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High-Performance Concrete: Need of Hour

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Abstract: **-- This paper highlights various factors responsible for the deterioration of conventional concrete, resulting in its malfunctioning during its service life. In order overcome these issues the development of High-Performance Concrete (HPC) has taken place. The primary cause for deterioration of concrete structures is found to be permeation. HPC development is aimed at minimizing this aspect with proper proportioning of available materials, apart from increasing its resistance towards sulphate attack, corrosion of embedded steel, abrasion, erosion and cavitation etc. The Desirable properties of ingredients like cement, aggregate, admixtures, water, etc. used for developing HPC1 have also been discussed. Approaches for reduction of capillary pore size and role of chemically active binding agents to improve the resistance to permeation have also been presented. Besides these, the role of quality control in placing, compaction and curing of concrete for its improved performance is also discussed.**

Keywords**:- High Performance Concrete, Cement, Admixtures, Aggregates.**

I. INTRODUCTION

Conventional Concrete is widely used as construction material in various structures and other infrastructure projects throughout the world. The conventional concrete is mainly designed on the basis of compressive strength alone and in many cases it fails to meet functional requirements due to insufficient properties like impermeability, resistance to frost, thermal cracking etc.

Conventional concrete is found deficient in respect of various aspects like:

- Durability i.e. exhibits shorter service life
- Deficient in tensile strength
- Deficient in energy absorption for earthquake-resistant structures
- Unsuitable in some cases of Retrofitting of Structures

Permeation is a major factor that causes premature deterioration of concrete structures. The provision of high-performance concrete must aim on minimizing permeation through proportioning methods and suitable construction/curing procedures to ensure that the exposure conditions do not cause ingress of moisture and other agents responsible for its deterioration.

On the basis of causes for transportation of moisture, vapour, air, gases, or dissolved ions into the concrete, permeation can be divided into three sections:

- Concrete takes in water by capillary suction. The rate at which water enters the concrete is called Sorptivity.
- The flow of fluid through concrete usually under a pressure differential is referred as Permeation.
- Vapour or gas ions are sucked through concrete under the action of ion concentration differentials known as diffusion.

It is important to identify the transport phenomenon, which one is more dominant among these and thereby designing the mix proportions, with the aim of reducing that transport mechanism to a predefined acceptable performance level based on permeability. High degree of impermeability is required to prevent the ingress of water/CO2/SO4/oxygen/chloride. High resistance to sulphate attack, corrosion of embedded steel, abrasion, and cavitation are desirable. Smooth fractured surface having no signs of micro-cracking, high electrical and chemical resistivity are also desirable.

1.1 HIGH PERFORMANCE CONCRETE (HPC)

High performance concrete (HPC), possesses most of the desirable properties during fresh as well as in hardened stages of concrete, which can efficiently take care of deficiencies of conventional concrete. The performance requirements may involve improvement in placement and compaction without segregation, to achieve long term mechanical properties, early age strength, continued strength development, high workability and control of slump, toughness, volume stability, service life, low water binder ratio, low bleeding and low plastic shrinkage, through a tight and refined pore structure of the cement paste.2HPC is supposed to possess the higher structural capacity while maintaining adequate durability and a significant reduction in construction time without compromising long-term serviceability. The performance

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requirements of concrete will not be the same for different applications.4

In general, a "HPC" has the better durability for any given grade of concrete and comparison between the concretes of different strength classes is not appropriate.

1.2 METHODS FOR ACHIEVING HPC

In general, better durability performance is achieved by using low water-cement ratio in concrete. Though in this approach the design is based on strength, the optimization of critical parameters like size of aggregates, water-cement ratio etc. result in better durability.

