Cement

What is cement?

- **Cement is any material that binds or unites**
- In construction, the word cement or cementitious material always refer to an ingredient in concrete, mortar or grout

Definition by ASTM (American Society for Testing and Material)

- ASTM C 150 defines portland cement as …

- Cements set and harden by reacting chemically with water.
- During this reaction, called hydration, cement combines with water to form a stonelike mass, called PASTE.
- When the paste (cement and water) is added to aggregates (sand and gravel, crushed stone, or other granular material) it acts as an adhesive and binds the aggregates together to form concrete, the world's most versatile and most widely used construction material.

- Cement + Water = Paste
- Sand + Gravel + Crushed Stone / Granular material = Aggregates

Paste + Aggregates = Concrete

History

Cement in the past

- People all over Asia and North Africa used cement as a mortar to stick bricks together, or to make a hard floor, from the Stone Age onward, for instance in the Great Wall of China (about 200 BC).
- But concrete was not used as a building material until the Roman Empire.
- Lime is mixed with powdered clay and water, make into shape and let dry.
- For a stronger building material, sand or gravel is added, and that makes concrete

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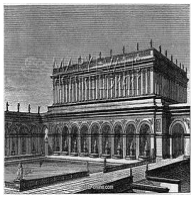
- Architects in the Roman Empire used cement and concrete as a main building material beginning in the reign of Nero, about 60 AD, to build palaces like Nero's Golden House



- Outside the Roman Empire, though, people did not use cement as a main building material. They continued to use cement as a mortar to stick stones or bricks together.

Modern cement: Portland cement

- In 1824, Joseph Aspdin, a British stone mason, obtained a patent for a cement he produced in his kitchen.
- The inventor heated a mixture of finely ground limestone and clay in his kitchen stove and ground the mixture into a powder create a hydraulic cement-one that hardens with the addition of water.
- With this invention, Aspdin laid the foundation for today's modern portland cement industry.

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- Aspdin named the product Portland cement because it resembled a stone quarried on the **Isle of Portland** off the British Coast.

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What is it made of?

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Primary constituents of the raw materials are:

Lime (CaO)

Silica (SiO_2)

Alumina (Al_3O_3)

- Portland cement consists essentially of compounds of lime (calcium oxide, CaO) mixed with silica (silicon dioxide, SiO_2) and alumina (aluminum oxide, Al_2O_3).
- The lime is obtained from a calcareous (lime-containing) raw material, and the other oxides are derived from an argillaceous (clayey) material.

- lime (calcium oxide, CaO)
  - obtained from a calcareous (lime-containing) raw material
  - limestone or chalk
  - 65%
- silica (silicon dioxide, SiO_2)
  - derived from an argillaceous (clayey) material
  - clay, shale, slate, estuarine mud
  - 21%
- alumina (aluminum oxide, Al_2O_3)
  - derived from an argillaceous (clayey) material
  - clay, shale, slate, estuarine* mud
  - 4.5%

*a water passage where the tide meets a river current

Other raw materials are

Silica sand,

iron oxide,

bauxite,

gypsum

- Additional raw materials such as silica sand, iron oxide (Fe_2O_3), and bauxite (containing hydrated aluminum, $Al[OH]_3$) may be used in smaller quantities to get the desired composition (less than 2.5%)
- Another essential raw material is gypsum, some 5%of which is added to the burned cement clinker during grinding to control the setting time of the cement.

Cement chemistry

- The four major compounds of portland cements are

1. Tricalcium silicate
   - ($3CaO.SiO_2$)
2. Dicalcium silicate
   - ($2CaO.SiO_2$)
3. Tricalciumaluminate
   - ($3CaO.Al_2O_3$)
4. Tetracalciumaluminoferrite
   - ($4CaO.Al_2O_3.Fe_2O_3$)

Principles compounds of cement

Compound	Chemical Formula	Industry Code (Abbreviation)	Rate of reaction with water
Tricalcium silicate	$3CaO.SiO_2$	C_3S	Medium
Dicalcium silicate	$2CaO.SiO_2$	C_2S	Slow
Tricalciumaluminate	$3CaO.Al_2O_3$	C_3A	Fast
Tetracalciumaluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	Medium

* The cement industry commonly uses shorthand notation for chemical formulas: C = Calcium oxide, S = silicon dioxide, A = aluminum oxide, and F = iron oxide

Types of Portland Cement

Ordinary Portland Cement (OPC)

- mostly used for common structures and civil engineering works.
- good for mixing concrete for slab and concrete structure
- low durability to sulfate acid attacks especially under ground and under water structure
- strength is attains within 28 days
- BS12:1978/MS 7.15

