Construction Materials
&
Management

For

Civil Engineering

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Syllabus for Construction Materials & Management

Construction Materials, Structural Steel - Composition, Material Properties and Behaviour, Concrete - Constituents, Mix Design, Short-Term and Long-Term Properties, Bricks and Mortar, Timber, Bitumen. Construction Management, Types of Construction Projects, Tendering and Construction Contracts, Rate Analysis and Standard Specifications, Cost Estimation, Project Planning and Network Analysis - PERT and CPM.

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"Success is achieved by those who try and keep trying with a positive mental attitude."
... W. Clement Stone

CHAPTER 1

Construction Materials

Learning Objectives

After reading this chapter, you will know:

1. Structural Steel
2. Cement
3. Concrete
4. Bricks Masonry
5. Timber
6. Bituminous Materials
7. Mortar
8. Joints

Structural Steel

Steel is probably the most versatile commonly used structural material. Not only is its versatility apparent in great variety of structures for which it is used but also in many different of structural steel of interest to the designer can be described by the behavior of steel during a simple tension test. The essential elements in steel are metallic iron element non-metallic carbon, with small quantities of other elements such as silicon nickel, manganese chromium and copper. It is thus an alloys. Though steel is usually more than 98% iron, with other element present in same quantities, these other element have pronounced effect on the properties of steel.

Various iron – carbon alloys used as structural material are of three types

(I) Cast iron
(II) Wrought iron
(III) Steel cast iron

Steel cast iron a low carbon content, while wrought iron has high carbon content. In many ways steels are intermediate in carbon content, between cast iron and wrought iron. The approximate limits for carbon in steel are between 0.04 to 2.25 percent, through the limits for carbon in structural steel are between 0.15 to 1.7 percent.

Cast Iron: Cast iron has low carbon percentage, which makes it very brittle

Wrought Iron: Wrought iron has high carbon content, imparting it the ability to permit large deformations without fracture. Due to this quality, it replaced cast iron. The wrought iron could be formed into plates which can, in turn, be cut and shaped into structural member.

Steel: Steel has carbon content intermediate between cast iron and wrought iron.

Depending upon the chemical composition, different types of steels are classified as
(I) Mild steel
(II) Medium carbon steel
(III) High carbon steel
(IV) Low alloy steel and
(V) High alloy steel
Out of these, the first three types of steels are known as structural steel, commonly used in steel structures. Indian standard IS 800-2007 is applicable to the types of structural steels covered by the following Indian Standards.
1. IS : 226-1975 Structural steel (standard quality)
2. IS : 1977-1975 Structural steel (Ordinary quality)
3. IS : 2062-1984 Weldable Structural steel.
4. IS : 8500-1977 Weldable structural steel (medium and high strength qualities)

Structural steel (Standard quality) IS : 226-1975
Steel in this designated as St 44-SC with copper content varying from 0.2 to 0.35%. Mild steel is used for manufacture of rolled steel sections, rivets and bolts. Steel conforming to IS : 226-1975 is suitable for all type of structures subjected to static, dynamic and cyclic loading and is suitable for welding upto 20 mm thickness. The chemical composition of this steel is given in below table

Chemical Composition of Steel IS-226-1975	
Constituents	Max. percent
Carbon (for thickness/dia. Upto 20 mm)	0.23
Carbon (for thickness/dia. Over 20 mm)	0.25
Sulphur	0.055
Phosphorus	0.055

The physical properties of mild steels are as under
(I) Mass : 7.85 kg/cm^2 (7850 kg/m^2)
(II) Young's modulus of elasticity (E): 2.04×10^5 MPa(or N/mm^2)
(III) Modulus of Rigidity (G): 0.785×10^5 MPa (or N/mm^2)
(IV) Poisson's Ratio (μ): 0.3 (in elastic range)
(V) Coefficient of thermal expansion or contraction: 12×10^{-10} per^o C or 6.7×10^{-6} per^o F
Structural steel is rolled into a variety of shapes and sizes. The shapes are designated by the shape and size of their cross-section. Following are various types of rolled structural steel sections commonly used
(I) Rolled steel beam section (I-section)
(II) Rolled steel channel sections
(III) Rolled steel angle sections
(IV) Rolled steel T-sections
(V) Rolled steel bars
(VI) Rolled steel plates
(VII) Rolled steel sheets and strips
(VIII) Mild steel flats

Advantage of Steel as Structural Material: Structural steel has several advantage over other similar materials. These are as follows

High Strength: Higher strength is obviously a major advantage of steel in comparison to its unit weight with similar metals.

