EFFECT OF VARIOUS MINERAL ADMIXTURES ON MECHANICAL AND DURABILITY PROPERTIES OF HIGH PERFORMANCE CONCRETE

Ch.Yamini Nikhita[1], P.Sowjanya[2], B. Sri Kalyan[3]

[1]PG Student, Department of Civil Engineering & Srinivasa institute of engineering and technology, Amalapuram,yamini.nikhita@gmail.com
[2]Asstiant Professor, Department of Civil Engineering & Srinivasa institute of engineering and technology, Amalapuram,sowji.soni@gmail.com
[3] Assistant Professor, Department of Civil Engineering& VSM College of engieering,Ramachandrapuram,srikalyan17@gmail.com

Abstract:

Concrete is a durable and versatile construction material. However experience has shown that concrete is vulnerable to deterioration, unless safety measures are taken during the design and production. It has been increasingly realized that besides strength, there are other equally important criteria such as durability, workability and toughness; and hence concrete is developing towards high performance, i.e., high strength, high toughness, high durability, and good workability. High performance concrete (HPC) is not a special type of concrete, it comprises of the same materials as that of the conventional cement concrete, by using silica fume and super plasticizer enhance the strength, durability and workability qualities to a very high extent.
The study is limited to a binary blended HPC mix modified by 10 % silica fume, 15% fly ash and 50% GGBS as cement replacement designed for characteristic strength of 70MPa. The strength tests are carried out after 28 day water curing except for compressive strength test which was carried out after 3, 7, 28, 56 and 90 day water curing. Two different curing conditions are examined for durability tests via 7 day water curing and 14 day water curing after which the specimens will be exposed to the respective chemical solution for a time period of 56 and 90 day. Laboratory scale specimens are prepared and tested for strength and durability of various mixes.
Keywords: *Silica fumes, Fly ash, GGBS, High performance concrete, strength, durability*

1. INTRODUCTION

Concrete is a durable and also a versatile construction material. However experience has shown that concrete is more vulnerable to deterioration, unless safety measures are taken during the design and production. For this it is necessary to understand the influence of components on the behaviour of concrete and to produce a concrete mixes within controlled tolerance. One of the main cause of deterioration in concrete structures is the corrosion of concrete due to its exposure to harmful chemicals that are found in nature such as, in some ground waters, industrial effluents and seawaters. The most aggressive chemicals that affect the long term durability of concrete structures are chlorides and sulphates. The chloride dissolved in water increase the rate of leaching of portlandite and thus increases the porosity of concrete, and lead to loss of stiffness and strength. Calcium, magnesium, sodium, and ammonium sulphates are in increasing order of hazard harmful to concrete as they reacts with hydrated cement paste leading to cracking, expansion, spalling and loss of strength. The rate at which the hardened cement paste is deteriorated due to the exposure to harmful chemicals depends mainly on the concentration of the chemicals in water, the time of exposure and the chemical resistance of concrete. HPC is a concrete mix made with appropriate materials combined according to a selected mix design; properly mixed, transported, placed, and cured so that the resulting concrete will give excellent performance in the structure in which it is placed, in the environment to which it is exposed and with the loads to which it will be subject for its design life. Mix proportion for HPC is influenced by many factors, including specified performance properties, local experience, locally available materials, personal preferences and cost. The HPC does not require special ingredients or special equipments except careful design and production of the concrete mix. HPC has improved durability characteristics and much lesser micro-cracking than normal strength concrete. Engineers are increasing the use of HPC since it is designed to give optimized performance characteristics for the given set of materials, exposure conditions and usage, consistent with requirements of cost, durability and service life.HPC works out to be economical even though its initial cost is higher than that of conventional concrete; it’s because the use of HPC in construction enhance the service life of the structure and the structure suffers less damage which would reduce overall costs.

