EXPERIMENTAL STUDY ON GEOPOLYMER CONCRETE WITH PARTIAL REPLACEMENT OF FINE AGGREGATE WITH FOUNDRY SAND

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ABSTRACT

The global use of concrete is second only to water. Since a lot of environmental issues are associated with the production of Portland cement, alternate materials should be found out. Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Geopolymer concrete is a concrete which does not utilize any Portland cement in its production. Used-foundry sand is a by-product of ferrous and nonferrous metal casting industries. Foundries successfully recycle and reuse the sand many times in a foundry. In this study an effort is made to found out the effectiveness of used foundry sand as a partial replacement of fine aggregate in geopolymer concrete. 0%, 5%, 10%, 15%, 20% and 25% by weight of fine aggregate is replaced with foundry sand in this study. 3 day, 7 day and 28 day compressive strength of samples were found out.

Keywords: Alkaline Liquid, Binder, Foundry Sand, Geopolymer, Polymerization

I. INTRODUCTION

The emission of greenhouse gases is a critical factor for industries like cement industries, as the greenhouse effect can produce an increase in global temperature and variations in climatic conditions. The studies conducted in this area shows that the production of cement is increasing about 3% annually. The production of one ton of cement liberates about one ton of CO_2 to the atmosphere.In 1978, Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term Geopolymer to represent these binders. Thus Geopolymer concrete is a concrete which does not utilize any Portland cement in its production. There are two main constituents in geopolymer concrete, namely the source materials and the alkaline liquids. The source materials forgeopolymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as metakaoline, clays, etc. Alternatively, by -product materials such as fly ash, blast furnace slag, rice husk ash, red mud, etc could be used as source materials. (Hardjito,2004)The most common alkaline liquid used for geopolymerisation is a combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate.Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline (Palomo et al. 1999). For geopolymer concrete, an increase in the compressive strength with increase in the molarity was seen. Importance of curing temperature also was clearly seen in the tests conducted. The introduction of a rest day, that is ambient curing for 24 hours prior to steam curing, resulted in elevated compressive strengths of the order of 20% (Lloyd 2010, Madheswaran 2013, Supraja 2012).Used-foundry sand is a by-product of ferrous and nonferrous metal casting industries. Foundries successfully recycle and reuse the sand many times in a foundry. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed as used or spent foundry sand.In case of experiments conducted on concrete with foundry sand, it was found that compressive strength, split-tensile strength, flexural strength, and modulus of elasticity of concrete mixtures increased with the increase in foundry sand contents. Results of this investigation suggest that used-foundry sand could be very conveniently used in making good quality concrete and construction materials. However, the research suggests that partial replacement should not exceed 20%. (Siddique 2012, Bhimani 2013)

In this work, silica ash and ground granulated blast furnace slag based geopolymer is used as the binder to produce concrete. Sodium silicate and sodium hydroxide is used as alkaline liquid and superplasticizer is added to improve workability. The effectiveness of foundry sand as partial replacement of fine aggregate in geopolymer concrete is analyzed in this study. Study was conducted for 0%, 5%, 10%, 15%, 20% and 25% replacement of foundry sand by weight of fine aggregate.

II. EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. GGBS can be used to make durable concrete structures.

Fig: 1. Ground Granulated Blast Furnace Slag

Table 1. Properties of GGBS

Characteristics	Value
Fineness	390
Specific Gravity	2.85
Moisture Content	0.10

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2.1.2 Silica Ash

Rice husk is an agricultural residue abundantly available in rice producing countries. The annual rice husk production in India amounts about 12 million tons. Among the different types of biomass used for gasification, rice husk has a high ash content varying from 18 – 20 %. Silica is the major constituent of rice husk. So it can be effectively used for green concrete applications.