High Elasticity: The basic law of elasticity, the Hooke's law. "Stress is Proportional to strain" is followed up to fairly high stresses in case of steel.

High Ductility: Due to its ductility. It can sustain more deflections and is advantageous for temporary overloading of the structure. It is more advantageous in resisting earthquake loads

Environment Friendly: A steel structural can be disassembled any time or at the end of its useful life. So it can be reused or recycled for which energy consumption and CO2 emission is reduced and, hence, it is eco-friendly.

Ease in Fabrication: Better weldability is advantages for fabrication of structures. Fabrication of steel can be done in the workshops or at erection sites, thus providing its versatile use. Prefabrication of steel structural results in proper planning, ease in erection, and better quality assurance.

Versatility in use: Structural steels are used in almost all types of structures and in all environments

Poor Fatigue Strength: In spite of its higher tensile strength, steel has poor fatigue strength, so it cannot be used where the structure is subjected to repetitive tensile stress. In such a case, special alloys of steel are used.

Susceptibility to Buckling: Due to its high ductility structural steel is susceptible to buckling

Susceptibility to Corrosion: Steel materials are always susceptible to corrosion when they come in contact with moisture. Therefore, special treatment become necessary to avoid corrosion.

Higher Maintenance cost: Due to susceptibility to corrosion, the maintenance cost of steel become more in comparison to other metals.

Cement

- Cement is an extremely important material having adhesive and cohesive properties which provides a binding medium for the discrete ingredients.
- It is obtained by burning together, in a definite proportion, a mixture of naturally occurring argillaceous (containing alumina) and calcareous. (Calcium carbonate or lime) materials to a partial fusion at high temperature (about 1450°C). The product obtained on burning called clinker, is cooled and ground to the required fineness to produce a material known as cement.
- Joseph Aspdin, a Leeds builder and brick layer first manufactured cement and called it Portland cement because when it hardened it produced a material resembling stone from the quarries near Portland in England.
- During grinding of clinker, gypsum or plaster of Paris is added o prevent flash setting of the cement. The amount of gypsum is about 3 to 5 percent by weight of clinker. It also improves the soundness of cement.

- The common calcareous materials are clay, shale, slate and selected blast furnace slag.
- Certain clays formed during volcanic eruption, known as volcanic ash or pozzolana found near Italy have properties similar to that of Portland cement.
- The processes used for the manufacture of cement can be calcified as dry and wet.
- In the wet process, the limestone brought from the quarries is first crushed to smaller fragments. Then, it is taken to a ball or tube mill where it is mixed with clay or shale as the case may be and ground to a fine consistency of slurry with addition of water. The slurry is stored in tanks under constant agitation and fed into huge firebrick lined rotary klins.
- In the dry process the raw materials are ground, mixed and fed to the rotary kiln in the dry state.
- The rotary kiln is fired from the lower end and the raw material or slurry is fed at the higher end.
- By the time the material rolls down to the lower end of the rotary kiln, the dry material undergoes a series of chemical reaction until finally, in the hottest part of the kiln where the temperature is of the order of 1500°C, about 20 to 30 percent of the material get fused.
- The fused mass turns into nodular form of size 3 mm to 20 mm known as clinker which has its own physical and chemical properties.
- This clinker is coated, crushed, mixed with 3 to 5 percent of crushed gypsum and fed into a tube mil for final grinding. The finished product known as Portland cement is finally bagged.

