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Experimental investigations on the production of alkali-activated lightweight concrete by blending natural and pozzolanic-based aggregates

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Abstract: The project involves the utilization of binders, fly ash (FA) and ground-granulated blast- furnace slag (GGBS) along with activators, sodium silicate and sodium hydroxide that facilitate the alkali activation process for the producing structural lightweight geo-polymer concrete (LGC). To find the ideal combination that would enhance the performance, the alkali binder ratio has been varied. Different percentage combinations of fly ash aggregates that were made by cold bonding FA, water and cinder aggregates were added to the concrete mixtures to determine how they affected the overall performance.

Experimental investigations were conducted to evaluate the mechanical properties, density, and durability of the lightweight concrete. From the obtained results we can conclude that the optimum alkali binder ratio for achieving desired properties is found to be 0.4 in which the concrete obtains a 21 MPa compressive strength. Notably, the use of 100% cinder as the coarse aggregate results in the highest strength, demonstrating its potential for structural applications. The obtained optimal curing temperature was 90°C, with a maximum strength of 28 MPa.

***IndexTerms* - Light weight aggregate, geopolymer concrete, geopolymer binders, fly ash aggregate.**

1 INTRODUCTION

Lightweight concrete is a specialized form of concrete that is characterized by its reduced weight, density and improved thermal properties in comparison with conventional concrete. This concrete can be produced by using lightweight aggregates such as expanded clay, pumice, LECA, vermiculite, or foam [1]. Alkaline activators and aluminosilicate elements like fly ash or slag react chemically to form geo-polymer binders [2]. Lightweight aggregates aid in lowering density while preserving structural integrity. This reduced weight offers several advantages in construction applications where weight reduction is beneficial, such as in high-rise buildings, bridge decks, and precast elements. The lighter weight of the concrete can lead to savings in transportation costs, easier handling during construction, and reduced structural loads on the overall building or structure. Despite its reduced weight, lightweight concrete can still maintain adequate strength and can also last longer. The lightweight aggregates are specifically chosen to provide sufficient strength, ensuring that the concrete can withstand applied loads and perform adequately in structural applications. It can be designed to meet specific strength requirements that the project needs.

The presence of air voids within the lightweight aggregate is responsible for its insulation capabilities. This translates to lighter-weight concrete having superior thermal insulation, which lowers heat transfer and raises building energy efficiency. Lightweight concrete also has other advantages such as increased fire resistance, acoustic insulation, and less shrinkage in addition to its structural and thermal advantages. Additionally, the air voids in lightweight concrete minimize sound propagation, making it a great choice for soundproofing [3].

The lower impact on the environment of this kind of concrete over conventional concrete is one of its many important advantages. Portland cement manufacture, a vital component of traditional concrete, is linked to substantial carbon dioxide emissions. Contrarily, geopolymer concrete uses industrial by-products like fly ash and slag, reducing the need for virgin resources and thereby reducing the carbon footprint. LGC also depicts excellent mechanical properties along with its environmental benefits. It possesses high strength, excellent fire resistance, and durability, making it a reliable substitute for traditional concrete [4].

2 MATERIALS

2.1 Fly ash

FA is a fine, powdery residue which is created when pulverized coal is burnt in coal-fired power plants. It is commonly used as a supplementary cementitious material. [6] FA used in this study has a specific gravity of 2.1 and it has been employed from Yermarus Thermal Power Station a coal-based thermal power plant located in Yermarus village in Raichur district, Karnataka. (Fig 1)

The FA employed in this study, recognised for its pozzolanic qualities, is classified as Class F-Fly ash and is commonly produced by burning the materials anthracite or coal. Iron oxide (Fe2O3), aluminium oxide (Al2O3), and silicon dioxide (SiO2) make up the majority constituents of this material. Compared to Class C-Fly ash, it typically has a lower calcium oxide (CaO) percentage. [6]

Fig 1: Fly ash (Class F)