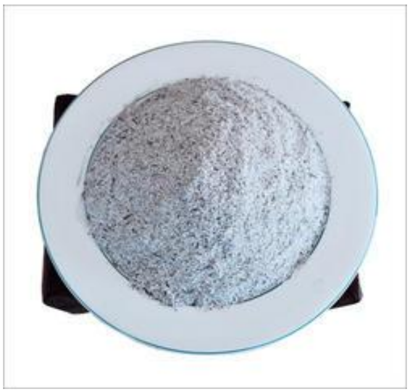

Fig.:2. Silica Ash

Table 2. Properties of Silica Ash

Characteristics	Value
Silica content	88.9%
Specific gravity	2.25
Moisture content	0.11%

2.1.3 Alkaline Liquid

A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions. It is recommended that the NaOH solution should be made 24 hours before casting and should be used with 36 hours of mixing the pellets with water as after that it is converted to semi-solid state. The mass of NaOH solids in a solution varies depending on the concentration of the solution expressed in terms of molar, M. For instance, NaOH solution with a concentration of 8M consisted of 8x40 = 320 grams of NaOH solids (in flake or pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 262 grams per kg of NaOH solution of 8 M concentration. Similarly, the mass of NaOH solids per kg of the solution for other concentrations were measured as 10 M: 314 grams, 12 M: 361 grams, 14 M: 404 grams, and 16 M: 444 grams. Note that the mass of NaOH solids was only a fraction of the mass of the NaOH solution, and water is the major component. The specific gravity of Sodium Hydroxide was 1.37. 10 M NaOH solutionwas used for the preparation of alkaline liquid.

Sodium Silicate is also known as water glass which is available in the market in gel form. The ratio of SiO_2 and Na_2O in sodium silicate gel highly affects the strength of geopolymer concrete. Mainly it is seen that a ratio ranging from 2 to 2.5 gives a satisfactory result. The specific gravity of Sodium Silicate was 1.59.

Fig: 3. Alkaline Solution

2.1.4 Fine Aggregate

Fine aggregate used in this study is M sand. Fine aggregates are the aggregates whose size is less than 4.75mm. Sand is generally considered to have a lower size limit of about 0.07mm, also free from clay, minerals and salt. The specific gravity of fine aggregate was found out using pycnometer and sieve analysis was carried out to find out the grading zone of aggregate.

Table 3. Properties of Fine Aggregate

Properties	Value Obtained
Specific Gravity	2.65
Fineness Modulus	3.28
Grading Zone	Zone I

2.1.5 Coarse Aggregate

Locally available coarse aggregate with maximum size of 20 mm were used in this project.

Table 4. Properties of Coarse Aggregate

Properties	Value Obtained
Specific Gravity	2.79
Bulk Density	1.32 g/cc
Water absorption	0.151%

2.16 Foundry Sand

Used-foundry sand is a by-product of ferrous and nonferrous metal casting industries. Foundries successfully recycle and reuse the sand many times in a foundry. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed used or spent foundry sand. Foundry sand was collected from a Grace foundry at Kottayam.

Fig.4. Foundry Sand

2.1.7 Superplasticizer

To improve the workability of the fresh geopolymer concrete, a naphthalene sulphonate based superplasticizer was used.

2.2 Laboratory Work

In the beginning, numerous trial mixtures of geopolymer concrete were manufactured. The trial mixes were prepared inorder to obtain a mix with good consistency and workability and to understand the basic nature of the mix.

2.2.1 Mixing

It was found out that fresh silica ash – GGBS based geopolymer concrete was dark in colour and was cohesive. The amount of water in the mixture played an important role in the behavior of fresh concrete.

For mixing, a drum mixer was used. The aggregates were prepared in saturated surface dry condition. The sodium silicate and sodium hydroxide solution was mixed together at least one day before casting. The materials were dry mixed for about 3 minutes and after that the alkaline liquid mixed with superplasticizerwas added and mixed for about 4 minutes. Small amount of water was also added to increase workability.

Fig.5. Mixing of Concrete

Cubes with 15 cm × 15 cm × 15 cm size were casted. Cubes were casted for 0 %, 5 %, 10 %, 15 %, 20 % and 25 % by weight replacement of fine aggregate with foundry sand. Compaction of the specimens was done on table vibrator.

