Impact Resistance of GGBS-Dolomite Geopolymer Concrete

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Abstract. Geopolymers are new alternative binders for cement in which polymerization gives strength to concrete. The present study highlights the development of geopolymer concrete from industrial by-products such as Ground Granulated Blast furnace Slag (GGBS) and dolomite. They are obtained from steel industries and rock crushing plants respectively. Standard mix design guidelines are not available for geopolymer concrete. The trial and error method was chosen for attaining a target compressive strength of 60 MPa. Impact strength plays an important role in structures like bridges, harbours, and barriers. The present paper investigates the impact resistance of GGBS dolomite geopolymer concrete using drop weight method. Procedures of ACI Committee 544 were used, and results were compared with that of cement concrete. Cylindrical specimens having 150 mm diameter and 50mm thickness were used. Maximum impact resistance was observed when GGBS and dolomite become 80:20, which is 42% more than GGBS geopolymer concrete without dolomite.

1. Introduction
Geopolymers are a promising alternative to ordinary portland cement concrete from the sustainability point of view. Production of geopolymer concrete (GPC) decreases the release of 80% greenhouse gases [1] and 60% energy required [2] compared to cement concrete. The main component of geopolymer concrete is alumina-silica based source material [3]. Fly ash [4], Ground Granulated Blast furnace Slag (GGBS) [5], Metakaolin [6], Rice husk ash [7], etc. are normally used binder materials for the development of geopolymer concrete. Alkaline solutions such as sodium-potassium hydroxide and silicates are essential for geopolymerisation, which gives strength to geopolymer concrete [8]. Geopolymer concrete has advanced engineering and durability properties, but they are brittle in nature [9]. Geopolymer concrete has better bond strength [10] and impact resistance [11] compared to cement concrete. Numerous studies were reported on the mechanical properties of GPC. Studies on the impact strength of geopolymer concrete were found to be scanty. Several methods are available for finding the impact resistance of concrete. Drop weight method (ACI (American Concrete Institution) committee 544) [16] is the simplest method used for finding impact resistance of concrete.

Recently [12], Geopolymer concrete was developed from GGBS and dolomite, which have advanced engineering and durability properties. Structures such as buildings in the hurricane region, bridges, harbours, etc. are subjected to impact loading [13]. In these structures impact resistance plays a main role than other strength properties. The present study investigates the impact resistance of GGBS-dolomite GPC and compares with that of OPC concrete.

2. Materials used

2.1. GGBS and Dolomite
The main source material used in this study was GGBS, which is obtained from steel industries as a by-product. Effect of rock crushing plant by-product (dolomite) on GGBS geopolymer concrete also has
been studied. The specific gravity of GGBS and dolomite are 2.9 and 2.85 respectively. Blaine’s fineness was observed as 4032 and 3500 cm$^2$/gm for GGBS and dolomite, respectively.

2.2. **Aggregate**
River sand and coarse aggregate (size 12 mm) were used as aggregate [15].

2.3. **Alkaline solution**
The alkaline medium was prepared from sodium hydroxide and sodium silicate solutions. The required quantity of sodium hydroxide (NaOH) pellets (97% purity) was dissolved in water to prepare a particular molarity NaOH solution. Sodium silicate solution (SiO$_2$ (27.2%), Na$_2$O (8.9%), and H$_2$O (63.9%)) is mixed with sodium hydroxide solution, 30 minutes before casting.

2.4. **Superplasticiser**
Sulphonated naphthalene based superplasticisers with a specific gravity of 1.2 was added to improve the workability [12].

3. **Mixing procedure for geopolymer concrete**
Proper mix proportioning guidelines are not available for slag based geopolymer concrete when subjected to ambient curing. GPC having compressive strength 60 MPa were achieved through trial mix proportioning process. Quantity of materials for developing 1m$^3$ geopolymer concrete and cement concrete are given in table 1 [9].

| Table 1. Mix proportioning of geopolymer and cement concrete. |
|----------------------------------|-----------------|-----------------|
|                              | Geopolymer concrete | Cement Concrete |
|-----------------------------|------------------|-----------------|
| Binder content/cement        | 400              | 556             |
| Alkaline solution/water      | 240              | 158             |
| Fine aggregate               | 646              | 698             |
| Coarse aggregate             | 1021.5           | 1067            |
| Superplasticiser             | 6                | 6               |

GGBS was replaced with 10%, 20%, 30%, 40% and 50% by dolomite and referred as G90:D10, G80:D20, G70:D30, G60:D40 and G50:D50 respectively. Binder material and aggregates were mixed in a pan mixer one minute. Alkaline solution followed by a superplasticiser was added and mixed for three minutes.

