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The Influence of Slag on the Properties of Fly Ash-based Geopolymer Composites

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Abstract

Inorganic molecules undergo a chemical reaction that results in the production of a brand-new building material known as geopolymer concrete. Otherwise known as an inorganic alumino-hydroxide polymer, geopolymer is made mostly from by-products like fly ash and geologically derived silicon (Si) and aluminium (Al). It is a superior building material for the future because of its great mechanical qualities, significant chemical resistance (attack by magnesium or sulphate), low shrinkage and creep, and environmentally benign nature. It has been proven that geopolymer concrete (GC) is suitable for use in construction projects, including the building of walkways, prefabricated elements, and pavements. The current study intends to construct a road network using GC while sustainably utilizing industrial by-products. GC is a creative and environmentally sustainable alternative to conventional Portland cement (OPC) concrete. In this study, the GC was produced using binders such as fly ash, ground granulated blast furnace slag, and cement. Two distinct types of solutions were required in order to activate these binders (an alkaline solution which was prepared in the laboratory and activator solution purchased commercially). The surface of the GC got denser, which decreased the permeability of chloride ions, water absorption, open porosity, and sorptivity values. The microstructural examination revealed distinct quartz, calcite, and C-A-S-H formations. The 0.45 S/B ratio mixes also showed greater Si/Al ratios and higher quartz and calcite percentages.

Keywords: Geopolymer composites, mechanical properties, microstructural properties, denser structure and durability

INTRODUCTION

After water, the most consumed product on earth is concrete. Every year, about three tons of concrete are created to meet one human need on earth. Almost every aspect of human existence is impacted by the production of and construction with concrete [1]. However, it is a well-known reality that one of the world's current primary crises is global warming. The release of very large quantities of greenhouse gases into the atmosphere, which trap and reflect sunlight back onto the earth's surface, is the most significant contributor to global warming. Human activities like burning fossil fuels and disposing of agricultural waste, among others, release greenhouse gases into the atmosphere, accounting for the majority of carbon dioxide (CO_2) in the world [2]. It has been determined that of the total greenhouse gases released into the atmosphere by all human-made activities, CO_2 makes up around three-quarters.

The manufacture of cement is one of the major sources of CO_2 emissions. However, the same amount of CO_2 is released into the atmosphere

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during the manufacturing of one tonne of cement. It was discovered that the cement content of the concrete directly relates to the CO_2 emission from concrete manufacture [3]. Many efforts are being made to limit the usage of ordinary Portland cement (OPC) in concrete, even if it will not be possible to do so for a while. Over the past 10 years, substantial attention has been focused on research into cement substitutes for concrete. These studies have sparked the development of several materials that have been successfully used to partially replace cement. These include using mineral admixtures as an alternative to OPC, such as fly ash (FA), silica fume, ground granulated blast furnace slag (GGBFS), rice husk ash, and red mud [4]. In addition to cement, FA-GGBFS based geopolymer concrete (GC) can be utilized to enhance fresh qualities without sacrificing the necessary hardened properties [2, 5]

It is believed necessary to create and research the behavior of GC in light of the many ideas covered above. It is necessary to investigate how GGBFS affects the microstructure of hydrated pastes and the interfacial transition zone. It is essential to determine whether using GGBFS in GC will enhance its characteristics and performance [6]. The conversion of industrial waste into viable construction material is improved by the application of GC. By lowering the need for cement, it also lowers CO_2 emissions. The finest binders for making GC are industrial wastes that contain Si- and Al-rich compounds. Additionally, this material mix eliminates oven curing. To achieve the requisite strength qualities, the FA-GGBFS based GC samples can be cured at room temperature. When compared to OPC samples, geopolymers' strength and microstructural characteristics are superior [7].

MATERIALS AND METHODS

The FA for this study was provided by NTPC in Vijayawada, Andhra Pradesh, India. In this project, class-F fly ash was employed, and it complies with ASTM C 618-19. FA has a 477 m^2/kg specific surface area and a specific gravity of 2.3, respectively. This paper's GGBFS came from JSW Cement Ltd. in Vijayawada, Andhra Pradesh, India. This research article only uses GGBFS that complies with ASTM C 989-2018. GGBFS has a specific surface area of 670 m^2/kg and a specific gravity of 2.8. To compare the findings with the geopolymer samples, the control mix in this study was made with cement. The cement for this project came from UltraTech cements Ltd in Vijayawada, India's Andhra Pradesh. The cement used in this study complies with ASTM C 150-19 [8]. Cement has a specific gravity of 3.14 and a specific surface area of 310 m^2/kg. The chemical compositions of the raw materials used for this investigation are listed in Table 1 (FA, GGBFS and cement).