2.2 Ground-granulated blast- furnace slag

GGBS is a by-product of the iron industry which is obtained during the manufacturing of iron.
It is mainly constituted of calcium, alumina, and silica. It is also used as a supplementary cementitious material. [7]
GGBS used in this project was employed from a local RMC, Bangalore, Karnataka and it has a specific gravity of 2.6. (Fig 2)

Fig 2: GGBS (Class F)

2.3 Solutions

The solutions that are utilised to make lightweight geopolymer concrete are sodium hydroxide (Fig. 3) and sodium silicate (Fig. 4). For the current work, straight Na_2SiO_3 liquid solution is combined with NaOH pellets at a concentration of 8 Molarity. It takes 24 hours to produce this alkaline solution before mixing. The alkaline binder ratio is varied as follows 0.3 0.4, and 0.45 to assess workability.

Fig 3: Sodium hydroxide pellets

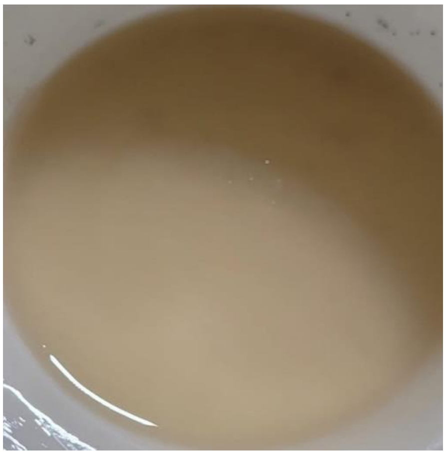

Fig 4: Sodium Silicate

2.4 Fine Aggregate

M- sand (fine aggregate) that passes through a 4.75mm IS sieve, has a specific gravity of 2.4 and a bulking of 1% has been utilized in this experiment. (Fig 5)

Fig 5: M-Sand

2.5 Coarse aggregate

2.5.1 Cinder is referred to as a type of volcanic material that is formed during volcanic eruptions. Porous rock particles known as cinder are formed when molten lava explodes from a volcano and rapidly cools and hardens in the atmosphere. Because of its lightweight and porous character, it can be used for applications after being crushed [8]. Cinder (Fig 6) used in this project is collected from AM Traders Outer Ring Road, Veerannapalya, Bangalore. Specific gravity of 2.15 and a moisture content of 1.47% were obtained from the results of the basic tests.

Fig 6: Cinder

2.5.2 Fly ash aggregate was produced in the laboratory. Performing basic tests on the fly-ash aggregate helped in obtaining crucial information about the characteristics, quality, and suitability of the coarse aggregate ensuring that the aggregate will contribute to the performance of the concrete mixture and provide desired properties. A composition of 90% Fly ash and 10% cement was used in preparing the aggregates and water is sprinkled accordingly until cold bonding occurs and pellets are formed. The fly-ash aggregate exhibited a specific gravity of 1.73 and a moisture content of 5.5%. (Fig 7)

Fig 7: Fly ash aggregates

Palletization: To create "fresh pellets," moistened particles are aggregated in a spinning drum or disc that is revolving at an angle. This process is known as palletization. The mechanics behind the balling phenomena of powdered materials are the foundation for pellet formation. When a fine-grained substance is moistened, bridges form where the moistened particles come in contact with each another and a thin liquid film is formed on the surface of each grain. Balls were formed when the particles rotated, and bonding forces eventually build up. Three days are given for the manufactured pellets to dry. After that, fly ash aggregates are placed for curing. [5] Fig 8 shows the manufacturing of Fly ash aggregate.

Fig 8: Manufacturing Fly ash aggregate in the laboratory

3 METHODOLOGY

All the raw materials are gathered according to mix proportions determined by the mix design, which aims for an 1800 kg/m3 density. The necessary quantity of NaOH pellets are totally dissolved in water, activating the GGBS and FA (Geo-polymer binders) and increasing their reactivity. To achieve even distribution, sodium silicate solution is gradually added to the mixture while being continually stirred or mixed. The mixture is allowed to sit for 24 hours.