Chemical Composition

- The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide.
- The relative proportions of these oxide compositions are responsible for influencing the various properties of cement.
- These oxides present in the raw materials when subjected to high clinkering temperature combine with each other to form complex compounds.
- The identification of the major complex compounds is largely based on R.H. Bogue's work and hence these are called Bogue's compounds.
- In addition to the four major compounds (Bogue's Compounds), there are many minor compounds formed in the kiln.
- The influence of these minor compounds on the properties of cement or hydrated compounds is not significant. Two of the minor oxides namely K_2O and Na_2O referred to as alkalis in cement are of some importance.

Constituents	Percentage	Average
Lime (CaO)	60 to 67%	63
Silica (SiO_2)	17 to 25%	20
Alumina (Al_2O_3)	3 to 8%	6
Iron Oxide (Fe_2O_3)	0.5 to 6%	3
Magnesia (MgO)	0.1 to 4%	2
Sulphur Trioxide (SO_3)	1 to 3%	1.5
Soda and Potash ($Na_2O + K_2O$)	0.5 to 1.3%	1

Bogue's Compounds

Name	Chemical Formula	Percentage
Tricalcium Silicate (C_3S)	$3\ CaO.SiO_2$	30-50
Dicalcium Silicate (C_2S)	$2\ CaO.SiO_2$	20-45
Tricalcium Aluminate (C_3A)	$3\ CaO.Al_2O_3$	8-12
Tetracalcium Alumino Ferrite (C_4AF)	$4\ CaO.Al_2O_3.Fe_2O_3$	6-10

Basic Properties of Cement Compounds

- C_3S and C_2S Which together constitute about 70 to 80 percent of the cement control most of the strength giving properties.
- C_3S Giving a faster rate of reaction accompanied by greater heat evolution develops early strength. On the other hand, dicalcium silicate (C_2S) hydrates and hardens slowly and provides much of the ultimate strength.
- A higher percentage of C_3S results in rapid hardening with an early gain in strength at a higher heat of hydration. On the other hand, a higher percentage of C_2S results in slow hardening, less heat of hydration and greater resistance to chemical attack.
- C_3A is characteristically fast reacting with water and may lead to an immediate stiffening of paste, and this process is termed as flash set. The role of gypsum added in the manufacture of cement is to prevent such a fast reaction.
- C_3A provides weak resistance against sulphate attack and its contribution to the development of strength of cement is perhaps less significant than that of C_3S and C_2S.
- Like C_3A, C_4AF also hydrates rapidly but its individual contribution to the overall strength of cement is insignificant. However, it is more stable than C_3A.
- Le Chatelier and Tornbohm observed four different kinds of crystals in thin sections of cement clinkers. Tornbohm called these crystals as Alite, Belite, Celite and Felite. His description of the minerals in the cement was found to be similar to Bogue's description of the compounds. Therefore Bougue's compounds C_3S, C_2S, C_3A and C_4AF are sometimes called Alite, Belite, Celite and Felite.
- A high lime and silica content generally increases setting time and results in higher strengths. On the other hand a decrease in lime and silica content reduces the strength of concrete.
- The presence of excess unburnt lime is harmful since it results in delayed hydration causing expansion (unsoundness) and deterioration of concrete.
- Iron oxide is not a very active constituent of cement and generally acts as a catalyst and helps the burning process. Owing to its presence cement derives the characteristic grey colour.
- Magnesia, if present in large quantities, causes unsoundness in cement.

Hydration of Cement

- The chemical reactions that take palce between cement and water is referred as hydration of cement.
- The hydration of cement can be visualized in two ways viz, "through solution" and "solid state" type of mechanisms.
- The reaction of cement with water is exothermic i.e., it liberates a considerable quantity of heat and this liberate heat is called heat of hydration.

