Properties of geopolymer bricks made with flyash and GGBS

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Abstract: Geopolymer bricks is the new innovation in the field of brick industry. Geopolymer bricks contain flyash as the source material and an alkaline activator for the activation of polymerization reaction. In this study, experimental work has been performed on geopolymer bricks with flyash and GGBS as source material and sodium hydroxide and sodium silicate as an activator. The molarity of sodium hydroxide was maintained at 12M for all the mixtures and the ratio of sodium hydroxide to sodium silicate was kept as 1:2.5. The brick properties such as compressive strength, water absorption, acid resistance and efflorescence test were conducted on the test specimens. Test results indicated that geopolymer concrete with higher GGBS content resulted in higher compressive strength and better properties compared to flyash based geopolymer brick.

1. INTRODUCTION

Brick is the most commonly used building material in India for more than 1000 years. Fired clay bricks are most commonly used in India. But nowadays fly ash bricks have been tremendously being used due to the reduction in cost as well as its light weight. Geopolymer bricks are the latest innovation in the brick industry which consists of supplementary cementitious materials such as fly ash or GGBS activated by an alkaline activator[1]. The application of geopolymer technology gained importance due to the reduction of the CO₂ emissions by utilizing the supplementary cementitious materials in place of cement. [2]. It has been noted that geopolymer bricks made with flyash requires higher curing temperature to achieve higher compressive strength and lower absorption [3]. El-Naggar etal [4] prepared geopolymer bricks using waste raw materials such as clay brick waste, slaked lime waste, de-aluminated kaolin and caustic soda. They were able to produce light weight bricks with densities around 1000 kg/m³ with a compressive strength of 1.4MPa.

Amin etal.[5] formulated geopolymer bricks using ceramic dust waste. They found that the cost of the geopolymer bricks produced from ceramic waste resulted in the reduction of production cost of bricks. Ahamari and Zhang [6] studied the durability and leaching behavior of geopolymer bricks made from mine tailings. They found that there was substantial reduction in the strength of the geopolymer bricks immersed in pH=4 and seven solutions. Silva etal. [7] performed optimization studies to find the optimum curing conditions of Fired clay bricks and Natural pozzolona based geopolymers. Their results indicated the compressive strength of 37 to 26 MPa has been achieved when proper production conditions are adopted. Gavali etal.[8] reviewed the development of geopolymer bricks using industrial wastes and reported that the variation in the source materials can significantly affect the physical, chemical and mechanical properties of alkali-activated bricks. In this research work, we aimed at developing geopolymer bricks and studying its properties such as compressive strength, water absorption and acid resistance test.
2 EXPERIMENTAL METHODS AND MATERIALS USED

2.1 Fly ash
Class F fly ash collected from Ennore thermal power plant, Tamil Nadu was used in this study. The specific gravity of flyash was worked out to be 2.1

2.2 Ground granulated blast furnace slag (GGBS)
GGBS was obtained from JSW cements Pvt. Ltd. The specific gravity of GGBS used in this study was 2.8

2.3 Fine Aggregate
The fine aggregate used was M-Sand of local sources. Care was taken to see that they were uniformly dry and clean. Locally available M-sand conforming to grading zone II of IS 383-1970 was used. The specific gravity of the M-Sand was worked out to be 2.52. The grading of the fine aggregate was shown in Table 1.

| Sieve size | Weight retained (grams) | Cumulative wt. retained | Cumulative % retained | % Passing |
|------------|-------------------------|-------------------------|-----------------------|-----------|
| 4.75mm     | 42                      | 4.2                     | 4.2                   | 95.8      |
| 2.36mm     | 85                      | 8.5                     | 12.7                  | 87.3      |
| 1.18mm     | 164                     | 16.4                    | 29.1                  | 70.9      |
| 600 μ      | 230                     | 23                      | 52.1                  | 47.9      |
| 300 μ      | 312                     | 32.2                    | 83.3                  | 16.7      |
| 150 μ      | 123                     | 12.3                    | 95.6                  | 4.4       |
| Pan        | 24                      | 2.4                     | -                     | -         |

Table 1 Particle Size of M-Sand

2.4. Alkaline activator solution
Alkaline activator binder is a solution of sodium hydroxide and sodium silicate. The ratio of sodium silicate to sodium hydroxide was kept at 2.5.

2.4.1. Sodium Hydroxide (NaOH)
12M NaOH solution was used for preparing the bricks. For preparing 12M NaOH solution, 480 gm of NaOH was dissolved in 1000 ml of distilled water. Figure 1 shows the preparation of 12M NaOH solution in the laboratory.

Figure 1: Preparation of 12M NaOH Solution
2.4.2. Sodium silicate (Na$_2$SiO$_3$)
Sodium silicate is a common name for compounds with Na$_2$SiO$_3$. It is also known as liquid glass or water glass, this is available in aqueous solution and solids form. The pure form is colourless or white in colour.