White Portland Cement

- the colour being the principle difference between it and ordinary portland cement.
- raw materials to manufacture white cement are iron and manganese oxide
- manufacturing process is controlled to produce white colour.
- use for architectural concrete products, cement paints, tile grouts and decorative concrete

Rapid Hardening Portland Cement

- same composition with OPC
- difference: ground to a very fine impalpable powder and attains strength much earlier than the common cement.
- strength is attains within 4 days
- formwork can be remove early and structure can be load much earlier to proceed the next construction works.
- used for important structures and underwater works

Quick Setting Portland Cement

- sets initially within 2-5 minutes time and the final set takes place within 30 minutes.
- as it sets too quickly, there is a need to work efficiently
- this cement is mainly used in **works under water or in running water**

Water Repellent Portland Cement

- manufactured by the addition of a small amount of calcium, aluminium to the clinker during final grinding.
- it is in either white or grey colour, and is used to reduce water penetration through the concrete.

Sulphate Resisting Portland Cement

- Primarily used where the soil or groundwater contains high sulfate concentrations and the structure would be exposed to severe sulfate attack

High Alumina Cement

- is another rapid hardening cement of chocolate colour.
- this cement contains over 32% of alumina than the OPC.
- this cement is very costly.
- it is capable of resisting the action of acids and high temperature.
- sets 2 hours after mixed and hardening 2 hours later.
- it reaches 45% of final strength within 4 hours after being mixed with water.
- suitable used at the ocean flood areas and high chemical such as manhole and chemical plants.

Pozzolanic cement

- Cement **made from volcanic ash or fly ash**
  - Pozzolan (Fly Ash)
  - Silica (glass) spheres
  - Small particles
  - Varied size particles
- This cement is prepared by mixing grinding clinkers and pozzuolana together.
- The combination produces a very dense matrix that has a slight porosity, thereby dramatically reducing the material's susceptibility to gas and liquid intrusion.
- It is specially useful in marine and underwater constructions. Such as, large hydraulic structures as bridges piers and dams

ASTM cement types

Type	Use
I	General purpose cement, when there are no extenuating conditions
II	Aids in providing moderate resistance to sulfate attack
III	When high-early strength is required
IV	When a low heat of hydration is desired (in massive structures)
V	When high sulfate resistance is required
IA*	A type I cement containing an integral air-entraining agent
IIA*	A type II cement containing an integral air-entraining agent
IIIA*	A type III cement containing an integral air-entraining agent

*Air-entrainment

- Air entrainment is the intentional creation of tiny air bubbles in concrete.
- The bubbles are introduced into the concrete by the addition to the mix of an air entraining agent, a surfactant (surface-active substance, a type of chemical that includes detergents).
- The air bubbles are created during mixing of the plastic (flowable, not hardened) concrete, and most of them survive to be part of the hardened concrete.
- The primary purpose of air entrainment is to increase the **durability of the hardened concrete, especially in climates subject to freeze-thaw; the secondary purpose is to increase workability of the concrete while in a plastic state**.

Manufacturing process

When cement raw materials containing the proper proportions of the essential oxides are ground to a suitable fineness and then burnt to incipient fusion in a kiln, chemical combination takes place, largely in the solid state resulting in a product named clinker.

This clinker, when ground to a suitable fineness, together with a small quantity of gypsum (SO_3) is called Portland Cement.

Clinker

- Cement plant tour
  http://www.cement.org/basics/images/flashtour.html

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The process

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Ball/Cement mill

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Clinker inside kiln

Two manufacturing process

Dry and wet

- Wet process
  - In the wet process, the raw materials, properly proportioned, are then ground with water, thoroughly mixed and fed into the kiln in the form of a "slurry" (containing enough water to make it fluid).
- Dry process
  - In the dry process, raw materials are ground, mixed, and fed to the kiln in a dry state.

In other respects, the two processes are essentially alike.

Physical properties of portland cement

- The constructive value of a cement is based upon the properties of the cement.
- The best guarantee of a cement comes from a reliable and well-known cement manufacturer, who exercises control on the quality of the cement by conducting regular analysis.
- A little deviation in the manufacture of cement may make a great difference in its quality.
- The colour of cement should be grey or greenish – due to oxides of iron and manganese.
- The colour also varies with the degree of calcination (burning).
- The brown colour indicates an excess of clay, which make cement shrink and disintegrate in setting.

