Experimental study on strength characteristics of geopolymer based voided specimens

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Abstract: Self-weight is the load imposed by its own weight upon a structure. The material density of the system directly influences the self-weight. By creating voids inside the structure, we can reduce the self-weight and material density. In this study, voids are created by using void formers made of recycled plastic materials that do not react with concrete and steel chemically. Tests are conducted on the plastic void former and voided specimen of 150mm x 150mm x 150mm size. Geopolymer concrete is a type of concrete produced by using waste materials generated from power plants along with an activator solution. For solid specimens, cubes of 100mm x 100mm x 100mm size are cast and tested by considering different curing methods. It can be concluded that the strength characteristics of geopolymer concrete was found to be significantly greater than that of conventional concrete. Voided specimens show reduced density apart from achieving comparable strength to that of solid specimens.

Keywords: GGBS, geopolymer concrete, sodium hydroxide solution, sodium silicate solution, plastic void former, strength characteristics.

1. INTRODUCTION

1.1 General
In any structure, self-weight is the load of the materials imposed on it. As the material density increases the load transferring to the foundation increases. In order to reduce the self-weight, there is method of eliminating some amount of concrete by creating voids inside. The concept was firstly invented by Jorgen Bruenig in the 90’s, who developed the first biaxial slab in Denmark. It is a new technique of construction using plastic void formers inside the slab to reduce the usage of concrete as well as saving time. Plastic void formers are of different shapes; spherical, donut, oval, or cuboid shapes made of recycled industrial plastic materials that do not react with concrete and steel chemically.

Ordinary Portland cement (OPC) is regularly used as binding content to produce concrete. But during the manufacturing of cement, emission of carbon dioxide into the atmosphere is more. At the same time, however, disposal of the huge amount of waste materials generated from power plant such as fly ash or slag is also becoming a major burning issue. Fly ash and slag are industrial by-products and both of these materials have a much lower emission level of carbon dioxide compared to cement. Geopolymer concrete use was reported to be able to reduce the total carbon dioxide emission by up to 64 percent compared to cement use. Industrial by-products or natural resources, and an alkaline solution that polymerizes these materials into chains or networks to produce hardened binders are key components of geopolymer concrete. For geopolymerisation reaction to take place a high content of alumina and silica are required and Ground granulated blast furnace slag (GGBS) is a good aluminosilicate source. Alkaline activator solution consists of sodium hydroxide (NaOH) or...
1.2 Literature review

Thaar S Al-Gasham et al [1] discussed about improving the punching shear strength by using a new and simple method by showing variation in the thickness of steel sheets and observed the behavior of voided slabs. Three sheets were orthogonally configured in each direction and inserted below the column stub. By the comparison of experimental and numerical results they concluded that enlarging the thickness of steel sheets obtained good results. Ali N Hiloa et al [2] concentrated on the effectiveness of void size on the structural behavior of one-way slab. It was found that the usage of 90 mm diameter balls reduced the strength, stiffness, ductility and toughness in comparison with the solid slab. Also, it was mentioned that the failure mode changed from flexural to shear with the use of 90 mm- diameter balls. Usage of balls with half the size of slab thickness was recommended, as it helped in limiting the reduction in the stiffness, ductility, and toughness of slab. It was also reported that no loss in the ultimate strength was observed. Churakov [3] had discussed about different types of voided slab technology that have emerged over the last 15 years. Advantages of voided slabs over solid slabs were explained. It was concluded that reduced material consumption allowed the construction time to be faster and the overall cost got reduced. David A. Fanella et al [4] have discussed about shear strength, flexural strength, fire-rating, deflection requirements for flat plate-voided slab. It was summarized that strength and serviceability could be satisfied but for vibration and fire resistance the minimum requirements could be satisfied by considering American Concrete Institute (ACI). Few benefits like reduction in weight, larger super imposed loads and smaller seismic force which reduces floor-to-floor heights for fire resistance structures were discussed. Joo-Hong Chung et al [5] concentrated on the experimental and numerical tests of punching shear strength of voided slabs by considering different pattern of voids. It was found that location of punching shear failure depends on arrangement of voids and the failure does not occur at the minimum section. A method was developed for calculating control perimeter by considering the b/d ratio (Length of control perimeter/effective depth of slab) and net cross-sectional area.