Table 1. Chemical composition of fly ash (FA), ground granulated blast furnace slag (GGBFS) and ordinary Portland cement (OPC)

Material	**Al_2O_3**	**Fe_2O_3**	**SiO_2**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**MnO**	**P_2O_5**	**SO_3**	**TiO_2**	**LOI**
Fly ash	25.08	4.56	58.23	2.87	1.21	0.41	0.87	2.94	0.2	1.16	0.83	1.64
GGBFS	12.14	1.10	32.25	44.7	4.23	0.87	-	1.96	-	0.84	-	1.91
Cement (OPC)	4.18	3.10	21.47	65.15	1.97	0.63	1.01	-	-	1.96	-	0.53

The production of GC typically employed sodium/potassium silicate (Na_2SiO_3/K_2SiO_3) and sodium/potassium hydroxide (NaOH/KOH) solutions as an alkaline activator solution. In comparison to sodium-based solutions, potassium-based alkaline solutions are more expensive. This is the reason why the combination of Na_2SiO_3 and NaOH solution was chosen in this research project as an alkaline solution. Sodium hydroxide solution is not offered commercially in the form of a solution. This resolution must be found. Commercially, sodium hydroxide is offered in white, pea-sized pellets. The sodium hydroxide solution can be made by combining with pure, purified water. The molarity of the required sodium hydroxide solution determines how much water needs to be combined with the pellets [9].

Dissolve 40 g of NaOH flakes in 1 L of water to create 1 L of NaOH solution with a normality/molarity of 1. For instance, 320 g of NaOH pellets need to be dissolved in 1 L of water to get an 8 molarity NaOH solution (of 1 L quantity). For this project, NaOH was purchased in pellet form from Vamshi Krishna Chemicals Private Limited in Vijayawada, Andhra Pradesh, India. Similar results were obtained with Na_2SiO_3 solution from Kiran Global Solution Private Limited, Hyderabad, Telangana, India. The Na_2SiO_3 solution is composed of 63.8% water by weight, 28% SiO_2, 8% Na_2, and 8% Na_2O. According to Kiran Global Solution, the activator solution is made up of 7% of additives, 43% silicic acid (H_4SiO_4), and 50% water. Numerous variables, such as the kind of alkaline solution, the molarity of NaOH, the S/B ratio, and the ratio of Na_2SiO_3 to NaOH, have an impact on the strength qualities of geopolymers. Two different geopolymer solutions are used in this work. The first is an alkaline solution made in a lab, and the second is an activator solution bought from a store. NaOH, Na_2SiO_3, and activator solution had specific gravities of 1.53, 2.13, and 1.5, respectively. The appearance of sodium hydroxide pellets and sodium silicate solution are shown in Figure 1. The mix proportions for geopolymer composites are presented in Table 2.

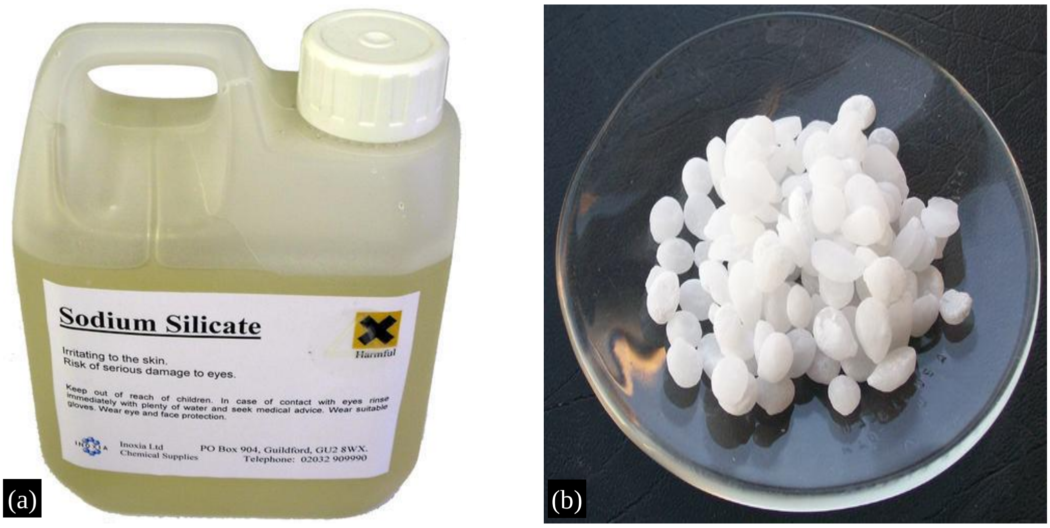

Figure 1. Sodium-based solutions: (a) sodium silicate and (b) sodium hydroxide pellets.

