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Fresh and hardened characteristics of a novel alkali-activated geopolymer concrete with GGBFS

ABSTRACT

The development of a country's infrastructure relies heavily on the use of cement concrete as the major building material. The cement industry significantly contributes to global warming due to its substantial carbon dioxide (CO_2) emissions. Reducing the consumption of cement in concrete while maintaining its essential features can lead to a more cost-effective and environmentally friendly advancement of the construction sector.

By looking at a new concrete mix that includes fly ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS), this study aims to develop cement less concrete. An Alkali-Activated Solution (AAS) was used as the liquid binder along with a dry mix of FA and GGBFS. This study examines the utilization and impact of liquid and solid binders in the production of alkali-activated GGBFS-based Geopolymer Concrete (GPC), as well as the optimal quantities required for their incorporation. Various ratios of AAS to GSB were experimented with to determine the optimum mixture. To find optimum mixture of GGBFS for the GPC, different amounts of GGBFS were utlised as a Partial substitution for fly ash. At 28 days, test specimens, such as cubes, cylinders, and beams, were cast and put to the test. The GPC has also decided to use heat curing to get good results. It is found that the ratio 0.5 between AAS and GSB and a makeup of 75% GGBFS made the strongest material. The results of the study show that using AAS and GGBFS in geopolymer concrete makes a better product, which could be used in places where there is not enough water.
Keywords: *Geopolymer; Geopolymer Solid Binder; Alkali-Activated Solution; Fly Ash; GGBFS*

1. INTRODUCTION

Portland cement has been the most often utilized substance to bind the components of traditional concrete. The strength and durability characteristics of Portland cement concrete have improved significantly as well. On the one hand, cement manufacture uses the natural resources and huge energy, and also, it releases solid waste and carbon dioxide (CO_2) gas that pollutes the environment. The cement sector is responsible for approximately 5-7 percent of global CO_2 emissions. [1, 2]. Fly ash and slag from the first stagesof the iron industry have accumulated in enormous amount. Industrial waste disposal is a difficult task. Although it may not be feasible to dispose of industrial and construction trash, the necessity of using these by-product wastes has grown due to rising raw material prices and demand, as well as irreparable environmental harm [3]. However, with the help of contemporary green engineering techniques, more energy-efficient and environmentally friendly binding materials are now feasible. Anthracite or bituminous coal is used to create "Class F" fly ash which is a natural pozzolonic materials and have low calcium content [4]. Class F fly ash undergoes a chemical reaction with a solution called alkali-activated solution (AAS), which consists of a combination of sodium hydroxide and sodium silicate solution, at elevated temperatures. An inorganic alumino-silicate

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polymer known as geopolymer is the reaction's end product [5,6]. The GGBFS-alkali activated geopolymer concrete utilizes fly ash and slag as the geopolymer solid binder (GSB), while AAS functions as the geopolymer liquid binder (GLB). Comparing Class F fly ash to other classes, greater alumina and silica compounds are present [7]. Calcium oxide, silica, and alumina are found in slag. The poor reaction between the solid binder and the liquid binder results in a delay in the geopolymerisation process when conducted under ambient conditions. [8]. The reaction between the solid binder and the liquid binder happens more quickly as the curing temperature rises.

During the heat curing process, the solid binders react with an alkali-activated solution, leading to the creation of sodium aluminosilicate and calcium aluminosilicate gels. The sodium aluminosilicate gel changes into calcium aluminosilicate gel at greater GGBFS/slag concentration levels. Due to its greater density, the matrix of the changed product benefits from increased strength and durability [9,10]. In order to improve the geopolymer's acid and temperature resistance as well as early strength, fly ash may be employed [7,11]. The strength qualities of geopolymer concrete are collectively influenced by various factors, including the concentration of the sodium hydroxide solution, the ratio of silicate to sodium hydroxide solution, the ratio of AAS to GSB, the quantity of fly ash, and the curing procedure. The mechanica properties of the geopolymer concrete is improved by the sodium hydroxide concentration. Numerous researchers [10,12–16] have discovered the ideal sodium silicate to hydroxide ratio to be between 1.5 and 2.5 while maintaining a higher sodium hydroxide molarity (10–16 M) to achieve higher strength. Geopolymer concrete composed of fly ash exhibits a gradual increase in strength when exposed to normal room temperatures. However, using oven curing at temperatures between 40 and 90 C has resulted in a respectable increase in strength [17]. The fly ash-based geopolymer concrete strengthened the most when it was dried for 24 hours at a temperature between 60 and 75 °C [18,19]. Additionally, the strength and durability qualities of geopolymer concrete have been enhanced by the addition of GGBS and slag [1,7-10,20]. Furthermore, it has been documented that the production of geopolymer concrete utilizing a composition of 75% fly ash, 25% slag, and a NaOH concentration of 14 M yielded a compressive strength measurement of 35 MPa, which remained consistent even after a 28-day period of ambient curing [7]. With an increase in slag content and NaOH solution concentration, geopolymer concrete's compressive strength improved [10,20]. Bellum (2019) conducted a study that found geopolymer concrete, consisting of 30% fly ash and 70% ground granulated blast furnace slag (GGBS), displayed a compressive strength of 34.15 MPa. The concrete specimens underwent a curing process that consisted of 24 hours of oven curing at a temperature of 70°C, followed by an additional 28 days of ambient curing. The ratio of alkali-activated slag (AAS) to GGBS in the mixture was 0.35 [21]. Ma et al. (2019) found that including 30% slag in geopolymer concrete led to the maximum level of compressive strength. Nevertheless, it is important to acknowledge that the concentration of NaOH had a minimal effect on the strength after a 28-day duration [22]. Studies indicates that the utilization of fly ash and alkali-activated solution (AAS) in geopolymer concrete yields the most significant compressive strength. This outcome is achieved by maintaining a sodium hydroxide (NaOH) concentration within the range of 15.5 to 16M, and a silicate to sodium hydroxide solution ratio ranging from 1.5 to 2.5. Only a limited amount of study has examined the mechanical properties of geopolymer concrete (GPC) made with fly ash and ground granulated blast furnace slag (GGBFS), as well as the ratio of alkali-activated slag (AAS) to GGBFS.

