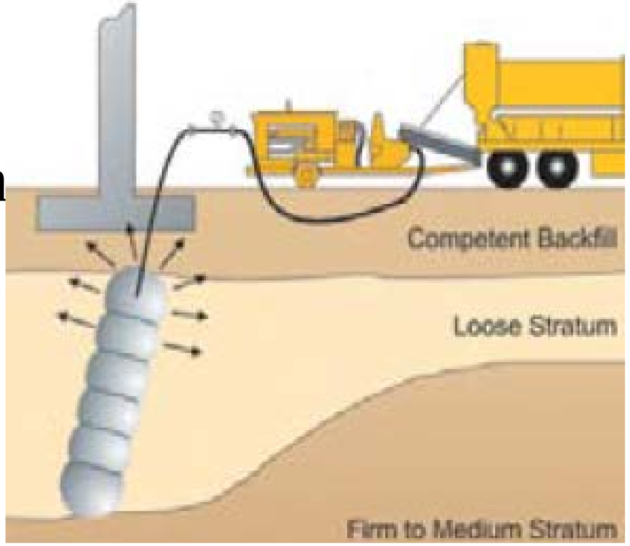
- They are sodium silicate in liquid form diluted and containing a reagent.
- They are used in soils with low permeability values such that all suspension grouts cannot penetrate.

ii. **Soft gels**

- They are a very low dosage silicate gels with a mineral reagent
- It is mainly for water stopping purpose.
  - There is also a slight improvement in strength

Grouting methods

I. Compaction/Displacement Grouting



- A stiff grout, injected under relatively high pressure through pipes or casings into soil, develops a growing grout bulb
  - It displace and densify the surrounding loose/granular soils from the point of injection
- Compaction grouting is usually applied in stages from the lowest point upward.
- On shallow applications, it can be injected from the top down.
  - Makes upper layer a dense cap of overburden to help contain the pressure at lower levels.
- used for settlement control and structural re-leveling .

Cont'd

Advantages

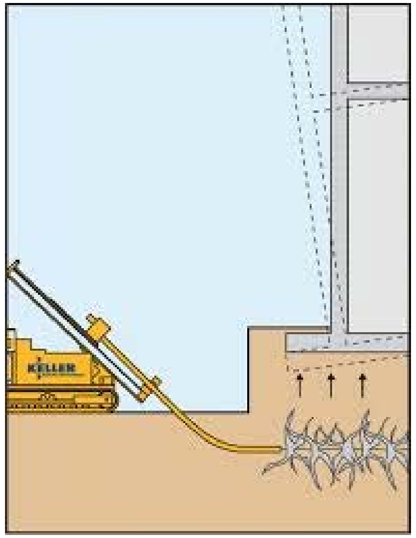
- Minimum disturbance to the structure & surrounding ground
- Effective in a variety of soil conditions
- Supports all portions of structures
- Non-hazardous
- No waste soil disposal

Disadvantages

- Grouting adjacent to unsupported slopes may be ineffective
- Effectiveness questionable in saturated clays
- Not suitable in decomposable materials

Cont’d

II. Hydfracture/Fracture Grouting /Compensation Grouting



- cement-based grouts, stable but fluid, is injected through grout pipes under high pressure into the soil. Fractures in soil are created which are then filled with grout.
  - used in low permeability soil types ranging from weak rocks to clays
- It is important to keep in mind that the effects are difficult to control and the potential danger of damaging adjacent structures by

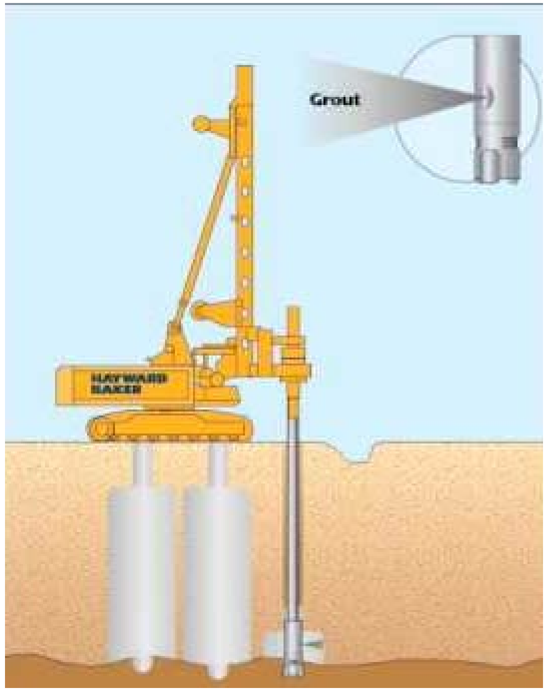
  the use of high pressure may prove prohibitive
- Used for
  - Soil strengthening to reduce lateral support requirements.
  - Repairing a ground underneath a formation

Cont’d

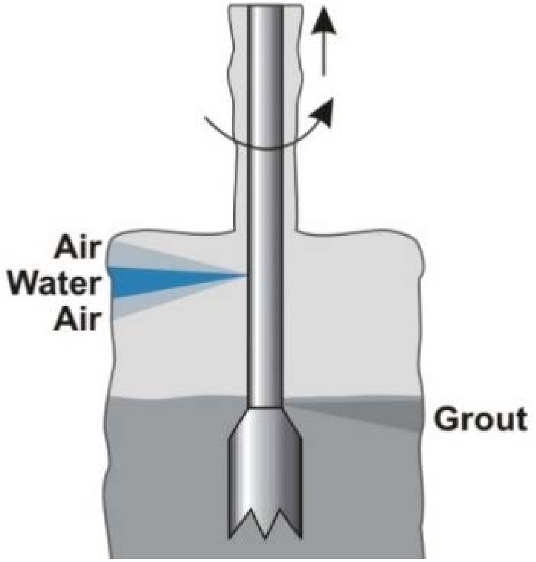
III. Jet /Erosion Grouting

- grout (usually neat cement grout) injected under high pressure and velocity from special drill bit with horizontal nozzle cuts and in-situ mixes the soil to be treated with cement or cementitious grout.
- Nearly all soil types groutable and any cross section
- Much faster than alternative methods
- Safest method of under pinning construction, excavation

  support and groundwater control



Cont'd



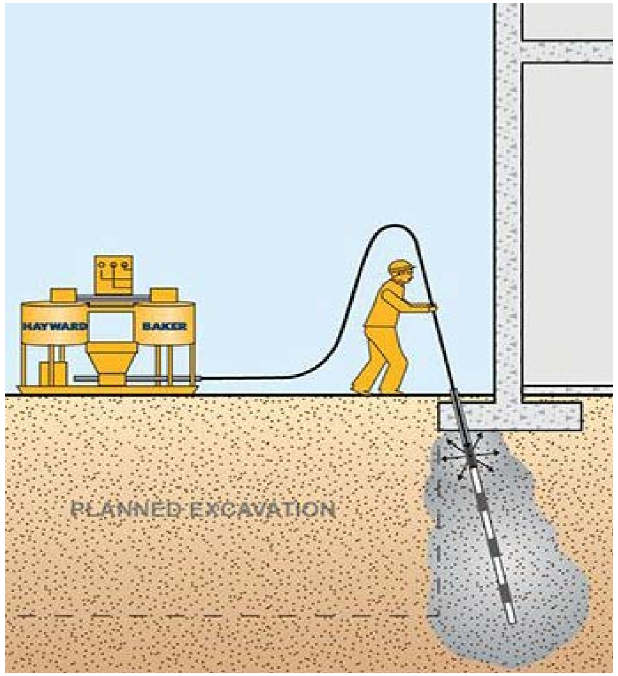
Jet grouting systems

- **Jet 1 -Single Fluid Jet Grouting (Soilcrete S)**
  - neat cement grout is pumped through the rod horizontal nozzle
  - most effective in cohesion-less soils.
- **Jet 2 -Double Fluid.**
  - neat cement grout and air are pumped through nozzles
  - Less strength as compared to the single fluid method.
- **Jet 3 -Triple Fluid.**
  - It is a soil replacement method not an in-situ mixing method.
  - Neat cement grout, air & water are pumped through different lines
  - the most effective system for cohesive soils.

Cont'd

IV. **Penetration /Permeation Grouting/Chemical Grouting**

- Done using chemical grouts or thin grout at low pressure
- Used for creating groundwater barriers or preparing ground before tunneling
- Formation is undisturbed
- A possible drawback
  - only certain soil types are amenable.
  - grouts seem to present the greatest risk with respect to handling, ground water pollution, and corrosion



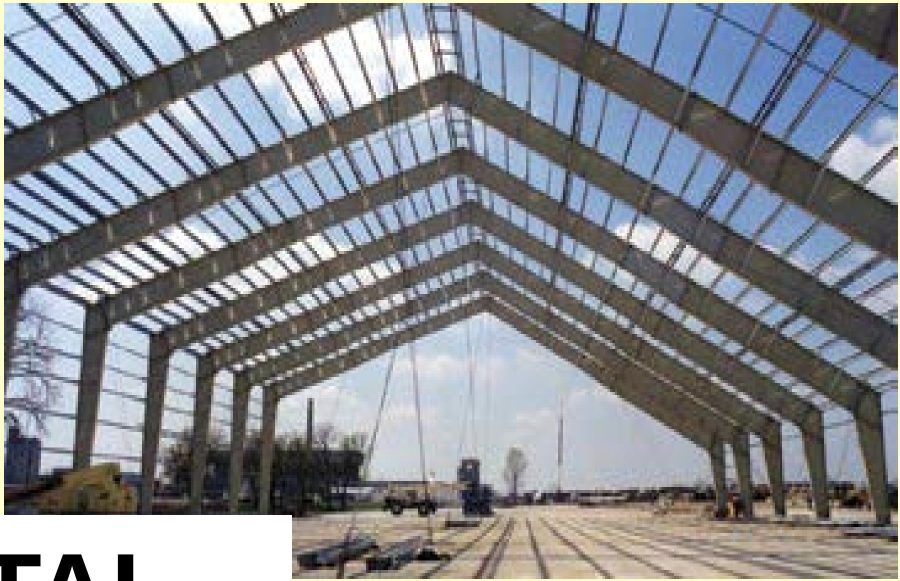
Grout design steps

1. Identify underground construction problem.
2. Establish objectives of grouting
3. Perform special geotechnical study
   - permeability of the soil
   - Groundwater of status and amount,
   - volume of the ground ready to accept grout
4. Develop initial grouting problem
5. Develop performance prediction
6. Compare with other solutions. Is Grouting best solution ?
7. Refine design and prepare specifications

- durability,
- Production, operation and Maintenance requirements
- Cost,
- Others

Use of Grouting

- embed re-bars in masonry walls, connect sections of pre-cast concrete, and seal joints (like those between tiles).
    - Tiling grout secure the tile to its base and acting as a sealant
- strengthen ground so that it can be used as a structural member.
    - as a preventive measure before construction or as a rehabilitative treatment for structures suffering post construction distress due to poor soil condition.
    - to alleviate settlement of ground caused by basement and tunnel excavation works,
    - improving the bearing capacity under a sluice
- decrease the permeability.
    - Used to prepare foundation and abutments for dams



METAL

Metal

- **Ferrous metal**
  (Iron as main constituent)
  - e.g. cast iron, wrought iron, steel

- **Non ferrous metal**
  (Iron is not the main constituent
  - e.g. copper, aluminum, zinc, tin