- The hydration process is not an instantaneous one. The reaction is faster in the early periods and continues indefinitely at a decreasing rate.
- During hydration, C_3S and C_2S react with water and calcium silicate hydrate (C-S-H) is formed along with calcium hydroxide $[Ca(OH)_2]$
- Calcium silicate hydrate is the most important product of hydration and it is the essence that determines the good properties of concrete.
  $2C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$
  $2C_2S + 4H \rightarrow C_3S_2H_3 + Ca(OH)_2$
- It can be seen from the above equation that C_3S produces a comparatively less quantity of calcium silicate hydrates and more quantity of calcium hydroxide that formed in the hydration of C_2S
- Calcium hydroxide is not a desirable product in the concrete mass, it is soluble in water and gets leached out making the concrete porous, particularly in hydraulic structures.
- C_2S reacts rather slowly and it is responsible for later strength of concrete. It produces less heat of hydration.
- The lack of durability of concrete, is on account of the presence of calcium hydroxide.
- The calcium hydroxide also reacts with sulphates present is soils or water to form calcium sulphate which further reacts with C_3A and cause deterioration of concrete. This is known as sulphate attack.
- The only advantage of calcium hydroxide is that being alkaline in nature it maintains pH value around 13 in the concrete which resists the corrosion of reinforcements.
- From the stand point of hydration, it is convenient to discuss C_3A and C_4AF together because the products formed in the presence of gypsum are similar.
  Gypsum and alkalis go into solution quickly and the solubility is depressed. Depending upon the concentration of aluminate and sulphate ions in the solution, the precipitating crystalline product is either calcium aluminate trisulphate hydrate or calcium aluminate momosulphate hydrate. The calcium aluminate trisulphate hydrate is known as Ettringite.
- It has been estimated that on an average 23% of water by weight of cement is required for chemical reaction with Portland cement compounds. This 23% of water chemically combines with cement, and therefore it is called bound water.
- A certain quality of water is imbibed within the gel pores.
  This water is known as gel water. The bound water and gel water are complimentary to each other.
- It has been estimated that about 15% by weight of cement is required to fill up the gel pores.
- Therefore, a total of 38% of water by weight of cement is required for the complete chemical reactions and occupy the space within gel pores.
- If water equal to 38% by weight of cement is only used it can be noticed that the resultant paste will undergo full hydration and no extra water will be available for the formation of undesirable capillary cavities.
- If more than, 38% of water is used, then excess water will cause undesirable capillary cavities.

Type of Cements

There are different types of cement as classified by the Bureau of Indian Standards (BIS)

(i) Ordinary Portland Cement
- (a) 33 grade – IS: 269-1989
- (b) 43 grade – IS: 8112-1989
- (c) 53 grade – IS: 12269-1987

(ii) Rapid Hardening Cement – IS: 8041-1990
(iii) Extra Rapid Hardening Cement
(iv) Low Heat Portland Cement – IS: 12600-1989
(v) Portland Slag Cement – IS: 455-1989
(vi) Portland Pozzolana Cement – IS: 1489-1991 (Part 1 and 2)
(vii) Sulphate Resisting Portland Cement – IS: 12330-1988
(viii) White Portland Cement – IS: 8042-1989
(ix) Colored Portland Cement –IS:8042-1989
(x) Hydrophobic Cement – IS: 8043-1991
(xi) High Alumina Cement –IS: 6452-1989
(xii) Super Sulphated Cement –IS: 6909-1990
(xiii) Special Cements
- (a) Masonry Cement
- (b) Air Entraining Cement
- (c) Expansive Cement
- (d) Oil Well Cement

Ordinary Portland Cement (OCP)

- The ordinary Portland cement of the setting cement is the basic Portland cement and is manufactured in larger quantities than all the other cements.
- It is presently available in three different grades viz. C33, C43 and C53. The numbers 33, 43 and 53 correspond to the 28 day (characteristic) compressive strength of cement as obtained from standard test on cement sand mortar specimens.
- It is used in general concrete construction where there is no exposure to sulphates in the soil or in ground water.

Rapid Hardening Cement (RHC)

- It is finer than ordinary Portland cement.
- It contains more C_3S and less C_2S than the OPC.
- The 1 day strength of this cement is equal to the 3 day strength of OPC with the same water cement ratio.
- The main advantage of a rapid hardening cement is that shuttering may be removed much earlier, thus saving considerable time and expenses.
- Rapid hardening cement is also used for road work where it is imperative to open the road traffic with the minimum delay.