The objective of this study is to create a concrete material by combining fly ash, blast furnace slag, and coarse and fine aggregates. This will serve the purpose of mitigating environmental pollution caused by the utilization of fly ash and blast furnace slag, while also eliminating the need for energy-intensive binding materials like cement. To create a better concrete material, different binding agents AAS have been tested. As a solid binder, fly ash and GGBFS have also been combined in a dry condition, in addition to the liquid binder. This research paper focuses on calculating the ideal proportion of GGBFS to fly ash to provide the highest fresh, hardened and durability characteristics.

Investigation has been done to find out how alkali activated GPC's mechanical properties are affected by the ratio of AAS to GSB. Heat curing at 60°C for 24 hours was used to test for any beneficial effects. The mechanical properties of GPC were examined by conducting experiments on compressive strength, flexural strength, modulus of rigidity, and split tensile strength. The objective was to improve these qualities by replacing a portion of fly ash with varied fractions of GGBFS.

2. EXPERIMENTAL PART

2.1. Materials

The geopolymer binding material is created via the process of geopolymerization, wherein a solid binder composed of "Class F" fly ash and GGBFS reacts with a liquid binder called "AAS". Tables 1 and 2 display the physical properties and compositions of Class F fly ash and GGBFS. The liquid binder mostly comprises sodium hydroxide and sodium silicate solutions. The procurement of fine and well-graded coarse aggregates from a local source was done for the purpose of using them in geopolymer concrete.

Table1. Physical properties: GGBFS and Fly ash

Tabela 1. Fizička svojstva: GGBFS i leteći pepeo

Properties	Specific gravity	Specific surface area (Blaine), (m^2/kg)	Autoclave expansion, (%)	Residue on 45 μm (%)	Moisture content, (%)
GGBS	2.79	380	0.40	2.25	0.12
Fly ash	2.25	389	0.05	1.25	0.10

Table 2. Fly ash and GGBF: Chemical composition

Tabela 2. Leteći pepeo i GGBF: Hemijski sastav

	CaO	Al_2O_3	SiO_2	Fe_2O_3	MgO	K_2O	SO_3	Na_2O	LOI
GGBS	40.5	13.9	32.0	1.8	6.0	0.40	1.70	0.6	3.9
Fly ash	2.9	26.0	59.9	3.9	0.9	1.9	0.70	0.78	1.95

2.2. Preparation of the Binder

The Solution Sodium hydroxide was made the day before the GPC was cast. Pellets of sodium hydroxide were stored in a plastic container with tap water that was 97% pure and had a pH between 7.12 and 7.20. They were thoroughly stirred with a magnetic stirrer until they dissolved. As a substantial amount of heat was produced by exothermic chemical reactions, safety precautions were taken. After that, the alkaline solution was covered and let to cool. Based on the findings of earlier research, the ideal sodium hydroxide to sodium silicate ratio of 1.8 and 16 M, respectively, were maintained. In a 16M NaOH solution, the specific gravity and pH value were1.44 and 12.4, respectively. The silicon dioxide (SiO2) content of the sodium silicate solution was 30.4%, disodium oxide (Na2O) was 11.6%, water was 56.9%, and the other components were filler materials. Sodium silicate has a specific gravity of 1.38. The sodium hydroxide solution and the sodium silicate gel were combined. This mixture underwent rigorous stirring for 5 minutes, which caused an exothermic reaction to produce an alkaline-activator solution (liquid binder) [23]. This solution was stored in a container with a tight lid.

2.3. Mix Proportion, Mixing, and Preparation of Sample

Geopolymer concrete can be prepared using either a dry blending technique or a wet blending technique. The experiment employed a dry mix approach. The composition of "Class F" Fly ash, GGBFS, alkaline-activator solution (AAS), fine aggregate, coarse aggregate, and water were established. The impact of the AAS to GSB ratio on the strength parameters of fly ash-based GPC was examined using various ratios (0.30, 0.40, 0.50, and 0.60). In addition, varying quantities of GGBFS were employed to substitute the fly ash in the mixture to assess the effectiveness of GGBFS in geopolymer concrete.

In amounts of 25, 50, 75 and 100% by the weight of fly ash in the mixture, GGBFS partially replaced the fly ash. Due to the lack of a precise design approach, the concrete constituents were proportioned using the trial-and-error method [15]. The specific gravity of the ingredients serves as the basis for the mix design criterion in this investigation. Table 3 lists the weights and ratios of each element in the GPC mix. The solid binder's weight, which was 460 kg/m3, remained consistent throughout. The quantity of aggregates has been determined by the utilization of absolute volume, aggregate grading curve, and material specific gravity.

A mixer machine was utilized for a duration of 120 seconds to blend surface-dried coarse and fine aggregates, fly ash, and GGBFS. The AAS and water (pH=7.12–7.20) were gradually mixed together for 60 seconds to form a uniform concrete mixture. Then, the mixture of coarse and fine aggregates, fly ash, and GGBFS was continuously mixed for an additional 180 seconds. In 150 mm cube, 150x300 mm cylinder, and 100x100x500 mm beam moulds, this freshly mixed geopolymer concrete was cast. On a vibration table, concrete moulds were compacted. To prevent free water from the green concrete from evaporating, a plastic wrapping sheet was placed around the concrete-filled moulds.

