#### **CVE 308**

# Materials for Civil Engineering Construction

## (3 Units)

## Course Synopsis:

*Concrete Technology* – Types of cements, aggregates – properties, Concrete mix, Design, Properties and their determination. *Steel Technology* – Production, fabrication and properties: corrosion and its prevention. Tests on steel and quality control. *Timber Technology* – Types of wood, properties and defects. Stress grading, Preservation and fire protection. Timber products.

Rubber, plastics; Asphalt, tar, glass, lime, bricks, etc. Application to buildings, Roads and Bridges.

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#### **1.0 CEMENTS AND THEIR USES**

#### What is cement?

Cement, in general, adhesive substances of all kinds, but, in a narrower sense, the binding materials used in building and civil engineering construction. Cements of this kind are finely ground powders that, when mixed with water, set to a hard mass. Setting and hardening result from hydration, which is a chemical combination of the cement compounds with water that yields submicroscopic crystals or a gel-like material with a high surface area. Because of their hydrating properties, constructional cements, which will even set and harden under water, are often called hydraulic cements. The most important of these is portland cement.

#### History of cement

The origin of hydraulic cements goes back to ancient Greece and Rome. The materials used were lime and a volcanic ash that slowly reacted with it in the presence of water to form a hard mass. This formed the cementing material of the Roman mortars and concretes of more than 2,000 years ago and of subsequent construction work in western Europe.

#### **Composition of raw materials**

Portland cement consists essentially of compounds of lime (calcium oxide, CaO) mixed with silica (silicon dioxide, SiO2) and alumina (aluminum oxide, Al2O3). The lime is obtained from a calcareous (lime-containing) raw material, and the other oxides are derived from an argillaceous (clayey) material. Additional raw materials such as silica sand, iron oxide (Fe2O3), and bauxite—containing hydrated aluminum, Al(OH)3—may be used in smaller quantities to get the desired composition.

The commonest calcareous raw materials are limestone and chalk, but others, such as coral or shell deposits, also are used. Clays, shales, slates, and estuarine muds are the common argillaceous raw materials. Marl, a compact calcareous clay, and cement rock contain both the calcareous and argillaceous components in proportions that sometimes approximate cement compositions. Another raw material is blast-furnace slag, which consists mainly of lime, silica, and alumina and is mixed with a calcareous material of high lime content. Kaolin, a white clay that contains little iron oxide, is used as the argillaceous component for white portland cement. Industrial wastes, such as fly ash and calcium carbonate from chemical manufacture, are other possible raw materials, but their use is small compared with that of the natural materials.

The magnesia (magnesium oxide, MgO) content of raw materials must be low because the permissible limit in portland cement is 4 to 5 percent. Other impurities in raw materials that must be strictly limited are fluorine compounds, phosphates, metal oxides and sulfides, and excessive akalies.

Another raw material is gypsum, some 5 percent of which is added to the burned cement clinker during grinding to control the setting time of the cement. Portland cement also can be made in a combined process with sulfuric acid using calcium sulfate or anhydrite in place of calcium carbonate. The sulfur dioxide produced in the flue gases on burning is converted to sulfuric acid by normal processes.

#### **Types of Cement**

#### 1. Hydraulic Cement

As the name indicates, hydraulic cement is those which harden by hydration in the presence of water. Limestone, clay, and gypsum are the main raw material to produce non-hydraulic cement. This raw material is burned at a very high temperature to manufacture Hydraulic Cement.

Hydraulic cement (cement that not only hardens by reacting with water but also forms a water-resistant product) produced by pulverizing clinkers which consist essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulphate as an inter ground addition.

#### 2. Non-Hydraulic Cement

The non-hydraulic cement doesn't require water to get harden. It gets with the help of carbon dioxide (CO2) from the air. This type of cement needs dry conditions to harden. Lime, gypsum plasters, and oxychloride are the required raw material to produce non-hydraulic cement. Example: slaked lime is a non-hydraulic cement.

#### 3. Ordinary Portland Cement (OPC)

In usual construction work, Ordinary Portland Cement is widely used. Portland cement clinker is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates, (3 CaO·SiO2, and 2 CaO·SiO2), the remainder consisting of aluminium- and iron-containing clinker phases and other compounds. The ratio of CaO to SiO2 shall not be less than 2.0. The magnesium oxide content (MgO) shall not exceed 5.0% by mass. European Standard EN 197-1

#### The composition of Ordinary Portland Cement:

- Argillaceous or silicates of alumina (clay and shale)
- Calcareous or calcium carbonate (limestone, chalk, and marl)

#### Uses of Ordinary Portland Cement

- It is used for general construction purposes.
- It is also used in most of the masonry works.