2.2.2 Curing

After casting the specimens, as per literature studies, a 24 hour rest period was given to the specimens. After 24 hours the specimens were demoulded and were subjected to oven curing. The specimens were cured at 80° C for 24 hours.

Fig: 6. Curing of specimens

2.3 Mix Proportion

The mix proportion of the concrete mix was designed based on the literature surveys conducted and the mix proportion was fixed on the basis of the trial mixes prepared.

- Ash used
  - Silica ash = 200 kg/m^3
  - GGBS = 300 kg/m^3
- Alkaline liquid
  - Ratio of sodium silicate to sodium hydroxide was fixed as 2.5.
  - Ratio of alkaline liquid to ash was fixed as 0.63.
  - 10 M solution was used for preparing the specimens. According to the literatures, the mass of NaOH solids per kg of the solution 10 M concentration is 314 g.
  - Alkaline liquid = 315 kg/m^3
- As per the literatures, geopolymer concrete attains more strength when aggregate content varies from 60% to 70%. Based on IS 10262, fine aggregate was fixed to be 34% of total aggregate content.
  - Fine aggregate = 539.32 kg/m^3
  - Coarse aggregate = 1102.5 kg/m^3
- Superplasticizer is added 1.75% by weight of ash used.
- Extra water is added to ensure consistency of mix.

III. RESULTS

3.1 Workability

Slump test was conducted on fresh concrete to find out the workability of the concrete mix. Slump test was conducted using slump cone of 300 mm height, 200 mm bottom diameter and 100 mm top diameter.

Fig.7. Measuring workability

Table 5 shows the slump value and other details of the concrete mixes. Slump value is observed to decrease with the increase in the foundry sand. Foundry sand is hydrophilic in nature and it attracts water to its surface.

Table 5. Details of mix

% Replacement	0 %	5 %	10 %	15 %	20 %	25 %
Silica Ash (kg/m^3)	200	200	200	200	200	200
GGBS (kg/m^3)	300	300	300	300	300	300
Alkaline Liquid (kg/m^3)	315	315	315	315	315	315
Coarse Aggregate (kg/m^3)	1102.5	1102.5	1102.5	1102.5	1102.5	1102.5
Fine Aggregate (kg/m^3)	**539.32**	**512.35**	**485.39**	**458.42**	**431.46**	**404.49**
Foundry Sand (kg/m^3)	**0**	**26.97**	**53.93**	**80.9**	**107.86**	**134.83**
Superplasticizer (kg/m^3)	8.75	8.75	8.75	8.75	8.75	8.75
Water added (kg/m^3)	75	75	75	75	75	75
Slump (mm)	**40**	**40**	**37**	**35**	**32**	**30**

3.2 Compressive Strength

150 mm × 150 mm × 150 mm cubes were casted for carrying out compression strength test. 3 day, 7 day and 28 day strength of the specimens were measured. The specimens were tested on a compression testing machine with capacity of 3000 kN.

Fig.8. Testing Compressive Strength

3.2.1 3 Day Compressive Strength

The 3 day compressive strength of the oven cured sample obtained a maximum strength of about 20.67 N/mm^2. This compressive strength was obtained for 15% replacement of fine aggregate with foundry sand. The strength of the control mix was 18.22 N/mm^2.