GGBS and FA (Geo-polymer binders) are blended in a mixer in the necessary proportions. For obtaining a homogeneous and uniform mixture, the aggregates were sieved using a 12.5 mm sieve, soaked in water for 24 hours, and then combined with the binder mixture. Water is added as needed to adjust the consistency. The quantity of water required depends on the desired workability of the concrete. Once the lightweight concrete mix is ready for use, it is poured or moulded into the cubes, cylinders and prisms as per the requirements of the project.

Concrete cubes using different alkaline binder ratios (0.35, 0.4, 0.45) are cast and tested for compression for determining the optimum ratio, followed by casting cubes with varying percentages of coarse aggregates: cinder and fly ash aggregate, and evaluating their compression strengths and density and optimum curing temperature.

4 SPECIMEN CASTING AND CURING

Concrete specimens of different shapes and sizes were prepared for compressive strength testing. The molds used included 100mm*100mm*100mm for cubes, 200mm in length and 100mm in diameter for cylinders, and 450mm*75mm*75mm for prisms. To ensure proper compaction and prevent segregation, bleeding, and leakage, the molds were prepared by oiling the walls and securing them tightly. Compaction was done using vibration for 15-20 seconds.

After casting, the specimens were left for 2 days to allow the concrete to set before being demolded. The demolded specimens underwent two types of curing: ambient curing and oven curing. These different curing conditions were applied to assess the concrete's performance and strength development under varying environments. Ambient curing represented normal field conditions, while oven curing accelerated the strength gain process.

5 Results and Discussion

5.1. Mechanical properties

5.1.1 Compressive strength

Three 100mm*100mm*100 mm cubes for each alkaline binder ratios of 0.3, 0.4 and 0.45 were cast and cured at ambient temperature for 3 days (Fig 9), compression tests were done and the results are shown below in **table 1**. The optimum alkaline binder ratio, 0.4 was determined and further three cubes in that ratio each and varying percentages of coarse aggregates were cast and tested for compression. The results are in **table 2**. The maximum strength was achieved for the combination of 100% Cinder and 0% Fly ash aggregate. Adding fly ash aggregates reduced the compression strength but a combination of 40% fly ash aggregate and 60% cinder gave a maximum compression strength of 15MPa.

Fig 9: Cubes cast for optimum alkaline binder ratio

Table 1: Compression results for optimum alkali binder ratio

SL No	Alkaline binder ratio	Compression Strength (MPa)	Density (kg/m³)
1	0.3	9.31	1792
2	0.4	21	1893
3	0.45	15	2000

Table 2: Compression results for varying percentages of coarse aggregate

SL No.	Percentage of Fly ash Aggregate	Percentage of Cinder	Compression Strength Obtained (MPa)
1	0%	100%	21
2	20%	80%	11
3	40%	60%	15
4	60%	40%	0.2
5	80%	20%	0.1
6	100%	0%	3

The compressive strength results obtained indicate that the alkaline binder ratio has caused a significant impact on the strength. From **table 1,** the highest strength was obtained at an alkaline binder ratio of 0.40 (21.00 MPa). The 0.40 ratio exhibited more than twice the strength compared to the ratio 0.35 (9.31 MPa). But when the alkaline binder ratio was raised even more, to 0.45, the compressive strength (15.00 MPa), was slightly decreased. The improved geo-polymerization process explains the observed rise in compressive strength with an increase in the alkaline binder ratio.

The type and proportion of coarse particles have a big impact on the compressive strength of LGC. From **table 2**, the compressive strength was quite high (21 MPa) when no fly ash aggregate was employed (0 percentage). The strength, however, significantly dropped as the aggregate's fly ash content rose. The ideal particle packing in the mortar mixture may be disturbed adding fly ash aggregates, especially at higher percentages. This will result in lower interparticle contact and interlocking behaviour, which will reduce strength.

