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A Study on Alkali-Activated Concrete with Ilmenite Mud, Slag and Lightweight Expanded Clay Aggregates

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Abstract. The aim of the study is to investigate the creation and functionality of alkali activated concrete (AAC) that contains ground granulated blast furnace slag (GGBFS) and ilmenite mud as precursors, with the usage of lightweight expanded clay aggregate (LECA) as a partial replacement of coarse aggregates. LECA is a lightweight and insulating material, used to lower the density of the concrete without compromising strength. The goal of integrating these materials is to create high-performing, environmentally friendly concrete. In keeping with the concepts of sustainable building, the use of GGBFS and ilmenite mud not only reduces landfill, but also lowers the need for raw natural resources. In this study, combination of sodium silicate and 12 M sodium hydroxide is used as the activator solution. The present study adopts an activator modulus (M_s) of 1.5, water/binder ratio of 0.45, Na_2O/binder ratio of 6 %. In this paper, compressive strength and ultrasonic pulse velocity of LECA-infused alkali activated concrete is tested. The study reports 10 % LECA as the optimum for obtaining maximum compressive strength and ultrasonic pulse velocity. Based on the preliminary findings, the combination of ilmenite mud, GGBFS, and LECA produces a composite material that has satisfactory mechanical qualities. By demonstrating the potential of AAC with GGBFS, ilmenite mud, and LECA as a workable substitute for conventional concrete for ecologically aware construction methods, this study adds to the expanding research on sustainable building materials.

Keywords: Alkali activated concrete, slag, ilmenite mud, LECA.

1 Introduction

In the realm of environmentally friendly building materials, alkali-activated concrete (AAC) is a potentially significant development. Because of its creative use of industrial byproducts and reduced carbon footprint compared to conventional Portland cement concrete, this type of concrete is more environmentally friendly. The creation and usage of AAC are in line with the global movement towards greener building methods and a decrease in the greenhouse gas emissions related to cement manufacturing [1]. Alternative binding materials that can partially or completely replace Portland cement in the manufacturing of concrete have been the subject of investigation due to environmental concerns [1, 2]. A workable alternative has been the development of alkali-activated binders, which are frequently made from industrial byproducts including fly ash, slag, and silica fume [2, 3]. Mixing these ingredients with alkaline activators causes a chemical reaction that produces a hardened binder that resembles Portland cement that has hydrated.

The utilization of Ground Granulated Blast Furnace Slag (GGBFS) in alkali-activated concrete (AAC) is widespread because of its advantageous characteristics that improve the durability and performance of concrete [3]. GGBFS is a byproduct of the iron and steel sector that is created when molten iron slag cools quickly, turning it into a granular, glassy substance [4]. Similar to the hydration process in regular Portland cement, GGBFS undergoes a chemical reaction upon activation with an alkali solution that results in a cementitious substance. Improved resilience to chemical assaults, decreased permeability, and increased durability are just a few benefits of using GGBFS in AAC [4, 5]. Additionally, by recycling industrial waste and lowering the carbon footprint associated with the production of traditional cement, the incorporation of GGBFS into concrete promotes sustainability [1]. Utilizing industrial byproducts through the use of GGBFS in AAC encourages a circular economy and lessens need on natural resources. As a result, GGBFS plays a crucial role in alkali-activated concrete, offering advantages for the environment and functionality. The drawback of GGBFS in alkali activated concrete is its less setting time and less workability but GGBFS alone can contribute high strength values.

To improve the mechanical and durability properties of alkali-activated concrete (AAC), ilmenite mud is combined with ground granulated blast furnace slag (GGBFS). The manufacturing of titanium dioxide yields ilmenite mud, which is rich in iron and titanium oxides and can strengthen and prolong the life of concrete [6]. Ilmenite mud helps create more cementitious compounds and improves the overall binder matrix when coupled with GGBFS and activated with an alkali solution [7, 8]. Because ilmenite mud uses less resources and has a smaller environmental impact than other construction materials, it also encourages the use of industrial waste [7, 8]. An environmentally friendly, high-performing concrete with exceptional mechanical qualities and durability can be created by mixing ilmenite mud with GGBFS in AAC.