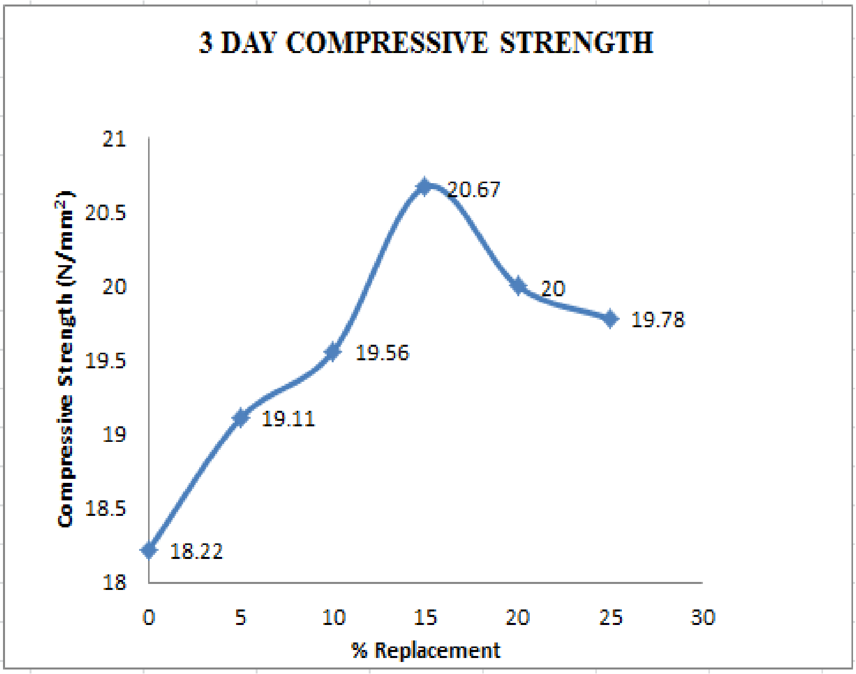

Fig.9. 3 Day Compressive Strength

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3.2.2 7 Day Compressive Strength

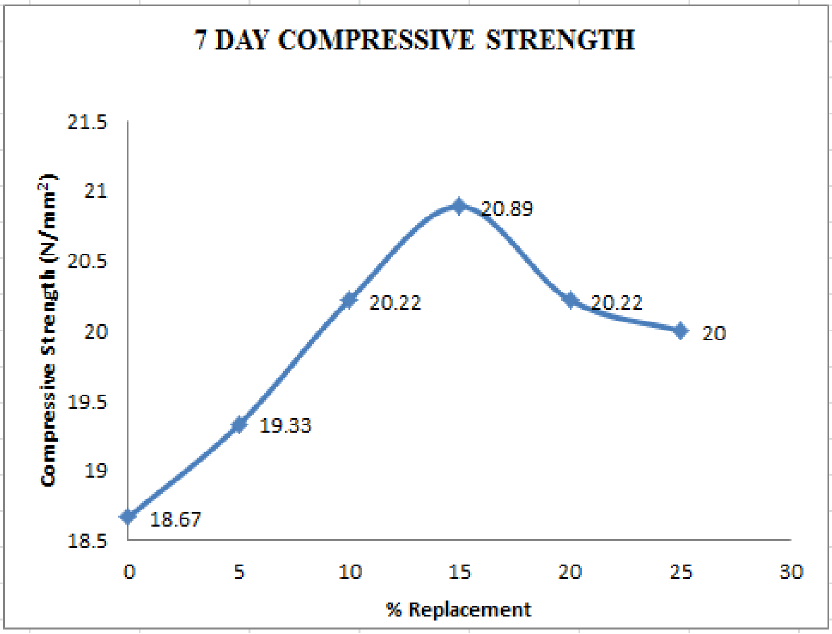

Fig.10. 7 Day Compressive Strength

The 7 day compressive strength of the sample obtained a maximum strength of 20.89 N/mm^2. The 7 day maximum strength was also obtained for 15% replacement of fine aggregate. It should be noted that there is no significant increase in compressive strength on 7th day. Since the sample was oven cured, the sample attained maximum strength within 3 days.

