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Research Article

Effect of Nano Ground Granulated Blast Furnace Slag (GGBS) Volume % on Mechanical Behaviour of High-Performance Sustainable Concrete

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Utilization of various mineral admixtures in producing mortar decreases the porosity and capillarity, hence improves the durability in opposition to water and competitive solutions. In this research work, Ground Granulated Blast Furnace Slag is used to replace 30 percent, 60 percent, and 70% of ordinary Portland cement (OPC) (GGBFS). Mechanical property (compressive strength) and durability properties (permeability, porosity, and sorptivity) of high-performance concrete (HPC) are tested. Water permeability of M85 is measured using three cell permeability apparatus. Compressive strength, porosity, and sorptivity of the same mixes are also found. According to the test results of HPC, 30% replacement level of GGBFS gives higher compressive strength than 60% and 70% replacement levels of GGBFS. An equation is developed for permeability of HPC based on mechanical strength and porosity. It is found that coefficient of permeability of water for HPC mixes ranges from 5.1 × 10-11 cm/sec to 7.8 × 10-11 cm/sec. It is concluded that 30% GGBFS used in HPC produces less porosity, less permeability, and less sorptivity than compared to other replacement levels.

1. Introduction

Excessive performance concrete (HPC) is a brand new magnificence of concrete that has evolved in latest decades. HPC has a low water content and can attain sufficient rheological properties by combining optimal granular packing with the addition of excessive-range water lowering admixtures. One primary high-quality best within the making of HPC is the virtual elimination of voids within the concrete matrix that generate deterioration. Therefore, HPC has a tendency to exhibit superior residences such as superior energy, durability, and lengthy-time period balance. In competitive contexts, the long-term durability of concrete systems is always a concern to consider. When it comes to structures that are continually in contact with water, such as offshore systems, parking decks, and dams, water penetration is the most important aspect that determines the structure's durability. As a result, the permeability of the concrete and its pore architecture are crucial to its long-term endurance. Supplementary cementitious materials in high-performance concrete showed excellent performance in durability [1]. Chakraborty et al. [2] reported concrete developed with

NANO GGBS produces a cohesive mix that reduces the permeability. Cheah and Chow [3] reported the replacement of cement by NANO GGBS improved the capillary penetration resistance of concrete significantly. Due to insufficient Ca (OH)2 from cement hydration, NANO GGBS produces high amount of secondary C-S-H and C-A-S-H bonds that reduced both micro and macro pores in concrete. Therefore, an optimum performance was observed in tests of porosity, permeability, water absorption, and capillary absorption. It was reported concrete with NANO GGBS exhibited high resistance to ingression of chloride ions. Upon 80% or above replacement of NANO GGBS, compressive strength was greatly decreased [4]. Xie et al. [5] reported geo-polymer concrete developed with high amount of NANO GGBS exhibited decrease. Even after sulphate exposure during acid evaluations, there was less mass loss and a larger residual compressive electricity. As the amount of NANO GGBS in the diet grows, so does the sulphate resistance. Based on the findings of this literature review, it was discovered that there has been little research done on high-performance concrete made with large amounts of NANO GGBS. As a result, the primary goal of this project is to investigate the mechanical and durability properties of HPC for the desired concrete mixes developed with high volumes of NANO GGBS.

2. Experimental Studies

2.1. Ingredients of HPC. The cement used was Ordinary Portland Cement (OPC) 53 Grade having a specific gravity of 3.01. Effect of high volumes of NANO GGBS on strength and durability of high-performance concrete uses locally accessible river sand that conforms to grading zone II.

IS: 383–1970 [6] was used. The sand was screened at site to remove deleterious materials. Locally available coarse aggregate (12.5 mm) from quarry was used. Specific gravities of the coarse and fine aggregates have a density of 2.71 and 2.65, respectively. GGBFS (Ground Granulated Blast Furnace Slag) is a type of slag that comes from a blast furnace. Astrra chemicals, a local manufacturer company in India, was collected. Chemical properties were studied and compared to cement since being replaced as shown in Table 1. Super plasticizer GLENIUM B233, a modified polycarboxylic ether having pH ≥6, was used.

