Impact of Ultrafine Ground Granulated Blast Furnace Slag on the Properties of High Strength Durable Concrete

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Abstract. Ultrafine ground granulated blast furnace slag (UFGGGBFS), because of its pozzolanic nature, could be an extraordinary resource for the advanced development needs, since slag cements concrete can be of elite, if properly planned. Improvement of the durability properties of concrete to support a more extended life expectancy and creating a climate amicable greener concrete are turning out to be significant standards in getting high quality concrete. Fusing Ultrafine Ground Granulated Blast Furnace Slag (UFGGGBFS) as a mineral admixture enhances the workability of fresh concrete and decreased the link between pores; in this way, decreasing the permeability and improving the obstruction of the solid against chloride infiltration. The measure of ozone depleting substance delivered in making the concrete and the energy needed to create the concrete are significantly decreased with the utilization of UFGGBFS. Ultrafine GGBFS (UFGGGBFS) with a normal molecule size less than 10m and a Blaine surface area more than 600m²/kg can significantly improve the properties of the concrete as far as diffusion and chemical reactivity impacts. Compared with GGBFS, the UFGGGBFS increases the rate of hydration and pozzolanic responses and has a superior filling impact. In this study, the early development of mechanical strength and permeability properties of high strength concrete with UFGGGBFS is examined. Total five mixes with 180kg/m³ each of both Ordinary Portland Cement (OPC) concrete and Ultrafine Ground Granulated Blast furnace Slag (UFGGGBFS) concrete were designed. The mixes starts from 0% replacement and gradually increases up to 20% (i.e 0, 5, 10, 15 and 20%) of identical all total cementitious materials with UFGGGBFS substitution were planned and a sum of 145 samples from the five blends were projected. Compressive strength parameters, flexural strength parameter, modulus of elasticity parameter and water permeability test outcomes are introduced.

1. Introduction

Establishing quality concrete in the current atmosphere doesn't rely exclusively upon accomplishing a high quality property. Improving the durable quality of the concrete to support a more drawn out life expectancy and delivering greener concrete are getting one of the principle rules in acquiring quality concrete. By utilizing modern byproducts, for example, Ground Granulated Blast furnace Slag (GGBFS) from industries as mineral admixture halfway supplanting Ordinary Portland Cement (OPC) in the concrete, the measure of ozone depleting substance delivered in making the concrete and the energy needed to create the concrete are diminished. GGBFS is an industrial byproduct produced when liquid iron blast furnace slag is quickly chilled by drenching it in water. To create environmental friendly concrete the best way is to replace the OPC content with some good mineral admixtures in the concrete. It has been all around archived that GGBFS is an awesome mineral admixture to be utilized in improving the properties of the concrete because of its beneficial outcomes on its feasible turn of events and the
climate. Significant level of strength value and durability of concrete are a need in diminishing the pace of decay of concrete. In mixing GGBFS with OPC, an improved flowable and reduced bleeding concrete can be accomplished.

It is fine reported that with the additional mix of GGBFS, the early strength of the concrete is influenced; anyway as the concrete curing age increases, the mechanical parameters of the concrete improves and matches that of the normal concrete at 56 days. Conversely, with the diminished fineness of the UFGGGBFS, rising the Blaine surface area and henceforth escalating the speed of hydration and pozzolanic response, the early strength of the designed concrete will improve altogether. The properties of GGBFS help the concrete in opposing chloride induced corrosion and the designed concrete will have a diminished pore connection which helps in preventing chloride entrance. The complete pore volume of concrete additionally diminishes as the slag fineness gets higher.

In this report, the impact of UFGGGBFS substitution on the durability and strength properties of high quality concrete is considered. Five blends in with various measure of UFGGGBFS substitution were considered. The measure of UFGGGBFS substitution was set from 0% to 20%. Compressive strength property, flexural strength property, and modulus of elasticity tests were performed to examine the impact of UFGGGBFS on the fresh and hardened properties of the concrete. The UFGGGBFS substitution brought about higher early strength, lower permeability, and better durable property.

2. Experimental investigations

A whole of 145 samples comprising of 100mm and 150mm dia. cylindrical specimens, 100mm cubical specimens, and 150mm cube specimens were examined. Compressive strength parameter, flexural strength parameter, and modulus of elasticity tests give the stage to focus on the mechanical viewpoint. The quality of UFGGGBFS utilized in this examination was inspected utilizing particle size analyzer and chemical study. The physical properties and oxide compositions obtained were recorded in Table 1.

Table 1: Chemical and Physical Composition of Ultrafine slag

| Chemical constituent | % by mass | Physical constituent | Range            |
|----------------------|-----------|----------------------|------------------|
| CaO                  | 32-35     | Bulk density         | 600-700 kg/m³    |
| Al₂O₃                | 18-20     | Surface area         | 12000 cm²/gm     |
| Fe₂O₃                | 1.8-2     | Particle shape       | Irregular        |
| SiO₂                 | 28-32     | Particle size, d₁₀   | < 2μ             |
| MgO                  | 8-10      | d₅₀                  | < 5μ             |
| SO₃                  | 0.3-0.7   | d₉₀                  | < 9μ             |

To get a minimum slump value of 150 mm, a polycarboxylate based high range water reducing agent (HRWRA) was utilized.