Production of ferrous metal

Raw Material

- **Iron ore**
- **Coke – supplies carbon**
- **Limestone – reduces impurities**

↓

Blast Furnace → **Slag removed**

Pig Iron

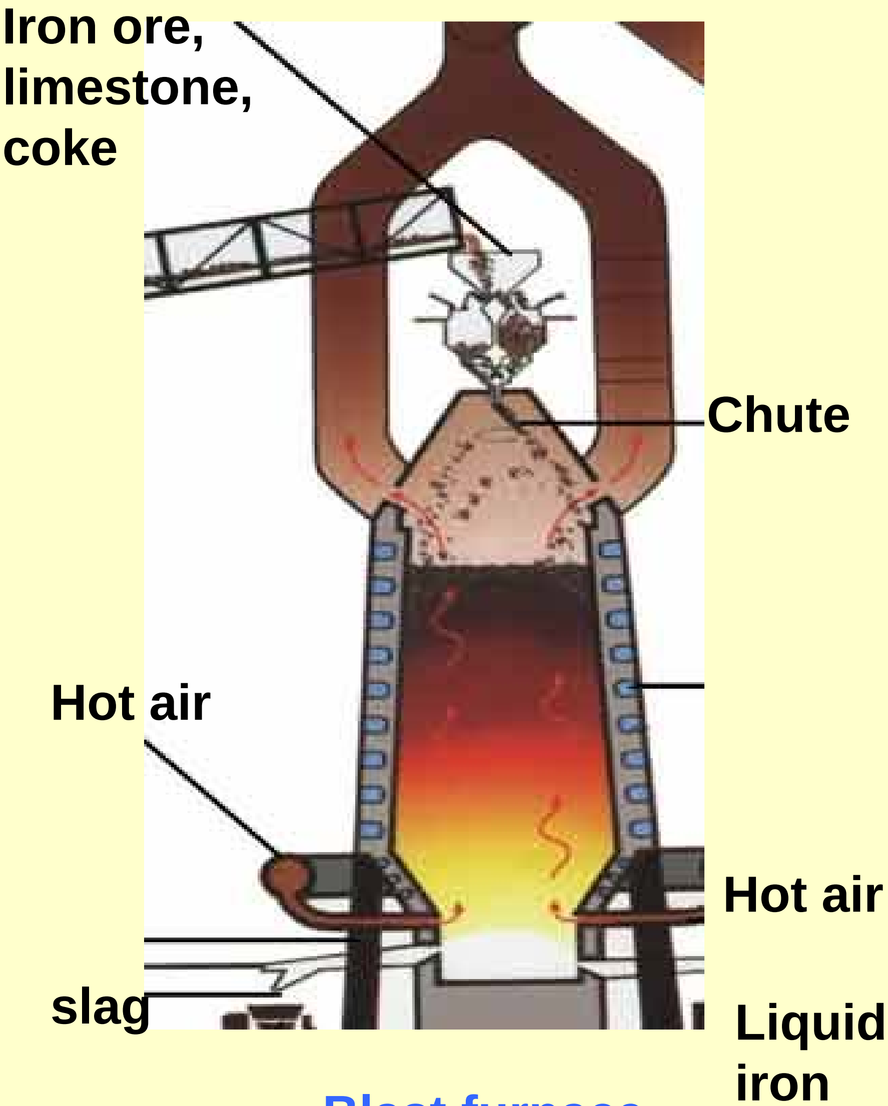
Cast iron | **Wrought iron** | **Steel**

(Commercial forms of iron)

Pig iron Production

Iron ore is reduced to pig iron in a blast furnace. Iron ore is combined with coke, and limestone. Hot air are forced through the material to ignite the coke and melt the iron ore. The impurities in the iron are absorbed by the limestone and forms blast furnace slag. The molten iron (with an excess carbon) collects at the bottom of the furnace.

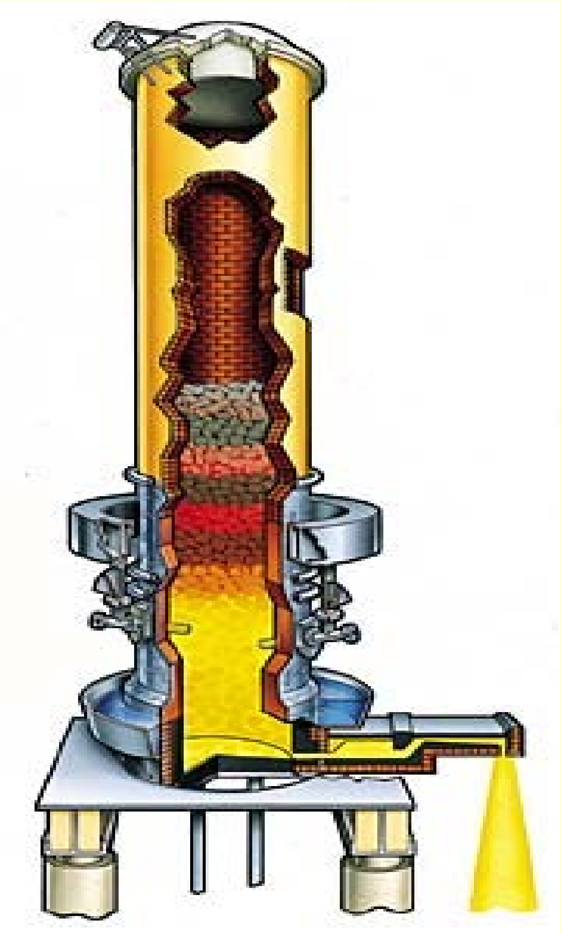
Pig iron content:
high carbon content : 4-5%. silicon : 2 %, manganese: 1 %, sulfur: 0.05 %, phosphorous: < 2%. Very brittle; not very useful directly as a material.



Blast furnace

Cast iron

- Made by remelting pig iron & removing impurities in a furnace (cupola)
- Contain
  - iron (92 – 95 %)
  - carbon (2 – 4 %)
  - silicon (1 - 3%)
  - traces of manganese, phosphorus, sulfur
- Shaped by being cast - iron is poured into a mold while it is liquid, allowed to solidify inside the mold.



cupola

Properties

- **Brittle – due to large carbon amount, difficult to weld.**
- **Low tensile strength (110 MPa) but high compressive strength.**

Types (depends on chemical composition and cooling rate)

- **Gray cast iron – commonly used**
- **White cast iron – harder, more resistant**
- **Malleable cast iron – can be malleable**

Uses

Manhole covers, engine blocks, machine tools, cookware, hardware, fire hydrants, pipes. (Not subjected to tensile strength)

Wrought iron

- Purest form of iron
- Made by refining pig iron in a furnace
- Contain
  - iron (98 %)
  - carbon (0.1 – 0.25 %)
  - slag (2-3%)
  - traces of sulfur, silicon, phosphorus, manganese

Properties

- Malleable, ductile, can be easily welded & machined.
- Good resistance to corrosion
- Moderate tensile strength (310 -380 MPa)

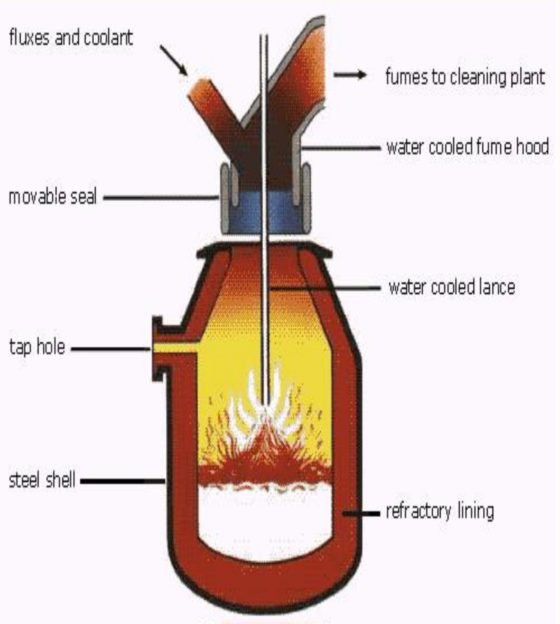
Uses

- Ornamental work, pipes, vehicle components, bars, chain.

Steel

- Invention of steel in 1856 by Henry Bessemer
- Bessemer process was the first inexpensive process for the mass-production of steel from molten pig iron.
- Replace by basic oxygen process.
- Contain
  - iron
  - carbon (0.12 –1.5 %)
  - phosphorous & sulfur < 0.1 %
  - manganese up to 0.5 %
  - silicon up to 0.3 %

Bessemer Converter



Basic oxygen furnace

Conversion to steel products

Molten steel

Continuous Casting

(poured directly into molds to make basic shapes)

Ingots

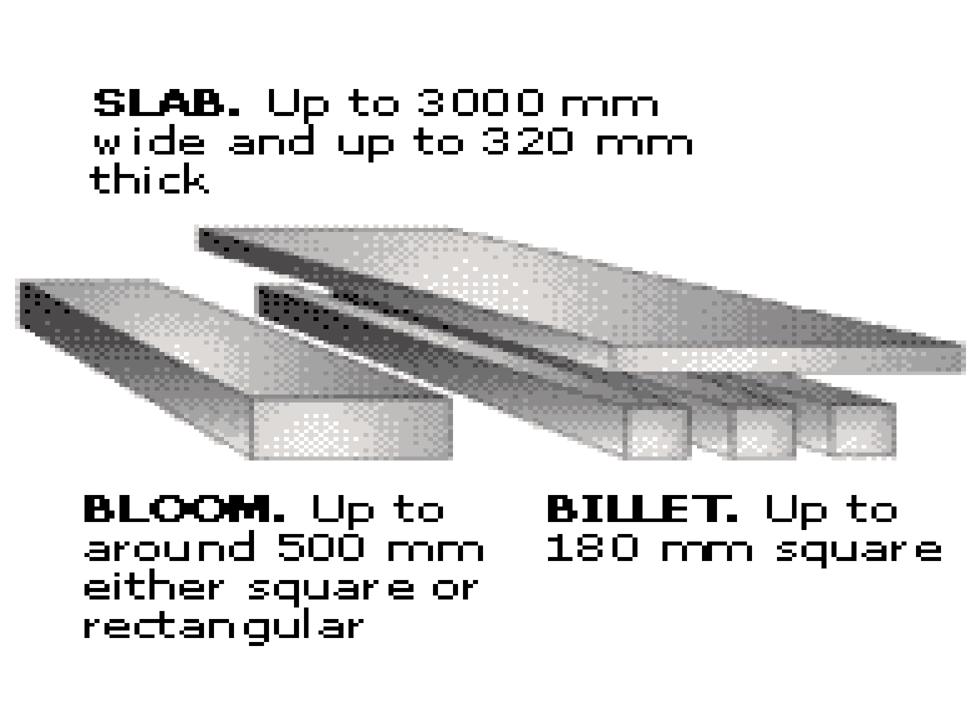
(6 x 2 x 2 ft)

Primary rolling

slab

billet

bloom



Continuos casting of billet

slab **billet** **bloom**

Plates **Sheets** **Wires** **Pipes** **Bar** **Structural shapes – beams,columns**