Table 2. Mix proportions of mix-A

Mix Id	Binders			Aggregates		Alkaline solution	
	FA	***GGBFS***	***Cement***	***Fine***	***Coarse***	***Na_2SiO_3***	***NaOH***
A1	407	-	-	610	1220	116.28	46.51
A2	366.3	40.7	-	610	1220	116.28	46.51
A3	325.6	81.4	-	610	1220	116.28	46.51
A4	284.9	122.1	-	610	1220	116.28	46.51
A5	244.2	162.8	-	610	1220	116.28	46.51
A6	203.5	203.5	-	610	1220	116.28	46.51
A7	162.8	244.2	-	610	1220	116.28	46.51
OPC	-	-	407	610	1220	-	-

FA, fly ash; GGBFS, ground granulated blast furnace slag; OPC, ordinary Portland cement.

RESULTS AND DISCUSSION

Compressive Strength

At all ages, the GC specimens performed better than OPC concrete specimens as well as GGBFS. A7 Mix-A produced specimens with higher compressive strength values when GGBFS was added at the recommended dosage. For Mix A7 (40% FA and 60% GGBFS), the greatest compressive strength was found to be 55.63 MPa after 28 days of ambient curing. Figure 2 demonstrates that the compressive strength of GC increases as the GGBFS increases. In comparison to the other mixes in Mix A, it was discovered that the 100% FA-based GC sample achieved a lower compressive strength. The lowest compressive strength value for this combination (A1) was foundto be 22 MPa after 27 days of ambient curing and 24 hours of oven curing (60°C). Additionally, it should be highlighted that the GC samples have superior compressive strength only at younger ages. One of the factors that contribute to achieving higher compressive strength values at early curing ages is the presence of calcium content.

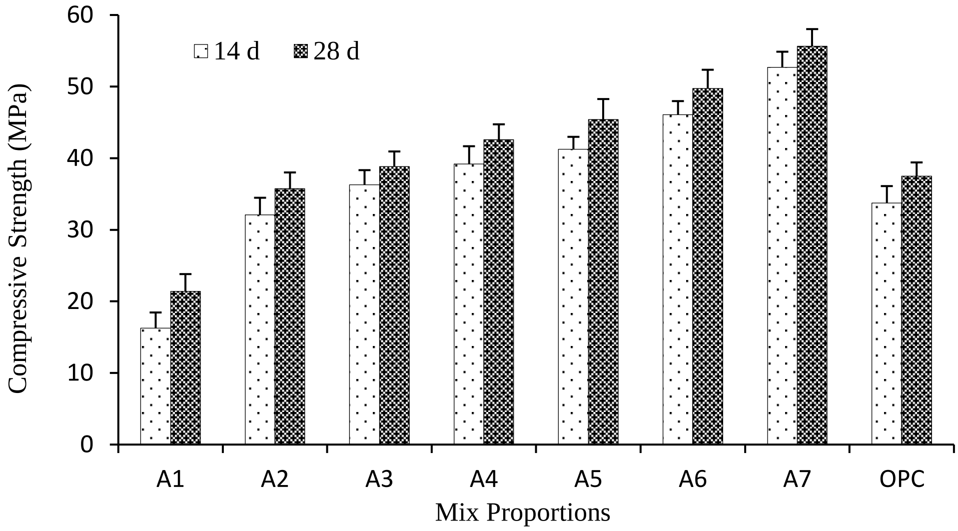

Figure 2. Compressive strength of geopolymer concrete (GC). OPC, ordinary Portland cement.

Splitting Tensile Strength

The variation in the splitting tensile strength of geopolymer samples made with two different types of solutions is depicted in Figure 3 The testing results showed that the GC samples made using alkaline solutions in the lab had higher splitting tensile strengths. However, the mild impact of the commercially available activator solution on the strength characteristics of geopolymers has been observed. Mix B2 prepared with alkaline solution had a splitting tensile strength of 7.46 MPa, compared to 5.78 MPa for Mix B4 prepared with activator solution [10]. It should be noticed that there was a 23% difference in average strength between these solutions. It means that samples of GC made with activator solutions that were purchased commercially had a 23% lower splitting tensile strength.

