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Performance of Paving Block Using Geopolymer Method with Slag and Fly Ash: A Review

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***Abstract*—Geopolymers, commonly called alkali-activated binding, have emerged as an acceptable substitute for conventional binders (such as cement) in the mixtures used for paving blocks. The increasing interest of researchers in the geopolymer method for paving blocks is driven by the exploitation of pozzolanic material as a source material, which results in zero percent consumption and a hundred percent utilization. Furthermore, the decrease in CO2 emissions results from reduced cement consumption. The geopolymer method employs a primary source material rich in silica and alumina, as an alternative to cement. An alkali solution, along with Na_2SiO_3 and NaOH, is used to process and activate the polymerization process. The polymerization process results in the formation of chains and bonds of silicon-oxygen aluminum, which improves the physical and mechanical qualities of the paving block. These paving blocks prefer curing methods at both room temperature and oven. The objective of this paper is to evaluate the efficacy of paving blocks that are composed of geopolymers based on ground granulated blast slag (GGBS) and fly ash. This study specifically examined the precursors of the waste industry, namely GGBS and fly ash. The results of tests measuring the unconfined compression strength (UCS) and water absorption of paving block samples were analyzed and discussed. The paper ultimately concludes that the fly ash and GGBS-based geopolymers have been effectively employed as binders in the paving block mixture. Nevertheless, further research is necessary to satisfy the SNI 03-0691-1996 standard's requirements for road construction applications.**

***Keywords*—Geopolymer; paving block; fly ash; compression strength; ground granulated blast slag.**

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I. INTRODUCTION

The utilization of paving blocks for constructing road infrastructure is today considered a viable alternative that is increasing popularity due to its numerous advantages, such as enhanced strength and durability, as well as reduced maintenance expenses [1]. Paving blocks are frequently encountered in various settings, including roadways, highways, and construction sites. However, the construction of concrete roadways necessitates a substantial quantity of cement [2]. The discharge of CO_2 emissions by Portland cement causes global warming. Specifically, the production of 1 ton of Ordinary Portland cement (OPC) results in the release of 1 ton of CO_2 emissions [3]. Hence, civil engineering companies persistently explore new paving block mixtures that possess minimal carbon emissions and are sustainable, to replace cement as an eco-friendly material [4], [5], [6].

Geopolymerization refers to the chemical process of synthesizing inorganic materials into geopolymers by polymerization [7], [8], [9]. Geopolymer has lately emerged as a viable alternative to cement in making paving block combinations [10]. Geopolymers exhibit exceptional engineering characteristics, including enhanced strength and improved adhesion [7]. This geopolymer material requires high concentrations of silica (Si) and alumina (Al) for its production [11].

The geopolymer technique utilizes Al and Si minerals found in industrial by-products like ground granulated blast furnace slag (GGBS) and fly ash, derived from iron and coal burning, to create mixtures for producing paving stones and other cement-based products [12], [13], [14]. Geopolymer production involves using silica and alumina sources, such as GGBS and fly ash, as precursors [7], [10], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30]. These precursors readily dissolve in alkaline solutions that are formed through base activation, so enabling the process of geopolymerization [21].

Geopolymerization is a comprehensive procedure used for producing geopolymers. It includes the stages of polymerization, condensation, reorientation, diffusion, and dissolution [31]. The polymerization process consists of three stages: (1) the dissolution of oxide minerals, including alumina and silica, from the source substances in intensely alkaline environments; (2) the alignment with the dispersed oxidation substances, which ensues through the formation of an emulsion; and (3) the polycondensation reaction that leads to the formation of a 3-D structure of silico-aluminate structures. Figure 1. illustrates a common process of geopolymerization.