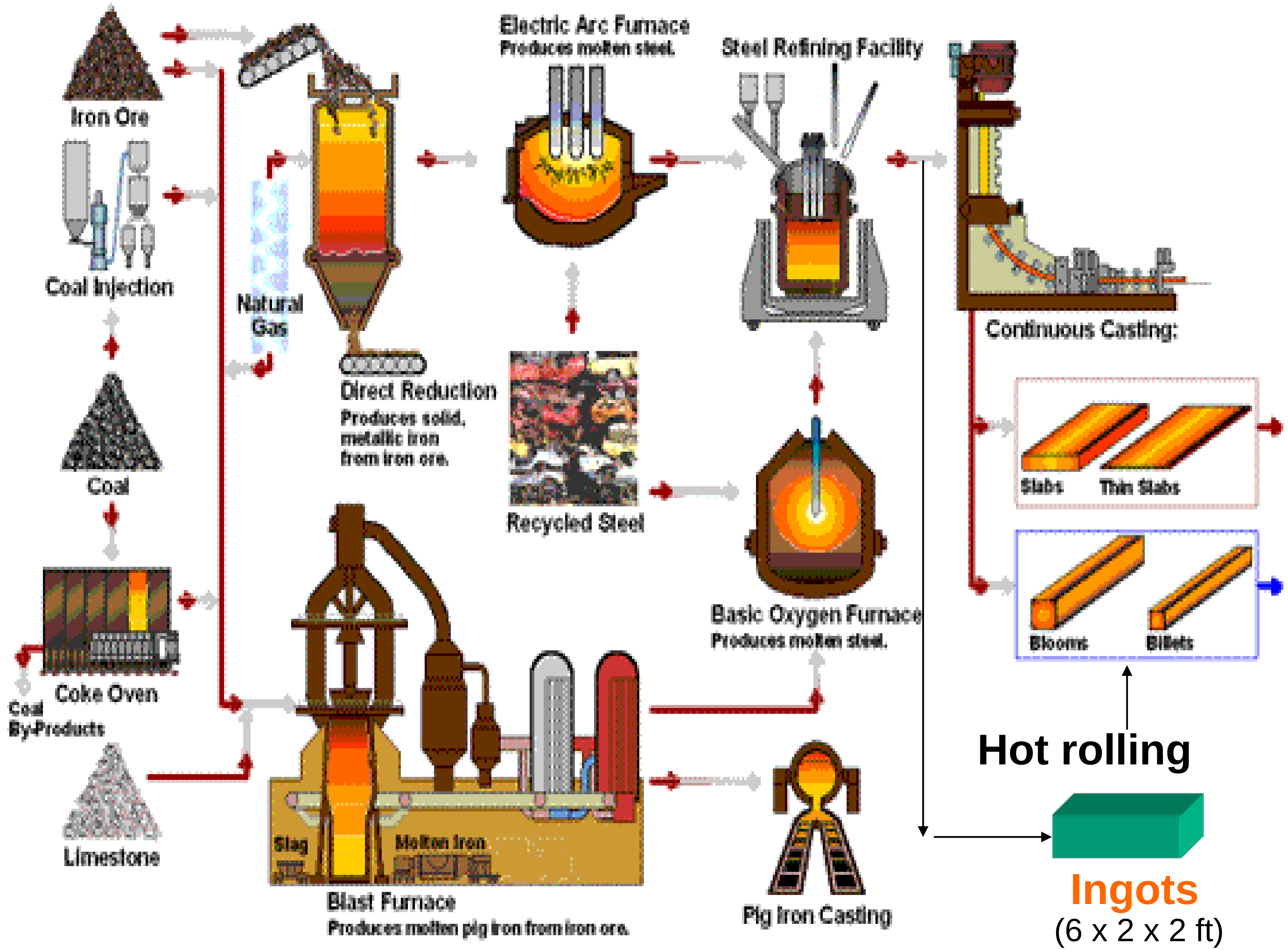
Steel forming

Molten steel are cast directly into the basic shape (slab, bloom, billets) or the ingot (once hardened) are rolled in rolling mills and transform into slab, bloom, billet.

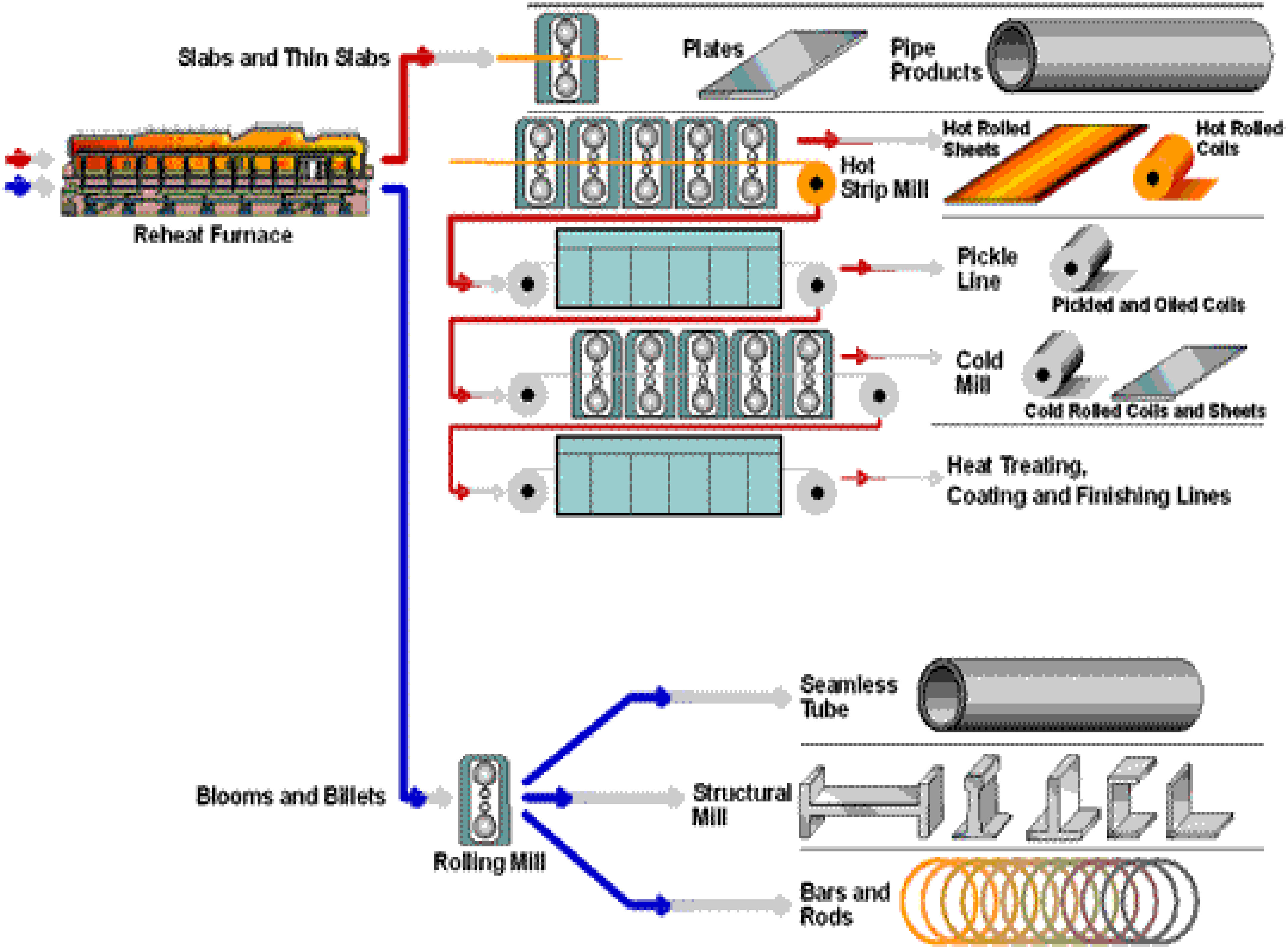
- a **slab** (For making plates, sheets, strip and other flat-rolled steel products)

- a **bloom** (For making beams and columns)

- a **billet** (Use to make bars, pipes, wire and wire products)



Iron Ore
Coal Injection
Natural Gas
Coal
Coke Oven
Coal By-Products
Limestone
Direct Reduction
Produces solid, metallic iron from iron ore.
Electric Arc Furnace
Produces molten steel.
Recycled Steel
Steel Refining Facility
Basic Oxygen Furnace
Produces molten steel.
Slag
Molten Iron
Blast Furnace
Produces molten pig iron from iron ore.
Pig Iron Casting
Continuous Casting:
Slabs
Thin Slabs
Blooms
Billets
Hot rolling
Ingots
(6 x 2 x 2 ft)



Slabs and Thin Slabs
Plates
Pipe Products
Hot Rolled Sheets
Hot Rolled Coils
Hot Strip Mill
Reheat Furnace
Pickle Line
Pickled and Oiled Coils
Cold Mill
Cold Rolled Coils and Sheets
Heat Treating, Coating and Finishing Lines
Seamless Tube
Blooms and Billets
Structural Mill
Rolling Mill
Bars and Rods

Mechanical operation

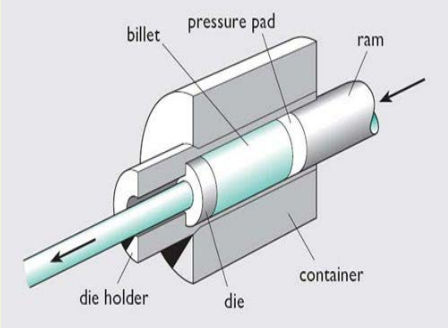
Steel properties are greatly influenced by the mechanical operation that change ingot, bloom, billets or slabs into useful shape.

The operations are **rolling, extruding and drawing**.

The operations can be done while the steel is in plastic condition (1090 ^{o}C) – **hot working** or at room temperature (**cold working**).

- **Rolling** - The shaping of metal by squeezing it through a series of rollers.


- **Extrusion** - Forcing a hot billet through a die of the desired shape.



- **Drawing** - Pulling steel through a small die to form wire or a small rod. (e.g. round, square)

Properties of steel

A steel with a wide variety of characteristics can be produced by

- **altering the carbon content**
- **adding alloy** (metal e.g. nickel, chromium, tungsten etc.) to steel to improve its characteristics e.g. corrosion resistance, strength, ductility and machinabilty.

  e.g. Stainless steel contains chromium and nickel. Anti corrosion & acid proof.
- **different heat treatment**
- **mechanical operation** (hot or cold rolling, drawing. extrusion etc.

Heat treatment of Steel

The heating and cooling processes are used to change the structure of a metal and alter its mechanical properties. (e.g. Cooling *rapidly* in cold water makes it *harder* and more *brittle*)

Ductility

Steel has high ductility. Ductility is the property of a material by which it can withstand extensive deformation without failure under high tensile stresses. It usually shows large visible deflections before failure or collapse.

Tensile Strength

Most important property. Depends on types of steel. Tensile strength for structural steel (400 – 900 MPa)

Types of steel

- **Mild steel (Low carbon steel)** < 0·25% carbon); cheap, strong and easily shaped. Main metal for construction.

- **Medium carbon steel** (0·25% - 0.5 % carbon) Rails, boilers, plates, axles, structures.

- **High carbon steel** **(0·5% - 1.5 % carbon);** **Stronger than mild steel but more brittle. Used to make tools and cutters.**

- **Steel Alloy**

  Ni-steel (Gear, shaft, cable), Mn-steel (Rail tracks)

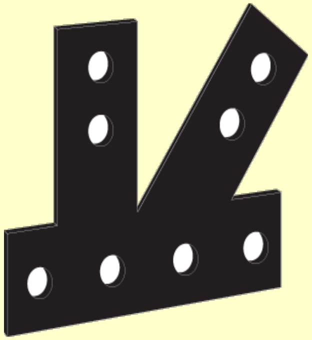
- **High tensile steel**

  e.g. as reinforcing material (in the form of wires) in prestressed concrete.