Fineness of Portland Cement

- Fineness of cement relates to the size of the cement grains
- It has considerable influence on the behaviour of cement during hydration
- The finer a cement is ground, the higher heat of hydration and resulting accelerated strength gain
- The strength gain due to fineness is evident during the first 7 days.
- Since the water is in contact with more surface area in a fine-ground cement, the hydration process occurs more rapidly.

Fineness of Portland Cement

- The finer the cement particles, the larger the surface area (of the cement) and the faster the hydration.
- Finer material results in faster strength development and a greater initial heat of hydration.
- The maximum size of the cement particles is 0.09 mm; 85% to 95% of the particles are smaller than 0.045 mm; and the average diameter is 0.01 mm.

Fineness of Portland Cement

- E.g. About 80% or more of the particles in Type I cement pass through No.200 sieve (75nanometer)
- A kilogram of portland cement has approximately 7 trilion particles with a total surface area of about 300 m2 to 400 m2.
- The rate of hydration increases with increasing fineness

Hydration

- Dry portland cement does not possess the cementing or binding property for it is a hydraulic material
- The chemical reaction between compounds of cement and water yields products that achieve the binding property after hardening
- This process, **the reaction between cement and water,** is called hydration
- **Hydration** is made up of 2 stages:
  - Setting
  - Hardening

Hydration

Setting

- When cement is mixed with sufficient water the resulting paste loses its plasticity and then slowly forms into a hard rock
- Within 1-2 hours after mixing the cement and water, the sticky paste loses its fluidity
- Within a few hours after mixing, noticeable stiffening commences
- This is called **setting** and is divided into 2 stages:
  - Initial set
  - Final set

Hydration

Setting

- Initial set is when the paste is beginning to stiffen
- Final set is when it is beginning to harden and able to sustain loads
- The rate of setting is also a measure of the rate of release of heat of hydration
- The compound **gypsum**, which is added to clinker when it is ground in the cement mill, retards setting and prevents **flash set**
- Flash set is defined as rapid development of permanent rigidity of the cement paste
- When a concrete mixture reaches a state in which its form cannot be changes without producing rupture, it is said to have set

Hydration

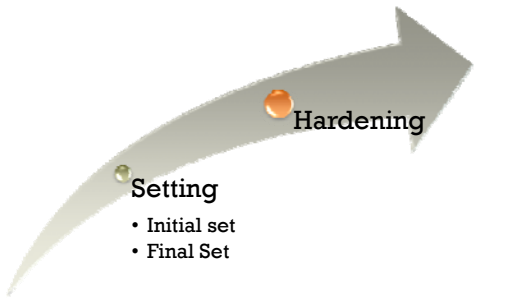
Hardening

- Setting occurs within a few hours but hardening is not completed for months or years
- Hardening is the development of strength over an extended period of time
- It is a net outcome of the hydration
- Portland cement is a mixture of several compounds all of which can hydrate or react with water
- Hydration is the key for strength development in concrete
- However, not all compounds hydrate at the same rate

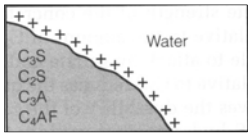
Hydration

Hardening

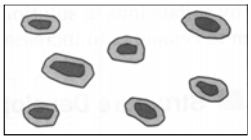
- The rate of hydration cement depends on
  - The relative proportions of silicates and aluminates
  - The fineness
  - The ambient condition i.e. humidity and temperature



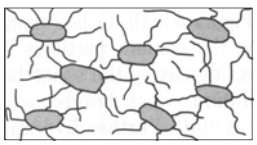
Structure Development in Cement Paste



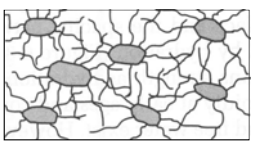
- The process begins immediately after water is added to the cement. The C-S-H phase is initially formed. C_3A forms a gel fastest.



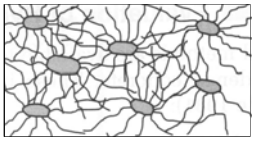
- The volume of cement grain decreases as a gel forms at the surface. Cement grains are still able to move independently, but as hydration grows, weak interlocking begins. Part of the cement is in a thixotropic state; vibration can break the weak bonds (break when you shake)



- The initial set occurs with the development of a weak skeleton in which cement grains are held in place



- Spaces between the cement grains are filled with hydration products as cement paste develops strength and durability



- Final set occurs as the skeleton becomes rigid, cement particles are locked in place, and spacing between cement grains increases due to the volume reduction of grains

