The Influence of Curing Treatments on Compressive Strength and Durability of Geopolymer Paving Blocks.

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Abstract. The current study focused on developing geopolymer paving blocks for infrastructure facilities utilizing industrial wastes. This research investigated the effect of various curing treatments on the compressive strength and durability of geopolymer paving blocks. Three curing methods, such as laying to room temperature, moist curing covered by a wet cloth sheet and total immersion in artificial acidic water, were studied. The geopolymer paver specimen was produced by mixing low calcium of fly ash, sand, and alkali activator, such as sodium silicate (Na_2SiO_3) with 8M and 10M sodium hydroxide (NaOH) with a ratio of 2.5. The hydraulic press machine was then used for pressing the specimen. The evaluation of these specimens included assessing their compressive strength, water absorption, resistance to sodium sulfate, and density following recommended standards. The results indicated that the geopolymer paver cured by total immersion in artificial acid water exhibited worse performance in strength and durability than the other two curing methods. The highest compressive strength, exceeding 35 MPa, categorizing it as class A, was achieved by the specimens subjected to moist curing. All geopolymer paving block specimens are suitable for various applications, pedestrian zones and city parks.

1 Introduction

With the rise in demand for housing and economic activity, there has been a significant increase in the construction of infrastructure facilities using concrete. This trend is a consequence of globalization and industrialization. It has been established that cement production emits a large amount of energy and carbon dioxide into the environment. Consequently, to create environmentally friendly concrete, an alternative binder must be sought [1]. Geopolymer is an innovation in the construction industry, aiming to produce concrete safely, economically, and with environmental sustainability in mind. Geopolymer

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concrete, distinct from traditional cement-based concrete, utilizes fly ash as its primary raw material along with sodium silicate (Na2SiO3) and sodium hydroxide (NaOH) activators. The waste utilization results in a carbon-negative environment, often known as a green environment or a green construction material. Geopolymer paving blocks are paving materials that incorporate pozzolanic materials containing Silica and Alumina compounds. Due to their fine nature, pozzolans can react with alkali activators. Moreover, the current study focused on creating paver blocks for pedestrian facilities by incorporating various wastes, such as fly ash and recycled asphalt pavement aggregate, for producing paving blocks and other wastes [2]–[5]. However, the method of curing has a major impact on the micro-structural and strength development of alkali-activated fly ash geopolymer [6]–[8].

This research explored the utilization of various fly ash from different sources, varying molarities, and curing methods in the production of geopolymer paving blocks. It aimed to assess the performance of geo-paving blocks in terms of compressive strength and density at 14 and 28 days. Additionally, it examines their water absorption characteristics and resistance to sodium sulfate at 28 days. The geo-paving blocks presented in this research hold the potential for significant value and application in infrastructure development.

2 Materials and Methods

2.1 Materials

Fly ash was obtained from Asam-Asam thermal power station and Tanjung Power Indonesia, a coal-fired electric power station in South Kalimantan, Indonesia. Asam-Asam fly ash can be categorized as Class F fly, with chemical composition of (SiO_2 40.92%, Al_2O_3 10.28%, Fe_2O_3 23.51%, CaO 12.86%, MgO 8.97%, Na_2O 0.26%, K_2O 0.74%, MnO_2 0.49%, TiO_2 0.62%, P_2O_5 0.2%, and SO_3 0.82% and undetermined 0.53%). Furthermore, fly ash from Tanjung Power Indonesia can be categorized as Class C fly ash, with chemical composition of SiO2 45.01%, Al_2O_3 10.11%, Fe_2O_3 13.01%, CaO 15.02%, MgO 11.02%, Na_2O 0.53%, K_2O 0.72%, MnO_2 0.20%, TiO_2 0.53%, P_2O_5 0.2%, and SO_3 3.12% and undetermined 0.53%. The composition ratio of Asam-asam fly ash and Tanjung Power fly ash was 75%:25% [9].

The alkaline solution consisted of a mixture of NaOH and Na2SiO3 solution in a 1:2.5 weight ratio. The NaOH was in crystal form (flake) with a purity level of 98%. Two different molarities of NaOH, 8M and 10M, were used in this research. The Na2SiO3 used was in liquid form with a specific composition. The ratio of fly ash to the alkaline solution was 60:30, while the ratio of fine aggregate to geopolymer paste was 65:35. Fine aggregate was sourced from the Barito River, categorized as Zone C. Fig. 1 displays the alkaline solution, fly ash, and fine aggregates used in the production of geopolymer paver blocks.