Table 3. Mix proportion of fly ash and slag based geopolymer concrete

Tabela 3. Udeo mešavine geopolimer betona na bazi letećeg pepela i šljake

Mix No.	AAS/GSB	W/GSB	Molarity of SH	SS/SH	% of GGBFS by weight of GSB	FA by weight of GSB	CA by weight of GSB
M0.20	0.30	0.25	16	1.8	0	1.07	2.47
M0.30	0.40	0.25	16	1.8	0	1.06	2.44
M0.40	0.50	0.25	16	1.8	0	1.05	2.41
M0.50	0.50	0.25	16	1.8	0	1.04	2.35
M25.50	0.50	0.25	16	1.8	25	1.07	2.46
M50.50	0.50	0.25	16	1.8	50	1.09	2.51
M75.50	0.50	0.25	16	1.8	75	1.11	2.55
M100.50	0.50	0.25	16	1.8	100	1.13	2.60

2.4. Slump Test

The workability of freshly mixed geopolymer concrete was assessed using a Slump cone. The gadget consists mostly of a steel mould shaped like a frustum of a cone and a steel rod used for tampering. The frustum has an inner diameter of 200 mm at its top and 100 mm at its bottom. The height of the frustum measures 300 mm. Workability was evaluated in accordance with the Indian Standard (IS: 7320)

2.5. Curing of Samples

The plastic-wrapped moulds, filled with concrete, were left at room temperature for a duration of 60 minutes. The moulds [24,25] underwent heat curing in an oven at a precisely controlled temperature of 60°C for a duration of 24 hours, after 60 minutes of ambient curing. Prior to testing, the oven-cured specimen moulds shown in Figure 1 were kept at a consistent temperature ranging from 24 to 26 degrees Celsius and a relative humidity ranging from 60 to 5%

Figure 1. GPC Specimens

Slika 1. GPC uzorci

2.6. Compressive Strength Test

The compressive strengths of GPC cubes were evaluated using a hydraulic digital compression testing machine with a capacity of 2000 kN and a least count of 0.1 kN as shown in Figure 2.a, following the guidelines of the Indian Standard IS: 516 [26]. The assessments were conducted after 3, 7, and 28 days. The test was conducted with a displacement rate ranging from 1.4 to 1.6 kilograms per minute. The compressive strength of each mix was evaluated by conducting tests on three cubes, and the mean value was determined.

2.7. Flexure Test

The flexural strength test was conducted using a digital flexure testing system that had a capacity of 100 kN and a minimum resolution of 0.1 kN as shown in Figure 2.b. A 100x100x500 mm beam was loaded at its centre point following the guidelines of ASTM Standard ASTM C-293-02, 2002, to determine its flexural strength [27]. Following the testing of three beams for each mixture, an average value for flexural strength was established.

2.8. Modulus of Elasticity

An extensometer equipped with a dial gauge was affixed to the centre of the cylindrical sample to quantify its deformation for testing modulus of elasticity as shown in Figure 2.c [28,29]. Experiments were performed on cylindrical samples utilizing a single-direction compression force at a displacement rate of 1.4 to 1.6 kg per minute.

2.9. Split Tensile Test

The split tensile test was conducted using the identical compressive testing instrument, as specified by the Indian standard IS:5816 [30]. The split strength of 150x300 mm cylinders, which were subjected to compression force perpendicular to the cylinder's longitudinal axis, as shown in Figure 2.d. The displacement rate was maintained at a consistent level of 1.4–1.6 kg/min. The average findings were calculated by conducting tests on three cylinders of each mixture after a period of 28 days.

(a) (b) (c) (d)

Figure 2. (a) Compressive strength test (b) Flexural strength test (c) Modulus of elasticity test (d) Split tensile strength test

Slika 2. (a) Ispitivanje čvrstoće na pritisak (b) Ispitivanje čvrstoće na savijanje (c) Ispitivanje modula elastičnosti (d) Ispitivanje zatezne čvrstoće rascepa

3. RESULTS AND DISCUSSION

3.1. Slump

The geopolymer concrete mixes were formulated using solid binders such as GGBFS and fly ash, a liquid binder known as alkaline activated solution, aggregates, and water. The water quantity acquired has been standardized for all design mixtures in the current investigation. The acquired water was divided into two equal parts. One component is allocated for the preparation of the AAS solution, while the other half is designated for the production of slump. Increasing the AAS to GSB ratios necessitated a greater amount of water for AAS preparation, with the excess water being utilized for slump. Due to the reduced water content in the preparation of AAS and increased water content in the creation of a more manageable GPC, the concrete mixture exhibited cohesiveness and excellent plasticity, even though it had a smaller proportion of AAS to GSB content. Figure 3 depicts the slump values corresponding to different ratios of AAS to GSB. The data demonstrated a decline in slump values as the ratio of AAS to GSB increased. Figure 4 illustrates the slump value of concrete mixes with GGBS replacement. The rigidity of the geopolymer concrete mixture escalates proportionally with the concentration of GGBFS in the mixture. Furthermore, there is a distinction in the rheological properties between Portland cement concrete and geopolymer concrete. The slump and hydration of Portland cement concrete were influenced by reactive and excess water, while in the case of GPC, water is exclusively utilized to prepare AAS and enhance workability. Previous studies have shown that the inclusion of slag in the GPC mix resulted in a decrease in workability [24,31]. To enhance the workability of the geopolymer mix at higher concentrations of GGBFS, the use of a superplasticizer is recommended. The workability of concrete can affect the mechanical and physical properties of the hardened material.