Chau-Khun Ma et al [6] has discussed the structural and material performances of geopolymer concrete. The findings of the study showed that geopolymer concrete presented higher durability, better mechanical properties and more desirable structural performances that can replace ordinary concrete. Salmabanu Luhar et al [7] compared the performance of both fly ash based geopolymer and Ordinary Portland Cement rubberized concrete strength. Waste rubber tire fibres are partially replaced with fine aggregates in this study. The development of rubberized Geopolymer concrete have been carried out based on strength and durability criteria. Panduranganaet al [8] concentrated on the bond strength of geopolymer concrete by considering various combinations of Fly ash and GGBS mixes. It was found that geopolymer concrete produce approximately five times higher bond stress than the value specified in IS 456:2000 specified for the ordinary concrete. Sai Kiran [9] had discussed the experimental investigation on GGBS based geopolymer concrete slabs, by comparing both cement concrete slab and geopolymer concrete slab and concluded that geopolymer slab gave more load versus deflection values than ordinary slab. It was concluded that increase in molarity increased the load carrying capacity of the slabs. Xin Ren and Lianyang Zhang [10] have researched on new geopolymer concrete by usage of recycled waste concrete. It was reported that geopolymer concrete produced by using waste concrete fines and recycled aggregates attain high compressive strength than geopolymer concrete produced by using natural aggregates and fly ash.

1.3 Research Significance

From the literature review it was concluded that less work was concentrated on geopolymer based voided specimens. Geopolymer concrete can be effectively used as a substitute for ordinary concrete in production of voided specimens. This study focuses on the strength characteristics of the GGBS based geopolymer concrete, plastic void former and geopolymer based voided specimen.
2. MATERIAL PROPERTIES

Ground granular blast furnace slag, sodium hydroxide solution, sodium silicate solution, potable water, distilled water, M-sand and coarse aggregates were used as components of concrete. Plastic void formers are used in voided specimens.

2.1 Ground granular blast furnace slag (GGBS)

Ground granular blast furnace slag was provided from local suppliers. The ground granular base furnace slag is shown in Figure 1. Its properties and chemical composition were shown in Table 1.

| Table 1. Properties and chemical composition of GGBS |
|-----------------------------------------------------|
| GGBS | Specific surface area(m²/kg) | Density (g/cm³) | SiO₂(%) | Al₂O₃(%) | CaO (%) | Fe₂O₃(%) | SO₃(%) | MgO (%) |
| GGBS | 420 | 2.8 | 36.73 | 12.46 | 37.84 | 0.58 | 1.81 | 9.61 |

2.2 Sodium hydroxide and sodium silicate solutions

The solution of sodium hydroxide (NaOH) was prepared by dissolving the flakes (99% purity) in the distilled water and potable water. Sodium hydroxide flakes are shown in Figure 2. The properties of sodium hydroxide solution are reported in Table 2. The sodium silicate solution (Na₂SiO₃) was supplied by local suppliers.

| Table 2. Properties of sodium hydroxide solution |
|-----------------------------------------------|
| Concentration(mol/L) | NaOH (WL%) | H₂O (WL%) |
|----------------------|------------|-----------|
| 12M                  | 39.43      | 60.57     |

2.3 Fine aggregate

Manufactured sand has been used as fine aggregate. The fineness modulus and specific gravity are 3.8 and 2.63 respectively confirming to zone-II as per IS :383-1970. [11]
2.4 Coarse aggregate
Crushed coarse aggregate of size 20mm were used in the study. The aggregates have been tested as per IS: 2386 (part 1)-1963 [12] and surface quality description of the aggregate are classified as per IS:383-1970.

2.5 Plastic void former
To reduce the self-weight of the slab and also effective in time-saving, voids can be created by the use of recycled plastic wastes. Plastic void formers are of different shapes like spherical, cuboid, donut type, etc. In this study, a spherical shape plastic void former of diameter 70mm is being used.

3. METHODOLOGY
Mix proportion for geopolymer concrete was prepared by considering the ratio of $\text{Na}_2\text{SiO}_3$ to NaOH as 1.5 with molarity 12 M and the ratio of activator solution to binder material as 0.45. The mix proportion followed for geopolymer as shown in Table 3. The different procedure followed to prepare the specimens are detailed in Table 4.

| Table 3. Mix proportion for geopolymer concrete |
|-----------------------------------------------|
|        | GGBS | NaOH | $\text{Na}_2\text{SiO}_3$ | FA  | CA      |
|------- |------|------|--------------------------|-----|---------|
|       | 1    | 0.18 | 0.27                     | 1.066 | 3.198  |

| Table 4. Procedure followed in specimen preparation |
|-----------------------------------------------------|
| **ID**     | **Size of specimens** | **Casting of specimens** | **Method of curing** |
|------------|-----------------------|--------------------------|----------------------|
| GC – 1     | (100 mm x 100 mm x 100 mm) | 1 hr. after preparation of solution using distilled water | Room temperature |
| GC – 2     |                       | 24 hrs. after preparation of solution using distilled water | Room temperature |
| GC – 3     |                       | 24 hrs. after preparation of solution using potable water | Room temperature |
| GC – O     |                       | 24 hrs. after preparation of solution using potable water | Kept in oven for 2hrs after demoulding |
| GC – V     | (150 mm x 150 mm x 150 mm) | 24 hrs after preparation of solution using potable water by placing plastic void former inside | Room temperature |

