

Asian Journal of
Applied
Sciences

Strength and Durability Characteristics of GGBFS Based HPC

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ABSTRACT

Concrete plays a very important role in infrastructure development like buildings, bridges and industrial structures etc. Long term performance of buildings without deterioration helps economies of nation. High Performance Concrete (HPC) is one which shows special performance than normal concrete. This necessitates use of mineral and chemical admixtures to improve concrete performance. In this study an attempt has been made to study strength and durability characteristics of M60 grade concrete by partial replacing natural sand and cement with ROBO Sand (crusher dust) and Ground Granulated Blast Furnace Slag (GGBFS), respectively. Experiments were conducted with different percentage replacements of sand of 40, 60 and 80% and cement of 40, 50 and 60% with ROBO sand and GGBFS, respectively. There were 16 combinations of mixes studied for its compressive strength and short term durability characteristics such as resistance against acid and sulphate attack. Finally, it was observed that the specimens with combination of GGBFS and ROBO sand for 40% had the optimum compressive strength and resistance against sulphate, acid attack as a result it can be concluded that replacement of cement and sand with GGBFS and ROBO sand improved the strength and resistance against sulphate and acid attack of the concrete compared to control concrete.

Key words: GGBFS, ROBO sand, acid attack, sulphate attack, compressive strength, HPC

INTRODUCTION

HPC is a concrete which exhibits better characteristics such as good strength, better durability and high workability. American Concrete Institute defines HPC as a concrete which is developed for certain application and environment with specific characteristics. It is also worth to mention that it is concrete with good quality of materials with suitable mix design. This concrete also is to be properly mixed, transported and placed with good period of curing to get excellent performance and to serve for its full term without any deterioration, the increase in water cement ratio makes more sensitive to drying curing conditions (Atis *et al.*, 2005). Mix design of HPC is influenced by number of factors like quality of materials, type of mineral and chemical admixtures, expertise available and production methodology (Bharatkumar *et al.*, 2001). The use of admixture is a widely used application in concrete production and many recent studies were done all over the world and brought out their beneficial effects on characteristics of concrete (Vejmelkova *et al.*, 2009; Turkmen, 2003; Lo *et al.*, 2009; Shariq *et al.*, 2010; Saridemir *et al.*, 2009; Pazhani and Jeyaraj, 2010). Hardened cement paste is severely attacked by sodium chloride, sulfate, acid solutions due

to acid attack corrosive products develop on the hardened cement paste surface and Mineral admixtures improved the compressive strength, appearing porosity and capillarity coefficient (Turkmen, 2003). The strength of concretes containing slag or fly ash when compared to control concrete appears to be sensitive to poor curing (Ramezaniapour and Malhotra, 1995). The addition of Silica fume, Blast furnace slag and flyash resulted in low permeability but increased the resistance to chloride ions. HPC with silica fume and natural pozzolana can show good strength and durability characteristics (Shannag and Shaia, 2003). When mineral admixtures were added to HPC some beneficent effects absorbed in concrete with low w/b ratio GGBFS perform well than fly ash (Shi *et al.*, 2009). Various types of curing materials and curing process are followed on slag based concrete which results in improvement of concrete (Yilmaz and Turken, 2012; Wang, 2008). The effect of GGBFS and ROBO sand as replacers for cement and sand, respectively on strength of High Performance Concrete for M30 grade concrete and found that both additions helped in improving the strength of concrete (Malagavalli and Rao, 2010). Many works were reported by many researchers in replacing cement with GGBFS and fly ash without affecting the strength. A number of studies (Pazhani and Jeyaraj, 2010; Malagavalli and Rao, 2010) have been conducted on the durability and strength of concrete made with mineral admixture concrete. The main constituents in production of concrete are Cement and River sand (Fine aggregate) which has become costly and scarce. Hence, searching for alternative materials has got a great attention in the research field. The crusher dust obtained from the granite crusher can be used as a substitute for river sand which is widely known and used as ROBO sand in western countries. Development in concrete industry has led to utilization of waste material in concrete. Steel industry growth is enormous; the GGBFS is obtained from iron and steel industries as by product. In the present study, sand and cement were replaced with ROBO sand and GGBS, respectively. The effect of these replacements on strength and durability characteristics of HPC was studied and optimum mix was arrived.

