A study on economic feasibility of fly ash and ground granulated blast furnace slag based geopolymer concrete

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Abstract. The rapid increase in the greenhouse gas emission has affected the ecological balance adversely which tends to the need of sustainable development in nature. The carbon dioxide produced during cement production is about 7% globally and it is the second most consumed product in the world. To mitigate this crisis, Geopolymer concrete (GPC) which constitutes industrial wastes like Ground Granulated Blast Furnace Slag (GGBS), flyash, rice husk is considered as a more eco-friendly and economically feasible alternative to Ordinary Portland Cement (OPC) based concrete. The reduction in the carbon dioxide emission from cement production can contribute significantly to the turning down of the global thermostat. The feasibility of production of GPC is much more safe, secure and reliable as it has more strength than conventional concrete [1]. The objective of the study is to compare the economic feasibility of conventional concrete and GPC. In this study, the rate analysis is done for optimum combination of flyash and GGBS based GPC and conventional concrete. From earlier studies flyash and GGBS based GPC is prepared by activating mixture of sodium silicate and NaOH solution. Optimum strength ratio obtained for flyash and GGBS is 1:1. In this study the analysis is done for GPC M 25 grade, conventional concrete of M 25 grade and is observed that GPC is more economical than conventional mix.

1. Introduction

Concrete is an extremely versatile material most commonly made from a heterogeneous mixture of cement, aggregates and water. It is the most widely used building material due to its high durability, strength and ability to sustain extreme weather conditions. Usage of concrete is about two times that of usage of wood, steel, plastic and aluminium combined.

The environmental issues associated with the production of OPC are well known. For every ton of OPC produced, the amount of CO\(_2\) released is 1 ton due to the calcination of limestone and fossil fuel combustion [1, 2]. Davidovits in proposition put forward in 1978, suggested that binders which he also termed as geopolymers, can be obtained with the polymeric reaction of alkaline liquids with alumino-silicate oxides present in the source material and by-products such as fly ash and rice husk ash. Alkaline liquid can be used to activate pozzolans such as GGBS, fly ash etc. to form binder and thereby replacing OPC as suggested by Palomo et al. [3].

2. Materials Used

The materials used in this experiment are:
2.1 Ground Granulated Blast Furnace Slag (GGBS)
Ground Granulated Blast Furnace Slag (GGBS) is a by-product obtained by quenching molten iron slag from a blast furnace in water or stream. The material properties of GGBS are determined by testing as per Indian standards confirming to IS 383-1970.

2.2 Flyash
Fly ash also known as pulverized fuel ash in UK, is a coal combustion product that is composed of the particulate matter that are cast out of coal-fired boilers along with the flue gases.

2.3 Ordinary Portland Cement (OPC)
Dalmia 53 grade ordinary portland cement confirming to IS 12269-1987 which are readily available in the market is used. The specific gravity of cement is 3.15.

2.4 Fine Aggregate (FA)
Manufactured sand (M sand) of uniform gradation confirming to the requirements of IS 383-1970 is used. Specific gravity obtained is 2.5.

2.5 Coarse Aggregate (CA)
Crushed angular shaped aggregates generally of size 10mm to 20mm complying with the requirements of IS 383-1970 are used. Specific gravity obtained is 2.67.

2.6 Alkaline liquid (Sodium silicate and 8 Molar Sodium hydroxide solution)
Commercially available sodium silicate is used. For the 8M NaOH solution, sodium hydroxide flakes with 97% purity were completely dissolved in water. Sodium silicate to sodium hydroxide solution ratio was fixed as 2.5. The alkaline solution was prepared by mixing both sodium silicate solution and sodium hydroxide solution together at least one day prior to use [4].

2.7 Water
Locally available test for potable water is used for the preparation of concrete

3. Mixing
The tests were conducted in the laboratory, and the results obtained were used for mix design. For conventional concrete water cement ratio 0.5 was fixed by slump test. The required slump in the slump test was obtained by taking various water content using trial and error method [5]. Geopolymer concrete was obtained by dry mixing coarse aggregate, fine aggregate, GGBS and flyash manually. Then alkaline activators were added and immediately water (same as that of conventional concrete) was added till the required workability was obtained.

4. Methodology
The preliminary tests for the flyash, GGBS, OPC, fine aggregate and coarse aggregate were done. Mix design for M 25 conventional concrete and GPC with various proportions of GGBS and flyash were prepared which is shown in Table 1.

| Combinations (Flyash% : GGBBS %) | 100 : 0 | 60 : 40 | 50 : 50 | 40 : 60 | 0 : 100 |
|---------------------------------|---------|---------|---------|---------|---------|
| Full replacement                | I       | II      | III     | IV      | V       |

Table 1. Various proportions of Flyash and GGBS
Standard cubes and cylinders for compression and split tensile test were casted and tests were conducted for 7 days and 28 days [6] [7]. The optimum strength combination of flyash and GGBS were found as 1:1 ratio [1]. The rate analysis is done by comparing the M 25 GPC with M 25 conventional concrete and M 40 conventional concrete.