(GC - Geopolymer concrete, GC – V – Geopolymer concrete with void)

Cube specimens (100 mm x 100 mm x 100 mm) shown in Figure 3 were cast for checking the compressive strength. Cubes were tested as per IS 516-1959 [13] till failure in Compression Testing Machine (CTM) of 3000 kN capacity after 7 and 28 days of curing are shown in Figure 4.
Cubes (GC – 1) were cast 1 hour after the preparation of sodium hydroxide solution by using distilled water. Cubes (GC – 2) were cast 24 hrs. after the preparation of solution with distilled water. Cubes (GC – O and GC – 3) were cast 24 hrs. after the preparation of solution with potable water. Cubes (GC – 1, 2, 3) were tested after 7 and 28 days without heating in oven. Cubes (GC – O) were heated in oven at 100°C for 2 hrs. after demoulding at 7 and 28 days and tested for compressive strength. The compressive strength test were carried out on the plastic void formers to check the ultimate load carrying capacity as shown in Figure 5. Cubes (GC – V) were cast by placing the plastic void former inside the cube, cured and tested for compressive strength.

4. RESULTS & DISCUSSION

Cubes of geopolymer concrete (GC and GC-V) were tested for density and strength characteristics. The results were compared and discussed.

4.1 Weight density of Geopolymer concrete specimens
Geopolymer concrete has less drying shrinkage compared to cement concrete. The weight density of geopolymer concrete for 7 and 28 days are compared in Table 5. There is no much difference in the density of concrete. The density of voided specimens got reduced by 6.02%, compared to that of solid specimens.

| ID   | Density (kg/m³) 7 days | Density (kg/m³) 28 days |
|------|------------------------|-------------------------|
| GC – 1 | 2820.73                | 2965.34                 |
| GC – 2 | 2885.34                | 2912.41                 |
| GC – 3 | 2856.73                | 2923.67                 |
| GC – O | 2812.34                | 2956.34                 |
| GC – V | 2624.51                | 2792.59                 |

4.2 Compressive strengths of geopolymer concrete

4.2.1 Solid specimens
Compressive strength results of the geopolymer concrete specimens for 7- and 28-days curing are compared in Figure 7. Cubes cast by using sodium hydroxide solution that was prepared by potable water achieved a strength of 49.32 MPa. Even though GC – 1 specimens were cast 1 hr. after the preparation of sodium hydroxide solution, it attained 28 days strength similar to GC – 2.

4.2.2 Void formers and voided specimen
The compressive test was carried out on a plastic void former. Ultimate load of plastic void former was 5.9 kN. Plastic void former regained its shape up to 75 % after testing, as shown in Figure 6(a). The voided specimen after failure was broken to reveal the void former as shown in Figure 6(b).
Figure 6(a). Tested void former

Figure 6(b). Failure of specimen

Figure 7. Variation of compressive strength

Geopolymer concrete attained the ultimate strength well in advance, compared to that of ordinary concrete. Usage of distilled water is normally adopted to prepare sodium hydroxide solution to achieve the maximum strength. The usage of distilled water resulted in high compressive strength compared to the design strength. Since distilled water is costly and it is not feasible to use, potable water was used in the preparation of solution. Potable water resulted in achieving the design strength. The compressive strength of cubes cured in oven was greater than the required design strength. Therefore, ambient curing could be adopted for practical purposes. The plastic void former was effective in taking compressive load, without any major deformation. Voided specimens not only reduced the weight, but also attained greater compressive strength compared to that of solid specimens.

5. CONCLUSION

From the above review it is found that, voided specimen using geopolymer concrete was limited and the preliminary studies was carried out experimentally. The following conclusions have arrived from the test results:

1. Density of geopolymer concrete was comparable to that of normal concrete. Whereas Geopolymer concrete achieved the ultimate design strength in less time compared to that of ordinary concrete.
2. Distilled water which is costly is being replaced with potable water for preparing sodium hydroxide solution to attain sufficient required compressive strength.
3. Since the ultimate strength of oven cured specimens was highly enhanced, ambient curing could be preferred for practical purposes.
4. Effect of compressive load on plastic void former is less, as the void former regained its shape.
and size by about 75%.

5. The density of voided specimen was reduced by about 6.02%, compared to solid specimens. Whereas the strength was increased by about 7.4%, compared to that of solid specimens.

6. Voided specimens not only reduced the weight but also attained compressive strength comparable to that of solid specimens.

Further research can be carried out on voided specimens cast by using geopolymer concrete. Study can be extended on effect of spherical ball diameter and pattern of void formers on the overall behavior of geopolymer voided specimens.

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