EXPERIMENTAL PROGRAM

Materials: Locally available pozzolana Portland cement complying with Indian standard grade 53 were used. Specific gravity of cement used is 3.15. Locally available Natural River sand passing 4.75 mm IS sieve is used. Physical properties of fine aggregate are fineness modulus 2.88, specific gravity 2.65 and density (loose) is 16 kN m^{-3} .

Coarse aggregate of size 12.5 mm available locally were used. Physical properties of coarse aggregate were studied fineness modulus 5.25, specific gravity 2.7 and density (loose) 14.4 kN m^{-3} . Super plasticizer in the form of high range water reducer (conplast SP430) was used. It also conforms to ASTM C-494 Type F. ROBO sand obtained from local granite crusher conformed to IS: 383 were used in concrete to cast cubes. ROBO Sand passed through 2.36 mm and retained in 150 micron is used as a replacer of sand. GGBFS complying with ASTM C 989 was supplied from steel industry, Salem, India. GGBFS were used as replacer for cement. The chemical composition and physical properties are given in Table 1. The water to be used for both curing and mixing should conform to IS: 456 2000 and should be free from harmful deleterious materials. In the present investigation potable water was used for curing and mixing.

Mix proportion: The concrete mix design is done as per ACI method for conventional concrete and finally 40, 60, 80% river sand has been replaced by ROBO sand and 40, 50, 60% cement replaced with GGBFS by volume. Water-binder ratio (w/b) of 0.27 was adopted and it is reduced to 0.25 by

Table 1: Physical and chemical properties of ground granulated blast furnace slag

Typical chemical composition	Values	Typical physical properties	Values
Calcium oxide (%)	41	Colour	off-white
Alumina (%)	13	Specific gravity (g cm^{-3})	2.9
Silica (%)	35	Bulk density (kg m^{-3})	1200
Magnesia (%)	9	Fineness ($\text{m}^2 \text{kg}^{-1}$)	>350

adding super plasticizer. Super plasticizer is added to maintain slumps of all investigated mixes at 70 ± 30 mm. The mix proportions of M60 concrete are 1:0.5:1.82.

Test procedure: Cement replaced by GGBFS for different percentage such as 40, 50, 60% and sand replaced by ROBO sand for different percentage such as 40, 60, 80%, respectively. Compressive strength testing was done on hardened concrete. For all the mixes Compressive strength tests were carried out in accordance with ACI method; three specimens of 100 mm cube were done for each mixture. After 24 h the sample was demoulded and cured for a period of 28 and 56 days, respectively and testing was done using compression testing machine of 2000 kN capacity at a rate of 150 kN min^{-1} conforming ASTM C 39 standards. And the average compressive strength of cubes has been reported.

Durability characteristics such as sulphate and acid resistance were studied by making cubic specimen of 100 mm size for different percentage of replacement of cement and sand with GGBFS and ROBO sand, respectively and acid curing was done for 28 and 56 days, respectively and compressive test was done according to ACI standards. And control concrete was compared with final result.