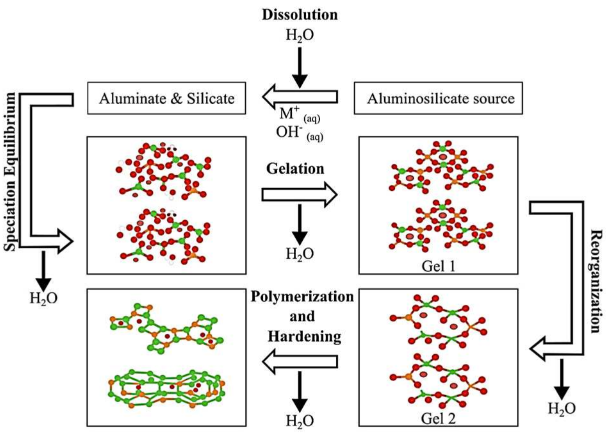

Fig. 1 Geopolymerization process [21]

Fly ash is the primary raw material used for creating geopolymers [1], [2], [15], [19], [22], [32], [33], [34]. The final characteristics can be influenced by the varying reactivity levels of fly ash to various sources when subjected to specific geopolymer synthesis conditions. The characteristics of fly ash geopolymer will be influenced by the composition of chemicals, the quantity of fly ash, and the activator solution used in both the fresh and hardened phases. The solution has a substantial impact on the geopolymer's efficacy, as it disrupts the aluminum silicate bond and releases the alumina and silica content of the original substance [11], [15], [21], [35]. Furthermore, research conducted by Mehdi Hosseini et al. [6], [36] indicates that utilizing fly ash, due to its circular morphology, might enhance porosity in concrete and promote additional chemical reactions within the cement gel. Figure 2. illustrates the morphology of fly ash.

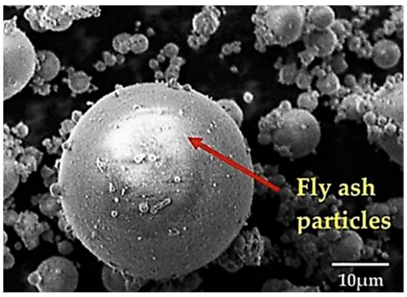

Fig. 2 The microstructure of fly ash [21]

In the year 1957, the initial application of GGBS-based geopolymer materials as a binding agent in construction was introduced [31], [37]. A granular glass, GGBS is primarily composed of oxides of calcium (CaO), dioxide of silicon (SiO_2), oxide of aluminum (Al_3), and oxides of magnesium (MgO) [15], [20], [21]. It is a shapeless byproduct that is produced during the production of iron-to-iron ore, the residual ash from burning, and substances such as lime that are employed to facilitate the process. The presence of calcium (CaO) in GGBS resulted in a reduction in the time it takes for the paving block to set and an increase in its compression strength [38], [39]. When GGBS is combined with an alkali activator solution, it leads to the creation of a calcium aluminate silicate hydrate form in the geopolymer matrix [7], [21]. The GGBS materials' considerable increase in strength was significantly influenced by the aluminum silicate framework and the presence of these products of hydration [15], [17], [18], [38], [39]. Figure 3 illustrates the morphology of GGBS.

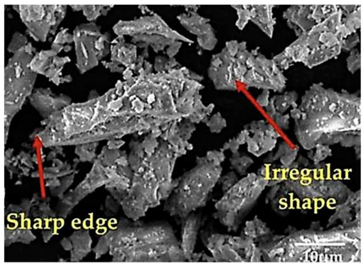

Fig. 3 The microstructure of GGBS [21]

A commonly utilized alkali solution for geopolymerization consists of a blend of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) [1], [2], [15], [21], [40]. The mechanical characteristics of the geopolymer materials in the mixture used to manufacture paving blocks are substantially influenced by the quantity of each component of NaOH solution. The sodium silicate (Na_2SiO_3) reaction for polymerization is essential for dissolving Si, whereas the proportion of sodium hydroxide (NaOH) is vital to obtaining optimal strength in the geopolymer result [21]. The chemical reaction of geopolymer concrete is shown in Table 1.