The mix calculations for 1 m$^3$ of M 25 and optimum mix proportion of GPC with 1:1 flyash-GGBS combination is given in Table 2.

### Table 2. Mix Calculation for 1 m$^3$

| Mix                  | Mass of Cement (kg) | Mass of Flyash (kg) | Mass of GGBS (kg) | Mass of FA (kg) | Mass of CA (kg) | Mass of NaOH (kg) | Mass of Na$_2$SiO$_3$ (kg) | Quantity of Water (L) |
|----------------------|---------------------|---------------------|-------------------|-----------------|-----------------|--------------------|--------------------------|-----------------------|
| M 25                 | 420                 | 0                   | 0                 | 617.23          | 1084.21         | 0                  | 0                        | 210                   |
| GPC of M 25 Flyash: GGBS 1:1 | 0                   | 210                 | 210               | 583.40          | 1024.85         | 42                 | 105                      | 210                   |

### 5. Results and Discussions

The obtained slump for conventional concrete is 70 mm, the degree of workability is medium. Similarly, same amount of slump is obtained for GPC work.

The 28-day compressive strength obtained for M 25 concrete is 30.62 N/mm$^2$& for M 25 GPC with 1:1 flyash-GGBS combination is 53.29 N/mm$^2$ [1].Figure 1 shows the graphical representation of compressive strengths of different combinations.

**Figure 1.** Bar chart of 7 day and 28 day compressive strength test
The 28-day split tensile strength obtained for M 25 concrete is 2.96 N/mm² & for M 25 GPC with 1:1 flyash - GGBS combination is 3.77 N/mm² [1]. Figure 2 shows the graphical representation of split tensile strengths of different combinations.

![Figure 2. Bar chart of 7 day and 28 day split tensile strength test](image)

**Table 3.** Rate analysis for 1 m³

| Material            | Rate (Rs.) | M 25 (Rs.) | GPC of M 25 Flyash : GGBS 1:1 (Rs.) |
|---------------------|------------|------------|-------------------------------------|
| Cement              | 7.5 / Kg   | 3150.00    | 0                                   |
| Flyash              | 1.5 / Kg   | 0          | 315.00                              |
| GGBS                | 4 / Kg     | 0          | 810.00                              |
| Fine Aggregate      | 1303.77 / m³ | 503.04 | 475.48                              |
| Coarse Aggregate    | 1403.77 / m³ | 1049.52 | 992.06                              |
| NaOH Flakes         | 45 / Kg    | 0          | 1512.00                             |
| Na₂SiO₃             | 18 / Kg    | 0          | 756                                 |
| **Total Cost Per m³** (Rs.) | 4702.56 | 4860.54 |                                      |

The feasibility of production of GPC with OPC based concrete in terms of the cost for production must be evaluated for its practicability. The cost of various materials for rate analysis was taken accordingly from various sources are given below:

- Fly ash: Neptune Ready-mix Concrete Pvt Ltd in Mundur, Thrissur
- GGBS: JSW Cement Ltd. in Ernakulam
- FA and CA: Project Information & Cost Estimation (PRICE) - MORTH rates (2016), Kerala
- 8M NaOH and Na₂SiO₃: Pentagon Chemical, Chennai
- Dalmia OPC 53 grade

The rate analysis of M 25 of conventional concrete and M 25 GPC with 1:1 flyash- GGBS combination is given in Table 3. and the bar chart of rate analysis is given in figure 3.
From the above study it can be seen that for M 25 GPC, even though the materials used for the production are industrial by-products, the cost for the production is 3.36% higher than the conventional M 25 mix. This is because of the transportation cost and cost of the alkaline activator solution. The strength obtained by M 25 GPC mix can be compared with M 40 conventional mix also. Therefore, when the strength and cost for the different mixes are compared, it can be concluded that Geopolymer concrete is more favourable than OPC based concrete.

6. Conclusions
The following conclusions were made from the study:

- From the cost analysis, it was observed that the optimum mix of GPC had a 3.36% increase in cost than the conventional mix. But with twice increase in strength it is still economical.
- From the analysis, GPC is a solution to solid waste disposal as well as to control the CO₂ emission from cement.
- The industrial wastes such as flyash and GGBS can be utilized for replacing cement in concrete.

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Figure 3. Bar chart of rate analysis