For production of HPC, two approaches are employed to achieve durability through different techniques are listed below:-

- In first approach we try to reduce the capillary pore system such that no fluid movement can occur. This is very difficult to realize and all concretes shall have some interconnected pores1. Refer Fig.1

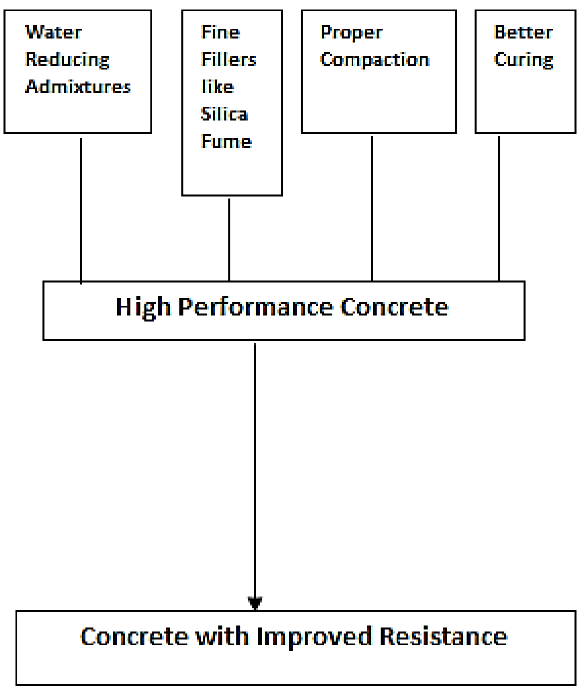

Figure 1: Reduction of Capillary Pore Size for Production of HPC.

-Introducing chemically active agents like fly ash, rice husk ash, various blended ashes, GGBS, metakaolin etc. which prevent transport of aggressive ions like chlorides due to their bonding action. The use of these chemically active binding agents has proved to be another effective technique for producing HPC. Refer Fig.2

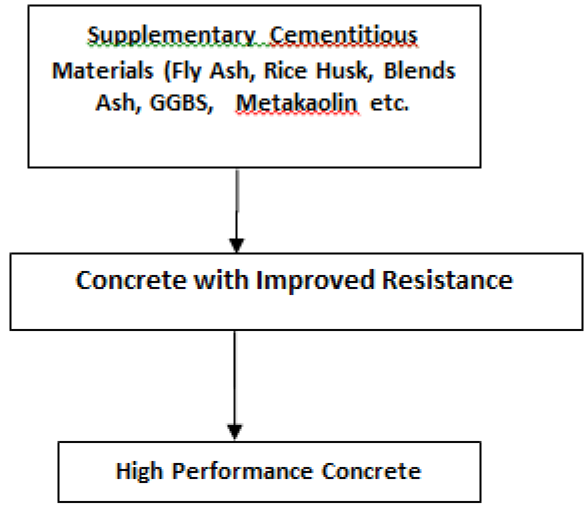

Figure 2: Role of Chemically Active Binding Agents to Improve Resistance of concrete.

1.3 Constituent Materials for HPC

(a) Cement

i. The rich C3A content in cement leads to a rapid loss of flow in fresh concrete. Therefore, cement used for HPC should have less C3A content.

ii. The cement should be compatible with the retarders and other admixtures being used for production of HPC.

iii. The fineness of cement plays a vital role. More fineness of cement increases the development of early strength, but results in rheological deficiency in most cases, as the higher cement content makes it sticky and henceforth sluggish for lower water-cement ratio.

(b) Aggregates

The strength of aggregate becomes important in case of HPC. Among the important parameters of coarse aggregate which influence the performance of concrete, are shape, texture and the maximum size:

i. Surface texture and mineralogy affect the bond between the aggregates and the paste as well as the stress level at which micro cracking begins. The surface texture, therefore, may also affect the modulus of elasticity, the shape of the stress strain curve and to a lesser degree, the compressive strength of concrete. Tensile strengths may be very sensitive to variation in aggregate surface texture and size i.e. surface area per unit volume. A rough and porous textured aggregate is desirable for good bonding and higher strengths. However the porous structure may affect the water demand for mix significantly.

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ii. The use of larger maximum nominal size of aggregate affects the strength in several ways. Since larger aggregates have less specific surface area and the aggregate-paste bond strength is less, the compressive strength of concrete is reduced. Also, for a given volume of concrete, using larger aggregate results in a smaller volume of paste thereby providing more restraint to volume changes of the paste. This may induce additional stresses in the paste, resulting in micro cracks prior to application of load, which may be a critical factor in very high strength (VHS) concretes.

iii. It is the general consensus that smaller size aggregate should be used to produce high performance concrete. It is generally suggested that 10 to 12 mm is the appropriate maximum size of aggregates for making high strength concrete. However, adequate performance and economy can also be achieved with 20 to 25 mm maximum size graded aggregates by proper proportioning with a mid-range or high-range water reducer, high volume blended cements and coarse ground Portland cement.