2. MATERIALS

The main ingredients of HPC are:

1. Cement
2. Fine aggregate
3. Coarse aggregate
4. Water
5. Chemical admixtures
6. Mineral admixtures

Chemical admixtures are the essential ingredients in the concrete mix, as they increase the efficiency of cement paste by improving workability of the mix and there by resulting in considerable decrease of water requirement. Retarders help in reduction of initial rate of hydration of cement, so that fresh concrete retains its workability for a longer time. Air entraining agents artificially introduce air bubbles that increase workability of the mix and enhance the resistance to deterioration due to freezing and thawing actions.

Mineral admixtures like fly ash, silica fume *etc*. act as pozzolonic materials as well as fine fillers, thereby the microstructure of the hardened cement matrix becomes denser and stronger. Pozzolona play an important role when added to Portland cement because, they usually increase the durability and mechanical strength of concrete structures. The term pozzolona refers to a siliceous material which is in a finely divided form and in the presence of water, will react chemically with calcium hydroxide to form cementitious compounds. The most important effects in the cementitiou's paste microstructure are changes in pore structure produced by the reduction in the pore size caused by the pozzolonic reactions and the obstruction of pore sand voids by the action of the finer grains (physical or filler effect) Silica fume is also known as micro silica, silica fume is a by-product of the smelting process in the silicon and Ferro silicon industry. Condensed silica fume, volatized silica or silica dust. It is usually a grey coloured powder, somewhat similar to Portland cement or some fly ashes. It can exhibit both cementitious and pozzolonic properties. The fly ash is produced from burning pulverized coal in electric power generating plants, also known as pulverized fuel ash. It is finer than Portland cement. Diameter of fly ash particles ranges less than 1–150 µm. Ground granulated blast furnace slag (GGBS) is by-product from the blast furnaces used to make iron. GGBS can be used as direct replacement for ordinary cement on one-to-one basis by weight. Metakaolin particles are extremely small with an average particle size of 3µm. It has an off-white colour. Major constituents of metakaolin are silica oxide and aluminium oxide. Metakaolin reacts with $Ca(OH)_2$, produces calcium silicate hydrate gel at ambient temperature. The formation of secondary calcium silicate hydrate gel reduces total porosity and refines the pore structure, improving the strength and impermeability of the cementitious matrix. The above discussed are the commonly used mineral admixtures. The type of mineral admixture to be used in concrete depends on the environment in which it is exposed to and to the loads it is being subjected to. For example the concrete having silica fume has high early strength so it can be used in places where high early strength is required. Similarly other mineral admixtures can also be selected for various purposes based on their behaviour. Mineral admixtures can also be used in combination in concrete i.e. as secondary or ternary blend.

3. TESTS AND RESULTS:

3.1 WORKABILITY MEASUREMENT TEST:

At present standard methods are not available to measure the workability of HPC. The compacting factor test is more appropriate in the case of high strength concrete which has low water binder ratio. Slump test was also done to measure the workability of HPC.The workability of various mixes was assessed as per the IS 1199:1959 specification. Table1 shows the values of compacting factor and slump for various mixes of HPC.

Table 1 Workability details of various HPC mixes

Mix Type	Compacting factor	Degree of workability	Slump (cm)
HPCL	0.957	High	22.5
HPSF	0.949	High	20.0
HPFA	0.971	High	25.5
HPGB	0.957	High	23.6

3.2 COMPRESSIVE STRENGTH TEST:

Testing of hardened concrete is important for controlling the quality of concrete. The main purpose of testing hardened concrete is to conform that the concrete has developed required strength. The compressive strength is one of the most important properties of hardened concrete and in general it is the characteristic value for classification of concrete in various codes. Compression test of cubes is the most common test conducted on hardened concrete because it is an easy test to perform and most of the desirable properties of concrete are comparatively related to its compressive strength. To find cylinder compressive strength, the cylinder of size 150mm × 300mm is kept on the bottom plate of the machine and the position of the cylinder is carefully checked to be in the centre of the plate. The cylinder is loaded at the rate of 14 N/mm^2/min up to failure. The cylinder compressive strength was determined for various HPC mixes after 28 day water curing. Fig 1 shows compressive strength test on cube and cylinder.