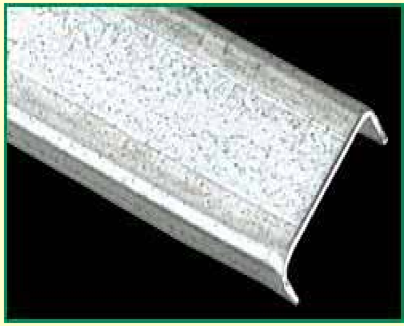
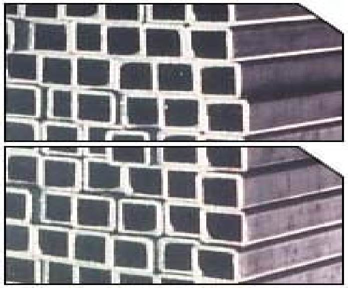
- **Galvanized Steel**

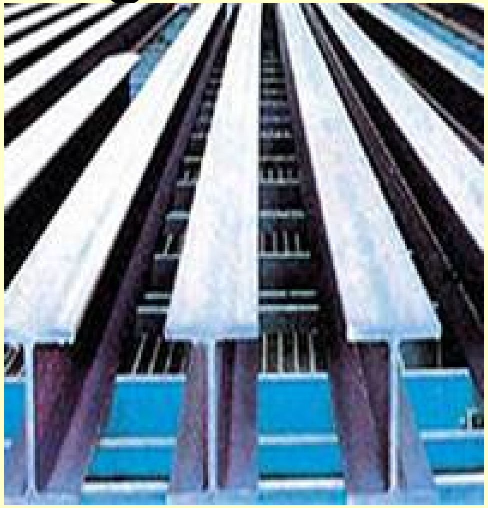
  Steel that has been plated with zinc to improve corrosion resistance.

Classification of steel products

- Structural steel – plates, bars, pipes, tubes, structural shapes – I, H beams, channel, angle

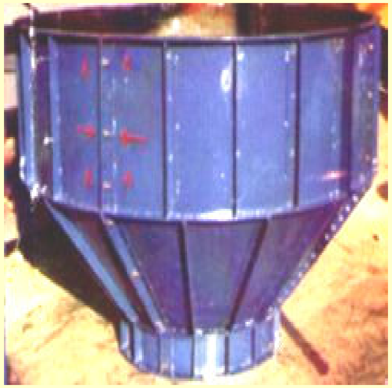



- Fastening product used for structural connections - bolt, nuts, washers



- Reinforcing steel - plain / deformed bar, wire fabric for concrete reinforcement

- Miscellaneous products e.g. forms, pans




Advantages of steel in building construction

1. High strength/weight ratio

Steel has a high strength/weight ratio. This property makes steel a very attractive structural material for high - rise buildings & long span bridges

2. **Ductility**

Steel can undergo large plastic deformation before failure, thus providing a large reserve strength. Properly designed steel structures can have high **ductility**, which is an **important characteristic for resisting shock loading such as blasts or earthquakes.**

3. Speed of erection.

Steel structures can be erected quite rapidly therefore reducing the cost of construction. Structural steel framing can be rapidly designed, purchased, fabricated and erected without need for curing and other delays of concrete and masonry construction.

4. **Quality of construction**

Steel structures can be built with high-quality workmanship.

5. **Ease of repair, modification & change**

Steel structures in general can be repaired quickly and easily. When building uses change or are improved, structural steel can be easily modified and reinforced to accommodate the new requirements.

6. **Adaptation of prefabrication**

Highly suitable for prefabrication and mass production.

7. **Repetitive use**

Steel can be reused after a structure is disassembled. Most steel today is a recycled product, and nearly all structural steel from building demolition is recycled. This provides salvage value, reduces demolition expenses, reduces landfill volume and helps the environment

8. **Expanding existing structures**

Steel buildings can be easily expanded in any direction.

Disadvantages of steel

1. **General cost**

Steel structures may be more costly than other types of structures.

2. **Fireproofing**

The strength of steel is reduced substantially when heated at temperatures commonly observed in building fires. Consequently, steel frames in buildings must have adequate fireproofing.

3. **Maintenance**

Steel structures exposed to air and water, such as bridges, are susceptible to corrosion and should be painted regularly. Application of weathering and corrosion-resistant steels may eliminate this problem.

4. **Susceptibility to buckling**

Due to high strength/weight ratio, steel compression members are in general more slender and consequently more susceptible to buckling than reinforced concrete compression members.

Non ferrous metal

- use as original metal or as alloy

Aluminum

- Lightweight - 1/3 weight steel and cooper; excellent corrosion resistance; low strength

Uses

- Roofing, window & door frames, door & window handles, protective covering

Copper

- High electrical conductivity; readily bent & cut; good corrosion resistance

Uses

- Electrical conductor, heating vessels

Zinc

- Good conductor of heat; high corrosion resistance,

Uses

- Roofing material, batteries, protective covering

Tin

- Resistance to acid corrosion, good conductor of heat & electricity

Uses

- Protective covering, alloy, household purpose, coating for food containers

MASONRY

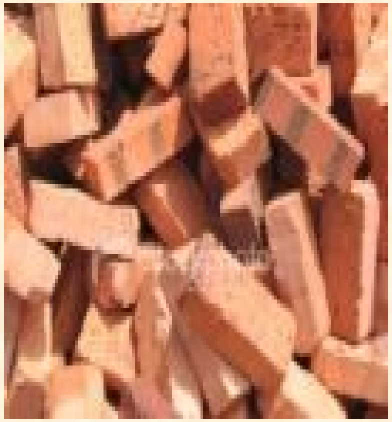


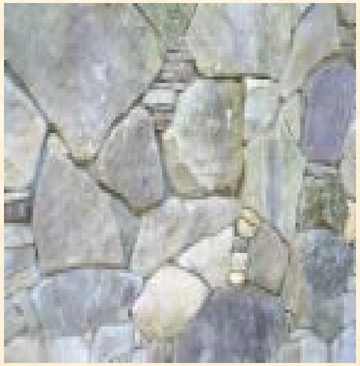
Definition

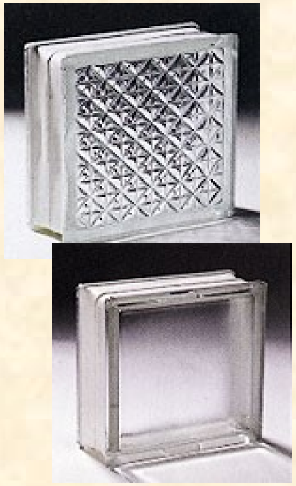
- **Masonry** refers to a construction material formed by combining individual masonry units e.g. brick, stone, with a binding material: mortar.
- Commonly used for walls of buildings.

Common materials of masonry construction:

- Brick (most common)
- Stone e.g. marble, granite, limestone
- Concrete block, glass block







The durability of the masonry construction is affected by

- The materials used
- The quality of the mortar and workmanship
- The pattern the units are laid

Bricks

- Usually made from clay and molded as a rectangular block.

Types of Bricks

- Clay bricks
- Fire bricks

made from clay

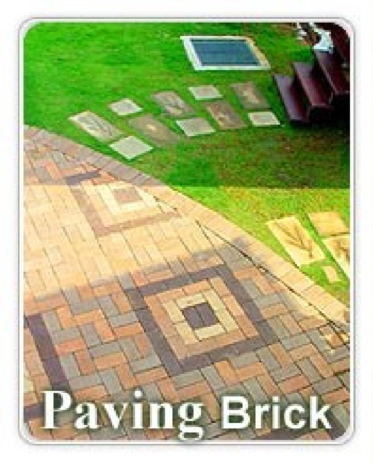
- Sand-lime brick

non-clay brick

- Concrete bricks

made from concrete

USES



- Structural uses such as foundations, walls and floors, drainage.
- Road pavement – traffic calming, decorative surface in pedestrian area.
- For lining furnaces, kiln and fireplace.

Advantages

- Size easily to work with.
- Good fire resistant.
- Durable and require little maintenance

Clay Bricks

- Principal ingredient: Clay (contain silica and alumina and other metal oxides e.g iron)

- Occurs in three principal forms:
  - Surface clays: found near earth surface
  - Shale: subjected to high pressures from soil above, relatively hard.
  - Fire clays: deeper levels. Can withstand higher temperature.

Brick manufacturing plant

Manufacturing of clay brick

Preparation of Raw Material

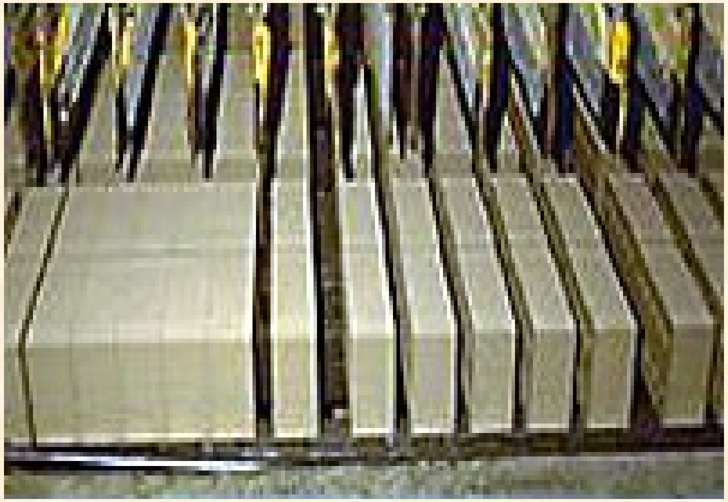
- Clay is in form of large clumps - crushed into small pieces; grinded to fine powder and blended with water.

Forming

Stiff mud process

(clay with 10 - 15 % water. Most common)

- Clay is forced into a die producing a continuous column of clay of proper size and shape, then cut to size with a wire frame.



Forming

Soft mud process

(clay with 20 - 30 % water). Oldest way of making brick.

- Clays which contain to much natural water.
- Clay is pressed in wooden /steel molds (press by machine).

Dry press process (<10% water)

Clay is placed into molds and compacted using a steel plunger. Expensive. Not common.

Drying

-Wet brick contains 7-30 % water.

- Bricks are dried in covered open area or in a drying chamber before firing to remove excess moisture.
- This excess moisture will burn off too quickly during firing causing cracking and warping.

