Applications of High-Performance Concrete in Heavy Civil Industry

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Abstract - *In rapidly growing industrial world, infrastructure projects are inevitable to cope up with demand of development. Concrete and steel are the most widely used construction material in infrastructure projects. Due to time and space constraints modification of concrete properties according to site conditions has become predominant. Hence, High Performance Concrete (HPC) has evolved as major area of research and its applications i.e., Heavy Civil Structures, High Rise Buildings, Industrial Structures, Hydraulic Structures, Transportation, Defense, etc. The term HPC here pertains to the essential feature of this concrete is that it's ingredients and proportions are specifically chosen so as to have particularly appropriate properties for the expected use of the structure such as high strength and low permeability. Having proved better workability, durability, high tensile strength, environment friendly material, HPC is getting wide acceptance in modern world. Today we cannot exploit environment at the expense of building materials. Hence there is need to rationalize use of waste material like fly ash from thermal power plants, silica fume, and blast furnace slag etc. Therefore, HPC is effectively consuming these materials in production with enhancing its desirable properties. On the other side cost of concrete is depend on the cost of its ingredients which is scarce & expensive and using these waste materials makes HPC economical. As HPC serves quality and economy, it has vast scope in research and its applications. Our quest is to justify that how different parameters right from trail mix designs & tests to handling & pouring on site affect the performance of concrete using statistical & graphical methods of data interpretation.*

Key Words: High Performance Concrete (HPC), Heavy Civil Structures, Environment Friendly Materials, Mix Design, Statistical & Graphical Method

1. INTRODUCTION

Concrete is the most widely used construction material in India with annual consumption exceeding 100 million cubic metres (S. Chaudhary, R. Bajaj, R. Sharma, 2014). Conventional Ordinary Portland Cement Concrete which is designed on the basis of compressive strength does not meet many functional requirements as it is found deficit in aggressive environments, time of construction, energy absorption capacity, repair and retrofitting jobs etc. So, there is a need to design High Performance Concrete which is far superior to conventional concrete as the Ingredients of HPC contribute most efficiently to the various properties (V. Patel & N. Shah, 2013). Also, it has to perform satisfactorily on properties like strength, permeability, workability, durability and cohesive mix which give a response to long term environmental effects (S. Patil, 2016).

1.1 WHAT IS HPC?

American Concrete Institute (ACI) states, "High Performance Concrete is concrete that meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing, and curing practices."
HPC can be termed as concrete having grade greater than M-45 (As IS: 10262-2009 caters for the concrete up to the grade M- 40).

1.2 Classification of HPC related to Strength.

Actually, high performance concrete evolved gradually over the last 15 years or so, mainly by the production of concrete with higher and higher strengths: 80, 90, 100, 120, 140 MPa, and sometimes even higher. Nowadays, in some parts of the world, 200 MPa can be routinely produced.

Table -1: Strength of HPC

Compressive Strength (MPa)	50	75	100	125	150	200
High Performance Class	I	II	III	IV	V	VI

2. MATERIAL USED FOR HPC

Ingredients	M50	M60
Cement OPC53	430	440
GGBS	70	35
Microsilica	NA	25
20mm down Aggregate	782	788
10mm down Aggregate	368	371
Crusher Sand	832	832
Admixture dosage	0.8%	1.1%
W/C Ratio	0.29	0.28

First, HPC very often contains silica fume whereas ordinary concrete usually does not. Secondly, high performance concrete usually, although not always, contains fly ash, or ground granulated blast furnace slag (or slag, in short), or both these materials. The aggregate has to be very carefully chosen and has a smaller maximum size than is the case with ordinary concrete: in high performance concrete, the maximum size is usually 10 to 20 mm. There are two reasons for this. First, with a smaller maximum size, the differential stresses at the aggregate-cement paste interface, which could lead to microcracking, are smaller. Second, smaller aggregate particles are stronger than larger ones; this is due to the fact that comminution of rock removes the largest flaws, which control strength.

2.1 Use of Admixtures in HPC

Admixtures play an important role in the production of HPC. Mineral Admixtures form an essential part of the HPC mix. They are used for various purposes depending upon their properties. Table 2 shows different types of mineral admixtures with their particle characteristics. Chemical composition determines the role of mineral admixtures in enhancing properties of concrete. Different materials with Pozzolanic properties such as Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), Silica fume (SF), High Reactivity Metakaolin (HRM), Rice Husk Ash (RHA), Copper Slag, Fine Ground Ceramics have been widely used as supplementary cementitious materials in the production of HPC [3-74]. Such applications not only help to improve the strength and durability characteristics of HPC but will also help to dispose more of the industrial by-products which are major environmental threats.

