HIGH PERFORMANCE CONCRETE & ITS APPLICATIONS IN CIVIL ENGG

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ASBTRACT

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 to conventional concrete. High Performance Concrete exceeds the properties and constructability of normal concrete. 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. The focus on High Performance concrete (HPC) has immensely increased due to utilization of large quantity of concrete, thereby leading to the development of infrastructure Viz., Buildings, Industrial Structures, Hydraulic Structures, Bridges and Highways. The application of high performance concrete has overcome the limiting features of ordinary reinforced concrete for the design and construction of civil engineering structures. High strength concrete having more than 60 MPA comprehensive strength with improved properties is generally known as high performance concrete

Keywords: High-Performance Concrete, Category of High-Performance Concrete, Materials Used in High-Performance Concrete, Admixtures, Applications of HPC.

I. INTRODUCTION

Modern Civil Engineering construction tends to progress towards more economic, design and construction of structures though, gradually improved methods of design and the use of higher strength materials. This has resulted in a reduction of cross sectional dimensions and consequent weight savings. Such developments are particularly important in the field of reinforced concrete, where the dead load represents a substantial part of the total design load. The application of high performance concrete has overcome the limiting features of ordinary reinforced concrete for the design and construction of civil Engineering structures. High performance concrete (H P C) is the latest catch phrase in concrete technology. 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. The development of high performance concrete

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(HPC) is a giant step in making concrete a high-tech material with enhanced characteristics and durability. High performance concrete is an engineered concrete obtained through a careful selection and proportioning of its constituents. The concrete is with the same basic ingredients but has a totally different microstructure than ordinary concrete. The low water cement ratio of HPC results in a very dense microstructure having a very fine and more or less well connected capillary system. • The dense microstructure of HPC makes the migration of aggressive ions more difficult, consequently HPC is more durable when exposed to aggregate environment conditions. • High performance concrete can hence be defined as an engineered concrete with low water/ binder ratio to control its dimensional stability and when receive an adequate curing. • The cementitious component of high or any combination of cementitious material such as slag, fly ash, silica fume and filler such as, lime stones. On the basis of their use, they offer different advantages such as enhanced ductility, reduced permeation of water and chemical ion, durability higher strength etc. at an economical cost.

II. CLASSIFICATION 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. The categorization of high-performance concrete is as follows:

2.1 Based on Characteristic Strength

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

(a) Ordinary Concrete*:* Concrete having 28-days compressive strength in the range of 10 to 20 MPa.

(b) Standard/Normal Concrete*:* Concrete having 28-days compressive strength in the range of 25 to 55 MPa.

(c) High-Performance Concrete : Concrete having 28-days compressive strength in the range of 60 to 100 MPa.

(d) Very High-Performance Concrete: Concrete having 28-days compressive strength in the range of 100 to 150 MPa.

(e) Exceptional Concrete: Concrete having 28-days compressive strength more than 150 MPa.

2.2 Based on Durability and Target Strength

The SHRP has defined high-performance concrete into four categories as the concrete with:

(a) A maximum water cement ratio of 0.35,

(b) A minimum durability factor of 80 percent,

(c) A minimum strength criterion,

(d) Fiber Reinforcement

2.3 High Early Strength Concrete- This type of concrete have good strength in early phase as compared to conventional concrete.

III. MATERIALS USED IN HIGH- PERFORMANCE CONCRETE

3.1 Cement

The first choice to be made when making high performance concrete is definitely that of cement, even when one or two supplementary cementitious materials will be used, because the performance of the cement in terms of Rheology and strength becomes a crucial issue as the targeted comprehensive strength increases. The standard strength performance of a given Portland cement measured using the mortar cubes does not always correlate

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well with the actual strength that can be reached when the cement is used at a very low water cement ratio. The physical and chemical characteristics of cement play a vital role in developing strength and controlling Rheology of fresh concrete. The cement for high performance concrete should contain a little Tricalcium Aluminate [C3A] as possible, because the lower the amount of (C3A) the easier the control of Rheology and lesser the problems of cement super plasticizer compatibility. The cement should contain the right amount of sulphur Trioxide [SO]3 in order to control rapidly an efficiently the formation of eccentricity.Finally, from strength point of view, the cement should be finely grounded and contain a fair amount of [C3S].

3.2 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.

3.3 Admixtures for high performance concrete

An admixture is a material other than cement, water and aggregates that is used as an ingredient of concrete and is added to the bath immediately before or during mixing. Admixture are also used to modify the properties of concrete so as to make it more suitable for any situation. It is difficult to predict the effect and the result of using admixtures because many a time the change in the brand of cement, aggregate grading, mix proportions and richness of mix sometimes usually alter the properties of concrete. Sometime many admixtures affect more, and the effect of more than one admixture is difficult to predict. Carefulness is the watch word in the selection of admixture, and in also predicting the concrete. The commonly used admixtures for most Engineering construction , refer to table 1.