Effects of cement on concrete properties

Cement Property	Cement Effects
Placeability	Cement amount, fineness, setting characteristics
Strength	Cement composition (C_3S, C_2S and C_3A), loss on ignition, fineness
Drying Shrinkage	SO_3 content, cement composition
Permeability	Cement composition, fineness
Resistance to sulfate	C_3A content
Alkali Silica Reactivity	Alkali content
Corrosion of embedded steel	Cement Composition (esp. C_3A content)

Test for cement

Lab test

- The quality of portland cement is judged by carrying out the following tests:
  - Colour test – the colour should be grey, greenish grey or dark brown.
  - Weight – varies with the degree of burning. Well-clinkers produce better cement than the lighter under-burnt clinkers. The light weight test is of little use in finding out the value of cement as regards its quality. The weight may vary from 1200 to 1800kg/m3.

- Specific gravity* – the specific gravity of good portland cement should be 3.15 and 3.20.
  - Le Chatelier's specific gravity test
  - Blount's specific gravity bottle
- Test for fineness – determining the proportion of cement which will not pass through a sieve of specified number or meshes per sq inch or sq mm. this is known as sieve analysis.
- Surface area test – ordinary portland cement has a specific surface round about of 2250 sq cms per gm, while high strength cement has 3250 sq cms per gm.

*Specific gravity test

- Le Chatelier's specific gravity test

- Blount's specific gravity bottle

- Soundness test – there are various methods for testing soundness of cement, Pat test, Accelerated test, Expansion test etc.
- Test for compressive strength – cubes of cement and sand (1:3) of 7 cm size are cured for seven days under water and tested in compression testing machine. The average compressive strength of three cubes should not less than 175kg/cm2 for ordinary portland cement. If cured for three days, the strength should be minimum 210kg/cm2. For rapid hardening cement, it should be 210kg/cm2, if cure for three days and 115kg/cm2 if one day only.

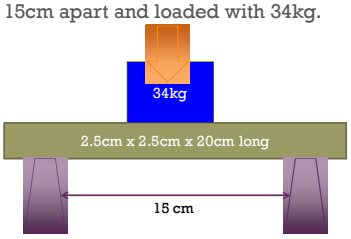
- Test for chemical composition
- Test for setting – setting power of cement. Time required for setting of cement is tested by Vicat's Needle Apparatus.

Test for cement

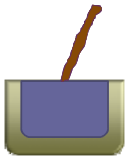
Field examination

- There are a few rough and ready methods of testing cement in field:
  - If one's hand is plunged into a bag of cement he/she should feel cool.
  - When a handful of cement is thrown into a bucket of water it would not float but sink.
  - A thin of portland cement with water should be felt sticky between the fingers
  - Reddish or blackish colour of cement will indicate adulteration of foreign materials.
  - If the cement is found in the form of impalpable powder (felt between fingers by rubbing) the cement may be trusted. The quality of cement is suspected, if it is felt gritty.
  - The cement paste will give an earthy smell, if it contain too much of pounded clay and silt as an adulterant.

- A bar 2.5cm x 2.5cm, 20m long made of cement and after seven days immersion in water should not show any sign of failure, if it is placed on supports 15cm apart and loaded with 34kg.



- Initial setting time may be observed in the field by preparing a thin cement paste in a ware and inserting a very thin stick or wire into it after 30 mins. If the paste resists penetration of the stick or the wire, the quality of cement may be ensured.



Storage of cement

Storage of cement

- Portland cement is a moisture-sensitive material; if kept dry, it will retain its quality indefinitely.
- When stored in contact with damp air or moisture, portland cement will set more slowly and has less strength than portland cement that is kept dry.
- When storing bagged cement, a shaded area or warehouse is preferred. Cracks and openings in storehouses should be closed.
- When storing bagged cement outdoors, it should be stacked on pallets and covered with a waterproof covering

Storage of cement

Open Space	Store or Warehouse
■ For small works only	■ Floor must be dry and higher
■ Platform is built by putting the plywood on the bricks or wood at least 100mm above ground level	■ The store does not need any windows
■ Plastic is put under the platform to avoid moisture	■ Cement bag must be at least 100mm away from the wall
■ Cements should be well covered with plastic	■ Cement bags can be stacked not more than 8-10 bags
	■ The quality of the cements stored will last 4-6 weeks only

Storage of cement

Storage of cement

- Storage of bulk cement should be in a watertight bin or silo.
- Transportation should be in vehicles with watertight, properly sealed lids.
- Cement stored for long periods of time should be tested for strength and loss on ignition.

Silo

Silo

Thank you

Portland Cement

Pozzolanic Cement