Different Chemical admixtures (Super plasticizers) are extensively used in development of HPC with very low water cement ratio are represented in Table 3 with their functions.

Table -2: Different mineral admixtures used in HPC

Mineral Admixtures	Classification	Particle Characteristics
Ground granulated blast furnace	Cementitious and pozzolanic	Unprocessed materials are grain like sand, ground to size < 45μm particles and have a rough texture.
Fly ash	Cementitious and pozzolanic	Powder consists of particles size < 45μm, 10% to 15% are more than 45μm, solid spheres and generally smooth.
Silica fume	Highly active pozzolana	Fine Powder consisting of solid spheres of 0.1μm average diameter.
Rice husk ash	Highly active pozzolana	Particles are 45μm in size and have cellular and porous structure.

Table -3: Different chemical admixtures used in HPC

Chemical admixtures	Function
Superplasticizer	To reduce the water requirement by 15% to 20% without affecting the workability leading to a high strength and dense concrete.
Accelerator	To reduce the setting time of concrete thus helping early of forms and therefore used in cold weather concreting.
Retarder	To increase the setting time by slowing down the hydration of cement and therefore are preferred in places of high temperature concreting.
Water reducing admixture	To achieve certain workability (slump) at low water cement ratio for a specified strength thus saving on the cement.
Air entraining admixture	To entrain small air bubbles in concrete which act as rollers thus improving the workability and therefore very effective in freeze-thaw cycles as they provide a cushioning effect on the expanding water in the concreting in cold climate.

3. METHODOLOGY FOR HPC

1. Raw materials collected and tested as per IS 2386.
2. Proportioning of aggregates on maximum density approach as per IS 2386.
3. Mix design is done by carrying out sufficient number of trial mixes to achieve desired strength.
4. Casting of samples for various cementitious contents with different percentage of fly ash and microsilica is done as shown in figure 1.
5. Testing of samples at 7 & 28 days age is performed as shown in figure 2.

4. LAB TESTS PERFORMED ON HPC

4.1 Cube Test

The concrete cube test is performed for the purpose of determining the compressive strength of a concrete element. The cubes used for this test have a dimension of 150 x 150 x 150 mm as long as the largest aggregate does not exceed 20 mm.

Fig -1: Cube casting in Moulds

Fig -2: Testing of Cube in CTM

5. STASTICAL AND GRAPHICAL ANALYSIS

5.1 Methodology

1. Compressive strength after 7, 28 days is plotted against M50, M60 design mix respectively.
2. Results are compared with target strength equation given by IS 10262:2019.

$$f'_{ck} = f_{ck} + 1.65 \times S$$

Where,
f'_{ck} = target mean compressive strength at 28 days,
in N/mm^2;
f_{ck} = characteristic compressive strength at 28 days, in N/mm^2;
S = standard deviation (5 N/mm^2)

3. Finally, the graphical analysis is done.

5.2 Results and Interpretation

Table -3: Compressive Strength of M50 & M60 HPC

Curing Period (Days)	Compressive Strength (MPa)	
	M50	M60
3	33.15	37.81
7	51.79	59.16
14	64.08	78.16
28	67.45	83.28

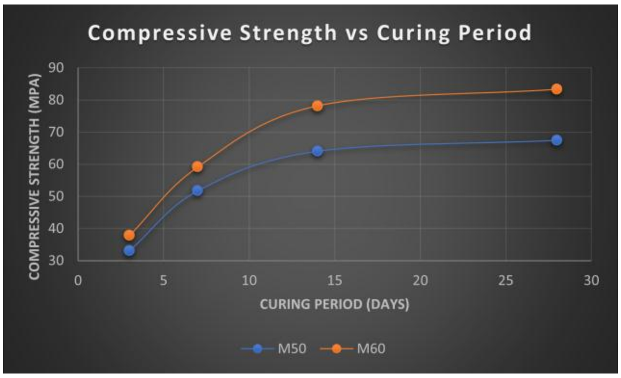

Chart -1: Compressive Strength vs Curing Period

6. CONCLUSIONS

As per IS 10262:2019, target strength for M50, M60 concrete mix design are 58.25, 68.25 MPa respectively. The strengths achieved in lab for M50, M60 mix design are 67.45, 83.28 MPa respectively. This implies achieved compressive strength is considerably higher than target strength as per IS 10262:2019. This is interpreted as designed mix has fulfilled standard criteria and hence can be used for manufacturing of M50, M60 or higher-grade concrete for Heavy Civil structures.

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