Drying chamber

Temperature : $43\ ^oC$ to $204\ ^oC$

Drying time: 24 to 48 hours

Burning and Cooling

- Bricks are burned in a kiln at a very high temperature ~1315 ^{0} C
- Periodic Kiln - loaded and unloaded
- Tunnel Kiln - continuous feed

Burning stages

1. **Dehydration** - removal of all water at temperature up to 600 ^{0} C
2. **Oxidation** (Burning of carbonaceous material between 300 - 900 ^{0} C)

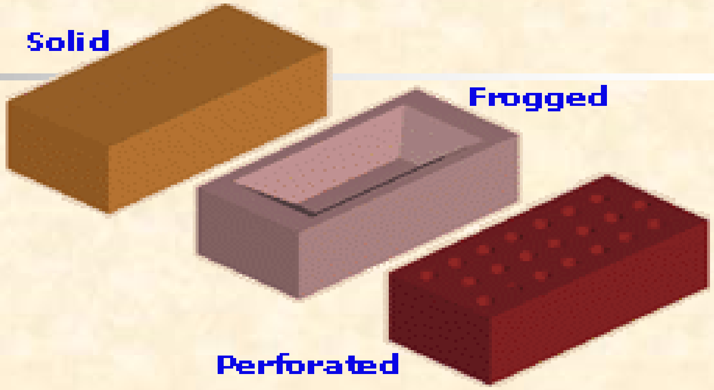
- Vitrification (900 - 1315 ^{0} C)
  (Change into a glassy substance)

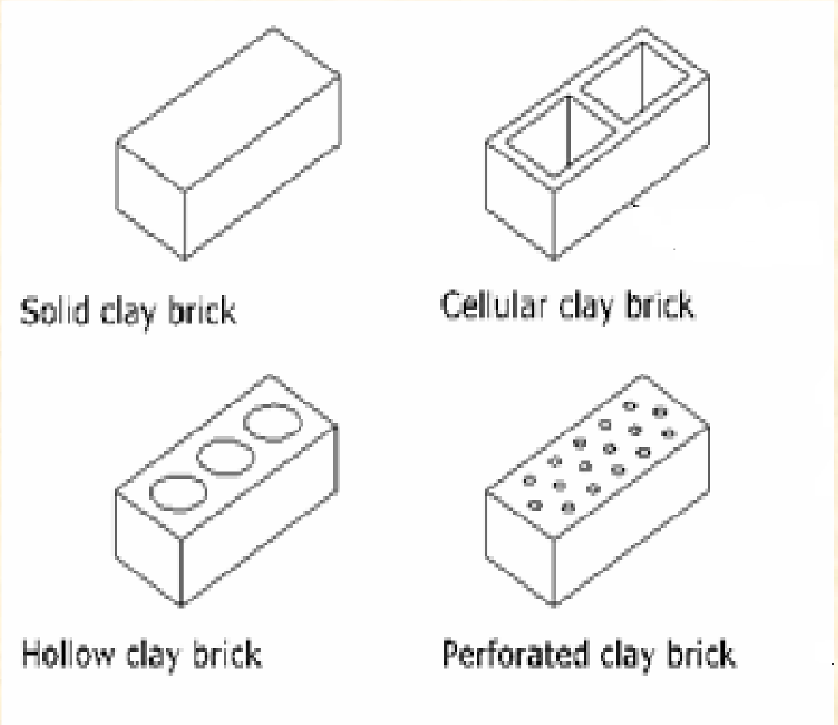
- Temperature affects color, strength, and absorption of bricks. Higher temperature gives darker color.

- Cooling for 2 - 3 days.
- Proper sorting and packaging of the brick.

Shapes of Bricks

- Solid
- Hollow
- Cellular
- Perforated





Shapes of Bricks

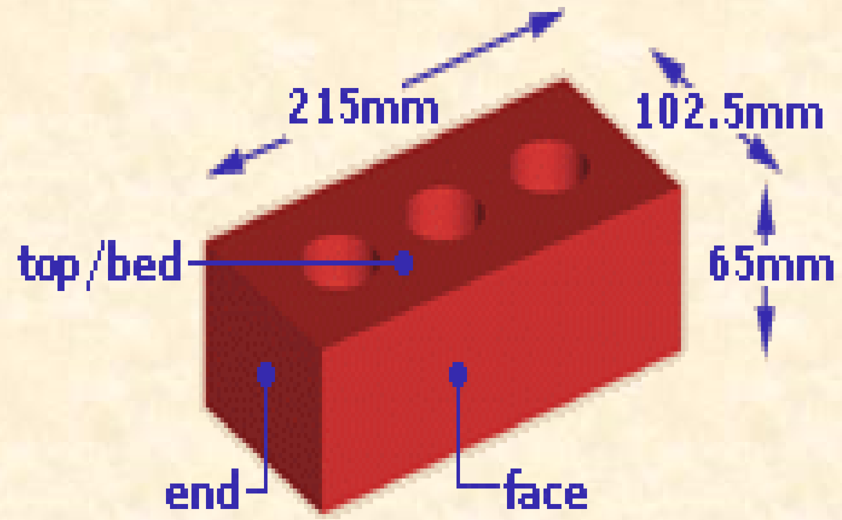
- **Cores / holes - vary in size & number**

  Purpose :
- Reduce volume & weight of brick
- Increase bond strength
- Allow even drying during burning

Sizes of Brick

The standard UK/ MS 7.6: 1972
215 x 102.5 x 65 mm

US brick :
8 x 4 x 2.25 inches
(203 x 102 x 57 mm)



Properties of bricks

- Size, texture, density & color
- Compressive & tensile strength

  - Affected by the properties of clay, methods of manufacturing (higher in stiff mud process than soft mud process) and burning process. (Higher degree of burning, higher strength).

  - Compressive strength between 7 - 21 MPa.

- Absorption

- Absorption of water depends on clay properties, manufacturing process and burning. Absorption determine the durability of bricks.

- High absorption capacity causes mortar to be dry & reduces mortar strength. Good brick should absorb < 20 % water.

Highly absorptive bricks can cause efflorescence.

Efflorescence – white, powdery deposits on bricks composed of soluble salts in the brick brought up to the surface by moisture. Aesthetic problem; may cause surface damage.

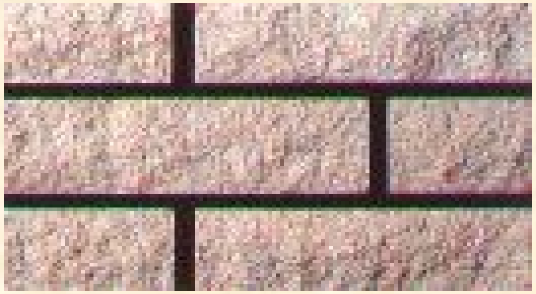
Bricks test

- Compressive strength test
- Water absorption test
- Efflorescence test (not common)

Types of clay brick

1. Common brick

- Brick for common building purposes. Strength & durability are important. Appearance (texture or color not so important.)
- Used for wall / partition wall which require plastering.



2. Face brick

Brick made especially for exterior use with special consideration of color, texture and size, and used as a facing on a building. High durability.

3. Engineering brick

- Dense, tough, strong brick which are used to construct

  - retaining wall

  - load bearing wall

  - brick sewer

4. Firebrick (refractory brick)

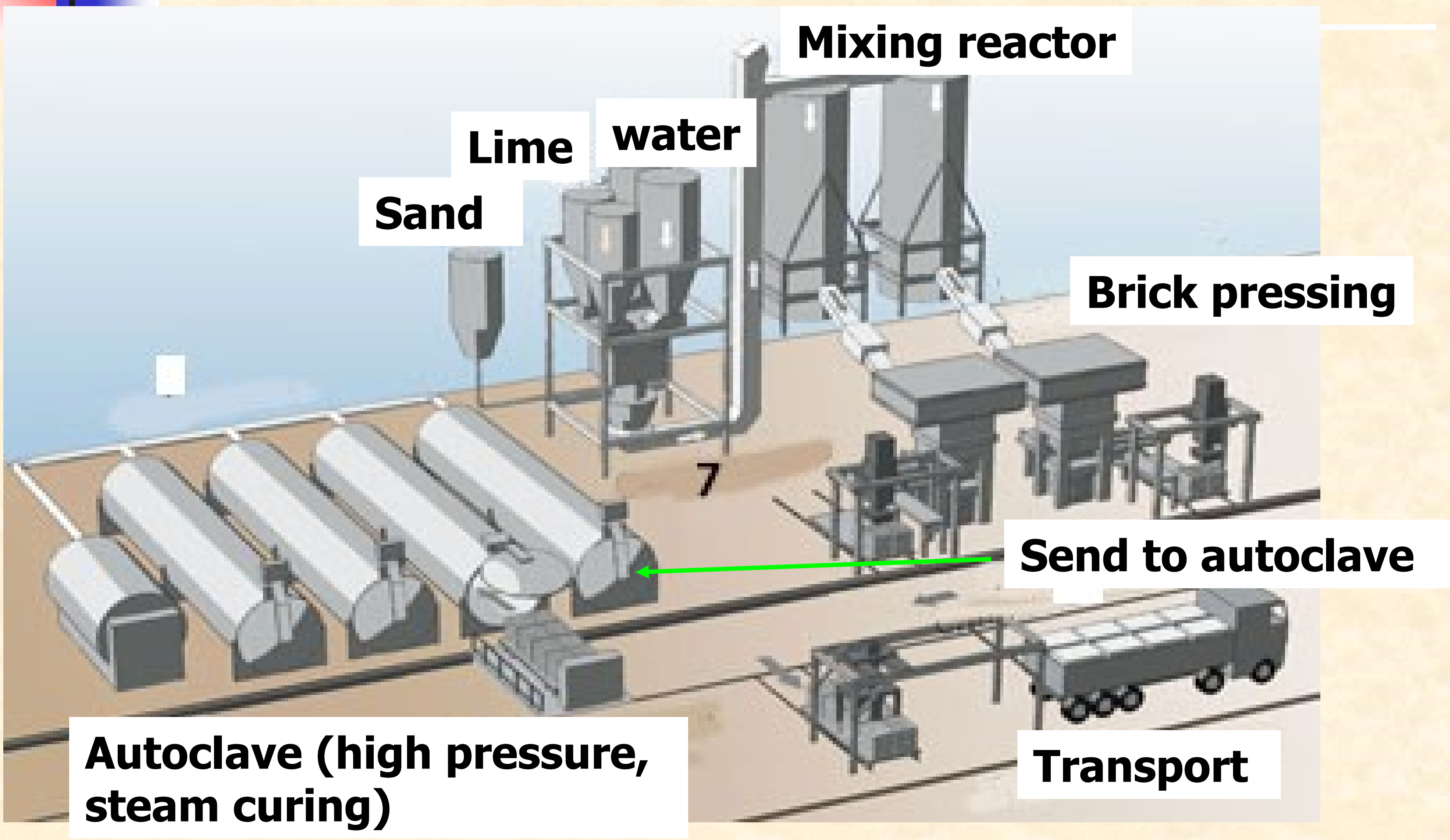
Used to line lining furnaces, kilns and fireplace. Built primarily to resist high temperature.

Non- Clay brick

1. Sand-Lime (Calcium- silicate) brick

A white brick made of lime, sand and water which is then molded at high pressure, followed by high-pressure steam curing.