The cementitious matrix of alkali-activated concrete (AAC) is formed in part by the reaction of sodium hydroxide, sodium silicate, and aluminosilicate elements. The components silica (SiO_2) and alumina (Al_2O_3) found in aluminosilicate materials, such as ground granulated blast furnace slag (GGBFS) and ilmenite mud, are critical to the geopolymerization process. A sequence of chemical reactions take place when combined with an alkali activator, which is usually a mixture of sodium hydroxide and sodium silicate. The main gels that are generated are sodium aluminosilicate (N-A-S-H) gels, calcium silicate hydrate (C-S-H) gels, and perhaps iron-rich aluminosilicate gels [2, 9]. C-S-H gels are essential for supplying cohesion and strength within the AAC matrix. They resemble those found in Portland cement concrete. As GGBFS dissolves in the alkali activator, silica and alumina species from GGBFS react with calcium ions to generate these gels. By joining the aggregates and other ingredients in the concrete mixture, the C-S-H gels aid in the formation of compressive strength [2, 4]. When the alkali activator interacts with the silica and alumina components found in both ilmenite mud and GGBFS, N-A-S-H gels are created. By plugging gaps and pores in the matrix, these gels provide AAC more cohesiveness and increase its longevity. They strengthen the resilience of concrete to chemicals, making it less susceptible to corrosive agents like sulphate and chloride ions, which over time can erode the material.

Lightweight geopolymer is a field of study gaining its popularity due to superior durability and insulation characteristics, lesser environmental impact and sustainable characteristics [9, 10]. Lightweight geopolymer can be developed by incorporating foaming agents or light weight aggregates onto the geopolymer concrete [11, 12]. Natural lightweight aggregates are expensive and widely studied, hence laboratory prepared lightweight aggregates are adopted for the study [11]. A flexible material that has garnered a lot of attention in the construction industry, especially in the area of sustainable building practices, is lightweight expanded clay aggregate, or LECA [13, 14]. By incorporating LECA into alkali-activated concrete (AAC), it can improve the concrete qualities and enhance the range of applications for AAC [15, 16]. This article highlights the potential for further reducing the environmental footprint of construction materials while maintaining or improving performance characteristics by exploring the synergistic effects of incorporating LECA into alkali-activated concrete. LECA is a lightweight aggregate that is produced by heating natural clay and bentonite powder to a high temperature in a rotary kiln [13]. This process causes the clay to expand and form a porous, honeycomb structure, which in turn produces lightweight granules with excellent insulation properties [14, 15, 16]. There are many applications for LECA in construction because of its low density, high strength, thermal insulation, and resistance to chemical attacks [15, 16].

A wide range of materials are used in the production of lightweight alkali activated concrete (AAC) that includes ilmenite mud, ground granulated blast furnace slag (GGBFS), and lightweight expanded clay aggregate (LECA) as a partial replacement material in order to achieve maximum performance and sustainability. In order to start the geopolymerization process and create a strong cementitious matrix, an alkaline solution usually consisting of 12 M sodium hydroxide (NaOH) and sodium silicate activates GGBFS, which acts as the main binder. The manufacturing of titanium dioxide yields ilmenite mud, which is put to concrete to improve its mechanical qualities and longevity. Because of its high iron and titanium oxide content, this mud promotes further cementitious reactions that strengthen the overall structure of the binder.