(c) Admixtures

Admixtures form an essential part of the high-performance concrete mix. Characteristics of admixtures play a vital role in determining properties of concrete7. Two types of admixtures are discussed below:

I .Mineral Admixtures

The mineralogical and granulometric characteristics of admixtures, intensifies concrete properties. The pozzolanic material with large surface area shows excellent reactivity imparting stability and cohesiveness to the mixture and prevents bleeding as well as segregation:

i. The Fly Ash (FA), the Ground Granulated Blast Furnace Slag (GGBS) and the Silica Fume (SF) Calcined clay and Calcined shale have been used widely as supplementary cementitious materials (SCM) in high performance concrete. These mineral admixtures, typically Fly Ash and Silica Fume (also called condensed silica or micro silica),reduce the permeability of concrete to carbon dioxide (CO2) and chloride-ion penetration without much change in the total porosity.

ii. The pozzolanas may also react with other alkalis such as sodium and potassium hydroxides present in the cement paste. These reactions reduce permeability, decrease the amounts of harmful free lime and other alkalis in the paste, decrease free water content, thus increase the strength and improve the durability.

iii. With use of Fly Ash, there is little evidence of carbonation, which has low to average permeability and good resistance to chloride-ion penetration.

iv. The concrete with silica fume appear to be more robust to early drying as compared to similar concretes that do not contain Silica Fume. Silica Fume is normally used in combination with high-range water reducers which increases achievable strength levels considerably11.

v. Silica Fume helps to improve resistivity of HPC to the tune of 20-25 times that of normal concrete, thereby increasing the resistance to electric circuit formation and thereby reducing the corrosion.

vi. In dry state, HPC plays the role of good dielectric medium. Although wherever there are cracks developed in HPC there is suppression to the macro-corrosion cell development due to strong resistivity of HPC. In such cases, the effect of corrosion is localised and negligible in nature.

vii. Since there is no interaction between Silica Fume, ground granulated blast-furnace slag and Fly Ash, and each component manifests its own cementitious properties. As hydration proceeds, higher strength and better flow ability can be achieved by adding a combination of Silica Fume (SF), Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS) to Ordinary Portland Cement (OPC) which provides, a system with wider particle-size distribution.

viii. Highly-reactive metakaolin (HRM) is also a good supplementary cementitious material. It is a reactive alumina-silicate pozzolana manufactured by calcining purified kaolinite at a specific temperature range. It is classified as a natural pozzolana, with silica and alumina oxides content exceeding 95 per cent. The particle size is smaller than Portland cement but coarser than Silica Fume. HRM improves the durability, impermeabilty apart from earlier strength gains

ix. The long-term performance of concrete can be affected by the reaction between the siliceous aggregates and alkali hydroxides present in cement. The properties of HPC that help combat Alkali Silica Reaction (ASR)are:

a) Very low water to cement ratios can help HPC to dry out at its own to levels which do not allow Alkali Silica Reaction (ASR) to occur.

b) The low permeability of HPC helps to minimize the entry of external moisture to the concrete.

c) Alkali Silica Reaction (ASR) inhibiting admixtures can be used to produce HPC which helps in controlling Alkali Silica Reaction (ASR).

d) These concretes are immune to Alkali Silica Reaction (ASR) and hence proper measures may be taken.

II. Chemical Admixtures

The efficient use of cementitious materials in large amount for producing HPC is possible only with the use of chemical admixtures. The chemical admixtures act as water reducers/retarders7.Hence for obtaining lowest water cement ratios the use of high-range water reducers or super-plasticizers is necessary:

i. The efficiency of Chemical admixture, its compatibility with cement and other supplementary cementing materials and other admixtures can be evaluated by trial batches. The workability, setting time of the mix and amount of water reduction for given admixture dosage rates and times of addition, can be checked through trials.

ii. Although for structures like bridges, concrete piles, piers, which are prone to freeze thaw environment, the entrained air is mandatory which can be achieved with the use of air entraining admixtures. The use of air-entraining admixtures is not necessary or desirable in high-strength concrete used for interior columns and shear walls of high-rise buildings, as these members are not exposed to weather directly.

iii. As Air entrainment decreases the strength of concrete mixes, the trials for optimum air contents may be conducted. For frost resistance, some high-strength concretes may not need as much air as normal-strength concrete to be frost resistant.