Figure 1: Compressive strength test on cubes and cylinders

Table 2 Average cube compressive strength for HPC mixes

Water curing (days)	Compressive strength for HPC Mixes (N/mm^2)			
	HPCL	**HPSF**	**HPFA**	**HPGB**
3	50.5	54.33	48.67	35.67
7	61.5	70.17	56.83	51.17
28	79.67	88.17	69.67	75.67
56	85.5	93.33	77.33	84.83
90	87.83	95.67	83.67	89.17

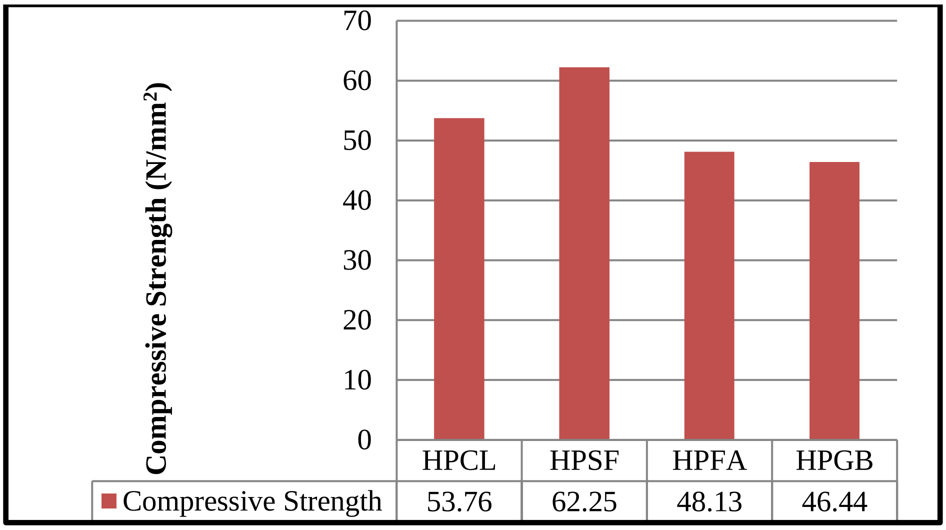

Figure 2: Graph for different HPC Mixes V/S Compressive strength

3.3 SPLIT TENSILE STRENGTH:

The split tensile strength test is a well-known indirect test used for determining the tensile strength of concrete. Test was carried out on concrete cylinder of size 150mm × 300mmas per IS 5816:1999 specification. In split tensile strength test, concrete cylinder was placed with its axis horizontal, between the loading surface of a compression testing machine and the load was applied until the failure occurred due to a splitting in the plane, containing the vertical diameter of the specimen. In order to reduce the magnitude of high compression stress near the points of application of the load, narrow packing strips of plywood were placed between the specimen and loading plates of the testing machine. The split tensile strength was determined for HPC mixes with various mineral admixtures after 28 day water curing. Fig3 shows split tensile strength test on cylinder.

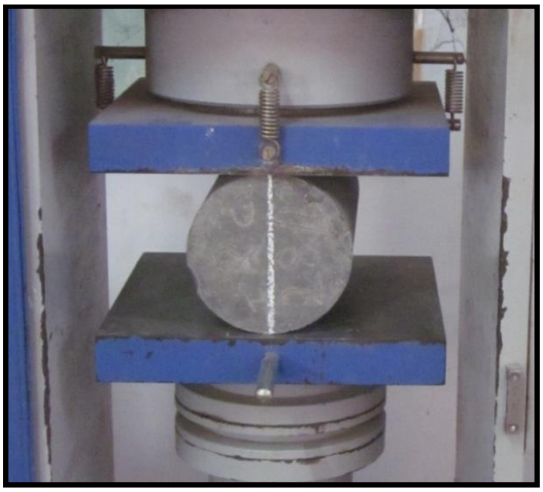

Figure 3: Split tensile strength test on cylinders

Table 3 Split tensile strength for various HPC mixes

Mix	Average compressive strength f_{ca} (N/mm^2)	Average split tensile strength f_t (N/mm^2)	$f_t / \sqrt{f_{ca}}$
HPCL	79.67	5.8	0.65
HPSF	88.17	6.224	0.663
HPFA	69.67	4.295	0.515
HPGB	75.67	4.564	0.525