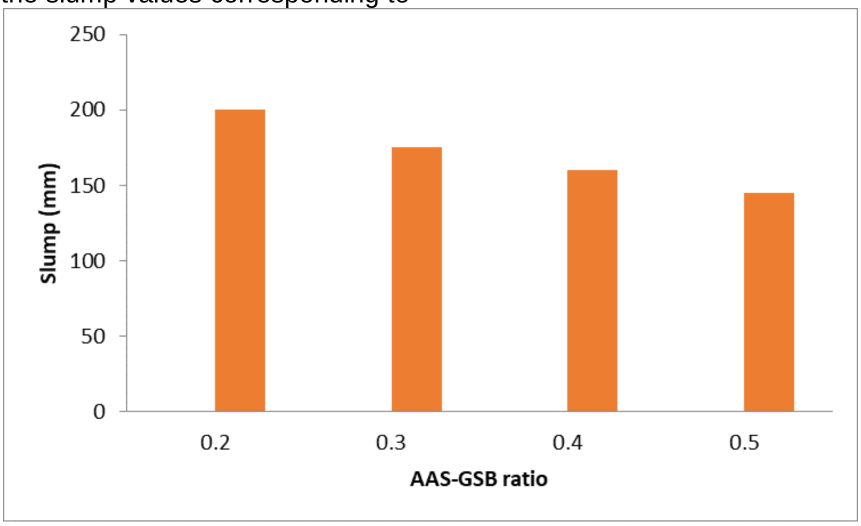

Figure 3. Slump of GPC concrete for various AAS-GSB ratios

Slika 3. Sleganje GPC betona za različite AAS-GSB odnose

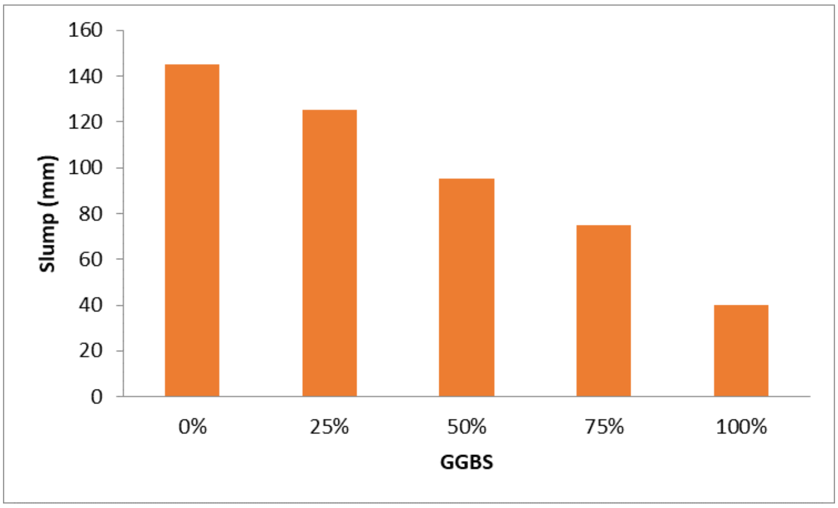

Figure 4. Slump of GPC concrete for various GGBB substitute

Slika 4. Sleganje GPC betona za različite GGBB zamene

3.2. Compressive Strength

Two significant GPC adjustments were taken into consideration in this analysis. Four different ratios of geopolymer solid binder (GSB) to alkali activated solutions (AAS) were used in the first experiment. These proportions were 0.2, 0.3, 0.4 and 0.5. Five different GGBFS substitutes for fly ash were used in the second. By weight of the entire fly ash, these replacements represented 25%, 50%, 75% and 100%. These modified GPC samples underwent testing. In Figures 5 and 6, the outcomes of compressive strengths are displayed.

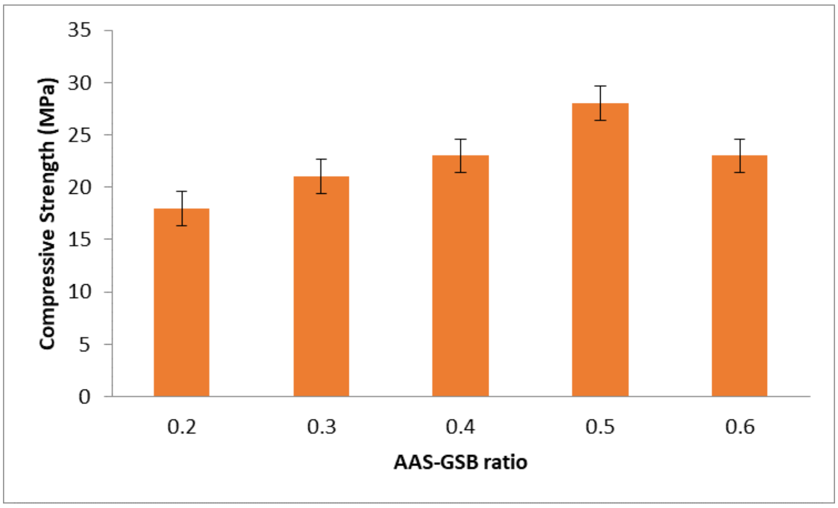

Figure 5. Compressive Strength of GPC for various AAS-GSB ratios

Slika 5. Čvrstoća na pritisak GPC za različite AAS-GSB odnose

Figure 5 displays a graph of the compressive strengths of GPC at 28 days for various AAS-to-GSB ratios. Figure 6 displays a graph of the compressive strengths of GPC at 28 days for various GGBS content. It can be seen that an AAS to GSB ratio of 0.5 results in the greatest gain in compressive strength value. AAS to GSB ratio was set at 0.50 while various GGBFS proportions were used to evaluate the impact of GGBFS content in the GPC. The effect of different GGBFS on compressive strengths at 28 days after curing is depicted in Figure 5. When 25%, 50%, 75 % and 100% of the fly ash was substituted by GGBFS, the compressive strength values at 28 days were found to rise by 7.1%, 13.3%, 25% and 10.7%, respectively, above the conventional (fly ash based) geopolymer concrete. It can be noticed that 75% fly ash substitution by GGBFS, a substantial increase in strength has been noted. A slight increase in strength is shown when GPC contains 100%

GGBFS. At 75% GGBFS concentration, the GPC had the best compressive strength.