Ilmenite mud, a byproduct of Travancore Titanium Private Limited, and ground granulated blast furnace slag (GGBFS) from UltraTech Company are used as the precursors for this study. 12 M Sodium hydroxide and sodium silicate are used as activator solutions. A BFS/binder ratio of 0.5, Na_2O/binder ratio of 6 %, Activation Modulus (M_s) ratio kept at 1.5, and a water/solid ratio of 0.45 are adopted for the study. The work focuses on assessing the hardened properties of lightweight geopolymer concrete, incorporated with light expanded clay aggregates (LECA) as partial replacement in coarse aggregates. LECA is prepared in TKMCE laboratory using bentonite clay (natural clay + bentonite powder in 5:1 ratio) as base materials with sodium silicate (water glass) binder solution in the ratio 1:2. Bentonite clay is mixed with water glass in the ratio 1:2 and pelletized, which is then heated at rotary kiln for polymerization and hardening. When it cools, it is crushed to obtain uniformly graded coarse aggregates that can be used for replacing natural coarse aggregates. Here, LECA is used as a partial replacement of coarse aggregate at 0, 5, 10 and 15 %.

2 Materials and Methods

2.1 Material properties

A combination of GGBFS and Ilmenite mud are taken as the precursor materials for this study. The optimum proportion of GGBFS and Ilmenite mud is found out from the paste study. The GGBFS is taken from the UltraTech cement and Ilmenite mud is taken from Travancore Titanium Private Limited. Figure 1 and figure 2 shows the XRD results on GGBFS and Ilmenite mud respectively. From the XRD test, GGBFS and Ilmenite mud contains aluminosilicates that enhance the geopolymerization process.

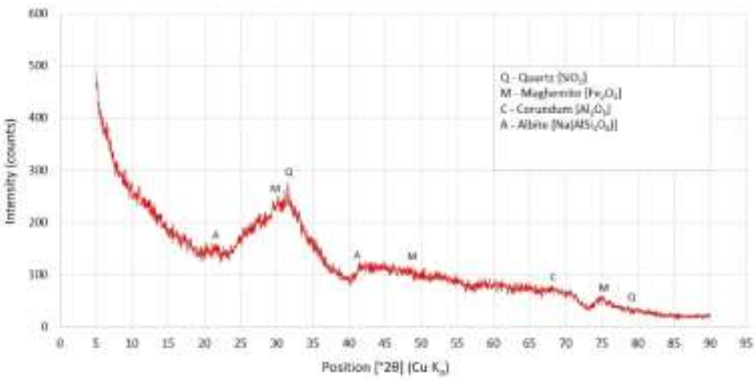

Fig. 1. X-Ray Diffraction Pattern of GGBFS

Based on the XRD examination, it was determined that the primary constituents of GGBFS were Quartz, Corundum, Albite, and Maghemite. Quartz dominates most of the peaks that were found in the XRD pattern. GGBFS is enriched with aluminosilicate compounds. The XRD pattern for the GGBFS suggested that the material is amorphous in nature. The major compounds identified in Ilmenite mud were Quartz, Corundum, Hematite and Gypsum, which also supports geopolymerization process.

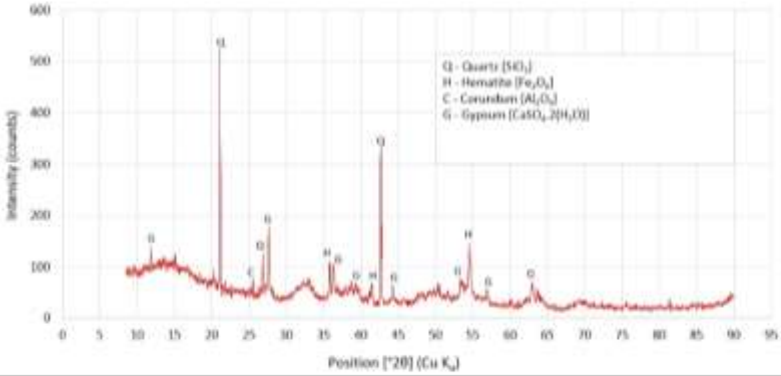

Fig. 2. X-Ray Diffraction Pattern of Ilmenite mud

Sodium silicate is obtained from Minar chemicals in Ernakulam and sodium hydroxide from Nice chemicals. The light expanded clay aggregate (LECA) is an artificial aggregate prepared in laboratory and tested its physical properties based on the standard tests for the coarse aggregate [17].