I) Plasticizers
II) Super plasticizers
III) Retarders
IV) Accelerators
V) Air- Entraining Admixture

TABLE NO 1

S.NO.	CHEMICAL ADMIXTURES	FUNCTION
1.	SUPER PLASTICIZER	To reduce the water requirement by 15% to 20% without affecting the workability leading to a high strength and dense concrete
2.	ACCELERATOR	To reduce the setting time of concrete thus helping early removal of forms and therefore used in cold weather concreting

3.	WATER REDUCING ADMIXTURE	To achieve certain workability (slump) at low water cement ratio for a specified strength thus saving on the cement
4.	AIR ENTRAINING ADMIXTURE	To entrain small air bubbles in concrete which act as rollers thus improving the workability, therefore very effective in freeze-thaw cycles as they provide a cushioning effect on the expanding water in the concreting in cold climate.
5.	RETARDER	To increase the setting time by slowing down the hydration of cement and therefore are preferred in places of high temperature concreting.

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 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.

IV. FEATURES OF HIGH-PERFORMANCE CONCRETE

A High Performance concrete element is that which is designed to give optimized performance characteristics for a given set of load, usage and exposure conditions, consistent with requirement of cost, service life and durability. High Performance concrete has very low porosity through a tight and refined pore structure of the cement paste, very low permeability of the concrete, high resistance to chemical attack, low heat of hydration, High early strength and continued strength development, high workability and control of slump, low water binder ratio and low bleeding and plastic shrinkage.

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 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. Such concrete is defined as ultra high strength concrete. As the compressive strength of concrete has been steadily increasing with ample experimental validation • In general, the addition of admixture does not improve the concrete strength only. Usually, other aspects of performance, like ductility and durability, are also enhanced.

4.2 Ductility

HPC is usually more brittle when compared with NSC, especially when high strength is the main focus of the performance. Ductility can be improved by applying a confining pressure on HPC. Besides confinement, the ductility of HPC can be improved by altering its composition through the addition of fibres in the design mix. Concrete with fibres inside is regarded as fibber 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

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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.

4.3 Durability

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. The permeability of concrete is a key factor influencing the durability of concrete. Concrete permeability is dependent on permeability of each constituent material and its geometric 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- to-cement ratio and the degree of hydration. Methods for achieving High Performance • In general, better durability performance has been achieved by using high-strength, low w/c ratio concrete. Though in this approach the design is based on strength and the result is better durability, it is desirable that the high performance, namely, the durability, is addressed directly by optimizing critical parameters such as the practical size of the required materials. • Two approaches to achieve durability through different techniques are as follows. • (1) Reducing the capillary pore system such that no fluid movement can occur is the first approach. This is very difficult to realize and all concrete will have some interconnected pores. • (2) Creating chemically active binding sites which prevent transport of aggressive ions such as chlorides is the second more effective method.

V. APPLICATION OF HIGH- PERFORMANCE CONCRETE IN CONSTRUCTION

Major applications of HPC have been in the areas of pavements, long-span bridges and high-rise buildings, In prestressed concrete bridges, concrete should have not only high strength, but reduced shrinkage and creep High performance concrete is being increasingly used for highway pavements due to the potential economic benefit that can be derived from the early strength gain of high performance concrete, its reduced permeability; increased wear of abrasion resistance to steel studded fires and improved freeze-thaw durability. The first and the foremost use of high performance concrete is in high rise buildings, where advantages like reduction in dead loads and reduced sizes of the columns which gives more rentable space can be employed.

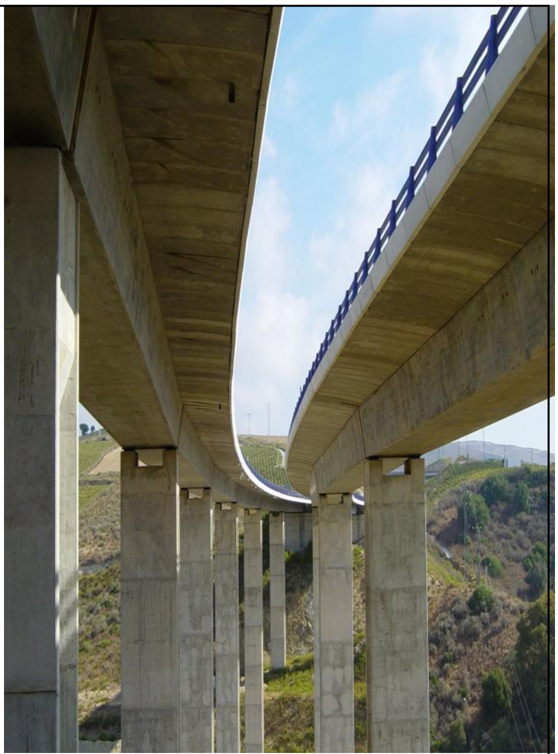
5.1 Pavements

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. While the conventional normal strength concrete continue to be used in most cases of pavement construction, different types of high performance concretes are being considered for pavement repairs for early opening to traffic, bridge deck overlays, and special applications in rehabilitation of structures and other developments. In many other applications, high performance concrete is required to meet certain specific performance requirements besides high strength.