No surface cracks were observed after the curing process in a 60°C oven. Nevertheless, certain researchers have observed the presence of surface fissures caused by the contraction of the alkali-activated slag concrete [10]. Several studies have reported that the addition of slag to geopolymer concrete (GPC) during ambient curing results in a moderate increase in compressive strength [21, 25, 32–34]. At a temperature of 60 °C, fly ash, GGBFS, and AAS demonstrate the most rapid rates of polymerization [25,35]. The greater enhancement in compressive strength is ascribed to the elevated calcium content of GGBFS [35]. The GGBFS primarily facilitates the interaction between calcium silicate, calcium aluminosilicate, and sodium aluminosilicate gel hydrates, which is responsible for the increase in compressive strength.

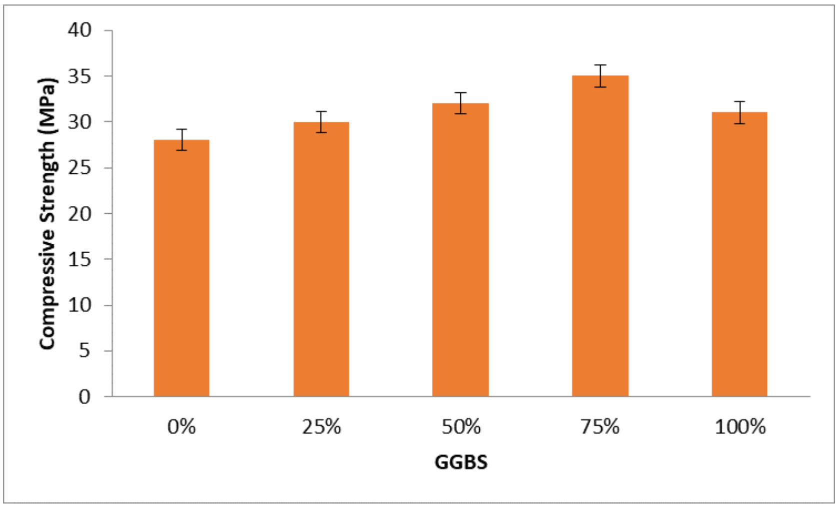

Figure 6. Compressive Strength of GPC for various GGBS substitute

Slika 6. Čvrstoća na pritisak GPC za različite GGBS zamene

3.3. Flexural strength

Flexural strength is the ability of a beam to withstand failure under bending forces. The discovery was made that the ratio of AAS (alkali-activated slag) to GSB (ground granulated blast furnace slag) in GPC (geopolymer concrete) had an influence on the flexural strength. The flexural strength of geopolymer concrete reached its peak when the AAS-to-GSB ratio was 0.5, without the presence of GGBFS. Figure 7 depicts the flexural strength of different ratios of AAS-GSB. At a GGBFS level of 75%, the flexural strength reaches its peak. Figure 8 displays the flexural strength of GPC concrete at different levels of GGBS substitution.

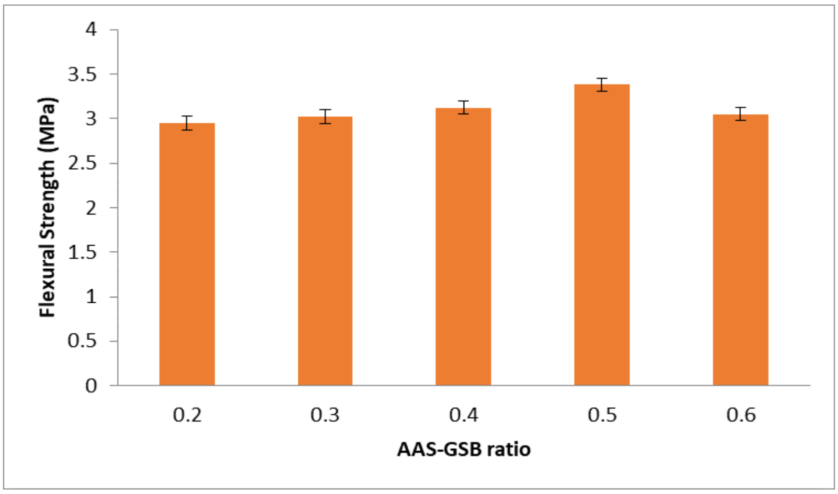

Figure 7. Split tensile Strength of GPC for various AAS-GSB ratios

Slika 7. Zatezna čvrstoća rascepa GPC za različite AAS-GSB odnose

Figure 8 displays the flexural strength of GPC concrete at different levels of GGBS substitution. Figure 8 demonstrates a notable link between the compressive and flexural strengths. The ACI 318 Building Code [36] can be used to determine the anticipated flexural strength of Portland cement concrete, and an expression for it can be expressed as fc as per Equation 1.

$$f_r = 0.62\sqrt{f_c} \quad (1)$$

Most of the specimens' flexural strengths were discovered to be between 20 and 30 percent greater than those predicted by Equation 2 (Figure 9). The authors arrived a formula for calculating the flexural strength of alkali-activated GGBFS-based geopolymer concrete as follows.