2.2 Experimental methods

The mix design for M20 AAC is prepared based on IS 17452 – 2020 [18, 19]. Preparation of alkaline activator solution, using 12 M sodium hydroxide (NaOH) and sodium silicate, is the first step in the alkali activation process. The ilmenite mud and GGBFS are combined with this solution to start the geopolymerization reactions. The alkaline activator forms a three-dimensional polymer network that binds the aggregates together by reacting with the oxides in ilmenite mud and the silicate and aluminate components of GGBFS [19, 20].

The alkali activated solution is prepared one day prior to concrete casting. From the study of fresh properties of GGBFS-Ilmenite mud alkali activated paste, an optimum proportion of 45 % GGBFS mixed with 55% Ilmenite were obtained. This value is adopted in preparation of AAC. The alkaline activator solution is added gradually after the dry ingredients have been thoroughly blended. In order to prevent segregation and promote consistent geopolymerization, it is imperative that the activator be distributed uniformly throughout the slurry through careful mixing. The mixed concrete is then poured into molds and allowed to cure in ambient environments. Ambient curing conditions are adopted for the study. 28-day compressive strength and ultrasonic pulse velocity tests were performed on the specimens to analyze the mechanical properties of LECA-infused alkali activated concrete. A relation between the two results were also developed in this paper.

3 Results and discussion

3.1 Compressive strength test

Table 1 shows the compressive strength result conducted on 150 mm cubes. Figure 3 illustrates the compressive strength of geopolymer concrete based on ilmenite mud and GGBS, partially replaced with LECA.

Table 1. Compressive strength and UPV results of alkali activated concrete

LECA (%)	Compressive strength (N/mm^2)	Ultrasonic Pulse Velocity (m/s)
0	26.56	3254
5	42.50	3278
10	45.34	4065
15	35.46	3924

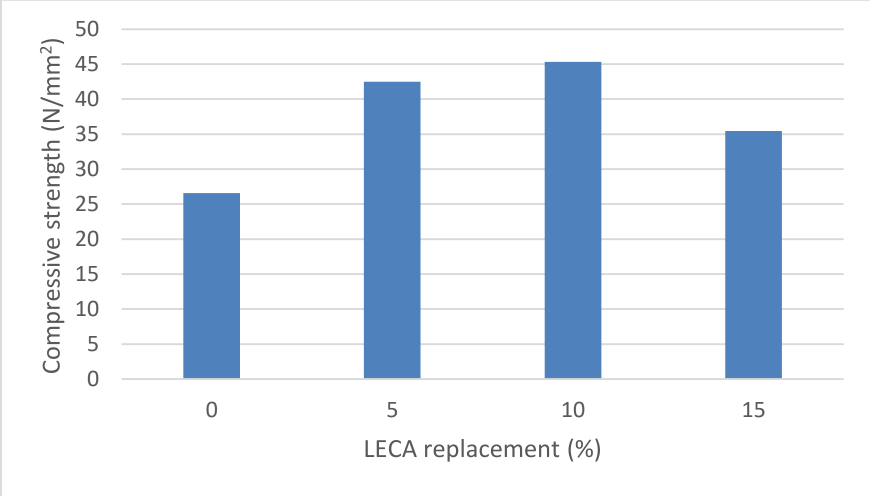

Fig. 3. Compressive strength of LECA infused GGBFS-Ilmenite mud AAC

From the compressive strength test it is clear that the result at zero percentage LECA gives 26.56 N/mm^2. With increase in percentage of LECA 5 %, 10 % and 15 % the values are 42.5, 45.34 and 35.46 N/mm^2 respectively. From Table 1, it can be found that the percentage increase in LECA will enhance the compressive strength value up to 10 % beyond which the strength decreases. From the figure it is clear that an optimum of 10 % increase in LECA will get an optimum value in test results.