The non-air-entrained, high-strength concretes had good frost and de-icer-scaling resistance at a water to Portland cement ratio8 of 0.25.

It was also found that good frost resistance with non-air-entrained concrete containing Silica Fume at a water to cementing materials ratio3 of 0.22. For mixes, with Portland cement only water to cement ratio of 0.28 was appropriate.

iv. The super-plasticizers are extensively used in HPCs with very low water cementitious material ratios. In addition to de-flocculation of cement grains, they help to increase the fluidity.

v. There is no prior way of determining the required super-plasticizers dosage; it must be determined by trial and error procedure. Basically, if strength is the primary criterion, then one should work with the lowest w/c

ratio possible, and thus the highest super-plasticizers dosage. However, if the rheological properties like workability of the HPC in fresh state are very important, then the highest w/c ratio possible consistent with the required strength should be used, with the super plasticizers dosage then adjusted to get the desired workability. In general, of course, some intermediate positions must be found, so that the combination of strength and rheological properties are optimized.

II. PLACING, COMPACTION, FINISHING AND CURING

After preparation of concrete mix, its arrival at job site, the foremost important role is of concrete placing, its compaction, finishing and thereby curing. Final adjustment to the concrete, if any required at site, should be properly supervised by the consultant familiar with HPC:

i. Delays in the process of delivery and thereby placing must be eliminated. The batch sizes may be reduced in case of placing activities are at a slower pace than anticipated. There should not be any addition of re-tempering water. The workability can be increased, in case required, by the addition of a super-plasticizers after consultation with designer.

ii. Compaction also plays a very important role in achieving the potentials of HPC. Concrete must be vibrated as easily as possible after placement in the forms. High-frequency vibrators should be small enough to allow sufficient clearance between the vibrating head and reinforcing steel. Over-vibration of workable concrete often results in segregation and loss of entrained air or both.

iii. On the other hand, HPC without super-plasticizers is relatively stiff and contain little air. Normally HPC is placed at slumps of 180mm to 220 mm. Even at these slumps, some vibration is required to ensure compaction. The amount of compaction should be determined by onsite trials.

iv. HPC is often difficult to finish because of its sticky nature. High cementitious materials contents, large dosages of admixtures, low water contents and air entrainment all contribute to the difficulty of finishing these concretes5. Because the concrete sticks to the trowels and other finishing equipment, finishing activities should be minimized. The finishing sequence should be modified from that used for normal concrete.

v. Curing of HPC is even more important than curing normal-strength concrete. Providing adequate moisture and favourable temperature conditions is recommended for a prolonged period.

vi. Additional curing considerations apply with HPC, where very low water-cement ratios are used, and particularly where Silica Fume is used in the mixture, there will be

vii. little bleeding before or after finishing.

In these situations it is imperative that fog curing or evaporation retarders be applied to the concrete immediately after the surface has been struck off. This is necessary to avoid plastic shrinkage cracking of horizontal

surfaces and to minimize crusting. Fog curing, followed by 7 days of wet curing has proven to be very effective.
To achieve comprehensive quality-control program is required at both the concrete plant and on site to ensure consistent production and placement of HPC. Inspection of concreting operations from stockpiling of aggregates through completion of curing is important. Also, routine sampling and testing of all materials is particularly necessary to control uniformity of the concrete.

III. CONCLUSIONS

The conventional materials like cement, aggregates and water used for production of concrete and the methods of normal mixing, placing, and curing fail to achieve the durability and strength requirements during service life. Depending on different applications, different type of HPC are developed by judicious use of cement, aggregates, water along with various sort of admixtures and other cementing materials. The characterised materials like cement with low C3A content, aggregates with specific shape texture and size are used apart from using various type of admixtures. The mineral admixtures like Fly Ash, GGBS, Silica Fume, High Reactive Metakaolin, etc. improve the impermeability and resistance to various threats for concrete structures like alkali, chloride ion penetration, corrosion and ASR etc. The use of chemical admixtures and super-plasticizers play a vital role in enhancing the properties of concrete. Above all the role of a comprehensive quality control at plant and construction sites fills the gap responsible for deterioration of concrete.

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