4. **Compressive strength test**
Compressive strength test was performed on concrete cube specimens (size 150 mm) as per the guidelines given in IS 516:1959. All specimens were demoulded within 24 hours and cured under ambient conditions (25-28°C). Compressive strength test was conducted in a load controlled compression-testing machine at a rate of 140 kg/sq cm/min. Table 2 shows the compressive strength at the age of 28 days of geopolymer concrete.

5. **Impact resistance test**

5.1. **Specimen details**
Cylindrical specimens having 150 mm diameter and 50 mm height were used for studying the impact resistance. Specimens are shown in figure 1.
5.2. Test setup
Impact resistance test was carried out by dropping weight method, in which a steel ball of weight 3 kg was dropped freely from a height of 457 mm. Number of blows that causes visible first crack are denoted as first crack blows, and failure blows were measured when the complete spreading of cracks occurred [14]. The test setup used for finding impact resistance is shown in figure 2.

5.3. Impact strength
Impact resistance of GGBS geopolymer concrete with different proportions of dolomite were found out by using dropping weight method. Number of blows that cause first crack (First crack blows) and failure crack are tabulated in table 2. Impact energy was calculated from the equation $E = N \times m \times g \times h$, where $N$ is the number of blows which cause the failure of specimen, $m$ is the weight of steel ball, $h$ is the freely falling height of ball and $g$ is the acceleration due to gravity. Impact energy for different specimens are also shown in table 2.

| Mix      | Compressive strength(N/mm²) | First crack blows | Failure crack blows | Impact Energy Nm |
|----------|----------------------------|-------------------|--------------------|------------------|
| G100:D0  | 64.5                       | 26                | 102                | 1371.85          |
| G90:D10  | 68.4                       | 30                | 130                | 1748.43          |
| G80:D20  | 70                         | 42                | 145                | 1950.17          |
| G70:D30  | 72.5                       | 35                | 140                | 1882.93          |
| G60:D40  | 65.7                       | 22                | 90                 | 1210.45          |
| G50:D50  | 60.4                       | 20                | 63                 | 847.31           |
| OPC100   | 71.5                       | 18                | 120                | 1613.94          |
The first crack blows of GGBS-dolomite geopolymer concrete were found as 2.3 times that of cement concrete. Maximum impact energy was observed for G80:D20, which is 21% more than cement concrete. G50:D50 less impact resistance compared to all other specimens. Variation of Impact energy along with the addition of dolomite, is shown in figure 3.

**Figure 3.** Variation of impact energy with dolomite.

Addition of dolomite (10-30%) improved impact resistance up to 28-42%. Microstructural (Scanning Electron Microscopy-SEM Analysis) studies were conducted on GGBS GPC and GGBS-dolomite GPC and are shown in figure 4.

**Figure 4.** SEM analysis of GPC.

Microstructural studies reveal that maximum denser microstructure was observed in GGBS-dolomite GPC than GGBS GPC [12]. This leads to more impact strength in GGBS-dolomite GPC.

5.4. *Failure modes and crack patterns*

Failure pattern for different mixes after impact testing is shown in figure 5.

**Figure 5.** Failure pattern after impact test.
All the specimens were failed into two or three pieces. G60:D40, G70:D30 and G80:D20 split exactly into two pieces, which indicate the higher impact energy of these mixes.

6. Conclusions
Blended geopolymer concrete has been developed from GGBS and dolomite, which are industrial waste by-products. Inclusion of dolomite up to 30% improved the compressive strength of GGBS geopolymer concrete. GGBS-dolomite concrete having compressive strength 60 N/mm² was developed through trial and error process. Impact resistance was 21% more for GGBS-dolomite GPC than that of cement concrete due to its dense microstructure.

7. References
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