# 4. Portland Pozzolana Cement (PPC)

Pozzolans are natural or synthetic materials that contain silica in reactive forms. It reacts with calcium hydroxide generated by hydrating cement to form additional cementations materials when it is finely divided.

# The composition of Portland Pozzolana Cement:

- OPC clinker
- Gypsum
- Pozzolanic Materials (Fly ash, volcanic ash, and Calcined clay or silica fumes.)

## Uses of Portland Pozzolana Cement

- PPC is usually used in hydraulic structures, marine structures, construction near the seashore, dam construction, etc.
- It is also used in pre-stressed and post-tensioned concrete members.
- As it gives a better surface finish, it is used in decorative and art structures.
- It is also used in the manufacture of precast sewage pipes.

# 5. Rapid Hardening Cement

When finely grounded Tri-calcium silicate (C3S) is present in OPC with higher content, it gains strength more quickly than OPC. This type of OPC is called Rapid Hardening Cement. It's initial Setting Time 30 minutes and Final Setting Time 600 minutes.

## Uses of Rapid Hardening Cement

- Rapid hardening cement is mostly used where rapid construction is needed like the construction of pavement.
- It also gives high strength.

# 6. Quick Setting Cement

Quick setting cement is the cement which sets in a very short time. The initial setting time is 5 minutes and the final setting time is 30 minutes.

# The composition of Quick Setting Cement:

- Clinker
- Aluminum sulfate (1% to 3% by weight of clinker)
- The aluminum sulfate increases the hydration rate of silicate.

## Uses of Quick Setting Cement

- It is used in underwater construction.
- It is also used in rainy & cold weather conditions.
- It is used a higher temperature where water evaporates easily.

• Used for anchoring or rock bolt mining and tunneling

# 7. Low Heat Cement

It is a spatial type of cement which produces low heat of hydration during the setting. Some chemical composition of Ordinary Portland Cement is modified to reduce the heat of hydration.

## The chemical composition of low heat cement:

- A low percentage (5%) of tricalcium aluminate (C<sub>3</sub>A)
- A higher percentage (46%) of declaiming silicate (C<sub>2</sub>S).

## Uses of Low Heat Cement

- It is used for the construction of dam's large footing, large raft slabs, and wind turbine plinths.
- It is also used for the construction of chemical plants.

# 8. Sulphate Resisting Cement

Sulphate resisting cement is used to resist sulphate attacks in concrete. Due to the lower percentage of Tricalcium aluminate, the production of calcium sulpho-aluminates gets reduced.

## Uses of Sulphates resisting Cement

- Construction in contact with soils or groundwater having more than 0.2% or 0.3 % g/l sulfate salts respectively.
- Concrete surfaces subjected to alternate wetting and drying such as bridge piers, concrete surface in the tidal zone, apron, Building near the seacoast.
- Effluent treatment plans, Chimney, Chemical industries, water storage, sumps, drainage works, Cooling towers, Coastal protective works such as sea walls, breakwaters, tetrapods, etc.

# 9. Blast Furnace Cement

Portland cement clinker and granulated blast furnace slag are intergraded to make blast furnace cement. A maximum of 65 percent of the mixture could be comprised of blast furnace slag.

## Uses of Blast Furnace Cement

- It is highly sulfate resistant
- Frequently used in seawater construction.

## **10. High Alumina Cement**

High Alumina cement is obtained by mixing calcining bauxite (aluminium ore) and ordinary lime with clinker during the manufacture of OPC. In which the total amount of alumina content should not be lesser than 32% and it should maintain the ratio by weight of alumina to the lime between 0.85 to 1.30.

#### Uses of High Alumina Cement

- It is used where concrete structures are subjected to high temperatures like workshops, refractory, foundries, etc.
- It also used where the concrete is subjected to frost and acidic action.

#### 11. White Cement

White cement is quite similar to Ordinary Portland Cement except for colour. Amounts of iron oxide and manganese oxide are low in White Cement. It is expensive than OPC so not economical for ordinary work.

