CHAPTER 1
INTRODUCTION

Shetty, M.S. (1) has reported that, cement concrete is one of the largest construction material used by mankind. In terms of consumption it stands second only to water. In terms of cost, generally it accounts for about 25 to 30 % of the national budget. Concrete is the main material used for the infrastructure development of every country of the world. As far as India is concerned, our infrastructure development is just started. In the years to come there will be a quantum jump in the production and use of cement and concrete. Concrete being such an important material for the development of any country, it is necessary that engineers should have an in depth knowledge of properties of this versatile and precious material.

Raghuprasad, P.S. and Pradeep Kumar, A. V.(2) reported that, the responsibility of the construction industry is not only to provide quality construction but to also provide a clean environment. In today's more-environmentally conscious world a more responsible approach to the environment would be to increasingly use the by-products of one industry, which are disposed off as waste, as a raw material, for some other industry. This is at present practiced in cement and construction industry to a certain extent.

Cement is one of the most important ingredient materials of concrete; generally the Ordinary Portland Cement (OPC). But unfortunately the manufacture of OPC is not only highly energy intensive but also a significant contributor of green house gas emissions generally carbon dioxide, methane and oxides of nitrogen. The production of one ton of OPC approximately amounts to the same amount of carbon dioxide into the atmosphere. Carbon dioxide emission is responsible for global warming and ecological imbalance. In addition, meager amount of methane and oxides of nitrogen are also released into the atmosphere. Fortunately, investigations have revealed that the utilization of mineral admixtures in the manufacture of blended cement can contribute significantly to the reduction of the above green house gas emissions to the extent of its proportions in cement and also savings in energy. Also the presence of SCM's improves the performance characteristics of concrete including durability. The common mineral admixtures in use are fly ash, ground granulated blast furnace slag, silica fume, metakaolin and rice husk ash (RHA); which are industrial by-products and possess
pozzolanic properties which can be used as an excellent blending material while making concrete or in the manufacture of blended cement in the cement plant itself.

1.1 Concept of Cement

The word cement is derived from Latin ‘caementtum’ which was used by Romans to denote the rough stone or chips of marbles from which mortar was made.

The raw materials for making Portland cement have the following principal components.

<table>
<thead>
<tr>
<th>Components</th>
<th>Composition, %</th>
<th>Compounds</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium oxide (CaO)</td>
<td>60 to 65</td>
<td>3CaO. SiO₂</td>
<td>C₃S</td>
</tr>
<tr>
<td>Silicon oxide (SiO₂)</td>
<td>20 to 25</td>
<td>2CaO. SiO₂</td>
<td>C₂S</td>
</tr>
<tr>
<td>Aluminium oxide (Al₂O₃)</td>
<td>4 to 8</td>
<td>3CaO. Al₂O₃</td>
<td>C₃A</td>
</tr>
<tr>
<td>Ferrous oxide (Fe₂O₃)</td>
<td>2 to 4</td>
<td>3CaO. Al₂O₃ . Fe₂O₃</td>
<td>C₃AF</td>
</tr>
<tr>
<td>Magnesium oxide (MgO)</td>
<td>1 to 3</td>
<td>3CaO. Al₂O₃ . SO₃</td>
<td>C₄A₃S</td>
</tr>
</tbody>
</table>

Ordinary Portland cements are of the grade 33, 43, 53 conforming to IS 269, IS 8112 and IS 12269 respectively.

Portland cements do not satisfy all the needs of the concrete industry; therefore, special cements have been developed by making some alterations in the Portland cement. One such innovative special cement developed is the Blended Cement. This cement is a modified Portland cement altered by blending with either rapidly cooled blast furnace slag, Pozzolanic material like fly ash, or any other such materials like silica fume, rice husk ash (RHA) and metakaolin thus the term blended cement was coined.

1.2 Blended cement

The current American approach is given in ASTM C 1157-94a, which covers blended hydraulic cement for both general and special application.

Blended hydraulic cement is defined as follows “Hydraulic cement consisting of two or more inorganic constituents which contribute to the strength-gaining properties of the cement, with or without other constituents, possessing additions and functional additions”.
The addition of blended materials is beneficial and compatible in OPC; in fact cost saving was probably the original reason for the development of blended cements. However, the impetus to rapid growth in the production of blended cements in many countries of Europe and Asia came as an energy saving potential. Also, in some respect, the blended cements perform better than ordinary Portland cement in majority of construction without causing any inconvenience. They are particularly useful in aggressive environmental conditions. Presently, the production of slag cements represents nearly one-fourth of the total cement production of Germany, the production of pozzolanic cement is nearly one-third of the total cement produced in Italy. In India the production of blended cement is at its infancy; however there is a growing interest to use (pozzolanic and slag based) blended cements.