2.5. Mix Proportions, Mixing and Curing
The cementitious content is fixed at 450 kg/m$^3$. The flyash is replaced with GGBS in 5, 10, 15, 20 and 25%. The solution to binder ratio is fixed at 0.5. The molarity and the ratio of NaOH/Na$_2$SiO$_3$ was fixed based on the previous work on the geopolymer concrete [9]. The mix proportions are tabulated in Table 2. The dry ingredients were placed in the pan mixer and mixed for three minutes and then the solution is mixed and mixing is continued till uniform blending is occurred. The specimens were prepared and vibrated in a table vibrator and kept in ambient curing for 24 hours. The mould used for the preparation was shown in figure 2. After 24 hours, three specimens were placed in accelerated curing tank to predict the 28 days strength earlier [10].

| Mix ID    | Fly-Ash kg/m$^3$ | GGBS kg/m$^3$ | M-Sand kg/m$^3$ | Sodium Silicate kg/m$^3$ | Sodium Hydroxide kg/m$^3$ |
|-----------|------------------|---------------|-----------------|--------------------------|---------------------------|
| GB100F    | 450              | -             | 1186            | 225                      | 90                        |
| GB95F5G   | 427.5            | 22.5          | 1193            | 225                      | 90                        |
| GB90F10G  | 405              | 45            | 1200            | 225                      | 90                        |
| GB85F15G  | 382.5            | 67.5          | 1206            | 225                      | 90                        |
| GB80F20G  | 360              | 90            | 1213            | 225                      | 90                        |
| GB75F25G  | 337.5            | 112.5         | 1220            | 225                      | 90                        |

Table 2 Mix proportions of geopolymer bricks

Figure 2. Brick mould of size 230*110*75

3. RESULTS

The Compressive strength of geopolymer bricks was tabulated in Table 3. The results revealed that the strength increased with respect to the increase in the GGBS content. The mix with 100% flyash attained around 9 MPa, whereas the mix with 25% GGBS replacement showed around 16 MPa higher strength than the 100% flyash based geopolymer mix. The accelerated compressive strength also showed a similar pattern to the 7 days results.
Table 3 Compressive Strength of geopolymer bricks

| Mix ID   | 7 DAYS COMPRESSIVE STRENGTH N/mm² | Accelerated compressive strength N/mm² (28 Days) |
|----------|-----------------------------------|-----------------------------------------------|
| GB100F   | 8.93                              | 15.37                                         |
| GB95F5G  | 13.30                             | 30.5                                          |
| GB90F10G | 16.28                             | 38.46                                         |
| GB85F15G | 18.81                             | 42.02                                         |
| GB80F20G | 23.06                             | 45.30                                         |
| GB75F25G | 25.22                             | 51.67                                         |

The water absorption results of geopolymer bricks was tabulated in Table 4. The results revealed that the water absorption value decreased with respect to the increase in the GGBS content.

Table 4 Water Absorption of geopolymer bricks

| Mix ID   | W1 (kg) | W2 (kg) | Water Absorption (%) |
|----------|---------|---------|----------------------|
| GB100F   | 3.715   | 3.980   | 7.13                 |
| GB95F5G  | 3.630   | 3.875   | 6.75                 |
| GB90F10G | 3.655   | 3.890   | 6.43                 |
| GB85F15G | 3.740   | 3.995   | 6.38                 |
| GB80F20G | 3.868   | 4.109   | 6.24                 |
| GB75F25G | 3.940   | 4.180   | 6.09                 |

The acid resistance results of geopolymer bricks were tabulated in Table 5. The results revealed that the acid resistance increased with respect to the increase in the GGBS content. The acid resistance increased with respect to the compressive strength of bricks obtained.

Table 5 Acid resistance of geopolymer bricks

| Mix ID   | Weight before immersed in acid (kg) | Weight after immersed in acid (kg) | % of weight loss |
|----------|-------------------------------------|------------------------------------|-----------------|
| GB100F   | 3.955                               | 3.897                              | 1.46            |
| GB95F5G  | 3.968                               | 3.911                              | 1.43            |
| GB90F10G | 4.015                               | 3.964                              | 1.27            |
| GB85F15G | 4.022                               | 3.978                              | 1.09            |
| GB80F20G | 4.025                               | 3.995                              | 0.75            |
| GB75F25G | 4.031                               | 4.002                              | 0.72            |

4. CONCLUSION

Based on the preliminary investigations on the geopolymer bricks done, the following salient conclusions can be drawn.

- Highest compressive strength is exhibited by the geopolymer bricks with the flyash: GGBS ratio 75:25 (with a constant water cement ratio of 0.7), compared to other combinations.
- The water absorption of geopolymer bricks show water absorption up to 6% whereas the normal clay bricks it will be around 20%.
- Acid resistance increased with respect to the increase in GGBS content in the mix proportion.

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