#### Uses of White Cement

- It is usually used in decorative work.
- It can also use for traffic barriers, tile grouts, swimming pools, roof tiles patching materials, and terrazzo surfaces.

## **12. Coloured Cement**

To make 5 to 10 percent of suitable pigments are ground with OPC. Types of pigments are selected according to the desired colour.

#### Uses of Coloured Cement

• Colored cement is used for different decorative work.

#### 13. Air Entraining Cement

It is seen that entrainment of air or formation of gas bubbles while applying cement increases resistance to frost action, fire, scaling, and other similar defects. Air-entraining cement is a special type of cement which entrains tinny air bubbles in concrete.

It is produced by grinding minute air entertaining materials with clinker by adding some resinous materials e.g. vinsol resin to ordinary portland cement.

When the water in concrete gets frizzed due to low temperature, it expands. When air-entraining cement, the air voids in concrete provides space for water to expand without cracking concrete. But this type of cement does not provide high strength in concrete.

#### Uses of Air-Entraining Cement

- Especially it is used in areas where the temperature is very low.
- It also resists the Sulphate attack.
- It is used where the de-icing chemical is used.

#### 14. Expansive Cement

In the hydration process, the expansive cement expands its volume. It can be possible to overcome shrinkage loss by using expansive cement.

#### There are three types of expansive cement:

- 1. K Type expansive cement
- 2. M Type expansive cement
- 3. S Type expansive cement

#### K Type expansive cement

Raw materials of these types of cement

- Portland cement
- Anhydrous tetracalcium trialuminate sulfate (C<sub>4</sub>A<sub>3</sub>S)
- Calcium sulfate (CaSO<sub>4</sub>)
- Lime (CaO).

## M Type Expansive Cement

Raw materials of these types of cement

- 1. Portland cement clinkers
- 2. Calcium sulfate.

## S Type Expansive Cement

Raw materials of these types of cement

- 1. Portland cement clinkers
- 2. Calcium sulfate (High amount)
- 3. Tricalcium aluminate (C<sub>3</sub>A) (High amount)

#### Uses of Expansive cement

- It is used in the construction of the pre-stressed concrete component.
- It is also used for sealing joints and grouting anchor bolt.
- In the construction of different hydraulic structures, this type of cement is used.

## **15. Hydrophobic Cement**

To resist the hydration process in the transportation or storage stage, clinkers are ground with water repellent film substance such as Oleic Acid or Stearic Acid. These chemicals form a layer on the cement particle and do not allow water to mix and start the hydration process. When cement and aggregate are

thoroughly mixed in the mixer, protective layers break and start normal hydration with some air- entrainment which increases workability.

## Uses of Hydrophobic Cement

- Usually, it is used in the construction of water structures such as dams, spillways, or other submerged structures.
- It is also used in the construction of underground structures like tunnel etc.

## 2.0 AGGREGATES

There are two main uses of aggregates in civil engineering:

- as an underlying material for foundations and pavements and
- as ingredients in portland cement and asphalt concretes.

By dictionary definition, aggregates are a combination of distinct parts gathered into a mass or a whole. Generally, in Civil Engineering the term aggregate means a mass of crushed stone, gravel, sand, etc., predominantly composed of individual particles, but in some cases including clays and silts. The largest particle size in aggregates may have a diameter as large as 150 mm (6 in.) and the smallest particle can be as fine as 5 to 10 microns.

Aggregates occupy at least three quarters of volume of concrete. Therefore, its quality is especially important. Aggregate is cheaper than the cement, and it is economical to put into the mix as much as possible. Economy is not only reason for using aggregates: but it has a higher volume stability and better durability than the cement pastes alone.

## **General Classification of Aggregates**

- According to Production Methods:
- According to Petrological Characteristics:
- According to Particle Size
- According to Their Unit Weights:

## According to Production Methods:

- 1. **Natural Aggregates**: These are taken from native deposits without any change in their natural states during production except for crushing, grading or washing. Example: sand, gravel, crushed stone, lime rock.
- 2. **By-Product Aggregates**: Comprise blast-furnace slags and cinders, fly ash, etc. Cinders are residue of coal or wood after burning.
- 3. **Processed Aggregates**: These are heat treated, expanded materials with lightweight characteristics. Example: Perlite, burnt clays, shales, processed fly ash.
- 4. Coloured Aggregates: Glass, ceramics, manufactured marble for decorative and architectural purposes.