TABLE I
CHEMICAL REACTION OF CONCRETE GEOPOLYMER

Chemical reactions of concrete [41]			
Hydration reaction:	C2S or C3S + H_2O	→	Primary CSH + Ca(OH)2
Chemical reactions of fly ash concrete geopolymer [42]			
Fly ash with alkali solution reaction	SiO_2+Al_2O_3+ OH^-	→	(Si-O-Al-O-Si)n+Ca^{2+} (Geopolymer gel) + C-A-S-H (Calcium-Alumino-Silicate-Hydrate)
Chemical reactions of GGBS concrete geopolymer [41]			
GGBS with alkali solution reaction	Ca^{2+}+ OH^-	→	Calcium hydroxideCa$(OH)_2$

This article reviewed and discussed the utilization of fly ash and GGBS-based geopolymers in mixtures for producing paving blocks. The evaluation of the paving block is based on data on compressive strength and water absorption.

II. Materials and Method

Geopolymers, which have been widely researched, are used in the manufacturing of ceramics and concrete. However, the concept of producing paving blocks using a geopolymer binder is a relatively recent development. This section summarizes the existing research incorporating fly ash and GGBS-based geopolymers in paving blocks. Table 2 and Table 3 provide a summary of previous studies on the production of paving blocks using fly ash and GGBS-based geopolymers.

A. Geopolymer paving block using fly ash properties.

Research by Chairunnisa et al. [1] investigated the influence of various curing procedures on the long-term resilience and compression strength of geopolymer paving blocks. The paver geopolymer sample was produced by mixing sand, alkali activator, and fly ash in a 2.5 ratio with 8M and 10M NaOH. According to the results, the paving geopolymer, which was cured by complete immersion in artificial acid water, exhibited inferior strength and durability in comparison to the other two curing procedures. The specimens that underwent moist curing achieved the maximum strength, surpassing 35 MPa, thereby qualifying them as class A.

Another study by Nugroho et al. [40] investigated the application of residue refuse from fly ash and andesite rock handcraft manufacture as eco-friendly construction products. The experimental design employed for achieving the most effective composition of pavement blocks involved using a ratio of 65 parts aggregate to 35 parts binder, along with the addition of 14M NaOH. The absorption of water is classified as grade A according to SNI 03-0691-1996 [43], and the compressive strength values are within the grade range of A to B. The optimal mixture for the manufacturing of geopolymer paving in this investigation is 2 parts Na_2SiO_3 to 1 part NaOH, with an alkaline solution of NaOH at a concentration of 14 M.

An additional investigation conducted by Nurwidayati et al. [2] examined the compressive property of mortar geopolymer when varying proportions of bottom ash are employed as a substitute for sand. The alkaline solutions used in the experiment consisted of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) at a ratio of 2.5. Two different molarities of NaOH, 8M and 10M, were employed. Bottom ash was substituted at a maximum percentage of 30%. The compression strength of the mortar geopolymer was greater when utilizing a 10M NaOH solution compared to an 8M solution. Increased proportions of bottom ash had a substantial negative impact on the compression strength. Nevertheless, when exposed to a concentration of 10M NaOH, the compression strength experienced a drop of just 11%, which corresponds to 20% of the substitution.

Research by Sengkey et al. [10] investigated the production of geopolymer pavement from fly ash type F was facilitated by the use of cement to be a replacement material. The geopolymer paving blocks were produced through the use of 10 mol sodium hydroxide, a sodium silicate: sodium hydroxide proportion of 2.5, a liquid to a solid proportion of 0.4, and cement substitution from 0% to 40% by the weight of Fly ash. At room temperature, the treatment process occurred. By adding 20% Portland cement (PC) to geopolymer paving blocks, the quality of the paving can be greatly enhanced and improved from grade D to grade B. Furthermore, increasing the PC content by 40% has the potential to achieve grade A.