NaOH Na_2SiO_3 Fine aggregate Various fly ash

Fig. 1. The constituent material of geopolymer paving block

2.2 Mix Composition

The research variables were the molarity of NaOH, and different curing types were studied. The molarity of NaOH was changed between 8M and 10 M. Moreover, specimens were cured in various types of curing to testing day, cured in room temperature treatment methods, cured in moist conditions covered with a wet cloth sheet and cured in total immersion in artificial acid water. All specimens were evaluated regarding compressive strength, water absorption, resistance to the sodium sulphate and density per the code recommendation. Geopolymer paving block mix design was done based on the findings of Mariamah et al. [10]. Table 1 and Table **2** provide the details of the mix compositions and specifications, respectively.

Table 1. Mix specification evaluated

Specimens	NaOH Molarity	Alkaline ratio	Evaluated test	Curing treatments
8GPV_R	8M	2.5	Compressive strength and density test	Room temperature
8GPV_H	8M	2.5		Moist temperature
8GPV_A	8M	2.5		Acid water immersion
10GPV_R	10M	2.5		Room temperature
10GPV_H	10M	2.5		Moist temperature
10GPV_A	10M	2.5		Acid water immersion
8GPV_RA	8M	2.5	Absorption test	Room temperature
8GPV_HA	8M	2.5		Moist temperature
8GPV_AA	8M	2.5		Acid water immersion
10GPV_RA	10M	2.5		Room temperature
10GPV_HA	10M	2.5		Moist temperature
10GPV_AA	10M	2.5		Acid water immersion
8GPV_RN	8M	2.5	Sodium sulphate resistance	Room temperature
8GPV_HN	8M	2.5		Moist temperature
8GPV_AN	8M	2.5		Acid water immersion
10GPV_RN	10M	2.5		Room temperature
10GPV_HN	10M	2.5		Moist temperature
10GPV_AN	10M	2.5		Acid water immersion

Table 2. Detailed of mix proportion

Test type	Fly ash (kg)	Fine aggregate (kg)	Na_2SiO_3 (kg)	NaOH (kg)
Compressive strength	4.326	12.354	1.662	0.666
Density	4.326	12.354	1.662	0.666
Absorption	2.163	6.177	0.831	0.333
Sodium sulphate resistance	2.163	6.177	0.831	0.333

2.3 Methods

Geopolymer paving block specimens were prepared using a similar method to conventional mortar specimens. These geopolymer paving block samples were created by mixing the constituent materials in a mixer. The research focused on evaluating the characteristics of these specimens, including their compressive strength at 14 and 28 days, following the ASTM C109 code [11], resistance to natrium sulphate, and absorption test.

Steel moulds with a gauge of 6 mm and dimensions of 200 mm, 100 mm, and 60 mm were used to produce all specimens. A replica of three specimens was created for each of the several tests. The alkaline solution was created before mixing the components in the pan mixer by combining NaOH and Na_2SiO_3 solution. In the mixer, fine aggregates were fully mixed with the type of fly ash. The mixing process was continued until a uniform and homogeneous mixture was obtained. Fresh mix was poured into greased steel moulds and compacted by a tamping rod. Figure 2 shows the steps in the production of geopolymer paver blocks.

a. Constituent materials b. Empty molds c. Mixer

d. Specimen in mould e. Paving block f. Paving block under curing treatments

Fig.2. Production Process of geopolymer paving block

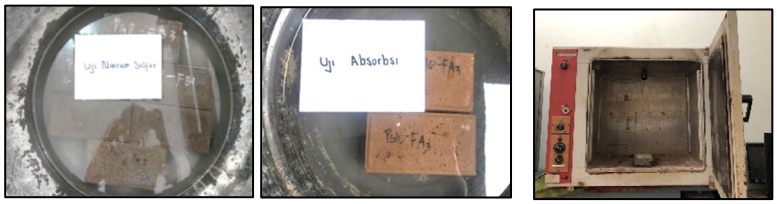
The curing of geopolymer paving block samples was carried out after removing the test object from the formwork. Three methods were applied in this research, such as room temperature, moist temperature and acid condition with pH3. First, the moist temperature or humid condition method was undertaken by wrapping the geopolymer test object in a moistened cloth and placing it in a container before the testing time. Second, the room temperature approach was used to treat the geopolymer test object by inserting it immediately into an open container before the testing time. Finally, artificial acidic water was made using a 32% HCl solution until the acidic water reached a pH of 3 for implementing the acid curing method. The analysis of test results was carried out using moist temperature, room temperature and acid water curing methods with tests for water absorption and resistance to sodium.

