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High Performance Concrete and its Applications in the Field of Civil Engineering Construction

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Abstract— Concrete as a construction material is widely used in India with annual consumption exceeding 100 million cubic meters. Conventional Ordinary Concrete which is designed on the basis of compressive strength does not meet many functional requirements since it is found deficit in aggressive environments conditions, time of construction, energy absorption capacity, repair and retrofitting jobs etc. So, there is a need to design High Performance Concrete (HPC) which is far superior than conventional concrete. High Performance Concrete exceeds the properties and constructability of normal concrete. These specially designed concretes are made up of normal & special materials which enable it to meets the general performance requirements in a particular structure. Special mixing, placing, and curing methodologies may be required in order to produce such type of concrete. When the general performance of concrete is substantially higher than that of normal type concrete, such concrete is regarded as high performance concrete. High-performance concrete has been primarily used in the construction of tunnels, bridges, pavements, high rise building structures because of its strength, durability, and high modulus of elasticity. High Performance Concrete has received increased attention in the development of infrastructure such as buildings, industrial structures, hydraulic structures, bridges, highways etc. leading to utilization of large quantity of concrete. This paper presents the general introduction of high performance concrete, its categorization, its composition and its applications in various civil engineering constructions.

Key words: High-Performance Concrete, Categorization of High-Performance Concrete, Materials used in High-Performance Concrete, Applications of High-Performance Concrete

I. INTRODUCTION

The rapid development of building and civil engineering after the Second World War is characterised by wide application of concrete as the basic material in all branches of the economy (A. Kmita, 2000). New types of structures and new technologies in building created more difficult requirements for this material. So in order to meet the requirements a special form of concrete is formed known as High-Performance Concrete (HPC). A High Performance Concrete is a concrete in which certain characteristics are developed for a particular application and environment so that it will give excellent performance in the structure in which it will be placed, in the environment to which it will be exposed, and with the loads to which it will be subjected during its design life (Vatsal Patel & Neeraj Shah, 2013). High Performance Concrete is also defined as concrete which meets special performance and uniformity requirements that cannot be always achieved routinely by using conventional materials and normal mixing, placing and curing practices (Vatsal Patel & Neeraj Shah, 2013). American Concrete Institute (ACI) defined High Performance Concrete as a concrete which meets combinations of performance and uniformity requirements that cannot be achieved routinely using conventional constituents and normal mixing, placing, and curing practices. In recent years, further improvements in concrete properties have been achieved in the so called High Performance Concrete by improvements involving a combination of improved compaction, improved paste characteristics, aggregate-matrix bond and reduced porosity (M.L.Gambhir, 2014). Although high-performance concretes are made with the same basic components as the normal concrete, their much higher qualitative and quantitative performances make them new materials. On the basis of their use, they offer different advantages such as enhanced durability, reduced permeability, higher strength etc. at an economical cost (M.L.Gambhir, 2014). The strategic Highway Research Programme (SHRP) has defined a High Performance Concrete as concrete meeting one of the following requirements: (a)4 hours compressive strength greater than or equal to 17.5 N/mm2, (b) 24 hours compressive strength greater than or equal to 35 N/mm2, (c)28 days compressive strength greater than or equal to 70 N/mm2, (d)Water-cement (W/C) ratio less than or equal to 0.

Fig. 1: High-performance concrete used in flyovers

Fig. 2: High-performance concrete used in tall building structure

II. Categorization of High-Performance Concrete

A suitable classification of HPC according to different levels of performance requirements would enable design engineers to select appropriate performance criteria of HPC for different applications in different environmental conditions (M.L.Gambhir, 2014). The categorization of high-performance concrete is as follows:

A. Based on Characteristic Strength Based on 28-days characteristic strength of concrete, the following classification has been suggested

1) Ordinary Concrete: Concrete having 28days compressive strength in the range of 10 to 20 MPa.
2) Standard/Normal Concrete: Concrete having 28-days compressive strength in the range of 25 to 55 MPa.
3) High-Performance Concrete: Concrete having 28-days compressive strength in the range of 60 to 100 MPa.
4) Very High-Performance Concrete: Concrete having 28-days compressive strength in the range of 100 to 150 MPa.
5) Exceptional Concrete: Concrete having 28-days compressive strength more than 150 MPa.