An additional investigation conducted by Qomaruddin et al. [19] examined the compression strength evaluation of geopolymer pavers utilizing carbide waste and fly ash as refuse substitutions. The paver sample in the study was created by combining carbide waste, fly ash, and an alkali activator in the form of Na_2SiO_3, together with 8M and 12M NaOH and sand. The binder and activator were present in the ratio of 65% and 35%, respectively. The curing process involved the utilization of a moist burlap sack for around 28 days. The paving geopolymer's compressive strength test resulted in 34.6 MPa and 39.8 MPa compression strengths on the mixture of fly ash and carbide waste (90%:10%).

Research performed by Tawalare et al. [18] examined the influence of the alkali solution on fly ash proportion in the characteristics of geopolymer paving blocks. The particles of fly ash, fine gravel, and coarse gravel were combined with a 14 mol amount of sodium hydroxide alkaline solution and subsequently cured at a temperature of 90°C. The Na_2SiO_3/NaOH ratio is directly proportional to the compressive strength of geopolymer paver blocks. The ideal number for compression strength testing is 35 MPa, whereas the water absorption value should be 9%.

TABLE II
SUMMARY OF PREVIOUS RESEARCH ON PAVING USING THE GEOPOLYMER METHOD WITH FLY ASH

No	Researcher	Assessment	Substances	Activator Chemical	Proportion of combining (%)	Treatment Conditions	Finding
1	Chairunnisa et al. [1]	• Compression Strength Test • Water absorption test	Fly ash	Sodium hydroxide and Sodium silicate	• Alkali activator ratio of 2.5. • The mixture proportion of Tanjung Power fly ash and Asam-asam fly ash was 25%:75%. • Molarity NaOH is 8M and 10M	The ambient temperature for 14 and 28 days.	• The maximum compression, which exceeds 35 MPa at 8M, is classified as class A. • Average absorption of water was 3%, 6%, 8%, and 10%.

No	Researcher	Assessment	Substances	Activator Chemical	Proportion of combining (%)	Treatment Conditions	Finding
2	Nugroho et al. [40]	• Compression Strength Test • Water absorption test	Andesite stone and Fly ash	Super Plasticizer, Sodium hydroxide, and Sodium silicate	• Aggregate to the binder ratio of 65:35. • NaOH with Na_2SiO_3 ratio of 1:2. • Molarity NaOH is 14M	The ambient temperature for 28 days	• The compression strength with a curing time of 28 days and water absorption value is 25,4 MPa and 1,41%.
3	Nurwidayati et al. [2]	• Compression Strength Test • Water absorption test	Fly ash and Bottom ash	Sodium hydroxide and Sodium silicate	• The amount of bottom ash has been substituted up to 30%. • Sodium silicate (Na2SiO3) and sodium hydroxide (NaOH) ratio of 2.5. • Molarity NaOH is 8M and 10M	The room temperature for 7 - 28 days	• The compression strength of the masonry geopolymer was greater than 8M when exposed to 10M of NaOH. • The absorption of masonry geopolymer materials was diminished as the molar concentration of NaOH was increased.
4	Sengkey et al. [10]	• Compression Strength Test • Water absorption test	Fly ash type F	Sodium hydroxide and Sodium silicate	• Alkali activator ratio of 2.5 • Liquid to solid ratio of 0.4 • The cement substitution levels are 0%, 20%, 30%, and 40% by weight of fly ash. • Molarity NaOH is 10M	The ambient temperature for 7,14 and 28 days	• The highest compression strength value is 40,2 MPa at 28 days of curing period. • The water absorption value is 4,16%.
5	Qomaruddin et al. [19]	• Compression Strength Test • Water absorption test	Fly ash type F and Carbide Waste	Sodium hydroxide and Sodium silicate	• The mixture consists of 70% fine aggregate, 30% binder, and activator, all calculated based on the weight of the paving material. • NaOH with Na_2SiO_3 ratio of 1:2. • Molarity NaOH is 8M and 12M	The ambient temperature for 28 days	• The highest compression strength value is 41.9 MPa and the water absorption value is 1.63%.
6	Tawalare et al. [18]	• Compression strength • Water absorption test	Fly ash type F and Slag	Sodium hydroxide and Sodium silicate	• Using fly ash as a 100% substitute for cement • Na_2SiO_3/NaOH: 2 and 2.5 • Liquid/Fly ash: 0.45 and 0,5. • Molarity NaOH is 14M	The room temperature for 7 days	• The optimum compression strength test value is 35 MPa and the water absorption value is 9%.