The water absorption test was performed after 28 days to determine the percentage of water absorption. This step was done immersing the paving block for 24 hours, then drying at 105ºC and weighing twice until the final difference in weight was less than 0.2%. According to SNI-03-0691-1996 [12] concerning water absorption, the procedure for testing water absorption on paving blocks is as follows. The absorption value was computed by subtracting the weight of the wet paving block from the weight of the dried paving block and dividing the weight of the dried paving block by the weight of the dried paving block in percentage. Five test objects were soaked in water until saturated (24 hours), and the specimen was then weighed wet. Subsequently, the wet specimens were dried in an oven for approximately 24 hours at approximately 105°C until their weight remained at two weighings, with no more than 0.2% of the previous weighing. Finally, the absorption was estimated.

Sodium sulfate resistance testing was also carried out as part of this research. The procedure for testing resistance to sodium sulfate was based on SNI-03-0691-1996 [12]. Two test specimens were cleaned to remove any adhering dirt, then dried in an oven at a temperature of (105+2)ºC until a constant weight was achieved, followed by cooling. Once the specimens had cooled, they were weighed with an accuracy of 0.1 grams and subsequently soaked in a solution of sodium sulfate salt dissolved at 340 grams per litre for 16 – 18 hours.

Next, the test specimens were placed in an oven at a temperature of (105 ± 2)ºC for approximately 2 hours and then cooled to room temperature. This soaking and drying cycle was repeated up to five times. During the final drying, the test specimens were washed until all traces of sulfate salt were removed. To expedite the washing process, the specimens should be washed with hot water at approximately 40 – 50ºC. After thorough washing, the test specimens were dried in an oven until a constant weight was maintained (± 2-4 hours), then cooled in a desiccator. They were weighed again with an accuracy of 0.1 gram.

In addition to the weight measurements, the condition of the test specimens was observed to check for any cracks, clusters, or other defects that might have appeared after immersion in the sulphate salt solution. If the difference in weight before and after immersion did not exceed 1%, and the test specimens were free from defects, they were considered in good condition. However, if the difference in weight between two out of the three test specimens exceeded 1%, even if they were defect-free, the overall test object was deemed defective. The test procedures for absorption and sodium sulphate resistance testing are illustrated in **Fig.3**.



a) Soaking in sodium sulphate solution b) Soaking in water for absorption test c) Drying of test objects

Fig.3. The test procedure of absorption and sodium sulphate resistance test

3 Results and Discussion

3.1 Setting time of Geopolymer Paste

This test aims to determine the initial setting time and final setting time of the geopolymer concrete binder. The setting time testing standard is ASTM C191[13]. Test results can be seen in **Fig.4**.

Fig.4. Sample setting time and vicat tool

Figure 5 shows that for paste with a molarity of 8M, the initial and final setting time was 32.21 and 90 minutes, respectively. In comparison, for the molarity of 10M, the initial and final setting time occurred at 51.11 and 105 minutes, respectively.

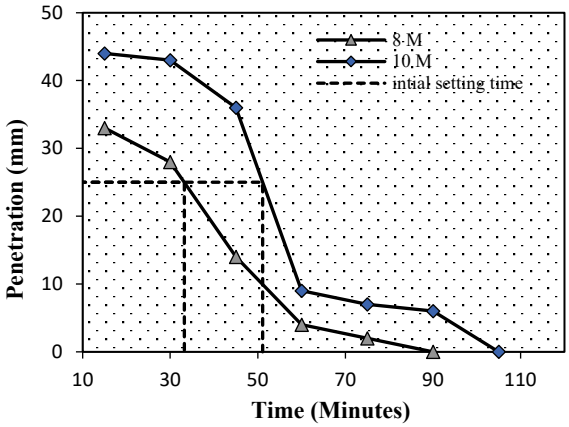


Fig.5. Setting time result from 8M and 10 M of Geopolymer Paste

These findings are similar to the previous research by Mariamah [10], revealing that the relationship between NaOH molarity and setting time at a ratio of 2.5 was the longest in 14M, with the initial and final setting time being 1890 and 1184 minutes. The test results indicate that the higher the molarity of NaOH, the longer the initial and final setting time of the mortar.