5.1.2 Splitting Tensile Strength

Three cylinders of 200mm length and 100mm diameter were cast with a coarse aggregate variation of 100% cinder and 0% cinder and optimum alkaline binder ratio and cured at room temperature. They were tested for splitting tensile strength in compression testing machine (Fig 10 and 11). The results of split-tensile test are in **table 3.**

Fig 10 and 11: Cylinders cast for split tensile testing

Table 3 Results of Split tensile test for cylinder specimens

Specimen	Split tensile strength (MPa)	Density (Kg/m^3)
1	2.5	1898
2	3	1993
3	3	1910

From **table 3**, the results indicate that the tensile strength is lower as compared to compressive strength values typically observed in geopolymer mortar. Non-uniformity can result in stress concentration points and weaker areas, contributing to lower tensile strength.

5.1.3 Flexural Strength

With a coarse aggregate variation of 100% cinder and 0% fly ash aggregate, three prisms (450 x 75 x 75 mm) were cast (Fig 12 and 13). A flexural test was performed, and the results as follows **table 4**.

Fig 12 and 13: Prisms cast for split tensile test

Table 4: Results of flexural test for prism specimens

Specimen	Flexural strength (MPa)	Density (Kg/m^3)
1	2.36	2079.4
2	2.52	2252.0
3	2.20	2015.8

The findings of the flexure strength tests showed relatively consistent flexural strength values and thegeopolymer mortar with a 0 .4 alkaline binderratio and 100% cinder as the coarse aggregate possesses relatively good resistance to bending stresses.

5.2 Curing Conditions

5.2.1 Effect of variation in curing temperature

Cubes of 100mm*100mm*100 mm dimension were cast and were subjected to oven curing at varying temperatures of 60°C, 70°C, 80°C, and 90°C. Compression tests were performed (Fig 14) and the results are as follows **table 5**.

Fig 13: Cubes cast for determining the optimum curing temperature

Table 5 Results of compression test for optimum curing temperature

SL No.	Temperature (°C)	Compression Strength (MPa)	Density (kg/m^3)
1	60	8	1945
2	70	8	2415
3	80	15	2358
4	90	28	2306

The findings indicate that varying curing temperatures greatly affected the specimens' compression strength. At 90 °C, a strength of 28 MPa was attained, while at 60 °C and 70 °C, a strength of 8 MPa was attained. Higher temperatures can speed up the chemical reactions, improve the activation of the alkaline binder (sodium hydroxide and sodium silicate), and accelerate the setting of the Geo-polymer.

5.2.2 Effect of curing duration

Cubes of 100mm*100mm*100 mm dimension were cast and were subjected to oven curing at optimum temperature of 90°C at varying durations 6hrs, 12hrs, 24hrs and compression tests were performed and the results are as follows **table 6**.

Fig 14: Cubes cast and cured in oven at different durations

Table 6 Results for curing of specimens with varying durations

SL No.	Duration of curing (hrs)	Compression strength (MPa)	Density(kg/m^3)
1	6	11	2284
2	12	16	2414
3	24	21	2386

From the results in **table 6**, we can observe that as the curing duration increases, the compression strength of the material also increases. compression strength increases from 11MPa at 6 hours of curing, 16MPa at 12 hours of curing to 21MPa at 24 hours of curing This indicates that extending the curing duration hours improves the material's strength. This is likely because the extended curing time allows for more complete hydration and bonding of the material's components, resulting in increased strength.