$$f_r = 0.682\sqrt{f_c} \quad (2)$$

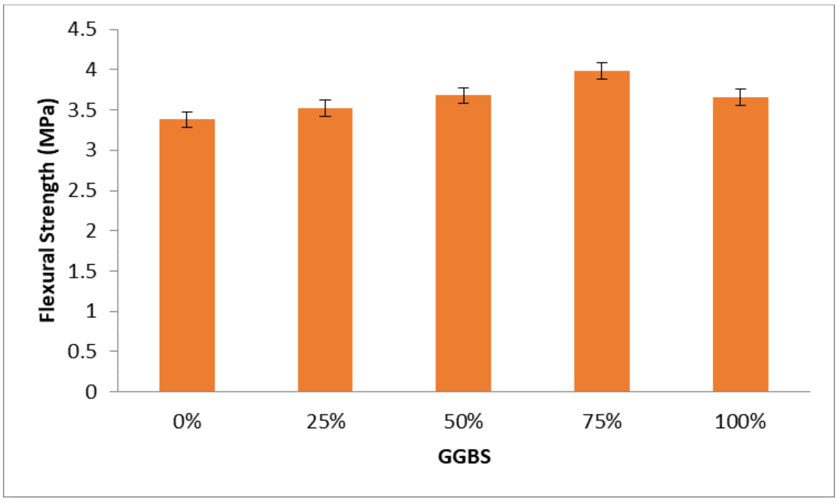

Figure 8. Split tensile Strength of GPC for GGBS substitute

Slika 8. Zatezna čvrstoća rascepa GPC za GGBS zamenu

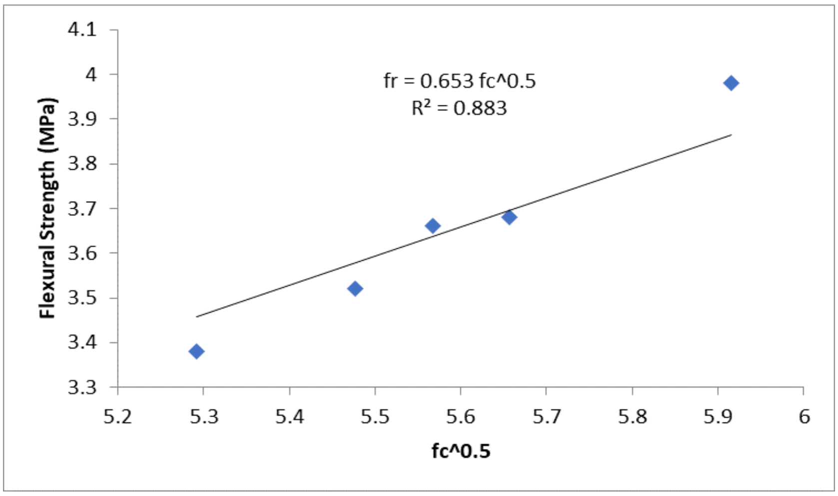

Figure 9. Correlation between flexural strength versus compressive strength

Slika 9. Korelacija između čvrstoće na savijanje i čvrstoće na pritisak

3.4. Modulus of Elasticity

Figure 10 depicts the modulus of elasticity of GPC wfor various AAS-GSB ratios. Figure 11 compares the elastic modulus of "class F" fly ash with geopolymer-based GGBFS concrete for various GGBS replacements. When the AAS-to-GSB ratio was raised to 0.50, the elastic modulus values began to rise. ACI Building Code [36] and "IS code" [26] compare the elastic modulus values to those expected for Portland cement concrete. Equation 3 & 4 represents to ACI code, and IS code for the elastic modulus of Portland cement concrete respectively.