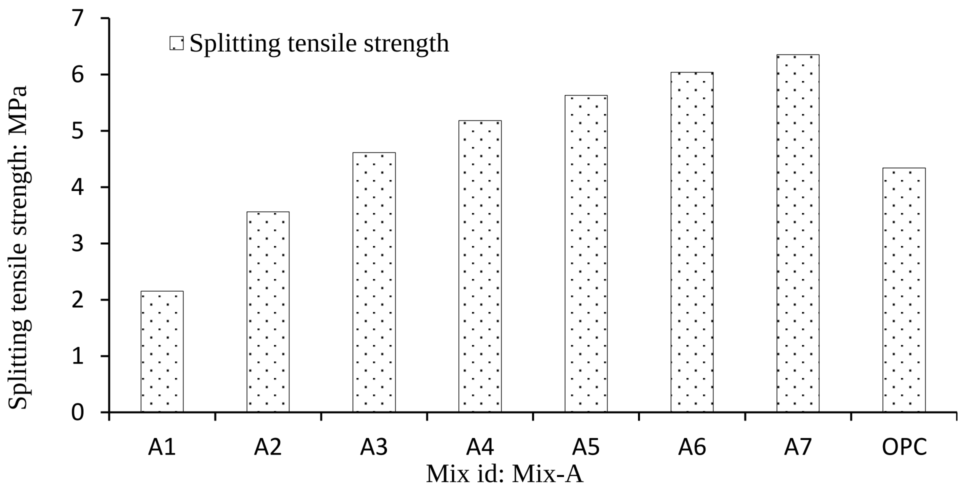

Figure 3. Splitting tensile strength after 28 days of curing.

The main causes of the strength variation in GC may be the chemical makeup of these two solutions. Contrarily, Mix-B also exhibits a variation in the splitting tensile strength with other binder mixtures, such as FA+GGBFS and FA+cement. However, the experimental findings showed that a very low splitting tensile strength was achieved with the FA+cement combination [11]. However, it can be said that under 28 days of ambient curing, FA+GGBFS has provided stronger strength values [12]. The amount of GGBFS is limited to 30% in order to use more FA in geopolymer mixtures.

Flexural Strength

Figure 4 displays the flexural strength of GC samples with various FA and GGBFS content ratios. It is evident from the experimental results that when the GGBFS percentage climbed, the values for flexural strength increased as well. However, when compared to all other mixes, 100% FA-based GC (Mix A1) has acquired a very low compressive strength. Lower flexural strength of 3.28 MPa was recorded after 27 days of ambient curing and 24 hours in a 60°C oven. It is obvious that the GGBFS addition has improved the flexural strength of FA-based GC samples. Mix A7 with 60% GGBFS and 40% FA, or 8.46 MPa, showed improved flexural strength after 28 days of ambient curing.

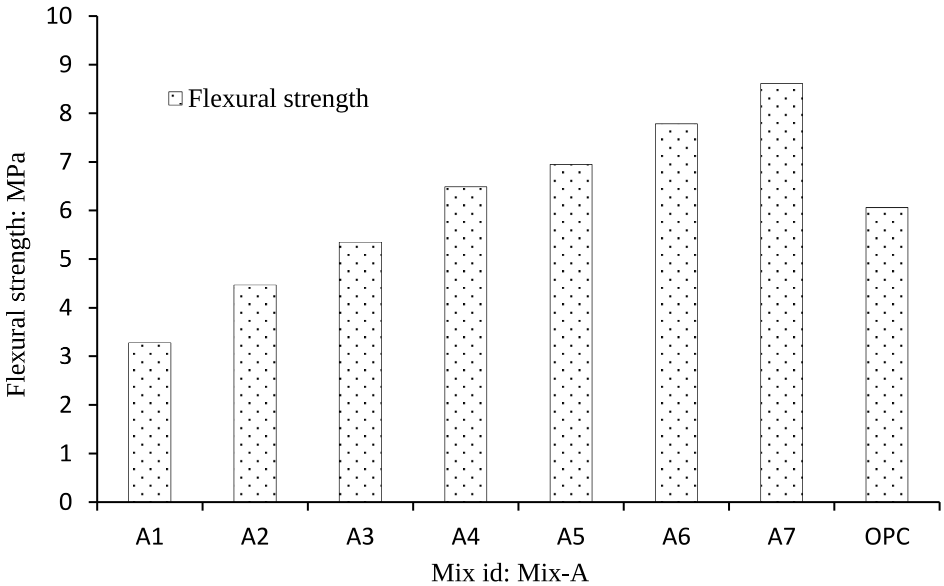

Figure 4. Flexural strength after 28 days of curing.

CONCLUSIONS

1. As GGBFS replacement levels in fresh GC increased, the initial and ultimate setting times reduced.
2. As the content of GGBGFS increased, the workability of geopolymers reduced. However, as S/B ratios rise, the workability values rise as well.
3. After 28 days of ambient curing, the mechanical characteristics of the GC specimens were higher than those of concrete of a comparable grade made with OPC.
4. The 100% FA-based geopolymer samples needed to be cured in an oven for at least 24 hours at 60°C (minimum). For FA-based GC samples, oven curing is necessary to achieve the requisite strength qualities.
5. Based on Mix B, the study came to the conclusion that the impact of commercially available activator solution on the strength increase of GC was less significant than that of alkaline solution made in the lab.
6. The samples of mix-C based geopolymers show that the S/B ratios significantly influence the strength enrichment. When compared to samples with 0.4 S/B ratios, the GC sample with a 0.45 S/B ratio had improved mechanical qualities.
7. None of the geopolymer mixes created using the FA-cement combination produced good strength ratings. Only binders based on industrial by-products are more suited for the geopolymers.

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