A durable concrete called fast track concrete designed to give high strength at a very early age without using special materials or techniques has been developed. The early strength is controlled by the water-cement ratio, cement content and its characteristics. Typically, a rich, low water content mix containing 1 to 2 per cent calcium chloride will produce adequate strength and abrasion resistance for opening the pavement to traffic in 4-5 hours at temperatures above 100C. 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 reconstruction processes, and air-field pavements.

5.2 Bridges

The use of high performance concrete would result in smaller loss 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 precast 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. In the construction of the concrete bridges and highway structures a general requirement of using a water-binder ratio of less than 0.40 combined with the use of silica fume so as to improve the chloride resistance against de-icing agents and marine environment is recommended. This process improvement will provide the advantages of reduced weight, increased strength and enhanced durability, refer to figure- 1.



(FIGURE- 1)

(FIGURE- 2)

5.3 High Rise Structures:

The reasons for using the high strength concrete in the area of high-rise buildings are to reduce the dead load, the deflection, the vibration and the noise, and the maintenance cost, refer figure 2 for high rise building.

5.4 Hydropower Structures:

Hydropower Structures are constructed to tap the untamed water resources and generate useful Electrical Energy for the benefit of mankind. The quantity of concrete consumed in making various components of hydropower structures is enormous. A few of its components viz. glacis of Spillway, Diversion Tunnel, Head Race Tunnel, Silt Flushing Tunnel, Tail race Tunnels etc. are required to be lined/coated with High Performance Concrete so that their performance in handling high velocities of water and huge quantities of silt is enhanced. The use of High Performance concrete has resulted into lesser repairs, on one hand, and increased durability, on the other hand. Some of the hydropower structures are Spillway, Tunnels, Dams, Intakes, etc. Refer to figure 3.

(FIGURE- 3)

5.5 Miscellaneous Applications:

Fibre reinforced concrete has been used with and without conventional reinforcement in many field applications. These include bridge deck overlays, floor slabs, pavements and pavement overlays, refractories, hydraulic structures, thin shells, rock slope stabilization, mine tunnel linings and many precast products. The addition of steel fibres is known to improve most of the mechanical properties of concrete, namely, its static and dynamic tensile strengths, energy abrasion and toughness, and fatigue resistance. Hence proper utilization of steel fibre reinforced concrete depends on the skill of the engineer. High-performance concrete is often used in bridges and tall buildings.

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VI. CONCLUSION

The paper presents an overview of the concept of high-performance concrete and some of its applications in civil engineering constructions. 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. On the basis of their use, they offer different advantages such as enhanced durability, reduced permeability, higher strength etc. at an economical cost. 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. There is little doubt that the use of high performance concrete will continue to grow. No technical difficulties exist. However, such growth necessitates a provision for ready mixed concrete producers of concrete made under a very high control of quality of ingredients and of processing. At the same time, such Provision is conditional upon demand from the Engineers and other professionals.

REFERENCES

1. A.Kmita,(2000), A New Generation of Concrete in Civil Engineering, Journal of Materials Processing Technology, Vol. 106, pp. 80-8 6.
2. Vatsal Patel, Neeraj Shah (2013), A Survey of High Performance Concrete Developments in Civil Engineering Fields, Open Journal of Civil Engineering, pp. 69-79.
3. M.L.Gambhir(2014), Concrete Technology, Theory and Practice, Fifth Edition.Oral Büyüköztürk and Denvid Lau, High Performance Concrete: Fundamentals and Application.
4. Dr. R. B. Khadiranaikar, High Performance Concrete
5. Gambhir ML (2004) concrete technology (third edition) Pg 507 Published by the Tata MC- Graw hill publishing company limited, New Delhi, India.
6. Proceeding of national seminar on "advanced concrete Technology, Patiala, India September, 22-23, 2000
7. State of art report on high strength concrete 1984, American Concrete institution (ACI 363) Detroit.
8. Neville AM (1981). Properties of concrete, fourth edition, PP 674-688
9. Gana AJ, Sanjeev N (2008). Modern Technological Era for High performance concrete. Published in Nigeria by NOM-NOM, Abuja (FCT)
10. M S Shetty (2000). Concrete technology (theory and practice) pg 321-323. Printed by Rejendra Rovindra printers New Delhi, and Published by S. Chand and company, New Delhi, India