$$E_c = 4700\sqrt{f_c}\ \text{MPa}. \quad (3)$$

$$E_c = 5000\sqrt{f_c}\ \text{MPa}. \quad (4)$$

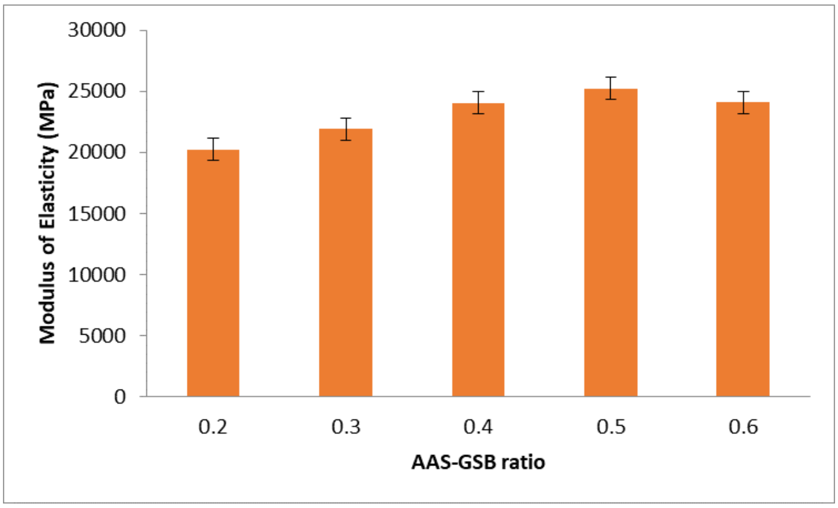

Figure 10. Modulus of elasticity of GPC for various AAS-GSB ratios

Slika 10. Modul elastičnosti GPC za različite AAS-GSB odnose

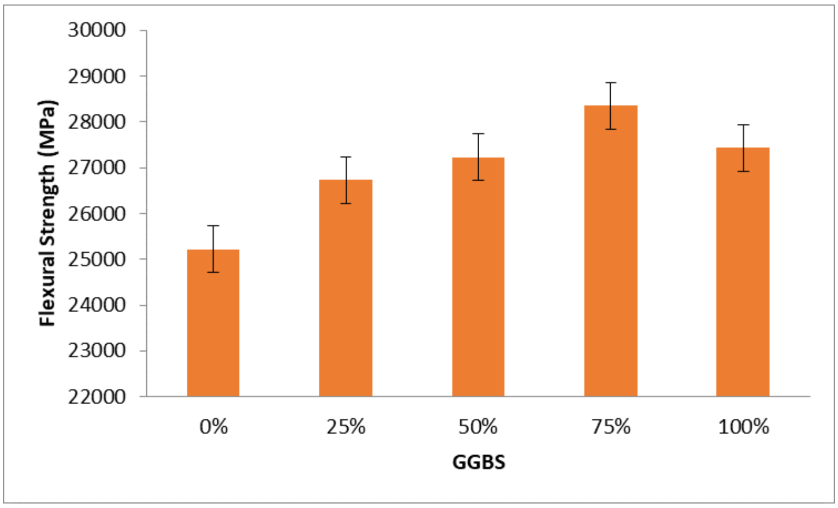

Figure 11. Modulus of elasticity of GPC for various GGBS substitute

Slika 11. Modul elastičnosti GPC za različite zamene GGBS

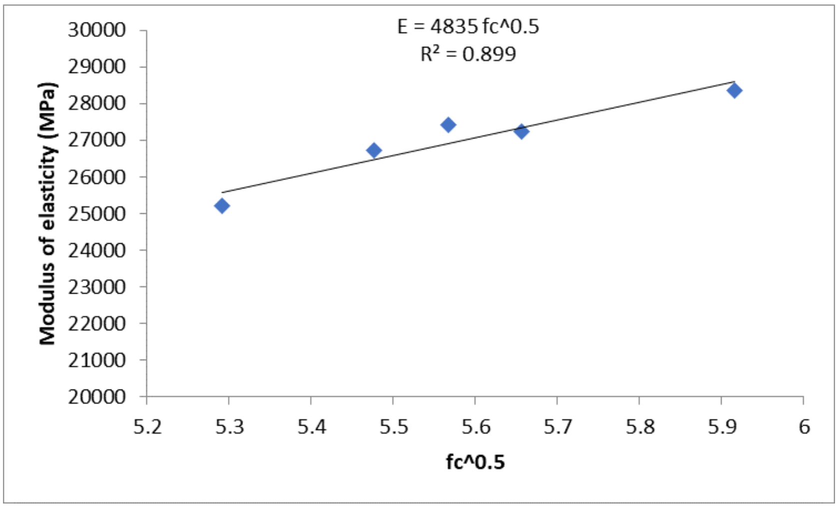

Figure 12. Correlation between Modulus of elasticity versus compressive strength

Slika 12. Korelacija između modula elastičnosti i čvrstoće na pritisak

Figure 12 illustrates the relationship between the modulus of elasticity and compressive strength. Equation 5 presents the authors' anticipated formula for determining the flexural strength of alkali-activated GGBFS-based geopolymer concrete.

$$E_c = 4950\sqrt{f_c}\ MPa. \quad (5)$$

3.5. Split tensile strength

The split tensile test is an indirect way of evaluating the tensile test of concrete [37]. Figure 13 illustrates the split tensile strength of GPC (Glass Powder Concrete) for different ratios of AAS (Alkali Activated Slag) to GSB (Ground Granulated Blast Furnace Slag). Figure 14 presents a comparison of the split tensile strength between "class F" fly ash and geopolymer-based GGBFS concrete at different levels of GGBS replacements.The split tensile strength of GPC is known to be associated with different aspects of crack initiation and propagation in the concrete structure [38]. An increase in the quantity of GGBFS in alkali-activated, GGBFS-based geopolymer concrete, while keeping the AAS/GSB ratio constant at 0.50, resulted in an improvement in the split tensile strength. The splitting tensile strength (ft) for Portland cement concrete can be determined using the CEB-FIP Model Code 95 [39] (Equation 6) and the ACI 318 Building Code [36] (Equation 7).

$$f_t=0.62\sqrt{f_c} \quad (6)$$

$$f_t=0.50\sqrt{f_c} \quad (7)$$

Figure 15 illustrates the relationship between the modulus of elasticity and compressive strength. The authors proposed a mathematical formula, denoted as Equation (8), to estimate the flexural strength of alkali-activated GGBFS-based geopolymer concrete.