B. Based on Durability and Target Strength

The Strategic Highway Research Programme has defined high-performance concrete into four categories admixtures plays an important role in the production of High Performance Concrete. Mineral Admixtures form an essential part of the High-Performance Concrete mix. They are used for various purposes depending upon their properties.
Table-1 shows different types of mineral ad- mixtures with their particle characteristics. as the concrete with

1) A maximum water cement ratio of 0.35,
2) A minimum durability factor of 80 percent,
3) A minimum strength criterion, &
4) Fiber Reinforcement

C. High Early Strength Concrete

Traditionally, interest in the strength and other properties of concrete has been focused on those at the age of 28 days and beyond. In the recent past, there has been an increasing interest in the properties of concrete at ages less than 28 days. Any strength measured at ages less than the standard 28 days is regarded as early strength (M.L.Gambhir, 2014). In high-performance concrete due to the greater accessibility of cement grain surfaces, the greater early hydration results in up to 24-hours strength of concrete being generally higher than that in the case of normal concrete of same water-cement ratio [Honey Gaur].

III. Materials Used in High-Performance Concrete

1) Cement The choice of cement for high-strength concrete should not be based only on mortarcube tests but it should also include tests of compressive strengths of concrete at 28, 56, and 91 days. A cement that yields the highest compressive strength at an extended ages is preferable. For high-strength concrete, a cement should produce a minimum 7-days mortar-cube strength of approximately 30 MPa.
2) Aggregates In high-performance concrete, the size of aggregates, shape, surface texture, mineralogy, and cleanness needs special attention. For each source of aggregate and concrete strength level there is an optimum size aggregate that will yield the compressive strength per unit of cement. To find the optimum size, trial batches should be made with 19 mm and smaller coarse aggregates and varying cement contents. Many studies have found that 9.5 mm to 12.5 mm nominal maximum size aggregates gives optimum strength. In high-performance concretes, the strength of the aggregate itself and the bond between the paste and aggregate becomes an important factor. Tests have shown that crushed stone aggregates produce higher compressive strength in concrete than gravel aggregate using the same size aggregate and the same cementing materials content. This is probably due to a superior aggregate-to-paste bond when using rough, angular, crushed material. For specified concrete strengths of 70 MPa or higher, the potential of the aggregates to meet design requirements must be established prior to use.
3) Admixture using additional cement alone. These admixtures are usually added at dosage rates of 5% to 20% or higher by mass of cementing material. Some specifications only permit use of up to 10% silica fume, unless evidence is available indicating that concrete produced with a larger dosage rate will have satisfactory strength, durability, and volume stability. The water-cement ratio should be adjusted so that equal workability becomes the basis of comparison between trial mixtures.

4. Features of High-Performance Concrete HPC should have a better performance when compared to normal strength concrete. Basic features of high performance concrete are its strength, ductility and durability. These parameters are the most important features that a construction material should possess from its performance point of view. 4.1 Strength In practice, concrete with a compressive strength less than 50MPa is regarded as Normal Strength Concrete (NSC), while High Strength Concrete (HSC) may be defined as that having a compressive strength of about 50MPa. Recently, concrete with the compressive strength of more than 200MPa has been achieved (Oral Büyüköztürk and Denvid Lau). Such concrete is defined as ultra-high strength concrete. In general, the addition of admixture not only improves the concrete strength but also enhances the aspects of performance, like ductility and durability. Hence, the characteristics of HSC are very similar to those of HPC. 4.2 Ductility High-Performance Concrete is more brittle as compared to Normal Strength Concrete (NSC), especially when high strength is the main criteria. Ductility in case of high-performance concrete can be improved by applying a confining pressure on HPC. Admixtures such as fly ash, silica fume, or slag are often necessary in the production of high performance concrete. The gain in strength obtained with the addition of these admixtures cannot be attained by besides confinement, the ductility of HPC can be improved by altering its composition through the addition of fibers in the design mix. Concrete with fibers inside is regarded as fiber reinforced concrete (FRC). The mechanical behavior of FRC can be categorized into two classes by their tensile response. The conventional

FRC made by adding fibers in NSC only exhibits an increase in ductility compared with the plain matrix, whereas high performance FRC made by adding fibers in HPC exhibits substantial strain hardening type of response which leads to a large improvement in both strength and toughness compared with the plain matrix. The improvement in terms of ductility, high performance FRC is referred to as ultra-ductile concrete as well.