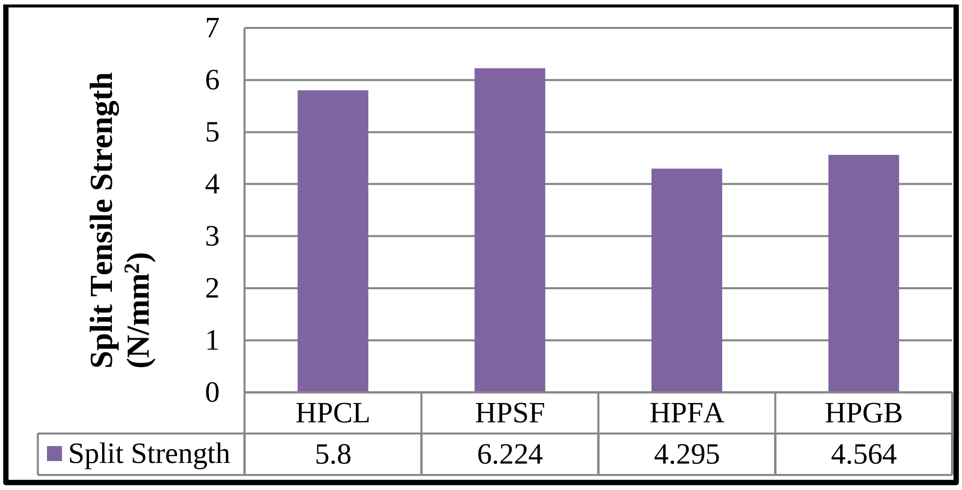

Figure 4: Graph for different HPC Mixes V/S Split tensile strength

3.4 FLEXURAL STRENGTH TEST:

Three beam specimens of size 100mm×100mm×500mm were tested for determining the flexural strength as per IS 516:1959 specification. Two-point loading was applied and breaking load was noted. The flexural strength was determined for all HPC mixes after 28 day water curing. Fig5 shows flexural strength test on beam.


Figure 5: Flexural strength test on beams

Table 4 Flexural strength for various HPC mixes

Mix	**Average compressive strength f_{ca} (N/mm^2)**	**Average flexural strength f_{cr} (N/mm^2)**	$f_{cr} / \sqrt{f_{ca}}$
HPCL	79.67	4.823	0.54
HPSF	88.17	5.831	0.621
HPFA	69.67	4.488	0.538
HPGB	75.67	4.64	0.533