3.2 Compressive Strength

The compressive strength of paving blocks is a crucial indicator of their quality. To test the compressive strength of specimens, the method outlined in SNI 03-0691-1996 [12], was employed. Geopolymer paving block specimens were cut into cubes, with dimensions adjusted to the thickness of the paving material being tested. Since the tested paving had a thickness of 6 cm, the specimens were cut into cubes measuring 6 x 6 x 6 cm. The compressive strength testing for geopolymer paving blocks with molarities of 8M and 10M, cured under varying conditions of humidity, room temperature, and acidic water with a pH of 3, was conducted following the criteria outlined in SNI 03-0691-1996 [12]. Table 3 and Fig.6 illustrate the relationship between the compressive strengths of specimens at 14 days and 28 days, considering different NaOH molarities and various curing methods.

Table 3. Compressive strength and density of all specimens

Specimens	The compressive strength (MPa)		Density (kg/m^3)
	14 days	28 days	
8GPV_H	38.27	57.81	3.08
8GPV_R	35.95	46.10	2.98
8GPV_A	35.12	40.09	2.88
10GPV_H	35.03	37.68	2.64
10GPV_R	31.91	34.24	2.69
10GPV_A	25.95	29.20	2.50

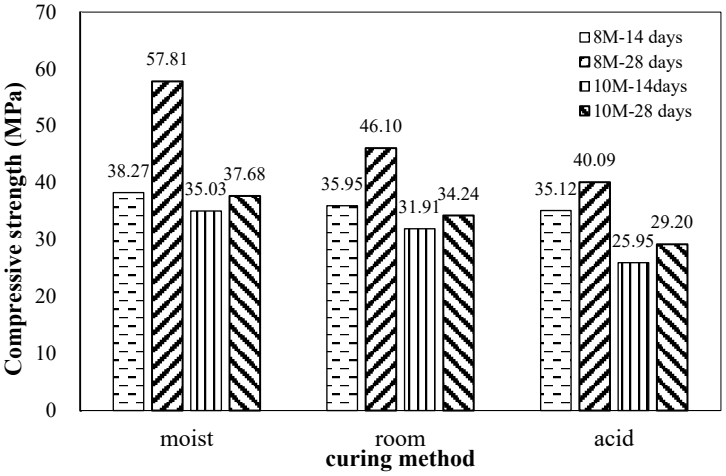


Fig.6. The compressive strength of 8M and 10 M of Geopolymer Paste

SNI 03-0691-1996 specifies that the average compressive strength of paving block at 28 days should not be less than 35 MPa for road pavement, 17 MPa for parking application, 12.5 MPa for pedestrian zones and 8.5 MPa for city parks, respectively. Fig.6 depicts the effect of NaOH molarity on the compressive strength of the geopolymer paving block at 14 and 28 days. The highest compressive strength of the test object was 57.81 MPa in the 8M NaOH test, while for 10M NaOH, it was 37.68 MPa. There was a decrease in strength of 34%, with an increase in molarity from 8M to 10M for the curing method. Furthermore, all specimens in moist cured with 8M and 10 M met the criteria of the standard requirement for road pavement. Similar trends in strength reduction for the higher molarity of specimens have been reported by Selvakumar [14].

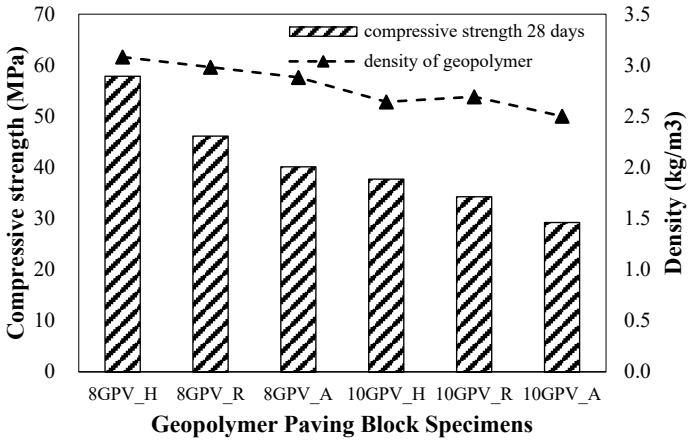


Fig.7. The compressive strength of 8M and 10 M and the density of specimens

The findings of the compressive strength test indicate a similar value trend as the density results. Fig.7 shows that the highest average density was for the paving block of 8GPV_H (3.08 cm^3), while 10GPV_A had the lowest density (2.5 cm^3).