B. Geopolymer Paving Blok Using Ground Granulated Blas Slag Properties.

Research by Ganesh et al. [20] examined the impact of substituting a portion of fly ash with GGBS. The fly ash is combined with GGBS in varying quantities of 0, 10, 20, 30, and 40%. The molarity of NaOH is evaluated within the range of 8 to 14 M. Both of these factors are subsequently improved. The utilization of slag as an alternative for sand from rivers in various proportions, varies from 10% to 45%. The compression strength was maximized when 20% of the fly ash was partially substituted with GGBS slag.

Another study by Zhang et al. [15] evaluated the performance and advantages of using sewage sludge ash–ground granulated blast slag (SSA–GGBS) geopolymer mortar in the same year. The ratio of Na_2SiO_3 to NaOH is 2.5, while the ratio of alkaline activator to FA is 0.4. The maximum compression strength recorded is 65.77 MPa after 28 days of cure.

In a study by Srividya et al. [44], fly ash and slag are utilized as precursors, which are then activated using a solution including NaOH and Na_2SiO_3, to produce paving blocks geopolymer. The experiment entails examining the ratio of Na_2SiO_3solution to NaOH solution (0.25-2.33) when combined with various combinations of the binder slag: fly ash (20:80, 30:70, 40:60, and 50:50) under standard curing conditions. The compression strength of the majority of general-purpose concrete mixes, which have different ratios of binder and alkalinity, surpasses 40 MPa, with a maximum strength of 72 MPa. The primary factor contributing to increased strength is the high proportion of silicates, which promotes a more rapid polymerization reaction.

In another study, Malliga et al. [39] investigated the development of geo-polymer paver blocks using GGBS and fly ash. The ratio of Sodium Hydroxide to Sodium Silicate is 1:2.5, with a molarity of 8M. The compression strength of 35.5 Mpa is attained by using a 30:70 ratio of fly ash and GGBS, compared to the 34 MPa strength of ordinary concrete. This strength is measured after 14 days of curing in potable water. Therefore, the highest level of strength is attained when 70% of GGBS is used as a replacement, compared to other replacement levels.

Research performed by Revath et al. [38] investigated the utilization of a blend of alkali-activated slag and bottom ash in the production of paver blocks. The ratio of slag to bottom ash was selected as 0:100, 25:75, 50:50, 75:25, and 100:0 for the origin source. The concentration of sodium hydroxide was measured at 8M. The stoichiometric ratio of SiO_2 to Na_2O was altered within the range of 1 to 4. Two treatment methods, specifically room temperature and heat curing at 60°C with a duration of 24 hours, were selected. The test findings demonstrate that the slag-bottom ash paving geopolymer achieved impressive compression strength both during heat curing and in ambient conditions after 3 days.