$$f_t=0.53\sqrt{f_c} \quad (8)$$

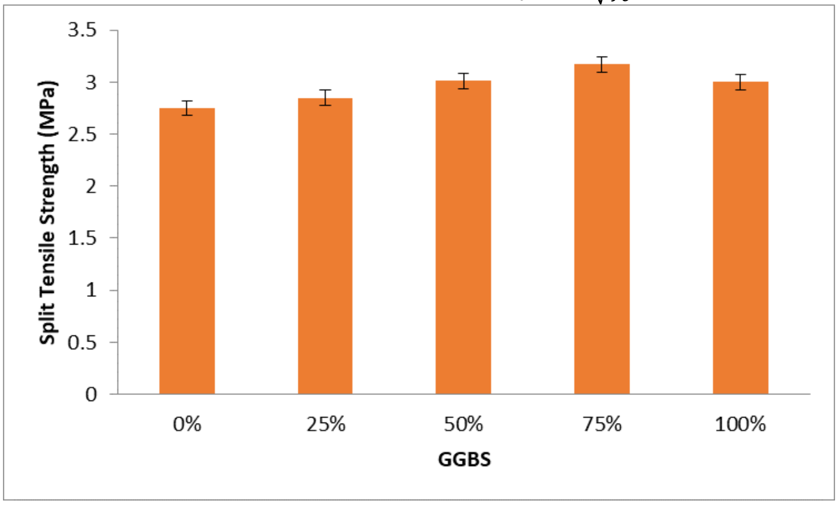

Figure 13. Split tensile strength of GPC for various AAS-GSB ratios

Slika 13. Zatezna čvrstoća rascepa GPC za različite AAS-GSB odnose

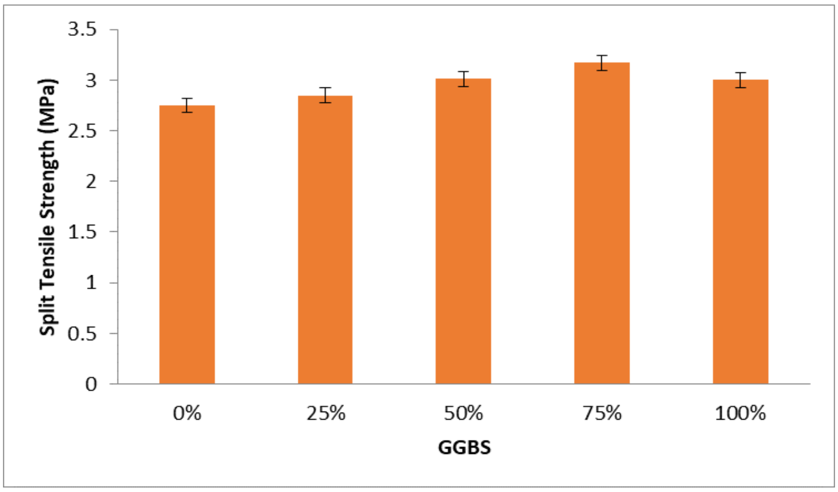

Figure 14. Split tensile strength of GPC for various GGBS substitute

Slika 14. Zatezna čvrstoća GPC-a za različite GGBS zamene

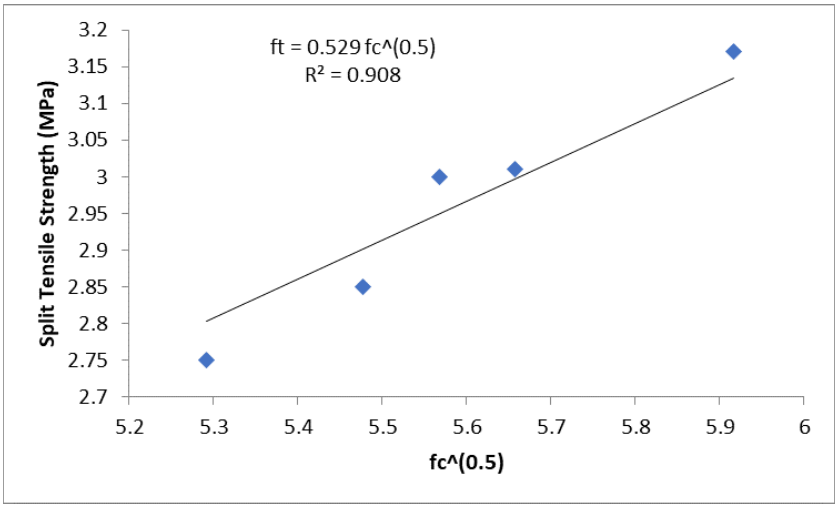

Figure 15. Correlation between Split tensile strength versus compressive strength

Slika 15. Korelacija između zatezne čvrstoće rascepa i čvrstoće na pritisak

4. CONCLUSION

The objective of this study is to develop a geopolymer concrete that exhibits a superior level of strength by utilizing an alkali-activated ground granulated blast furnace slag (GGBFS) as its primary component. The strength of this is attributed to the alkali-activated solution (AAS), which consists of sodium hydroxide and silicate solutions, as well as GGBFS. The subsequent information was revealed during an examination of strength and workability.

- The geopolymer concrete's workability rises when the AAS-to-GSB ratio rises but falls when the GGBFS content rises.
- The higher AAS-to-GSB ratio in fly ash-based GPC accounts for the increased strength. A ratio rise above 0.5, however, has no appreciable impact on the strength. An AAS-to-GSB ratio of 0.50 results in the fly ash-based GPC's highest compressive strength value.
- With the addition of more GGBFS, the mechanical properties of GPC are significantly improved. It can be shown that 80% GGBFS in GPC has generated the strongest results. When GPC contains more than 80% GGBFS, the increase in strength is minimal.
- GPC can reach high early strengths of up to 77-86% of the 28-day compressive strength when it is cured at 60° C for 24 hours.
- Empirical equations have been formulated to determine the flexural strength, elastic modulus, and split tensile strength of GPC that has undergone a curing process at 60°C for 24 hours, based on its compressive strength. These equations are expected to be advantageous for professionals in the field of concrete technology.

The objective of the present investigation was to develop a novel concrete material that has notable mechanical properties by utilizing industrial waste materials. It was based on GGBFS and an AAS. It is anticipated that this concrete would find extensive use as structural concrete. In places without access to mixing water, it would be considerably more useful.

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IZVOD

KARAKTERISTIKE SVEŽEG I OČVRSLOG ALKALNO AKTIVIRANOG GEOPOLIMERNOG BETONA SA GGBFS

Razvoj infrastrukture jedne zemlje u velikoj meri se oslanja na upotrebu cementnog betona kao glavnog građevinskog materijala. Industrija cementa značajno doprinosi globalnom zagrevanju zbog značajne emisije ugljen-dioksida (CO_2). Smanjenje potrošnje cementa u betonu uz zadržavanje njegovih osnovnih karakteristika može dovesti do isplativijeg i ekološki prihvatljivijeg napretka građevinskog sektora.

Posmatrajući novu mešavinu betona koja uključuje leteći pepeo (FA) i mlevenu granuliranu šljaku iz visokih peći (GGBFS), ova studija ima za cilj razvoj betona bez cementa. Alkalno aktiviran rastvor (AAS) je korišćen kao tečno vezivo zajedno sa suvom mešavinom FA i GGBFS. Ova studija ispituje korišćenje i uticaj tečnih i čvrstih veziva u proizvodnji geopolimer betona (GPC) na bazi GGBFS aktiviranog alkalno, kao i optimalne količine potrebne za njihovu ugradnju.

Eksperimentisani su različiti odnosi AAS prema GSB da bi se odredila optimalna smeša. Da bi se pronašla optimalna mešavina GGBFS za GPC, različite količine GGBFS su korišćene kao delimična zamena za leteći pepeo. Nakon 28 dana, uzorci za testiranje, kao što su kocke, cilindri i grede, su liveni i stavljeni na ispitivanje. GPC je takođe odlučio da koristi toplotno očvršćavanje da bi dobio dobre rezultate. Utvrđeno je da je odnos 0,5 između AAS i GSB i sastav od 75% GGBFS čini najjači materijal. Rezultati studije pokazuju da se upotrebom AAS i GGBFS u geopolimer betonu dobija bolji proizvod, koji bi se mogao koristiti na mestima gde nema dovoljno vode.

Ključne reči: *Geopolimer; Geopolimerno čvrsto vezivo; Alkalno aktivirani rastvor; Pepeo; GGBFS*

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