RESULTS AND DISCUSSION

Compressive strength: Specimens of different combination and control concrete were cast and tested for its 28 and 56 days strength. The 28 days average compressive strength of specimen under normal curing is shown in Table 2. Figure 1 shows percentage decrease in strength at the ages of 28 and 56 days with respect to CC in normal curing condition. Table 3 shows the 56 days average compressive strength of specimens under normal curing. It can be seen from the table that compressive strength of concrete decrease with increase in slag and also due to the addition of mineral admixture workability of concrete are reduced. Replacing cement with GGBFS for 40, 50, 60% and sand with ROBO Sand for 40, 60, 80% and combination of both GGBFS and ROBO sand has shown decrease in strength when compared with control concrete. Compressive strength was found to be in the range of 56.4 to 61.5 Mpa for 28 days aged concrete and from 67.9 to 72 Mpa for 56 days aged concrete and the lowest value belong to GGBFS 60% and ROBO sand 80% combination. Since GGBFS were much finer than cement, it filled the micro pores in the cement paste. The decreased percentage difference between CC and slag based concrete was found to be between 0.3 to 8.2%. Hence, it is concluded that 50% GGBFS can be used as an optimum percentage of replacement for cement, if cement only replaced. For concrete subjected to combined replacement of cement and sand with GGBFS and ROBO sand, the optimum percentage was 40% GGBFS and 40% of ROBO sand. Similar findings were also arrived by Patel *et al.* (2013). They found that 50% of cement can be replaced with GGBFS. They also highlighted that concrete with 40% GGBFS and 20% ROBO sand has given 16.54% increase in compressive strength. Pathan *et al.* (2012) found that concrete with 40% GGBFS has resulted an increase in compressive

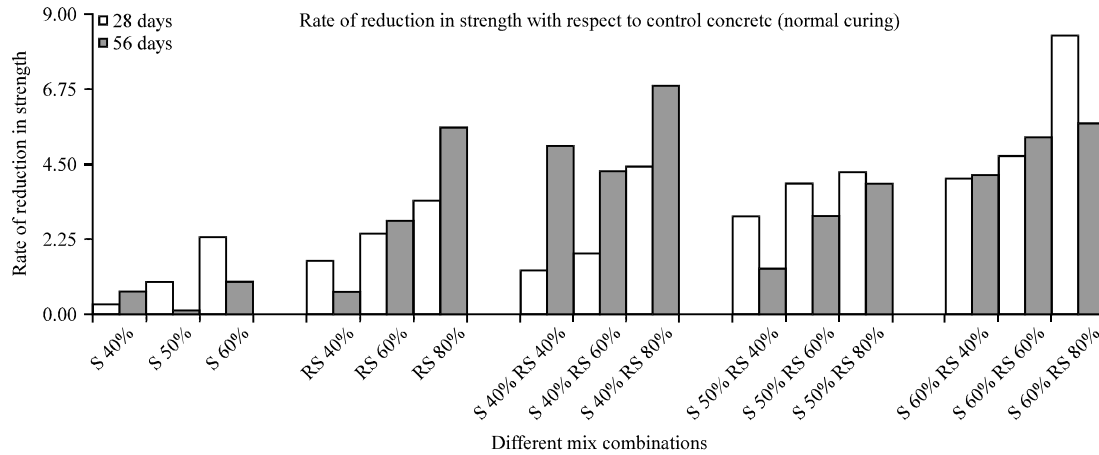


Fig. 1: Rate of reduction in strength of admixed concrete at the ages of 28 days and 56 days (normal curing)

Table 2: Compressive strength of different mixes at the age of 28 days

Specimen	Average compressive strength in MPa		
	Normal curing	H ₂ SO ₄ curing	HCl curing
CC	61.5	71.00	73.00
S 40%	61.3	71.50	73.50
S 50%	60.9	72.00	74.80
S 60%	60.1	74.00	75.00
RS 40%	60.5	73.00	74.00
RS 60%	60.0	74.00	74.70
RS 80%	59.4	72.00	75.80
S 40%RS 40%	60.7	78.70	81.00
S 40%RS 60%	60.4	76.00	78.00
S 40%RS 80%	58.8	75.20	77.00
S 50%RS 40%	59.7	76.90	74.90
S 50%RS 60%	59.1	77.00	80.00
S 50%RS 80%	58.9	77.40	79.30
S 60%RS 40%	59.0	76.00	78.00
S 60%RS 60%	58.6	77.90	78.20
S 60%RS 80%	56.4	78.00	77.70

strength to an extent of 5% than the control concrete and further addition of GGBFS reduced the strength of concrete. Brindha *et al.* (2010) studied the possibility of replacing sand and cement with copper slag for ordinary concrete. They found that the compressive strength of slag concrete for all the replacements (20, 40 and 60% of copper slag) were more than the strength of control concrete. They also concluded that concrete with 40% slag gave higher increase in strength compare to other mixtures.