2.2. Mix Design and Methodology. Methodology as shown in Figure 1 is followed in this research work. Concrete cubes of size 15 cm^3 were kept in curing for 28 days to test permeability and sorption characteristics and also to determine strength as explained in methodology. Mix design procedure according to modified ACI method (Aitcin Method [7]) was followed and proportion is as shown in Table 2. In this mix, 30%, 60%, and 70% cement turned into changed by floor Granulated Blast Furnace Slag, retaining W/B ratio equal and the mix design named as GGBFS-30%, GGBFS-60%, and GGBFS-70% shown in Table 3. Formation of calcium silicate hydrate gel is the most important parameter in the concrete. The effect of maximum percentage of NANO GGBS may lead to less compressive strength in concrete.

Table 1: Chemical properties of mineral admixture.

Compound	Cement	GGBFS
SiO_2	23.1	35.34
Al_2O_3	4.51	11.59
Fe_2O_3	2.5	0.35
CaO	63.3	41.99
MgO	1.0	8.04
Alkalies	0.88	0.94
SO_3	1.3	1.3
Loss on ignition	2.41	0.45

2.3. Mixing and Specimen Testing Procedure. Mixing was performed in a concrete mixer gadget. Coarse aggregates, great aggregates, cement, and admixtures have been introduced to the mixer device and allowed to combine for 1 minute. Super-plasticizer was blended with the total water and then 50 percentage of water added to the mixture machine and allowed to mix for 2 minutes. Then, remaining 50 percentage of water poured in mixture machine and continued to mix for 2 minutes. Total mixing time was 5 minutes. Mixes were tried with varied mixing proportions and finally the proportion which gives the best results in terms of consistency and strength was selected. After demolding, the specimens had been saved for 28 days in curing water tank before testing. Dried specimens were examined for compressive electricity, porosity, permeability, and sorptivity. Compressive electricity takes a look at turned into carried out conforming to IS: 516 [8] on dice specimens of size one hundred mm × a hundred mm × a hundred mm. Permeability of 150 mm cube specimens and porosity of 100 mm cube specimens were calculated according to IS: 3085–1965 [9] and ASTM C642 [10], respectively. Sorptivity test of 100 mm cube specimens was carried out based on Taywood engineering (1993).

3. Results and Elobarations

3.1. Mechanical Strength. Compressive strength reduced with an addition of high volume of NANO GGBS as shown in Figure 2 and this reduction may be due to slower hydration rate and prolonged pozzolanic reaction [11]. Maximum compressive strength of 96.4 MPa at 28 days is found for the HPC specimens replaced with 30%. Table 4 shows the compressive strength of HPC concreate of GGBFS in Normal water curing. It is observed that performance of 30% replacement is almost similar to 0% replacement. This is due to the increase in the percentage of NANO GGBS in the mix design. Quantity of NANO GGBS decreases the quantity of gel formation.

3.2. Permeability. High volumes of NANO GGBS seriously affect durability. Permeability reduction is predominant at high NANO GGBS content [12]. As shown in Figure 3, permeability of HPC based on compressive power is expected. In comparison to GGBFS with a 30% substitution level, it has a low permeability value (3.2×10^{-11} cm/sec). It is

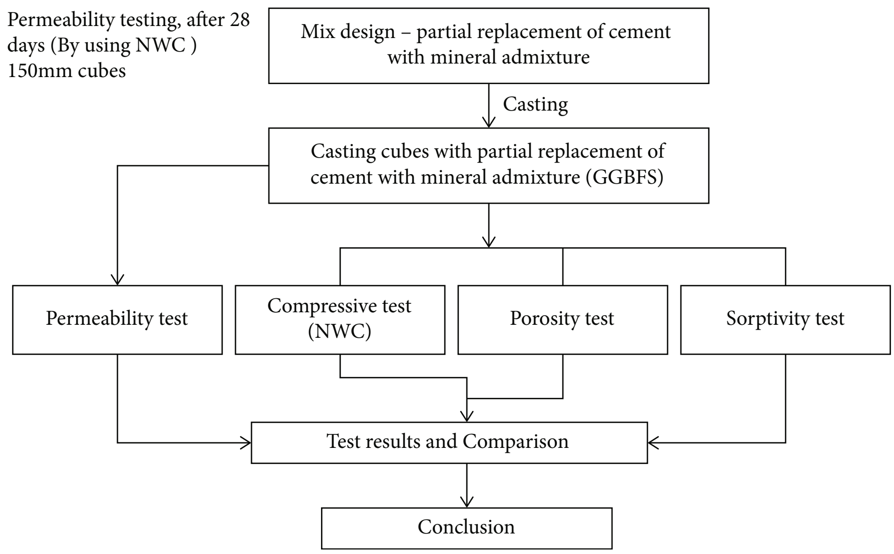

Figure 1: Methodology followed for testing HPC.