TABLE III
SUMMARY OF PREVIOUS RESEARCH ON PAVING USING THE GEOPOLYMER METHOD WITH SLAG

No	Researcher	Assessment	Substances	Activator Chemical	Proportion of combining (%)	Treatment Conditions	Finding
1	Ganesh et al. [20]	• Compression strength	GGBS and Fly ash (FA)	Super Plasticizer, Sodium hydroxide, and Sodium silicate	• fly ash and GGBS sources proportions, including 100:0, 90:10, 80:20, 70:30, and 60:40. • Molarity NaOH is 8M, 10M, 12M and 14M • Slag as a substitute for sand from rivers in a variety of proportions, including 10, 15, 20, 25, 30, 35, 40, and 45%. • The ratio of Na_2SiO_3 to NaOH is set as 2.5	7 and 28 days at room temperature	The optimal compression strength value is 48.5, achieved after a curing period of 28 days at a pressure of 12 Mol.
2	Zhang et al. [15]	• Compression strength	Sewage sludge ash and GGBS	Sodium hydroxide and Sodium silicate	• Na_2SiO_3/NaOH ratio of 2.5, • Liquid to solid proportions of 0.4 • Cement proportions of 0%, 20%, 30%, 40% by weight of Fly ash • The NaOH is 6M, 8M, and 12M	7 and 28 days at room temperature	The highest compression strength value is 65.77 MPa at 28 days.
3	Srividya et al. [44]	• Compression strength	GGBS and Fly ash (FA)	Sodium hydroxide and Sodium silicate	• The slag: fly ash proportions of 20:80,30:70,40:60 and 50:50	The room temperature for 3,7, 28 days	The optimum compression strength, exceeding 72 MPa
4	Malliga et al. [39]	• Compression strength	GGBS and Fly ash (FA)	Sodium hydroxide and Sodium silicate	• Mix composition of 4% cement, 6,4% fly ash, and 6% GGBS. • Sodium Hydroxide and Sodium Silicate ratio 2.5 • The NaOH is 8M	7 and 14 days at room temperature	The greatest compression strength of 35.5 MPa is attained when 30% of fly ash is replaced by 70% of slag.
5	Revath et al. [38]	• Compression strength • Water absorption test	GGBS and Bottom ash	Sodium hydroxide and Sodium silicate	• The percentage ratio of BA: GGBS was selected as 100:0, 75:25, 50:50, 25:75, and 0:100 for the source material • The Sodium Hydroxide is 8 Mol	7 and 28 days at room temperature	The optimum compression strength test value is 58.2 MPa at 7 days of curing and the water absorption value is 0.76%.

III. Result and Discussion

Geopolymer-based paving blocks typically utilize GGBS and fly ash as the primary materials of origin. Silica and alumina are abundant in these materials, which readily dissolve in alkaline solutions during the process of geopolymerization in the production of paving block mixtures. The properties of geopolymers are influenced by several essential aspects, which contribute to creating an optimal geopolymer design and formulation. These factors consist of the concentration of NaOH, the ratio of Na_2SiO_3 to NaOH, the optimal percentage of fly ash and slag proportion and the effect of fly ash and slag on slump and ITZ of paving block geopolymer.

A. The Impact of the Concentration of Sodium Hydroxide on the Geopolymerization of paving.

The concentration of the NaOH solution (sodium hydroxide) is a critical determinant of the properties of the geopolymer. It is an alkali activator used in the production of geopolymer. The concentration of the NaOH solution has a notable impact on the ease of handling, the reaction of geopolymerization, and the strength development of the end product [6], [20], [21]. The difficulty in using NaOH solution for geopolymer production arises from the restricted enhancement of strength when the molarity used is either overly high or excessively low [7], [36], [45], [46].

Several researchers have examined the impact of different concentrations of NaOH on the geopolymer. Research by [2], [20], [47] states that a potent alkali is necessary because of the alkali activator's role in partially or completely dissolving the alumina and silica found in the original materials, as elaborated in the polymerization mechanism. The researcher discovered that a 10 M NaOH is appropriate for fly ash type F and GGBS-based geopolymer, respectively [10], [18].

B. The impact of the sodium silicate to sodium hydroxide proportion on the geopolymer used for paving.

In the study by [39], [48], and [18], the responsiveness of the primary geopolymer substance decreases as the Na_2SiO_3/ NaOH ratio becomes overly elevated. The reason for this is that sodium hydroxide solution has a crucial function in dissolving the raw materials. Multiple other research has corroborated these findings, demonstrating that a Na_2SiO_3/ NaOH proportion of 2.5 yields the most optimal results for producing paving block combinations through fly-ash and GGBS-based geopolymer methods [1], [2], [15], [18], [20], [39].