3.2.3 28 Day Compressive Strength

The 28 day compressive strength was also maximum for 15% replacement of fine aggregate with foundry sand.Fig.12 shows the comparison of 3 day, 7 day and 28 day compressive strengths of the specimens

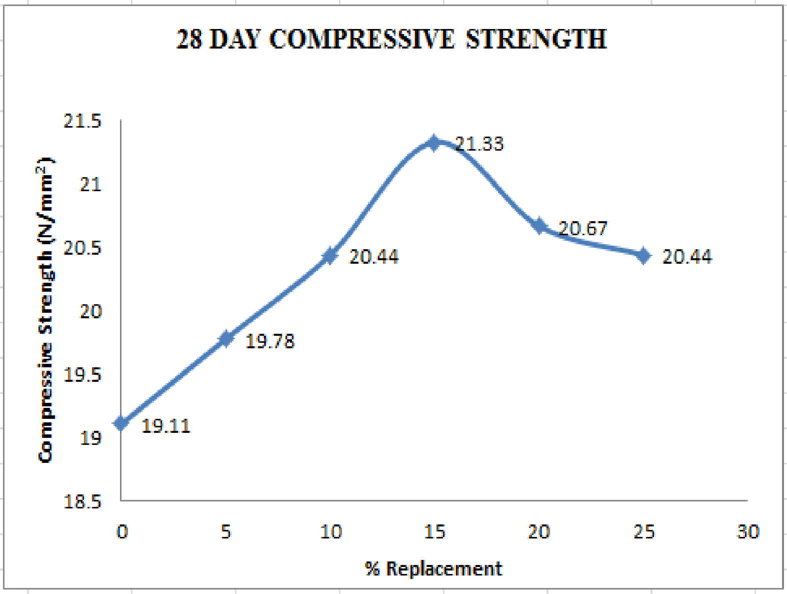

Fig.11. 28 Day Compressive Strength

From the graph, it can be seen that the optimum percentage of replacement of fine aggregate with foundry sand is 15%.

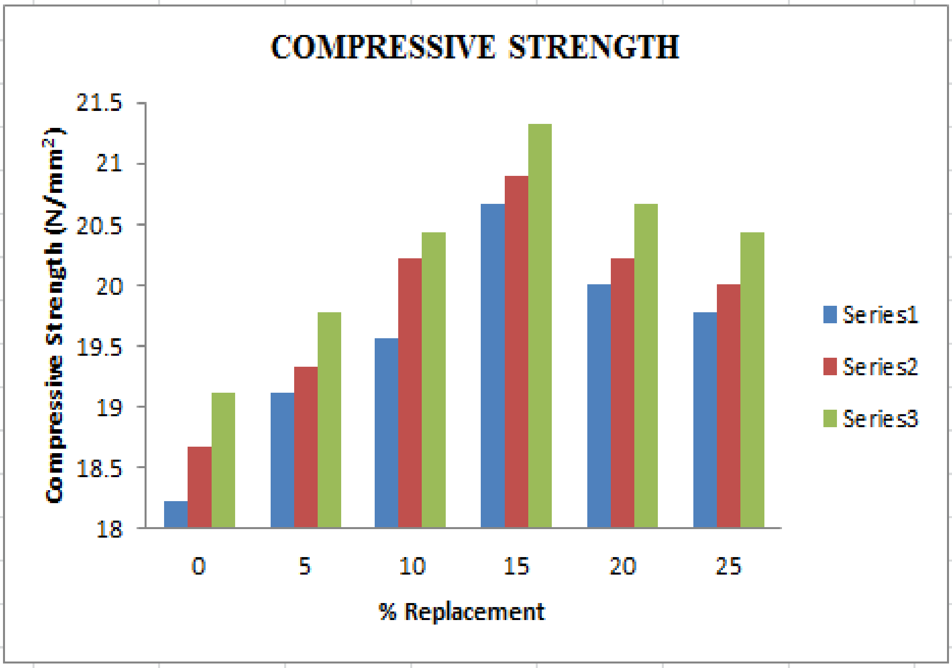

Fig.12. Comparison of Compressive Strength

IV. CONCLUSION

- The workability of the sample decreased with increase in foundry sand content.
- The silica ash – GGBS based geopolymer concrete gained strength with earlier time period through oven curing at 80° C.
- The mix with 15% replacement of fine aggregate gives maximum strength of 21.33 N/mm^2.
- The optimum amount of replacement was found to be 15%.

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