Table 2: Mix Proportion per cubic meter (For SSD Condition)

| Constituents      | Mixes     | M-300 | M-305 | M-310 | M-315 | M-320 |
|-------------------|-----------|-------|-------|-------|-------|-------|
| Cement (OPC)      | 533.33    | 506.67| 480   | 453.33| 426.67|
| UFGBGFS           | 0         | 26.67 | 53.33 | 80    | 106.67|
| Water             | 160       | 160   | 160   | 160   | 160   |
| Aggregate (20mm)  | 605.03    | 604.48| 603.94| 603.39| 602.85|
| Aggregate (10mm)  | 600.94    | 600.4 | 599.85| 599.32| 598.77|
| Natural Sand      | 677.46    | 676.85| 676.24| 675.63| 675.10|
| Density           | 2576.76   | 2575.06| 2573.36| 2571.67| 2569.97|
Mix 300 with the 5 % UFGGBFS replacement. Similarly M-310, M-315, M-320 were obtained. The particulars of the blends are introduced in Table 2. The samples were cured in water in lab temperature of near 25 °C for 3, 7, 28 and 56 days. Five varieties of samples were casted in two batches as indicated by each blend plan.

3. Results and discussion

3.1. Workability of the designed concrete

The workability of designed concrete blends was obtained by conducting slump test and the outputs are reported in Table 3. The slump value of 180 mm was obtained in Mix-320 and only 140 & 120 mm was obtained in Mix-310 and Mix-315 respectively.

| Table 3: Slump test value (mm)       |
|--------------------------------------|
| Mix abbreviation | % of Admixture Dosage | Slump value (mm) |
|-------------------|------------------------|------------------|
| M-300             | 0.40                   | 130              |
| M-305             | 0.30                   | 140              |
| M-310             | 0.25                   | 140              |
| M-315             | 0.20                   | 120              |
| M-320             | 0.15                   | 180              |

Figure 1. Freshly mixed and casted concretes

Figure 2. Relation between UFGGBFS with Admixture dosage in (%)

Freshly mixed concretes
3.2. Hardened properties (Compressive strength)

Compressive strengths of the cubical specimens inspected are assembled and recorded in Table 4. A research of the impact on the compressive strength properties due to increase volume of UFGGBFS in concrete was observed. As presented in Table 4, each mix achieved higher compressive strength at 28 days curing, whereas the 56 days curing strength remains almost same as the 28 days compressive strength. The UFGGBFS prompts a higher rate of hydration and pozzolanic response compared with the normal GGBFS. Likewise, the UFGGBFS can top off the pores in the Interfacial Transition Zone (ITZ) better contrasted with GGBFS.

![Figure 3. Compressive strength test set up](image)

**Table 4: Compressive strength results (kg/m³)**

| Mixes | 3 Days | 7 Days | 28 Days | 56 Days |
|-------|--------|--------|---------|---------|
| M-300 | 67.45  | 83.51  | 91.33   | 93.46   |
| M-305 | 66.51  | 76.55  | 91.80   | 93.92   |
| M-310 | 74.67  | 75.43  | 88.29   | 96.78   |
| M-315 | 75.96  | 83.61  | 93.40   | 98.53   |
| M-320 | 68.57  | 85.76  | 93.55   | 105.78  |

![Figure 4. Compressive strength values at different ages](image)
3.3. Hardened properties (Split tensile strength)

Figure 6 is the graphical representation of the outcomes of the Split tensile strength tests got from this investigation. The standard deviation of the strength values is relatively small, representing a reliable blend. From the outcomes, it tends to be seen that the blends in with UFGGBFS accomplished higher flexural strength compared with the normal OPC concrete. Addition of UFGGBFS, Mix-320 acquired a split tensile strength of 5.37 MPa after 56 day compared with 3.92 MPa for the normal OPC concrete, i.e Mix-300.

![Figure 5. Split tensile strength set up](image)

![Figure 6. Relation between concrete mixes with split tensile strength](image)

3.4. Hardened properties (Elastic modulus)

The static modulus of elasticity estimations of different concrete blends is introduced. Each value is the average of three estimations of 56 days.
Figure 7. Elastic modulus of the designed concretes

4. Water permeability
Water permeability depth was measured using the permeability testing apparatus. The 28 days and 56 days water permeability test outcomes are presented in the Figure 9. A notable difference between 28 days and 56 days was obtained where all the 56 days permeability depth were quite less than 28 days permeability results.

Figure 8. Water penetration depth shown using marker

Figure 9. Relation between design mixes with permeability depth
5. Conclusions
The accompanying ends can be made dependent on the aftereffects of this investigation:

- UFGGBFS has a bigger whole surface area, and subsequently, a greater amount of it is accessible for hydration and pozzolanic response, compared with ordinary GGBFS. Likewise, improved workability and high consistency were accomplished by using UFGGBFS. This will prompt an early strength improvement regarding compressive and flexural strength, as contemplated.

- A continuously increased compressive and flexural strength was accomplished with the step by step increased substitution of UFGGBFS at each age.

- With the inclusion of UFGGBFS into the concrete, it is probable to get a reliable blend, as the high surface area of UFGGBFS enhances the rheology of freshly mixed concrete.

- With the inclusion of UFGGBFS, there is a noteworthy improvement in the mechanical properties of the concrete. The improvement is more evident for higher grade concrete.

- With the inclusion of UFGGBFS, the permeability of concrete is notably decreased. Because of the diminished permeability, chloride infiltration into the hardened concrete is decreased. This denoted a critical improvement in the durability part of the concrete.

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