#### According to Petrological Characteristics:

- 1. **Igneous Rocks**: Solidification of molten material, magma forms igneous rocks. If cooling is slow crystalline structure, if cooling is rapid amorphous structure forms. Example: Quartz, granite, basalt, obsidian, pumice, tuff.
- 2. Sedimentary Rocks: Obtained by the deposition of weathered and transported pre-existing rocks. Example: Sandstone, limestone, shale. If these are hard and dense, OK. If not, high absorption capacity gives unsatisfactory results.
- 3. **Metamorphic Rocks**: Formed at a depth under high heat and pressure by the alterations of either igneous rocks or sedimentary rocks. Example: Marble, slate, schist. If hard and dense, OK. If laminated, undesirable.

## According to Particle Size

In producing good quality concrete, the aggregates should be grouped at least in two groups. Therefore, according to the size of aggregate particles, it (generally) can be classified as:

- 1. **Fine Aggregate (sand)**: Fine aggregate includes the particles that all passes through 4.75 mm sieve and retain on 0.075 mm sieve.
- Coarse Aggregate (gravel): Coarse aggregate includes the particles that retain on 4.75 mm sieve. Aggregate particles with sizes 0.002-0.075 mm are called as silt and particles smaller than that known as clay.

#### According to Their Unit Weights:

- 1. **Normal Weight Aggregates**: Sand, gravel, crushed stone is called as normal weight aggregates. Concrete produced by these aggregates weighs from 2160 to 2560 kg/m3.
- 2. Light Weight Aggregates: Lightweight aggregates are slag, slate and other light stones that the concrete produced by them weighs from 240 to 1440 kg/m3. This concrete is normally used for insulation purposes.
- 3. **Heavy Weight Aggregates**: Hemotile, barite magnetite, steel and iron punchings are used to make heavy weight concrete that weighs from 2800 to 6400 kg/m3.

#### **Particles Shape and Texture:**

The shape and texture of the surface of aggregate particles influence the properties of fresh concrete, more than those of hardened concrete. Sharp, angular and rough aggregate particles require more paste to make good concrete, than do rounded ones (Table 1).

Classification	Description	Examples
Rounded	Fully water-worn or completed shaped by attrition	River or seashore gravel; desert, seashore and wind- blown sand
Irregular	Naturally irregular, or partly shaped by attrition and heaving rounded edges	Other gravel; land or dug flint
Flaky	Material of which the thickness is small relative to the other two dimensions	Laminated rocks
Angular	Possessing well defined edges formed at the intersection of roughly planar faces	Crushed rocks of all types
Elongated	Material, usually angular in which the length is considerably larger than the other two dimensions	
Flaky and Elongated	Material having the length considerably larger than the width and the width considerably larger than the thickness	

 Table 1. Shape Classification of Particles (BS 812 Part 1)

The classification of the surface texture (Table 2) is based on the degree to which the particle surfaces are polished or dull, smooth or rough. Surface texture depends on the hardness, grain size and pore characteristics of the parent material. (Hard, dense and fine-grained rocks generally having smooth fracture surfaces).

 Table2. Surface Texture of Aggregates (BS 812 Part 1)

Surface	Texture Characteristics	Example
Glassy	Irregular break with curved face	Black flint (chalk), vitreous slag
Smooth	Water-worn, or smooth due to fracture of laminated or fine-grained rock	Gravels, marble, slate
Granular	Fracture showing more or less uniform rounded grains	Sandstone
Rough	Rough fracture of fine or medium grained rock containing no easily visible crystalline constituents	Limestone
Crystalline	Crystalline constituents. Containing easily visible crystalline	Granite
Honeycombed	Constituents with visible pores and cavities	Brick, slag

## **Physical Properties of Aggregates**

#### **Specific Gravity**

The specific gravity of an aggregate is a characteristic of the material, which needs to be determined in making calculations of mix design of concrete. There are several types of specific gravities:

#### **Bulk Density**

It is well known that in the metric system the density of a material is numerically equal to its specific gravity. Because specific gravity has to be multiplied by the unit weight of water in order to convert it into absolute density (specific weight).

Absolute density (or specific weight) refers to the volume of the individual particles only and of course it is not physically possible to pack these particles so that there are no voids between them. When aggregate is to be actually batched by volume it is necessary to know the weight of aggregate that would fill a container of unit volume. This is known as the bulk density of aggregate and this density is used to convert quantities by weight to quantities by volume.