Resistance to sulphate and acid attack: Specimens with various percentage replacements were cast and cured in H₂SO₄ and HCl. Resistance to sulphate and acid attack greatly increased with the use of GGBFS and ROBO sand. Table 2 shows the average compressive strength of specimens

Table 3: Compressive strength of different mixes at the age of 56 days

Specimen	Average compressive strength in MPa		
	Normal curing	H ₂ SO ₄ curing	HCl curing
CC	72.0	75.00	77.00
S 40%	71.5	77.00	79.30
S 50%	71.9	78.20	80.00
S 60%	71.3	78.60	80.80
RS 40%	71.5	79.40	82.00
RS 60%	70.0	81.00	82.90
RS 80%	68.0	78.30	79.00
S 40%RS 40%	68.4	82.90	82.70
S 40%RS 60%	68.9	81.50	83.00
S 40%RS 80%	67.1	79.60	81.40
S 50%RS 40%	71.0	79.00	83.90
S 50%RS 60%	69.9	77.80	80.00
S 50%RS 80%	69.2	78.10	83.10
S 60%RS 40%	69.0	80.20	84.60
S 60%RS 60%	68.2	81.70	82.80
S 60%RS 80%	67.9	81.40	83.60

at the age of 28 days under H₂SO₄ and HCl curing and Table 3 shows the average compressive strength of specimens at the age of 56 days under H₂SO₄ and HCl curing. Twenty eight days average compressive strength has shown increase in strength when compared to CC in both curing condition. GGBFS and ROBO sand for 40% combination have shown good performance when compared to other combinations where as GGBFS 60% and ROBO sand 40% has shown good performance in 56 days curing. The percentage increase also found to be around 10% for H₂SO₄ and HCl curing when compared with CC. Figure 2 and 3 shows percentage increase in strength at the ages of 28 and 56 days curing in H₂SO₄ and HCl with respect to CC. Mineral additive content in cement decreased the deterioration of specimens. The slag based concrete has shown good results under H₂SO₄ and HCl curing when compared with normal curing. Due to the addition of GGBFS and ROBO sand durability properties were improved the predominant reaction is due to alkali hydroxide but later the reaction is due to calcium hydroxide, replacement of cement with 40% GGBFS and sand with 40% ROBO sand in which pozzolanic reactions occurs hydration products are yielded by GGBFS and good grading of ROBO sand fills the pores. Modified microstructure and low heat of hydration helps in improving the durability of concrete. Presence of correct fines in GGBFS reduces the hydration of concrete. For 28 days H₂SO₄ and HCl curing, average compressive strength was found to be between 71-81 Mpa. For HPC with GGBFS and ROBO sand with w/b ratio of 0.25 durability characteristics were found to better at optimum replacement of 40%. When comparing the performance of slag based concrete under normal curing condition and acid curing condition, specimens under acid curing has performed well. Due to cubicle particle shape, consistent gradation of ROBO sand and normal fines of GGBFS creates a good microstructure as result durability characteristics were achieved. The cementitious system of slag based concrete is low and benefits were exhibited at later stage. Optimum replacement of mineral admixture improves the bonding by filling the voids. Brindha *et al.* (2010) have done experiments on resistance of slag based concrete against sulphate and acid attack and found that slag added concrete had lesser resistance than that of control concrete. They also concluded that concrete with 40% slag gave