Considerable focus has been directed towards utilizing waste materials in the composition of paving block mixes. However, only a limited number of researchers have explored the application of geopolymers in paving block mixes. This research examines the composition for producing paving blocks by utilizing slag and fly ash via a geopolymer method. The approach involves directly combining slag and fly ash with an alkaline solution to create the block paving. In simple terms, the slag and fly ash serve as the fundamental components for polymerization, resulting in the creation of paving blocks made from geopolymers.

C. The impact of the percentage of fly ash and slag on the geopolymer strength used for paving.

The dosage of fly ash and slag in geopolymer concrete significantly influences its mechanical properties. A study by Behzad Mehdikhani et al. [36] indicates that including fly ash mixtures can enhance the fracture characteristics of cement geomaterials and geopolymer concrete. Fly ash, known for its slow geopolymerization process, provides excellent long-term strength, especially at higher dosages (above 70%), but lower early strength [2], [18], [49]. Conversely, slag, with its high calcium content, accelerates geopolymerization, leading to rapid early strength development, particularly at moderate to high dosages (30-50%) [20], [38], [44]. However, excessive slag (above 50%) can reduce workability and increase the risk of shrinkage cracks due to rapid reactions and heat release [7], [14], [21].

A balanced mix of fly ash and slag, typically with 60-70% fly ash and 30-40% slag, combines the benefits of both materials, offering good workability and rapid early strength gain [7], [18], [20], [21], [38], [39]. Fly ash enhances the mix's workability and long-term performance, while slag provides early strength [3]. This combination is ideal for most applications and can be adapted for the manufacture of paving blocks [49], [50]

D. The effect of fly ash and slag on slump and ITZ of paving block geopolymer

The inclusion of fly ash and slag in geopolymer paving blocks significantly affects their slump, which is an indicator of workability [22], [51]. Fly ash, characterized by its spherical particle shape and smooth surface, enhances the workability of the mix, resulting in higher slump values [7], [21], [52]. This makes it easier to mold and compact the paving blocks, particularly in mixes with higher fly ash content [7], [49]. Whereas, slag, characterized by its coarse and angular particles, diminishes workability by hastening the geopolymerization process owing to its elevated calcium content [7], [53], [54], [55]. This results in reduced slump values and a more rigid mixture, potentially necessitating the incorporation of superplasticizers or water to ensure sufficient workability [53]. Optimizing the proportions of fly ash and slag is essential for achieving the desired slump while maintaining the requisite strength for paving block applications [4], [22], [53], [56].

Fly ash, with its fine spherical particles, enhances interfacial transition zone (ITZ) properties by filling micro-voids and reducing porosity, which leads to a denser. While slag enhances early strength through rapid geopolymerization but may cause microcracks if used excessively [57]. The balanced use of fly ash and slag optimizes ITZ performance, where fly ash provides long-term durability by improving pore structure, and slag ensures early strength development [57], [58], [59].

IV. Conclusion

This research showcases the efficacy of paving blocks manufactured by a geopolymer technique that relies on fly ash and GGBS. The experimental findings demonstrate that incorporating fly ash and GGBS into paving blocks using the geopolymer technique can result in a substantial enhancement in compression strength, exceeding 25 MPa. However, further research is needed to fulfill the requirements of the SNI 03-0691-1996 standard for road construction applications. The geopolymerization process is an innovative way of producing paving blocks that can surpass traditional processing techniques. This study proposes various next works based on the discovered gaps, as indicated below.

Previous investigations have demonstrated that the utilization of GGBS and Class F fly ash as raw materials in the production of geopolymer paving blocks can enhance their compression strength. Hence, it is advisable to focus future efforts on utilizing Class C geopolymer fly ash as a material for paving blocks, incorporating coconut fiber as a reinforcing agent, and substituting stone ash for sand.

The design of geopolymer mixes for paving blocks plays a crucial role in enhancing the mechanical qualities of paving. Hence, it is imperative to do further investigation into the ideal solid-to-liquid ratio, the ratio of sodium hydroxide to sodium silicate, and the molarity of NaOH. Further investigation is required to determine the impact of different curing temperatures and conditions on the geopolymer-based paving blocks.

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