The specifications for Portland pozzolana cement (PPC) conforms to BIS: 1489 Part I (fly ash based) and PART II (Calcined clay based) and Portland slag cement (PSC) conforming to BIS: 455.

Disposal of fly ash and slag is a colossal challenge. The Govt. of India issued a circular in Sept. 1999 directed towards encouraging the use of fly ash in various activities such as land fills, reclamation, roads, back floors, bridges etc. including cement and concrete. However, the circular specifies the need for assumed quality of fly ash to be established prior to its use in cement/concrete.

About 85 million tones of fly ash is being generated by the coal based thermal power stations in India every year and this may increase over 100 million tones per year in next couple of years and it is expected that it may double in the next decade. Similarly the steel industry in India is producing about 12 million tones of blast furnace slag which when granulated and used can be an excellent blending material whilst the production of silica fume in India is very small. There are large quantities of rice husk which when burnt under certain thermal discipline can produce ash which can be a potential valuable blending material.

Such blending materials can be advantageously utilized either by mixing them directly in concrete or by mixing them while making cement to produce blended cements at the cement plant itself which in turn can be used in concrete making.
Fly ash produced has variable qualities. It needs to check from time to time, batch to batch and season to season. They are classified as grade I, grade II in BIS: 3812 (under revision)-Oct. 1999. However, the codal provisions permit sufficiently wide permissible variation as acceptable limits. This needs to be reviewed.

Finally, the use of blended cement in constructing large dams is well known, particularly the reduction in exothermic reaction during the setting phase and the resulting lower danger of cracking.

1.3 Ordinary Portland Cement

This is by far the most common cement in use. This is the basic type of cement which is used on large scale in all general types of construction works. The details regarding the composition and properties of this type of cement are given in BIS: 269.

This cement is admirably suitable for use in general concrete constructions where there is no exposure to Sulphates in the soil and ground water. These cements are available in different grades viz; 33, 43 and 53 grade OPC.

1.3.1 43 Grade OPC

In these type of cement the 28 days cement strength is expected to have a minimum value of 43 MPa.

1.3.2 53 Grade OPC

In these type of cement the 28 days cement strength is expected to have a minimum value of 53 MPa.

The use of high grade cement should not be taken for granted to yield high grade (strength) concrete as the strength of concrete depends on the mixture of cement, sand, coarse aggregate and water. In fact, the cement’s grade has no relationship to the strength of concrete. It is possible to produce concrete of wide-ranging strength using a particular grade of cement. Moreover the “Grade” has nothing to do with quality; increase in the grade does not increase the quality of the cement. The quality guarantees a set of minimum standards prescribed. Two cement of different grades can have the same quality.

Every structure has to satisfy the requirements of strength and durability. Strength is the ability of the structure to withstand load. Durability refers to the period of trouble free life.
A structural cement of concrete may possess high strength, but may deteriorate sooner than expected, making it a material of poor quality. Here the quality is with reference to concrete and not that of the cement. A grade of cement can be said to be of good quality if the concrete made with it satisfies both strength and durability requirements.

The strength requirements (i.e. the strength of concrete) is satisfied by choosing the proper amount of cement, limiting the amount of water, consolidating the mixture well and curing the hardened concrete as long as possible. Durability on the other hand depends on the several factors that are attributable both to the material and to the exposed environment.

1.4 Concept of Concrete

Concrete is derived from ‘concretus’ which signifies ‘growing together’- a concise description of the ‘binding of loose particles’ into a single mass. Clay was probably used for this purpose. The remains of Babylonian and Assyrian buildings indicate an appreciation of the value of clay mortars.

The important factors contributing to the advanced state of civilization of ancient Egyptians was their discovery of lime and gypsum mortars as building agents for building the structures like pyramids.

1.5 Why Concrete is the Most Widely Used Engineering Material?

Concrete is neither as strong nor as tough as that of steel, but it possesses excellent resistance of water. Its wide usage is because of the ease at which structural concrete elements can be formed into a variety of shapes and size. This is because freshly made concrete has a plastic consistency, which permits the material to flow into prefabricated formwork. The popularity of concrete with engineering is that it is usually the cheapest and most readily available material on the job. Therefore in the future, considerations of energy and resource conservation are likely to make the choice of concrete as a structural material even more attractive.

1.6 Features of the Concrete Structure

The structure of concrete has generally two phases. The two phases can be distinguished are:
Phase I: The aggregate particles of varying size and shape and the binding medium.
Phase II: The composition of an incoherent mass of the hydrated cement paste \((hcp)\).

At the microscopic level, the complexities of the structure begin to show. The above two phases are neither homogeneously distributed with respect to each other nor they themselves are homogeneous. Many aspects of concrete behavior under stress can be explained only when the cement paste and aggregate interface is treated in the third phase which is a unique feature of concrete structure also called the transition zone.