3.3 Water Absorption and Sodium Sulphate Resistance of Specimens

Water absorption is important in determining the porous nature of geopolymer paving blocks. This test was performed 28 days after curing, and the influence of molarity and curing process on water absorption of geopolymer paving blocks is depicted in Fig. 8. Water absorption was limited to an average of 3%, 6%,8% and 10% by mass for road pavement, parking lot, pedestrian zone and city park utilization respectively, following SNI 03-0691-1996 [12].

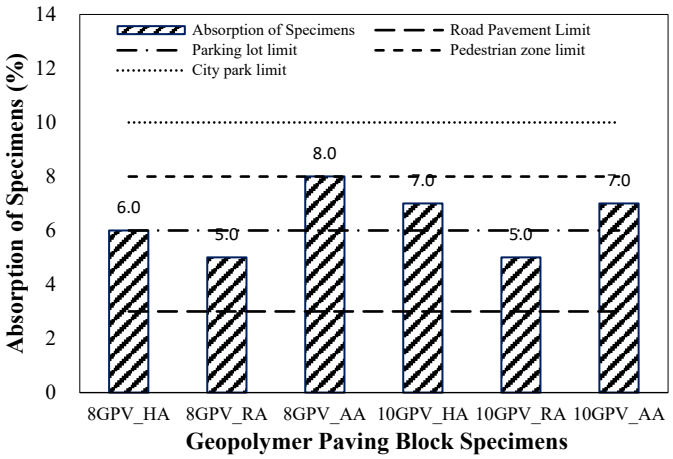


Fig.8. Effect of molarity and curing method on water absorption of Geopolymer paving blocks.

The results indicate that all specimen mixtures met the requirements of codal provision. It was also observed that water absorption increased when specimens were cured in an acidic environment. Additionally, the lowest absorption levels were observed in specimens cured at room temperature. Furthermore, specimens with compositions of 8M and 10M, cured at room temperature, exhibited the lowest water absorption compared to other curing methods. As a result, all the specimen paving blocks can be utilized for various applications, such as parking lots, pedestrian zones, and city parks.

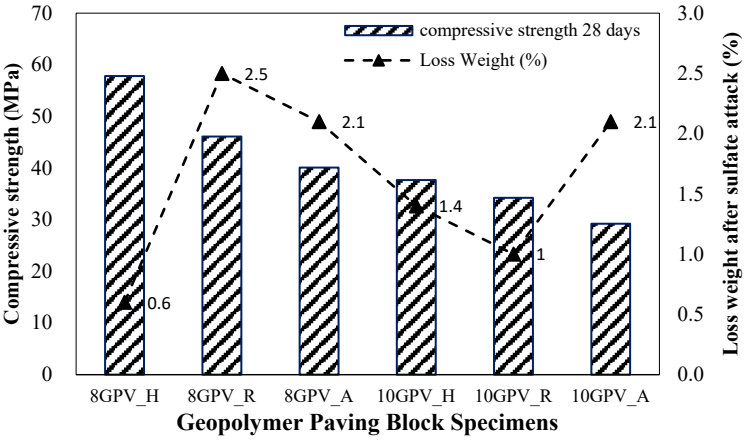


Fig.9. Effect of molarity and curing method on sodium sulphate resistance of Geopolymer paving blocks.

It can be observed that both room-temperature curing and immersion in acid water tend to result in a significant loss in the weight of the specimens. Additionally, all types of specimens exhibited varying degrees of weight loss and did not meet the requirement set by SNI 03-0691-1996 [12]. This specifies a limit value for sodium sulfate resistance as a weight reduction of paving blocks of no more than 1.0%.

Figure 9 depicts the sodium sulphate resistance of geopolymer paving blocks under different curing conditions. It can be described that both curing type room temperature and acid water immersion tend to exhibit a sharp loss in the weight of specimens. Additionally, all types of specimens exhibited varying degrees of weight loss and did not meet the requirement set by SNI 03-0691-1996 [12]. This specifies a limit value for sodium sulphate resistance as a weight reduction of paving blocks of no more than 1.0%.

4 Conclusion

1. In this study, the molarity of 8M showed a higher compressive strength than 10M because of the curing method utilized, such as moist temperature, room temperature, and acidic water. The compressive strength at molarity 8M had the highest compressive strength with the moist temperature curing method compared to 10M with the similar curing method.
2. The moist temperature condition for the curing method produced good results, as the paving was fully hydrated and had the highest compressive strength of 57.81 MPa and density of 3.08%.
3. Water absorption testing on geopolymer paving specimens met the requirements of codal provision and testing of the resistance of geopolymer paving to sodium sulphate showed a different weight reduction for each specimen.

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