The bulk density depends on how dense the aggregate is packed. For a coarse aggregate of given specific gravity, a higher bulk density means there are fewer voids to be filled by sand, and cement and the bulk density test has at one time been used as a basis of proportioning of mixes.

Bulk density is determined in two ways as, compacted or uncompacted. Therefore, the test to which basis is applied should be given.

Empty space between the aggregate particles is termed VOIDS. It is the difference between the gross volume of aggregate mass and volume occupied by the particles alone.

Voids ratio indicates the volume of mortar required to fill the space between the coarse aggregate particles.

#### **Porosity and Absorption of Aggregates**

The porosity of aggregate, its permeability, and absorption influence the bonding between aggregate and cement paste, the resistance of concrete to freezing and thawing and resistance to abrasion.

When all the pores in the aggregate are full it is said to be saturated. If just the surface of aggregate is dry then it is said saturated-surface-dry. If the aggregate in saturated surface dry condition allowed to stand free in dry air, some water from pores will evaporate and it is said to be air dry condition. (See Figure 1)

The water absorption of aggregate is determined by measuring the increase in weight of an oven-dried sample when immersed in water, for 24 hours (The surface water being removed). The ratio of the increase in weight to the weight of dry sample, expressed as a percentage is termed absorption.

Although there is no clear-cut relation between the strength of concrete and the water absorption of aggregate used, the pores at the surface of the particle affect the bond between the aggregate and the cement paste, and thus may exert some influence on the strength of concrete.

Normally, it is assumed that at the time of setting of concrete the aggregate is in a saturated-surface-dry condition. If the aggregate is batched in a dry condition it is assumed that sufficient water will be absorbed from the mix to bring the aggregate to a saturated-surface-dry condition, and this absorbed water is not included in the net mixing water. It is possible, however, that, when dry aggregate is used the particles become quickly coated with cement paste which prevents further ingress of water necessary for saturation.

#### **Moisture Content of Aggregate**

Any water on the surface of the aggregate will contribute to the water in the mix. The surface moisture is expressed as a percentage of the weight of the saturated and surface dry aggregate, and is termed as moisture content on saturated surface dry basis.

Since absorption represents the water in aggregate in a saturated and surface dry condition, and the moisture content is the water in excess of that saturated surface dry state, the total water content of a moist aggregate is equal to the sum of absorption and moisture content.



Different moisture conditions of aggregates.

#### Mechanical Properties of Aggregates Bond of Aggregate

Bond between aggregate and cement paste is an important factor in the strength of concrete, especially the flexural strength (bending strength) is very related. Bond is due, in part, to the interlocking of the aggregate and the paste owing to the roughness of the surface of the former. A rough surface, such as

that of crushed particles, results in a better bond; better bond is also usually obtained with softer, porous and mineralogically heterogeneous particles.

The determination of the quality of bond of aggregate is rather difficult and no accepted test exists. Generally, when bond is good, a crushed concrete specimen should contain some aggregate particles broken right through, in addition to the more numerous ones pulled out from their sockets. An excess of fractured particles, however, might suggest that the aggregate is too weak. Because it depends on the paste strength as well as on the properties of aggregate surface, bond strength increases with the age of concrete.

#### **Strength of Aggregate**

It is obvious that the compressive strength of concrete cannot significantly exceed the compressive strength of aggregate contained, although it is not easy to state what is the strength of the individual particles. Indeed, the crushing strength of aggregate cannot be tested with any direct test. There are some indirect tests to inform us about the crushing strength of aggregate.

One of the indirect tests to have information about the crushing strength of aggregate is "crushing value test". There is no explicit relation between this crushing value and the compressive strength, but the results of the two tests are in agreement.

#### **Other Mechanical Properties of Aggregates:**

- a) Impact value: Impact value of aggregates measures the toughness of particles by impact.
- b) Abrasion: Abrasion of aggregates measures the resistance of aggregates against wearing.

It is an important property of concrete in roads and in floor surfaces subjected to heavy traffic. The most frequently used test method is the Los Angeles Abrasion Test.

Los Angeles Abrasion Test: The aggregate of specified grading is placed in a cylindrical drum, mounted horizontally. A charge of steel balls is added and the drum is rotated a specified number of revolutions. The tumbling and dropping of the aggregate and the balls result in abrasion and attrition of the aggregate. The resulting grading should be compared with the standard limitations.