Sand-Lime (Calcium- silicate) brick production

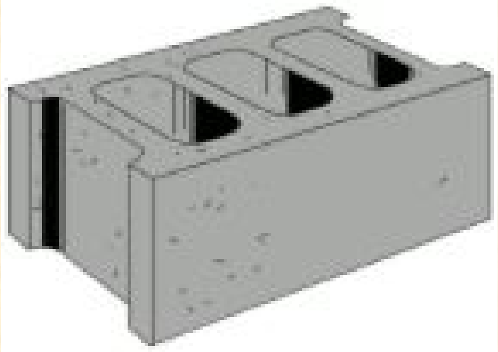


2. Concrete brick

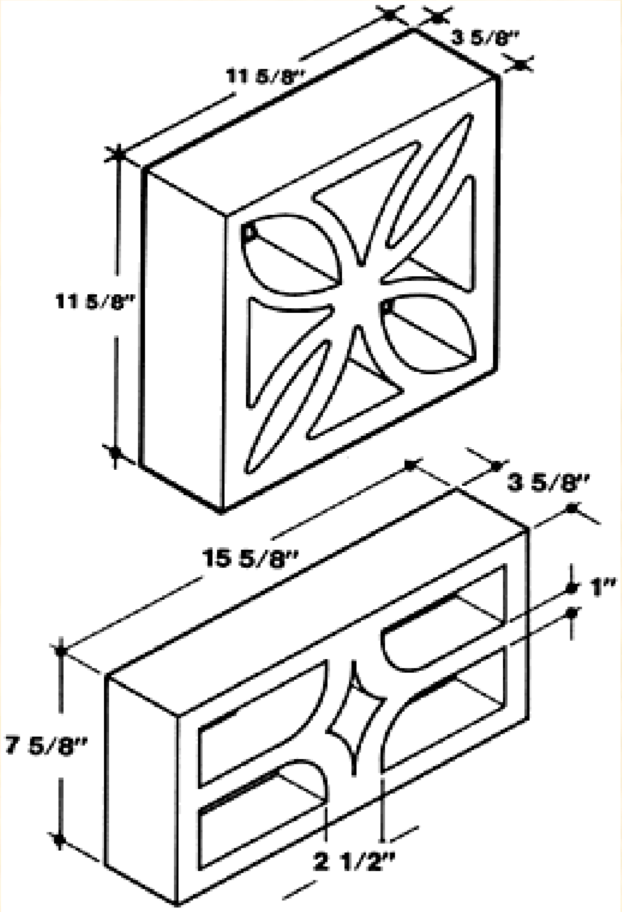
Solid concrete unit in clay brick dimensions. A mixture of cement and aggregate, usually sand, formed in molds and cured.

Concrete block

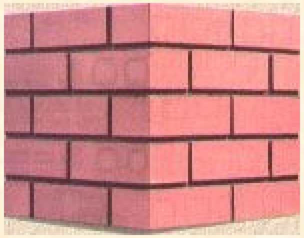
A large unit, usually 8 inches high, 16 inches long, and of various thicknesses.



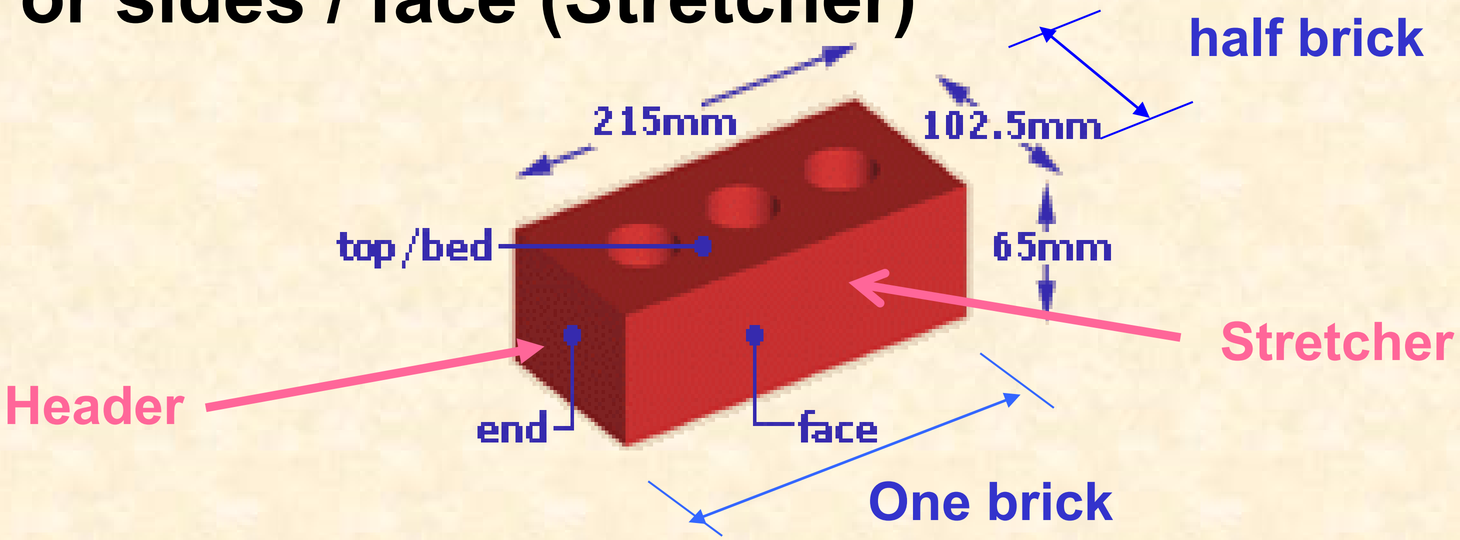
Screen wall blocks have an open web pattern to be used where the admission of air and light is needed in connection with separation of areas.



Brickwork



Bricks are laid to expose their ends (Header) or sides / face (Stretcher)



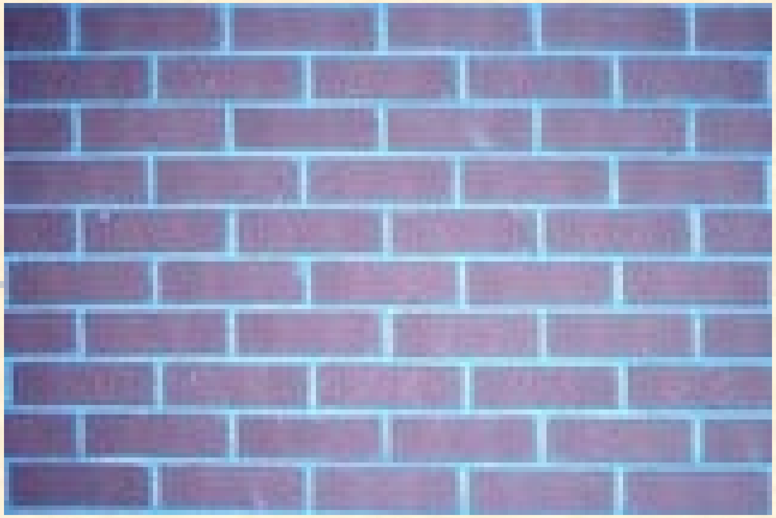
Bricks are laid in rows called *courses* (layers).

The manner in which the bricks are arranged as they are laid up is called *bond*.

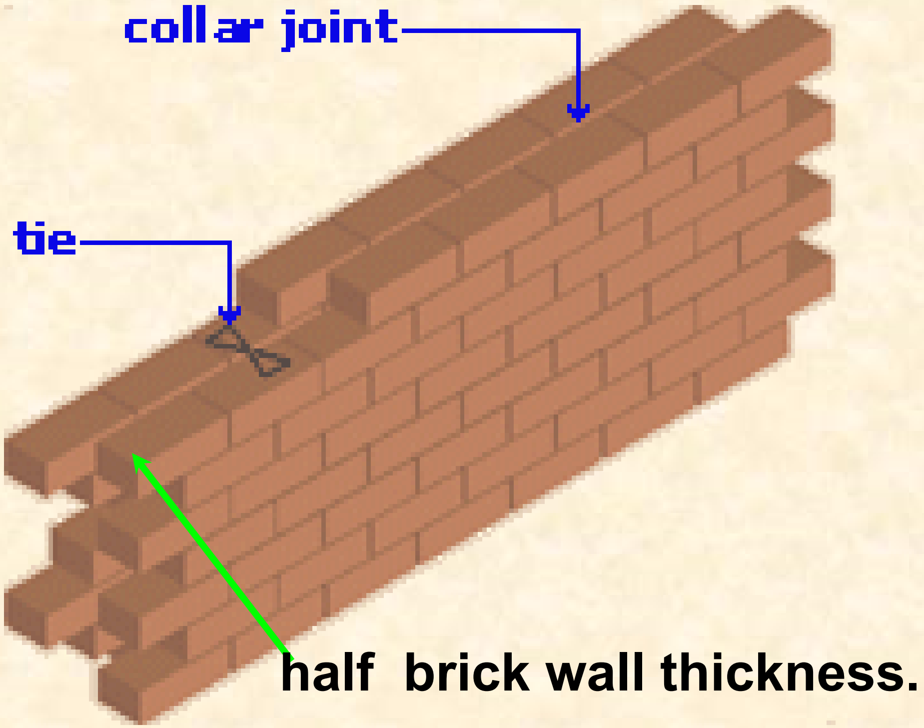
Types of bond

- Stretcher (most common)
- Header
- English
- Flemish

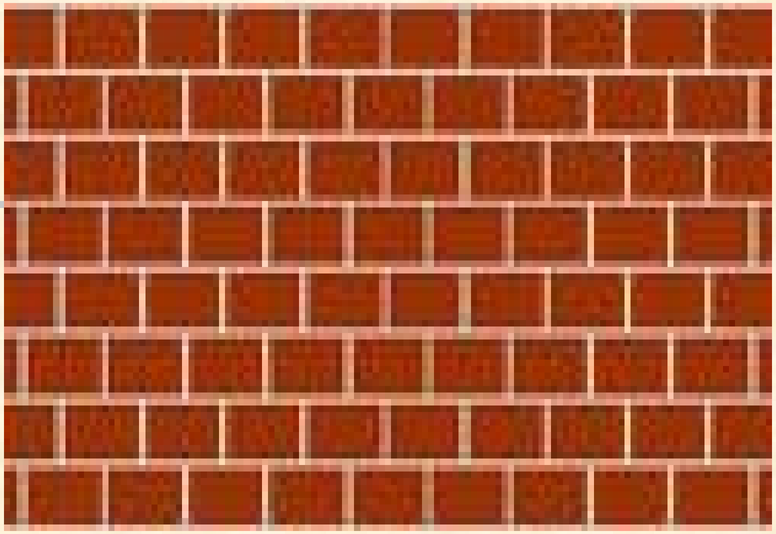
Stretcher bond



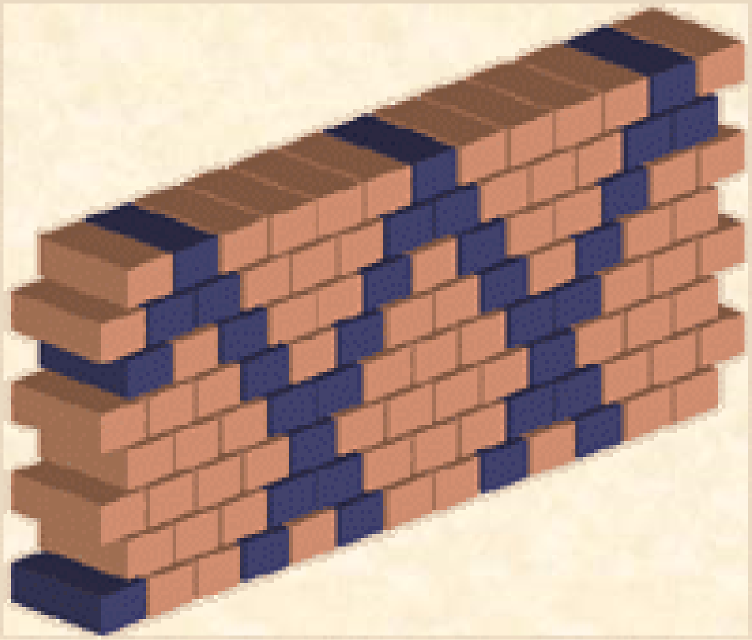
- Most common bond in modern times; easy to lay.
- consists of course entirely comprised of stretchers (shows only the long side-surface of the brick.)
- Produce half brick wall thickness.