Phase III: Transition Zone: This represents the interfacial region between particles of coarse aggregate and the \(hcp\). Thus the transition zone is generally weaker than either of the two components of concrete.

1.7 Cements and Cementitious Materials in BIS: 456-2000

The literature of Rajkumar, C\(^{(3)}\) indicates that the formulation of BIS: 456 can be traced back to the fifties when the standard was first published in 1953 and subsequently revised in 1957. This code was further revised in 1964. The 1978 revision incorporated a number of important changes. Besides other major changes, this revision permitted use of more types of cement and pozzolans in concrete. The types of cement permitted included OPC, PPC and PSC. Fly ash or burnt clay pozzolana may be used as part replacement of unblended cements provided uniform blending with the cement is ensured.

The latest revision of this code was in 2000 and this new version recognizes more choice of binder additions than has ever been in the evolution of BIS: 456. The cements that are currently familiar to engineers are PPC and PSC i.e. fly ash or slag blend when they are added as separate powders at the concrete mixer.

The new version places further emphasis on use of mineral admixtures, when they are added as separate powder at the concrete mixer. A mineral admixture is the terminology used in BIS: 456 for materials such as:

- Fly Ash
- Ground Granulated Blast Furnace Slag
- Silica Fume
- Rice Husk Ash
- Metakaolin
Out of the above mentioned materials only fly ash and ground granulated blast furnace slag are discussed below as these two materials are related to the topic.

1.7.1 Fly Ash

Fly ash is a by product from coal based thermal power plant. During the combustion of coal in the modern power plants, as coal passes through the high temperature zone in the furnace, the volatile matter and carbon are burnt off, whereas most of the mineral impurities, such as clays, quartz and feldspar, will melt at high temperature. The fused matter is quickly transported to low temperature zone, when it solidifies into spherical particles of glass. Some of the mineral matter agglomerates following bottom ash; most of it flies out with fuel gas stream and is called fly ash (pulverized fuel ash). This ash is subsequently removed from gas by electrostatic precipitators.

Mehta, P.K. and Paulo, J.M., Monterio, (4) reported that the particle size vary from <1|μm to 100|μm in diameter with more than 50 percent under 20|μm. The particle size distribution, morphology, and surface characteristics of the fly ash used as a mineral admixture exercise a considerable influence on the water requirement and workability of freshly made concrete and the rate of strength development in hardened concrete.

The chemical composition of the fly ash depends on the sources of coal and also an operating parameter of the boilers, thus the quality varies from source to source and within the same source also. With the use of pulverized coal and efficient combustion system, loss on ignition (LOI) is very much controlled in most of the fly ashes. High-unburnt coal is a point of concern in principle, which increases demand for air entrained agents and plasticizers in the production of concrete. Though a fly ash complies to code specification of chemical characteristics, it cannot be correlated with performance in concrete.

It is generally agreed that the workability of mortars and concretes increases over that of controlled concrete for the given water cement ratio, provided the fly ash is of desired quality. Strength development in fly ash blended concrete is indispensable and depends on the fly ash particle size, reactivity and temperature of curing.

Permeability is the prime cause for the problem of concrete associated with several types of chemical attacks. The addition of fly ash becomes significant for the
durability of concrete. Pozzolanic reactions with hydrated lime in transition zone are associated with two physical effects namely, pore-size refinement and grain size contributes to impermeability of concrete, grain-size refinement influences the transition zone towards densification there by minimizing chances for micro-cracking. Such improved microstructure of cement paste mitigates various chemical attacks and contributes towards improved durability of concrete.

1.7.2 Ground Granulated Blast Furnace Slag (GGBS)

It is a by-product of steel industry. In the production of cast iron, also called pig iron, if the slag is cooled slowly in air, the chemical component of slag are usually present in the form of crystalline melilite (C₂AS-C₂MS₂ solid solution), which does not react with water at ordinary temperature. If ground to very fine particles the material will be weakly cementitious and pozzolanic. However when liquid slag is rapidly quenched from a high temperature by either water or a combination of air and water, most of the lime, magnesia, silica and alumina are held in non crystalline or glassy state. The water-quenched product is called granulated slag due to the sand-size particles. When ground to 400 to 500 m²/kg Blaine, both products develop satisfactory cementitious properties.

The concrete mixtures when correctly proportioned made with the combination of Portland cement and GGBS can exhibit higher strength, greatly-reduced permeability, potentially greater durability and better performance in aggressive environments than OPC concrete. Where as optimum proportion of slag to achieve greatest strength at most favourable cost benefit ratio appears to be 50% or less of the total cementitious material. These considerations highlight the need for flexibility using different proportions of slag content in the total cementitious material.