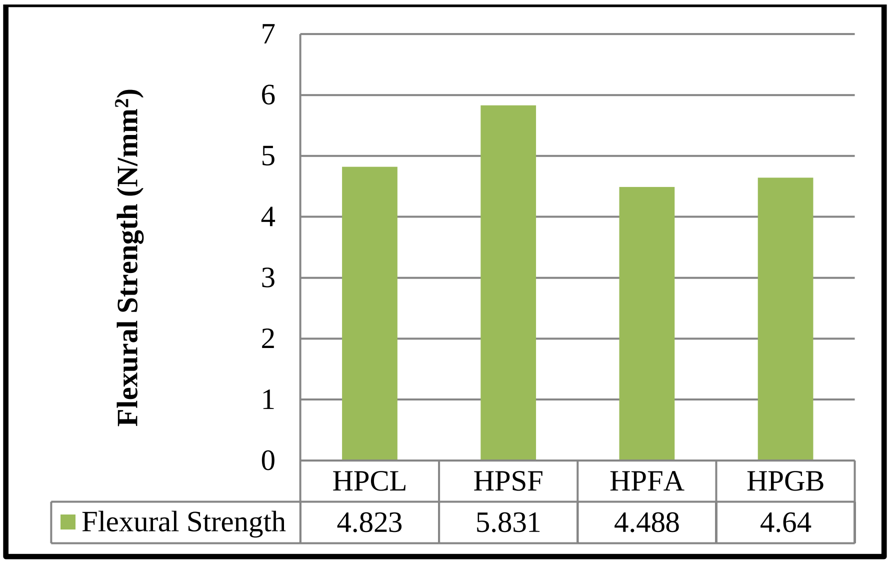

Figure 6: Graph for different HPC Mixes V/S Flexural strength

3.5 SULPHURIC ACID ATTACK TEST AND SULPHATE ACID ATTACK TEST:

To check the durability of HPC with various mineral admixtures against sulphuric acid, 100mm concrete cube specimens were tested based on modified ASTM C 267-01 test method. After 7 days of water curing or 14 days of water curing, the concrete specimens were exposed to 3% sulphuric acid solution for 56 days and 90 days, and the surface colour change and surface deterioration were studied. The 3% sulphuric acid solution was prepared by diluting 98% concentrated sulphuric acid with tap water. After 56 days and 90 days of acid exposure, specimens were tested for compressive strength. The compressive strength of HPC mix with mineral admixtures was then compared with HPC mix without mineral admixture exposed to acid environment as shown in Fig7 the specimen exposed to 3% sulphuric acid solution and 20,000 ppm sulphate solution.

Figure 7: Specimens exposed to sulphric acid and sulphate attack

Table 5 Compressive strength of various HPC mixes subjected to acid attack

Mix	Compressive strength (N/mm^2)				
	28 day water curing	7 day water curing		14 day water curing	
		56 day acid exposure	90 day acid exposure	56 day acid exposure	90 day acid exposure
HPCL	79.67	50.67	45.83	52.67	48.33
HPSF	88.17	66.83	63.67	69.67	67.33
HPFA	69.67	51.17	47.33	50.33	47.83
HPGB	75.67	52.83	50.67	55.33	54.17

Table 6 Compressive strength of various HPC mixes subjected to sulphate attack

Mix	Compressive strength (N/mm^2)				
	28 day water curing	7 day water curing		14 day water curing	
		56 day sulphate exposure	90 day sulphate exposure	56 day sulphate exposure	90 day sulphate exposure
HPCL	79.67	72.17	67.67	74.67	71.33
HPSF	88.17	84.83	82.83	84.33	83.33
HPFA	69.67	65.67	63.83	66.33	64.83
HPGB	75.67	71.83	71.33	73.17	72.67

4. CONCLUSIONS:

Based on the experimental work carried out on investigation to study the effect of various mineral admixtures on the mechanical and durability properties of HPC, the following conclusions are shown below:-

- By the addition of silica fume resulted in lower workability, addition of fly ash and GGBS improved the workability of the mix.
- The addition of the different mineral admixtures significantly influences the compressive strength of the HPC mixes. The HPSF mix exhibited higher strength

values at all ages than HPCL, HPFA & HPGB mixes. Due to the slower reactivity of GGBS, their inclusion reduces the early strength of the concrete but at later ages the strength was similar to that of HPCL mix. HPFA mix exhibited a strength lower than HPCL mix at all ages but the rate of strength development for the mix was found to increase after 28 day compared to HPCL mix and ultimately it is expected to exceed the strength of HPCL mix.

- In case of split tensile strength and flexural strength at 28 day, HPSF mix showed the maximum value compared to all other mixes and the replacement of cement by GGBS or fly ash decreased the split and flexural strength compared to HPCL mix.
- In this study the acid curing is done for 56 days and extended to 90 days and because of the addition of the admixture to the concrete, the compressive strength increases for both 56 days and 90 days than for conventional concrete, and the compressive strength of concrete for 56days shows much increase than for 90 days.
- The mass loss is minimum for 7 days acid curing for HSPF and for 14 days water curing for HPGB.
- The strength loss due to sulphate attack is minimum for both the 56 days and 90 days of curing for HPGB mix than the strength loss for HSPF and HPFA mix for same curing conditions.
- Even though silica fume mix is not as efficient as GGBS mix in retaining strength under severe environmental exposure conditions, but owing to its contribution in progressively enhancing the strength could be considered as the most appropriate in cement replacement in exposure conditions where strength values is the evaluation criterion.

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