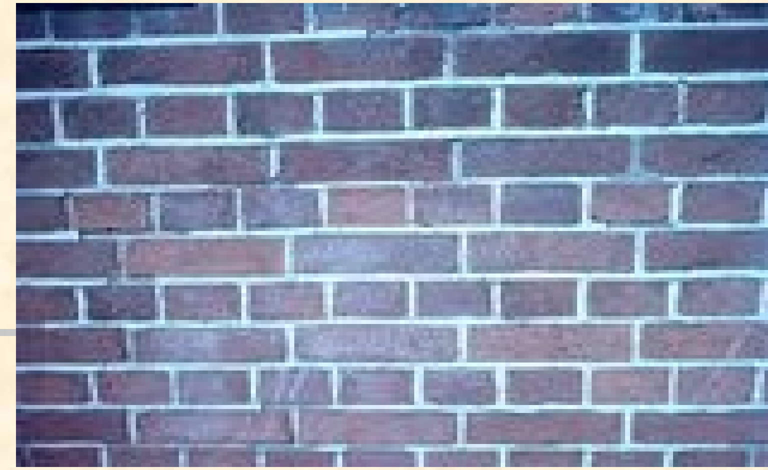
Header bond



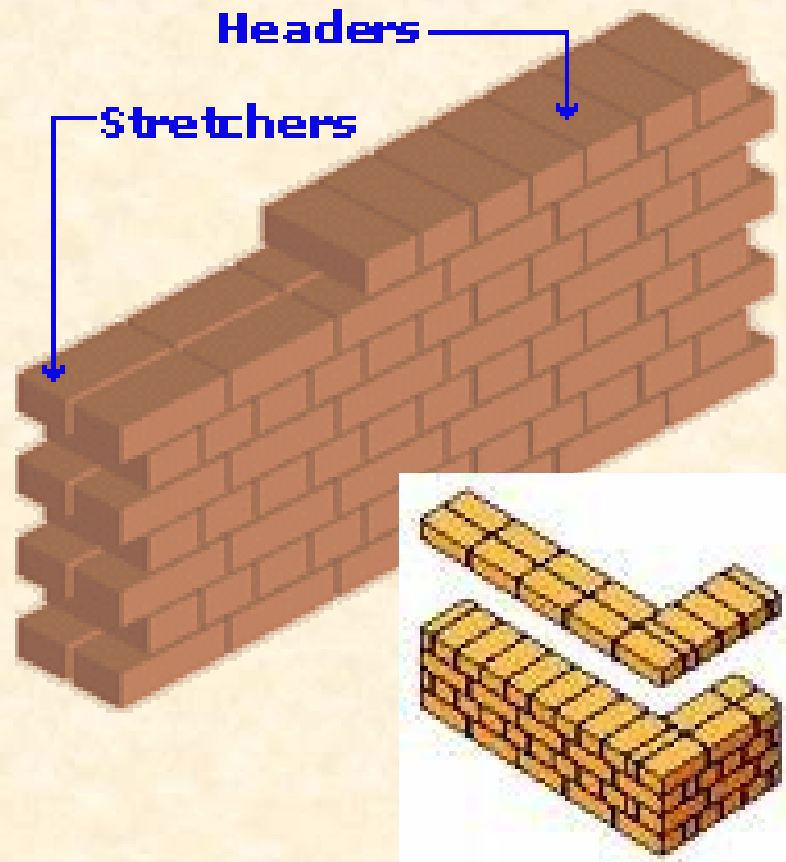
- Course consists of header
- Useful for producing one brick wall thickness & curve wall.
- Weak bond



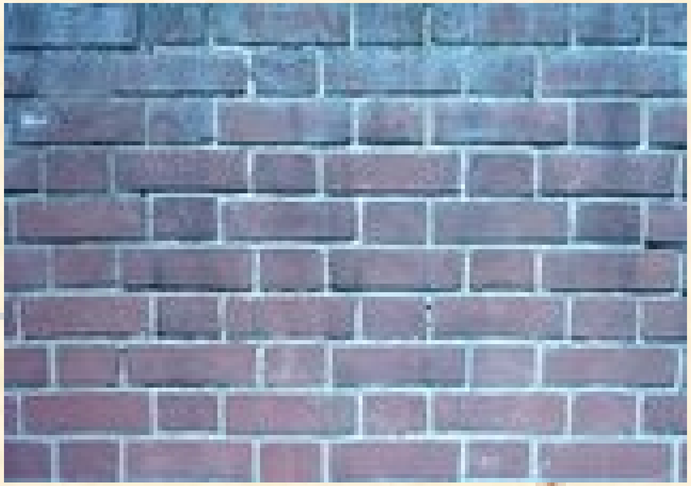
English bond



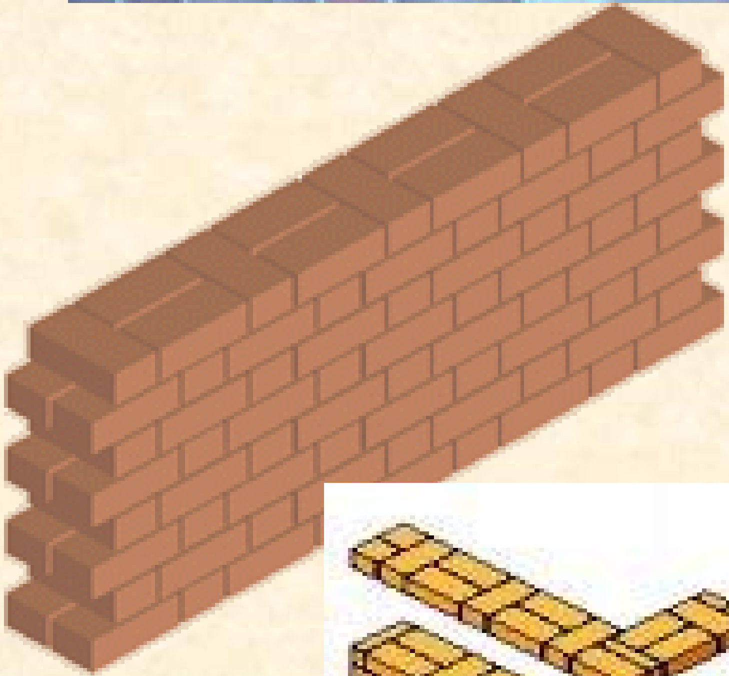
- Made up of alternating courses of stretchers and headers.
- This produces a solid wall that is a full brick in width.
- The strongest bond for a one-brick-thick wall.

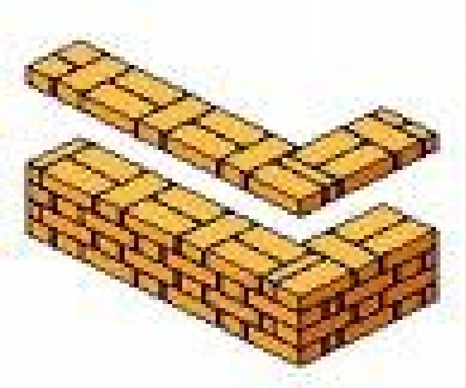


Flemish bond



- Alternately laying headers and stretchers in a single course.
- The next course is laid so that a header lies in the middle of the stretcher in the course below.
- Quite difficult to lay properly.





Mortar

- **Mortar** is a material used in masonry to fill the gaps between blocks (e.g. brick, stone) in construction and bind the blocks together.
- Mortar is a mixture of sand, cement, lime & water.
- Thickness of mortar : 6 – 9 mm

Types of Mortar

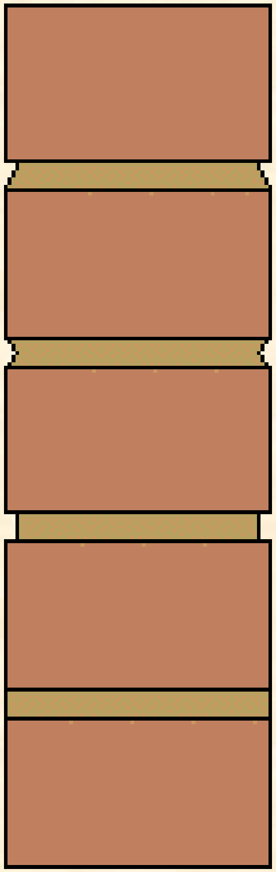
Lime mortar	1 part lime, 3 - 4 parts sand; low strength, poor durability but good workability.
Cement mortar	1 part Portland cement, 3 - 4 parts sand. High strength, harden quickly, good durability but low workability. Should be used immediately.
Lime - cement mortar	1 part Portland cement, 1 part lime, 6 parts sand. Good strength, moderate hardening, good workability and good durability. The addition of lime increases mortar workability.

Methods of finishing joints / Pointing

.

- A process of filling in the joints of brickwork with mortar
- Pointing is carried out on face brick or on exposed brick surface.
- The process can be carried out while laying the bricks or at a later stage.

Types of joint



Plastering

- To finish off brick wall (interior or exterior wall) and give a smooth surface.
- A fluid mixture of lime, Portland cement, sand and gypsum.
- Stucco – a plaster used to cover exterior walls.

Types of Plaster

Lime plaster	A mixture of lime and sand.
Cement plaster	A mixture of Portland cement and sand.
Gypsum plaster	A mixture of gypsum (calcium sulfate) and sand.

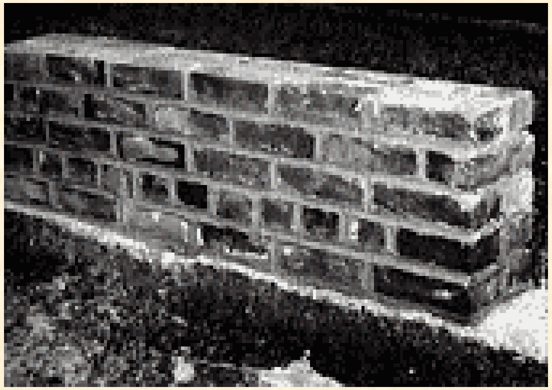
Plastering is normally done in two coats:

(Combination of the three materials is normally used)

Base coat: e.g. Lime plaster & with cement or gypsum

Finish coat: Lime plaster & with gypsum

Basic Brick Construction



History of Construction Block

- ✓Blocks sometimes referred to as artificial stone, and have been used since 4000 BC.
- ✓<u>MIDDLE EAST</u>:-The earliest brick were dried brick meaning that they were formed from clay bring earth or mud.
- ✓The oldest discovered bricks originally made from shaped mud and dating before 7500BC were found at TELL ASWALD.
- ✓<u>CHINA</u>:-The earliest fired bricks appeared in Neolithic China around 4400BC at Chengtoushan, a walled settlement of the DOXI culture.
- ✓<u>Europe</u>:-Europe were also called roman brick.

BLOCKS VS. BRICKS

- A **brick** is building material used to make walls, pavements and other elements in masonry construction. Traditionally, the term brick referred to a unit composed of clay. A brick can be composed of clay-bearing soil, sand, and lime, or concrete materials.
- Block is a similar term referring to a rectangular building unit composed of similar materials, but is usually larger than a brick. Lightweight bricks (also called lightweight blocks) are made from expanded clay aggregate.