5.3 Durability parameters

5.3.1 Fire resistance

The specimens are subjected to fire resistance testing at temperatures of 200°C, 400°C, and 600°C for durations of 2 and 4 hours (Fig 15). The specimens were placed in oven. After the duration they are taken out cooled and compressive strength test is conducted. The results are shown in **table 7.**

Fig 14: Cubes cast and subjected to higher temperatures

Table 7 Results for fire resistance (24hrs)

SL No.	Temperature (°C)	Average Compression strength (MPa)	Density (kg/m^3)
1	200	15	2346
2	400	16	2205
3	600	5	2315

From **table 7**, the observed variations in compression strength can be attributed to the response of the material to different temperatures. At 200°C and 400°C, the material shows a relatively similar level of fire resistance, suggesting that it maintains its structural integrity and can withstand the respective temperatures. However, at 600°C, the material experiences significant degradation, leading to a substantial decrease in compression strength.

5.3.2 Acid and sulphate resistance

The acid attack test was conducted on 100mm*100mm*100 mm concrete cubes by immersing them in 5N 10% sulphuric acid solution (Fig 15). Similarly, cubes were casted to immerse them in 5N 10% Sodium sulphate solution for sulphate attack test. (Fig 16). The compression strength of the concrete cubes was measured after 7 days. The results are given in **table 8**.

Fig 15: Specimens subjected to acid attack

Fig 16: Specimens subjected to sulphate attack

Table 8 Results for acid and sulphate resistance test

Type	Weight (kg)	Compression Strength (MPa)
Acid attack	2354	11
Sulphate attack	2387	9

Based on the observations from **table 8**, it can be concluded that the specimens exhibit a notable level of resistance to both sulphate and acid attack. The data suggests that the specimens are able to withstand the corrosive effects of sulphates and acids to a considerable extent.

5.3.3 Water absorption

The water absorption test evaluates the permeability and porosity of concrete. Specimens are prepared, dried, and weighed. They are then submerged in water for 24 hours. After removing and drying the specimens, their wet weight is recorded. The water absorption was determined to be 5.1%.

A water absorption value of 5.1% suggests that the concrete has a certain degree of resistance to water penetration. This suggests that the concrete's mix design and lightweight aggregates used in its composition contribute to a denser and less porous material. It also means that the concrete is less susceptible to moisture-related issues, such as freeze-thaw damage or chemical attack, which can deteriorate the material over time.

6 CONCLUSIONS

From the experimental investigations and analysis conducted, the following conclusions can be drawn:

1. Optimum Alkali Binder Ratio: According to the findings, 0.4 is the ideal alkali binder ratio for lightweight concrete. The concrete shows a compressive strength of 21 MPa at this ratio, indicating a level of strength appropriate for structural purposes. This ratio makes sure that the binders are activated properly and makes the Geo-polymerization process easier.

2. Influence of Aggregate Composition: In comparison to employing fly ash aggregates, adding cinder as the coarse aggregate increased the compressive strength. The highest strength was shown when 100% cinder as the coarse aggregate was used, demonstrating its suitability for structural applications. The compressive strength was observed to be reducing by the addition of fly-ash aggregates, indicating the need for careful consideration of aggregate selection while producing lightweight concrete.

3. Optimum Curing Temperature: The trials showed that 90 °C was the ideal curing temperature for the LWC to achieve its maximum compressive strength. Concrete exhibited a compression strength of 28 MPa at this temperature. Higher curing temperatures promote polymerization processes, which improve strength development.

4. Effect of varying curing temperature: The compression strength consistently increases from 6 hours of curing (11 MPa) to 12 hours (16 MPa) and further to 24 hours (21 MPa). This trend suggests that prolonging the curing duration enhances the material's strength.

5. Durability parameters: The specimens demonstrate similar fire resistance at 200°C and 400°C, maintaining its structural integrity. However, at 600°C, significant degradation occurs, resulting in a substantial decrease in compression strength. The specimens exhibit notable resistance to acid and sulphate attack, with compression strengths of 11 MPa and 9 MPa, respectively. The material can withstand the corrosive effects of acids and sulphates to a considerable extent. The specimens demonstrate notable resistance to water absorption of 5.1%. Overall, the concrete shows promising durability in terms of fire resistance, acid and sulphate attack resistance, and water absorption resistance.

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