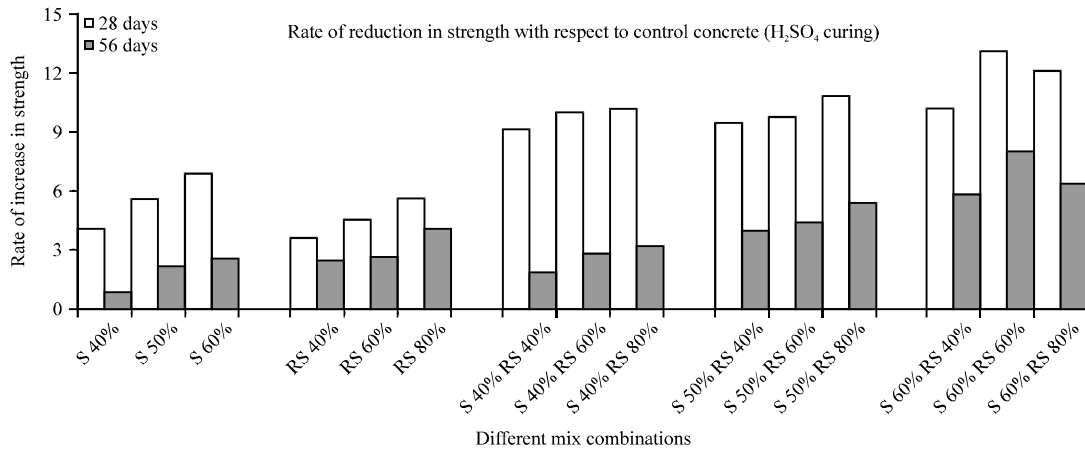


Fig. 2: Rate of increase in strength of admixed concrete at the ages of 28 days and 56 days (H_2SO_4 curing)

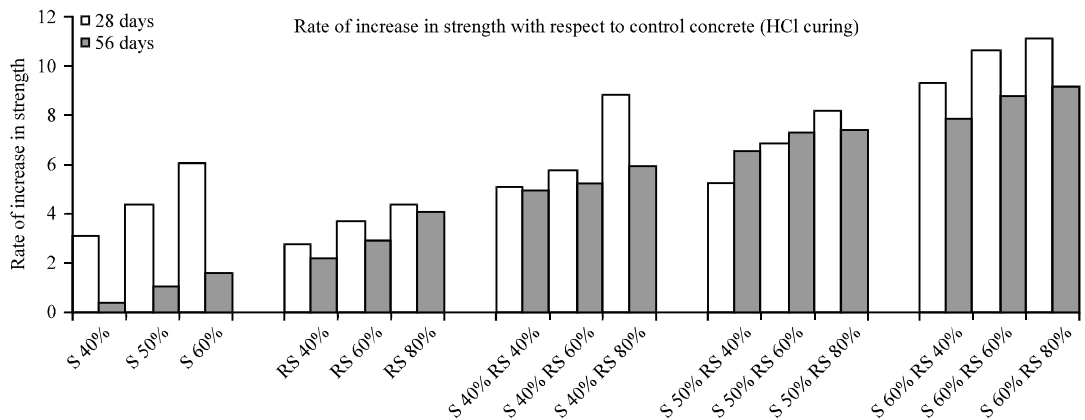


Fig. 3: Rate of increase in strength of admixed concrete at the ages of 28 days and 56 days (HCl curing)

higher increase in strength compare to other mixtures. Murthy *et al.* (2007) studied the effect of fly ash on ordinary, standard and higher grade concrete on resistance to sulphate attack and found that addition of fly ash improved the resistance to sulphate attack because of modification of microstructure in the concrete.

CONCLUSION

Based on detailed experimental investigations carried out on concrete with GGBFS and ROBO sand to replace cement and sand respectively, following conclusions were drawn:

- From the experimental results obtained it is proved that GGBFS can be used as an alternative material for cement and ROBO Sand can be used as an alternative material for sand
- Replacement of cement with GGBFS and sand with ROBO sand resulting strength reduction to an extent of only 3 and 5%, respectively. The above values are very much acceptable in the

field. When both cement and sand were replaced with replacement of sand with effected only 5% reduction with sand was found to be with in 5% and both combination of GGBFS and ROBO sand was found to be with in 10% in normal curing

- Durability characteristics of concrete have shown good performance for different percentage of replacement of GGBFS and ROBO sand. Replacement of both GGBFS and ROBO sand for 40% gave a satisfactory result
- Resistance to acid and sulphate attack of admixed concrete has given 10% more strength than the control concrete. It was also found that, admixed concrete exhibited better resistance to acid attack than sulphate attack at the later age
- Usage of GGBFS and ROBO sand is eco friendly, but setting time of slag based concrete was found to be more when compared to control concrete

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