3.2 Ultrasonic pulse velocity test (UPV)

Table 1 shows the UPV result conducted on 150 mm cubes. Figure 4 shows that, Ultrasonic pulse velocity of GGBFS-Ilmenite mud alkali activated concrete is 3254 m/s. When 5 % of the aggregates in the mix is replaced with LECA, the UPV value becomes 3278 m/s. When the aggregates replacement considered is 10 %, the UPV value becomes 4065 m/s. An increase of about 820 m/s is observed with the AAC is replaced with 10 % LECA as aggregate. A further increase of 5 % replacement causes a reduction in UPV value to 3924 m/s, which is significantly higher than the UPV value of 0 % replaced AAC. Higher the UPV value, higher is the quality of concrete. From Table 1, it is clear that the percentage increase in LECA will enhance the compressive strength as well as UPV value up to 10 %. From the figure it is clear that an optimum of 10 % increase in LECA will exhibit maximum compressive strength and UPV value.

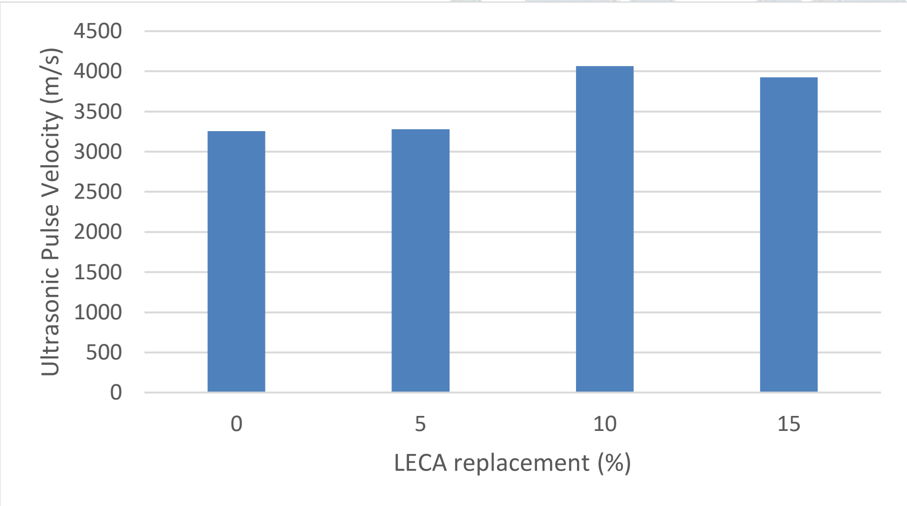

Fig. 4. Ultrasonic Pulse Velocity Value of LECA infused GGBFS-Ilmenite mud AAC

Since higher UPV values are correlated with greater concrete density and homogeneity, higher UPV values with less time generally indicate higher quality of concrete. Better compaction, better packing density etc. could be the reason for higher UPV value at 10 % LECA replaced mix. Defects like voids, fractures, or inadequate compaction may be indicated by lower UPV values.

4 Conclusion

Lightweight alkali activated concrete incorporating GGBFS and Ilmenite mud as precursors and LECA as partial replacement of aggregates is studied. Compressive strength and ultrasonic pulse velocity of 150 mm cubes at 28 days are measured. From the study, it can be concluded that:

- A combination of GGBFS – Ilmenite can be used as a precursor material for alkali activated concrete.
- Light expanded clay aggregate can be adopted as a building material.
- From the test results an increasing percentage of LECA will contribute the compressive strength and UPV values.
- From the test results an optimum value of 10 % in LECA will give maximum compressive strength as well as maximum UPV values.

- Beyond 10 % increase in LECA, drastically reduction in the test results values can be observed.

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