Table 2: Mix proportions for M80 grade concrete (Aitcin Method) were as mentioned.

W	C	FA	CA	SP
140	560	710.2	1075	5.7

Table 3: Mix design details of NANO GGBS.

Components	Replacement levels of NANO GGBS		
	GGBFS-30%	GGBFS-60%	GGBFS-70%
Water (lit.)	150.79	150.79	150.79
Cement (kg)	392	224	168
GGBFS (kg)	168	336	392
Coarse aggregate (kg)	1075	1075	1075
Fine aggregate (kg)	710.2	710.2	710.2
Super plasticizer (lit.)	5.503	5.503	5.503

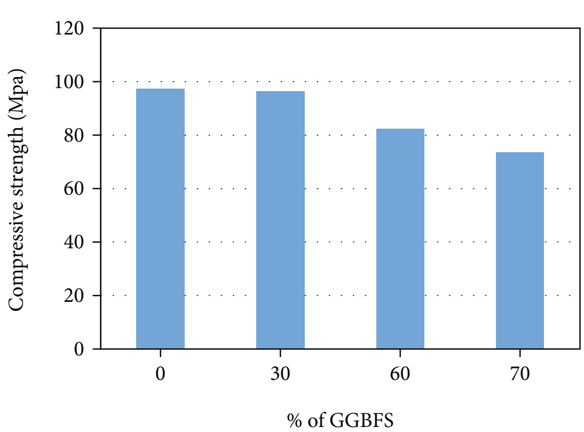

Figure 2: Variation of compressive strength at 28 days curing period.

Table 4: Compressive strength of HPC concrete at 28th day for various dosages of GGBFS.

Type of specimen	28th day compressive strength in N/mm^2 (NWC)
0% GGBFS	97.375
30% GGBFS	96.4
60% GGBFS	82.34
70% GGBFS	73.5

observed 30% NANO GGBS exhibited promising performance amongst all concrete mixtures tested. NANO GGBS refines capillaries and hence dense structure of micro-pores is responsible for absorption.

$ok = A(\text{fck})^2 + B(\text{fck}) + C$, where k and fck are the permeability (150 mm dice) and compressive energy (100 mm die) of concrete, respectively. The coefficients A, B, and C are obtained from the regression analysis [13].

The relationship between permeability and compressive power of concrete has been shown in parent four by way of employing NWC for GGBFS alternate levels [14]. From parent four, it was discovered that there was a significant association between permeability and concrete compressive strength, resulting in a regression coefficient (R^2) of zero. Permeability and compressive strength is shown in Figure 4.

3.3. Porosity. HPC was tested for porosity with various mineral admixtures (GGBFS). Table 5 shows the porosity results for the specimens that were tested [15]. GGBS gives more porous as this size is higher than the cement particles. That the reason we used NANO GGBS for better strength in the concrete. When compared to other replacements, GGBFS with 30% replacement level has a low porosity value (1.42 percent). To calculate the permeability of HPC using the porosity data provided in Figure 5 is sufficiently accurate [16].

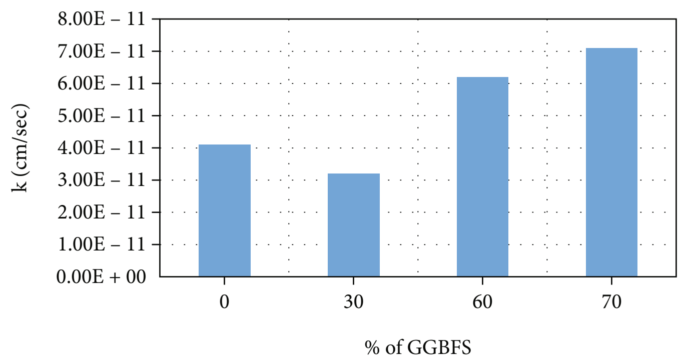

FIGURE 3: Variation of permeability at 28 days age.