Construction Block

Construction Brick

Properties of building blocks

- It consider implementation and usage and involve to exploit technology and standard.
- It may assembled from other building blocks.
- Ideally a building block is reusable and replaceable and well specified.
- Structural properties
- Fire resistance
- Water resistance
- Aesthetic properties
- Insulating properties
- Acoustic properties

Types of concrete block used in building construction

1. Hollow concrete blocks

- Commonly used in the construction industry, concrete hollow blocks are usually manufactured using ***lightweight aggregates*** with a certain design load.
- There are two kinds of concrete hollow blocks;

I. load-bearing concrete hollow blocks and

II. Non-load bearing concrete hollow blocks.

- It is available in sizes such as *100x200x400mm, 200x200x400mm, 150x200x400mm and so on*

2. Aerated Autoclaved Concrete Block (AAC)

- Most of the time compared with bricks but is different in a lot of ways:
- Aerated Autoclaved concrete blocks are ***lighter and bigger version of bricks***
- *Studies show* that using autoclaved aerated block has ***diligently reduced the overall steel and concrete*** consumption by *15% and 10%.*
- Apparently, in the ***cost-benefit factor part***, autoclaved aerated block past by bricks in several areas such as construction time, adaptation to various surfaces, fire resistance, and cost.

3. Concrete Bricks

- Concrete bricks typically are ***small rectangular block arrange*** and piled systematically to create a rigid wall.
- Usually made up of ***cooked clay or concrete***
- Some manufacturers use ***solid concrete*** while others play with its cement and aggregates ratio for economic purposes.
- Concrete bricks are usually used in <u>*fences, facades, as it provides good aesthetic and slick look.*</u>

4. Solid concrete blocks

- ✓ Solid concrete blocks are manufactured to be strong, heavy, and created out of naturally dense aggregates.
- ✓ These solid concrete blocks are strong enough that it is used for large masonry units that are load-bearing in nature

5. Lintel blocks

- ✓ These concrete blocks are used in preparation for lintel beams
- ✓ These lintel blocks are manufactured in such a way that it serves as a masonry unit and a formwork itself.
- ✓ They serve as permanent formwork system for the lintel beam member.
- ✓ This is found to be efficient and useful by most builders as they served two different purposes.

6. Paving Blocks

- ✓Paving blocks are generally just a ***rectangular or square box*** made up of ***reinforced concrete***.
- ✓These blocks are used in paving and road shoulders, these have to be painted with high-visibility concrete paints so motorists and drivers could see it right away.
- ✓Paving blocks are also used in parks, walkway, and sometimes in parking areas. ***The common size of paving block is 60mm.***

7.concret stretcher block

- *Similar* to corner block, concrete stretcher block are ***used to combine masonry units.***
- Concrete stretcher block is relatively the ***same with common hollow block*** *but their faces are laid parallel with respect to the face of the wall.*
- Choosing a masonry unit is solely dependent on the needs of the builder, the combination of this masonry unit is advisable.

Use of building block

- ✓***Inexpensive*** in comparison to other types of building materials.
- ✓***Lightweight***, which is very beneficial in working on a job that requires heavy manual labor.
- ✓Can also be used as a form of ***insulation against heat or cold***, assisting in the cost of energy bills.
- ✓***Durable***: concrete block is great when building a foundation because unlike wood, it is immune to termites and extreme temperatures.
- ✓***Versatile***: can be used in a varieties of different ways, from backyard landscape, partition walls, or even used to soundproof rooms.

Top 6 Important Quality Tests Of building block

- ❖Slump test before leaving the batching plant and on arrival on site
- ❖Compressive strength test
- ❖Water Permeability test
- ❖Rapid Chloride Ion Penetration Test
- ❖Water Absorption Test
- ❖Initial Surface Absorption Test

1. List And Discuss the Building Construction Materials?
2. What are Building Stones? Discuss their Requirement and Types?
3. What are the Properties of Good Building Stones?
4. What are the uses of Common Building Stones?
5. List out Useful Building Stones in Ethiopia?
6. Write a Brief Notes on Methods Of Quarrying Of Building Stones? And Also Define What Do Mean By ‘Quarrying’
7. What Is Dressing of Stones? When We Apply and Why?
8. What Are The Deteriorating Agencies of Stones? And How (Methods of Preservations)
9. List and Discuss both Laboratory and Field Tests on Building Stones?
10. What are Artificial Stone? Give the Examples?
11. What are Advantages of Building Stones?
12. What Are Bricks? Discuss their Requirement and types? Standard Size or Dimensions as Worldwide and Ethiopia Context?
13. Discuss in details the four bonding types of bricks with their figures and sketches?
14. Define Building Blocks and Discuss in Details its type, Standard Size and General Requirement? Don’t Miss to compare it with that of Bricks?
15. List out those metals used in constructions? What are the general properties of steel and aluminum alloys? Why reinforced concrete?
16. What Is Bitumen? Discuss the Grades of Bitumen, types of Bitumen, the Basic Function of Bitumen, the General Requirements of Bitumen, and Tests on Bitumen?
17. What is timber? The general requirements of timber? List out those timber products in details?

Assignment 2 (Workout)

General Instructions

- All the group members must be participated in doing the workouts.
- The neatness and accuracy have their own value.
- The procedure must be followed in using the table of Concrete Mix design.
- There must Given data information, the required and the solutions discretely.

1. Concrete is required for a portion of a structure that will be below 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 (cylindrical). It is determined that under the conditions of placement to be employed,
   - a slump of 75-100 mm should be used
   - The coarse aggregate has a nominal maximum size of 37.5 mm and dry-rodded mass of 1600kg/m^3.
   - Other properties of the ingredients are:
     - cement – Type I with specific gravity of 3.15;
     - Coarse aggregate-bulk specific gravity 2.68 and absorption 0.5 percent;
     - Fine aggregate - bulk specific gravity 2.64, absorption 0.7 percent, and fineness modulus 2.8.

Calculate the weights of all materials that you would use for the first trial mix on a concrete mix.

Good luck!

Assignment 2 (Workout)

2. Calculate the weights of all materials that you would use for the first trial mix on a concrete mix required to achieve Characteristic compressive strength of 25 N/mm2 at 28 days (cubic strength). The following information on material properties and plant performance is available to you.

Cement Type, specific gravity respectively	O.P.C, 3.15
Max. Aggregate size, rodded bulk density of aggregate	19mm,1600kg/m^3
Rel. Density (S.G) of combined aggregate (SSD)	2.75
Required Slump	25mm
Maximum Cement Content	500 Kg/m^3
Max free water/cementratio	0.5
Fineness modulus	2.97
Air content	1%
Freemoisturecontentofsandandcoarseaggregaterespectively	8%, 1%
Bulk specific gravity of coarse and fine aggregate respectively	2.7, 2.6
Absorption of coarse and fine aggregate respectively	0.3%, 0.8%

Good luck!

Assignment 2 (Workout)

3. Calculate the weights of all materials that you would use for the first trial mix on a concrete mix required to achieve Characteristic compressive strength of 40 N/mm^2 at 28 days (cubic strength). The following information on material properties and plant performance is available to you.

Cement Type, specific gravity respectively	O.P.C, 3.15
Max. Aggregate size, rodded bulk density of aggregate	12.5mm,1700 kg/m^3
Rel. Density (S.G) of combined aggregate (SSD)	2.7
Required Slump	50mm
Min. Cement Content	320 Kg/m^3
Max free water/cementratio	0.7
Fineness modulus	2.93
Air content	1%
Freemoisturecontentofsandandcoarseaggregate respectively	8%, 1%
Bulkspecificgravityofcoarseandfineaggregaterespectively	2.7, 2.6
Absorption of coarse and fine aggregate respectively	0.3%, 0.8%

Good luck!

The table below shows the type of structure with exposure conditions. From this we can have Maximum Permissible Water/Cement ratios for different types of structure. Hence it is a must to see or revise our calculation for what type structure. Summarize the example for the exposure given. See the 'star' and 'dollar' symbol at the last of the table and differentiate it as much as possible.

Table 4.5. Maximum Permissible Water/Cement Ratios for Different Types of Structures in Severe Exposure, Prescribed by ACI Standard.

Type of structure	Exposure conditions	
	Structure wet continuously or frequently and exposed to freezing and thawing*	Structure exposed to sea water or sulphates
Thin sections, such as railings, kerbs, sills, ledges, ornamental work, and sections with less than 25mm cover to the reinforcement.	0.45	0.40$
All other structures	0.50	0.45$

* Air-entrained concrete should be used under all conditions involving severe exposure.
$ When Type II or Type V cement is used, maximum water/cement ratio may be increased by 0.05.

Remember the definition of 'slump' from the tests from checking concrete workability. We have different slumps for different types of constructions. So it is your duties or turn to check for the type of structure given in the questions or any related calculations and or examples. For what of structure we are going to prepare concrete? It is a must to answer this question before starting the workout.

Table 4.6a
RECOMMENDED SLUMPS FOR VARIOUS TYPES OF CONSTRUCTION (SI)

Types of Construction	Slump, mm	
	Maximum	Minimum
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

For the table depicted below we have different parameters must be understood. Here there are slump and aggregate for which we use them to obtain Water (kg/m^3) and air content for both Non-air entrained and air entrained concrete. Try to check the exposure while finding the recommended air content in percentage. Read the note at the end of the table for different case if may happen on workout.

Table 4.6b
APPROXIMATE MIXING-WATER AND AIR-CONTENT REQUIREMENTS

	Water, kg/m^3, for Indicated Nominal Sizes of Aggregates (mm)							
Slump mm	**9.5**	**12.5**	**19**	**25**	**37.5**	**50**	**75**	**150**
	Non-Air-Entrained Concrete							
25 – 50	207	199	190	179	166	154	130	113
75 – 100	228	216	205	193	181	169	145	124
150 - 175	242	228	216	202	190	178	160	-
Approximate entrapped air (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-Entrained Concrete								
25 – 50	181	175	168	160	150	142	122	107
75 – 100	202	193	184	175	165	157	133	119
150 – 175	216	205	197	184	174	166	145	-
Recommended air content (%)								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Severe Exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Note: Mild exposure-where air entrainment is not required for durability.
Moderate exposure where concrete will not be continually exposed to water before freezing or to deicing agents.
Severe exposure – where deicing or similar agents are used or where concrete may be highly saturated before freezing.

The table below describes how we can access fresh concrete from the table with help of nominal maximum size of aggregate for the two cases of air entrained and non air entrained. Here such a calculation is not a final one rather it is a first estimate of concrete unit mass, kg/m^3

Table 4.7
FIRST ESTIMATE OF MASS OF FRESH CONCRETE (SI)

Nominal Maximum size of aggregate, mm	*First Estimate of Concrete Unit mass, kg/m³* Non- Air Entrained Concrete	Air Entrained Concrete
9.5	2280	2200
12.5	2310	2230
19	2345	2275
25	2380	2290
37.5	2410	2350
50	2445	2345
75	2490	2405
150	2530	2435

Table 4.8
VOLUME OF COARSE AGGREGATE PER UNIT OF VOLUME OF CONCRETE

	Volume of 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

Table 4.9
ESTIMATED AVERAGE STRENGTHS FOR CONCRETE (MPa)

	Water/Cement Ratio (by Mass)	
Compressive Strength, 28 Days (MPa)	**Non-Air Entrained Concrete**	**Air-Entrained Concrete**
40	0.42	-
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70