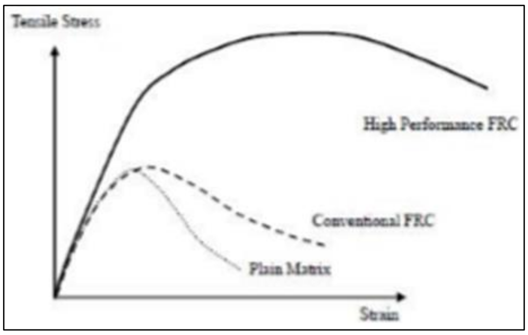

Fig. 3: Mechanical Behavior of FRC compared with plain matrix

4) Durability Permeability of concrete is a key factor influencing the durability of concrete. Concrete permeability is dependent on permeability of each constituent material and its geometrical arrangement. The permeability of cement paste is primarily related to pore structure, which includes porosity, pore size and connectivity, while pore structure is a function of the water-cement ratio and the degree of hydration. The aggregates have a much lower permeability than cement pastes. In view of the durability characteristic of high performance concrete, it is proposed that to achieve a durable concrete, three criteria may need to be considered in concrete mix design. The three criteria are strength, permeability and crack resistance. A strength criterion ensures that concrete can resist the design stress without failure. A permeability criterion ensures that concrete has a limited flow penetration rate so as to minimize vulnerability to water and chemical ion attack during the design period of service life. A crack resistance criterion ensures that concrete has a minimum capability to resist the cracking due to environmental conditions, such as thermal and moisture shrinkage (Oral Büyüköztürk and Denvid Lau).
5) 3.5. Application Areas of High-Performance Concrete Major applications of high-performance concrete in the field of Civil Engineering constructions have been in the areas of longspan bridges, high-rise buildings or structures, highway pavements, etc. Some of the application areas are discussed in brief below :

- Bridges The use of high performance concrete would result in smaller loss in pre-stress and consequently larger permissible stress and smaller cross-section being achieved, i.e. it would enable the standard pre -stressed concrete girders to span longer distances or to carry heavier loads. In addition, enhanced durability allow extended service life of the structure. In case of pre-cast girders due to reduced weight the transportation and handling will be economical. Concrete structures are preferable for railway bridges to eliminate noise and vibration problems and minimize the maintenance cost (Dr. R. B. Khadiranaikar).
- High Rise Structures The reasons for using the high strength concrete in high-rise buildings are to reduce the dead load, the deflection, the vibration and the maintenance cost.
- Highway Pavements High Performance concrete is being increasingly used for highway pavements due to the potential economic benefits that can be derived from the early strength gain of high performance concrete, its reduced permeability, increased wear or abrasion resistance to steel studded tires and improved freeze-thaw durability. A durable concrete known as fast track concrete designed to give high strength at a very early age without using special materials or techniques has been developed. Fast Track Concrete Paving (FTCP) technology can be used for complete pavement reconstruction, partial replacement by an inlay of at least one lane, strengthening of existing bituminous or concrete pavements by a concrete overlay, rapid maintenance and re -construction processes. The benefits of applying FTCP technology in such applications are : (a) a reduced construction period, (b) early opening of the pavement to traffic, and (c) reducing the use of expensive concrete paving plant.

IV. Conclusion

1) The paper presents an overview of the concept of high-performance concrete and some of its applications in civil engineering constructions.
2) Although high-performance concretes are made with the same components as of normal concrete, their much higher qualitative and quantitative performances make them new material for usage.
3) On the basis of their use, they offer different advantages such as enhanced durability, reduced permeability, higher strength etc. at an economical cost.
4) The purpose of high-performance concrete is not to produce a high cost product, but simply to provide a means for producing concrete that will perform satisfactorily with reasonable cost for intended service life.

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