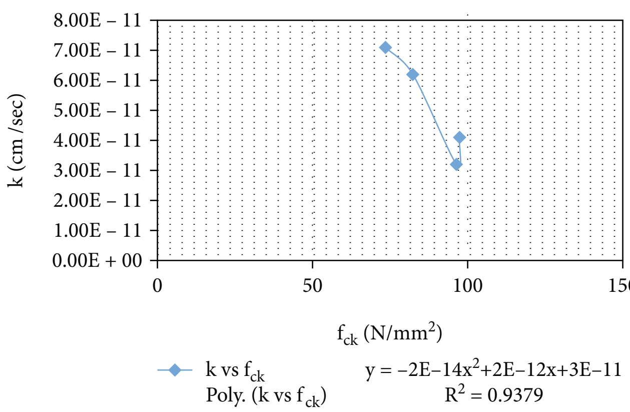

FIGURE 4: Permeability vs compressive strength.

TABLE 5: Porosity of HPC.

Mix	Porosity (%)
0% - GGBFS	1.65
30% - GGBFS	1.42
60% - GGBFS	2.08
70% - GGBFS	2.47

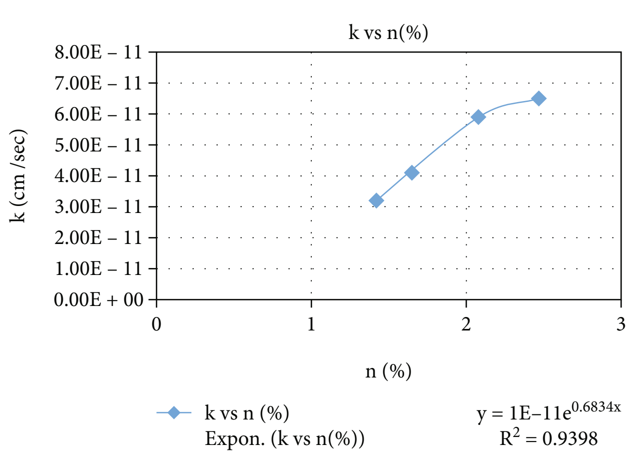

FIGURE 5: k vs n for GGBFS replacement levels.

TABLE 6: Sorptivity of HPC.

Mix	Sorptivity (m/√s) x 10^{-6}	
	30 minutes	60 minutes
0% - GGBFS	1.68	1.95
30% - GGBFS	1.99	2.33
60% - GGBFS	2.13	2.6
70% - GGBFS	2.17	2.8

TABLE 7: Quality of concrete suggested by Taywood Engineering.

Concrete quality	Sorptivity (m/s1/2) ∗ 10^{-4}
Good	0.13
Acceptable	0.13 to 0.26
Poor	>0.26

Correlation between permeability and porosity

$k = A\, e^{Bn}$,where 'k' represents the concrete's permeability (150 mm cubes) and 'n' represents the concrete's porosity (100 mm cubes).

The coefficients A and B are the results of the regression analysis. For GGBFS replacements, a study of permeability vs porosity was conducted. Because of the significant association between permeability and porosity of the concrete shown in Figure 5, regression analysis yielded a correlation coefficient (R^2) of 0.939 [17].

3.4. Sorptivity. The test for sorptivity was conducted on 100 mm cubes [18]. Cubes were placed in a hot air oven at a temperature of 105°C up to which constant mass is obtained at an interval of time [19] and the weight was noted [20]. Then, the specimen is immersed in water for different interval of time (30 and 60 minutes), till the constant mass was obtained and it was noted. After 28 days of curing, all replacement levels of admixtures show less sorptivity as given in Table 6. 30-GGBFS replacement shows less value of sorptivity in 28 days curing. The obtained sorptivity values of HPC were in acceptable range according to Taywood engineering limits as given in Table 7.

4. Conclusions

NANO GGBS in high-performance concrete has exhibited promising performance in durability characteristics at 30% replacement compared to other concrete mixes. High volumes of NANO GGBS seriously affect durability. Permeability reduction is predominant at high NANO GGBS content. It is observed 0% NANO GGBS exhibited lower performance amongst all concrete mixtures tested. Compressive strength reduces with an increment in NANO GGBS content for cement replacement. However, 30% NANO GGBS concrete mix has mere performance to ordinary concrete. Both porosity and water absorption declined at 30% and increased at further replacements. Sorptivity values were in acceptable range and surface absorption increased due to NANO GGBS in concrete. It is necessary to evaluate the impact of twofold blending on HPC permeability and diffusivity.

Data Availability

The data used to support the findings of this study are included within the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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