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(Research Article)

The effect of mixture composition on the compressive strength and absorption of geopolymer paving blocks

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Abstract

Paving blocks as a material for road infrastructure, the quality is influenced by many factors, one of which is the composition of the materials that make up it. This geopolymer paving blocks is made using several materials, namely a fly ash-based geopolymer binder (B), sand (S), rock ash (RA), and coarse aggregate (CA). Comparison of the composition of the materials forming geopolymer paving blocks is the focus of the study to determine its effect on the compressive strength and absorption of geopolymer paving blocks. A total of 4 variations of mixture composition were made using weight ratios, namely 1B:2S:1CA, 1B:2S:1RA, 1B:2S:0.5CA:0.5RA, and 1B:1S:1CA:1RA. The geopolymer binder was made with a composition of 10M sodium hydroxide (NaOH), a sodium silicate (Na_2SiO_3)/NaOH ratio of 2.5, and an alkali activator/fly ash solution ratio of 0.4. Paving blocks are cured at ambient temperature. The test results show that there is an influence of the mixture composition on the compressive strength and absorption of geopolymer paving blocks. The highest compressive strength and lowest absorption values were obtained in the mixture composition 1B:1P:1BP:1AB. The smaller the paving absorption value, the greater the compressive strength. The grain size distribution of each material plays an important role in producing interlocking properties which have an impact on the strength and absorption of paving blocks.

Keywords: Absorption; Compressive Strength; Geopolymer Paving Blocks; Mixture Composition

1. Introduction

Portland cement production to meet construction needs has an impact on increasing CO_2 emissions which cause global warming. One way to reduce CO_2 emissions released by Portland cement is to use alternative binders such as geopolymer. Apart from releasing less CO_2 into the air than Portland cement, geopolymer binders can utilize waste materials such as fly ash from coal production residues [1].

The potential for using geopolymer binders in making concrete is quite large due to the abundant availability of fly ash as a base material. In Indonesia, the amount of fly ash produced by coal products in 2019 amounted to 9.7 million tons and is estimated to reach 15.3 million tons in 2028 [2]. Abundant fly ash needs to be utilized optimally. By reusing fly ash, we can reduce the burden on the environment and also reduce the use of natural resources.

Making geopolymer paving blocks using fly ash is one way that can be done. Paving blocks are widely used as road infrastructure materials, including public roads, vehicle parking lots, sidewalks and park roads. The quality of paving blocks is influenced by many factors, including material composition, especially aggregate. The need for aggregate in a concrete mixture is around 60-70% of the total weight of concrete so it can affect the resulting performance.

Research on making geopolymer paving blocks has been carried out by previous researchers [2, 3, 4, 5, 6, 7] but did not study the influence of material composition. Research on the composition of fly ash-based geopolymer paving blocks

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using varying $Na_2SiO_3/NaOH$ ratios, carried out by Jonbi et al [8] showed optimal performance predicted in the $Na_2SiO_3/NaOH$ ratio range of 1.5 to 2.5.

Based on a literature review, there are still few who study the influence of mixture composition in making geopolymer paving blocks. Therefore, the influence of mixture composition, especially aggregate composition, on the compressive strength and absorption of fly ash-based geopolymer paving blocks is the focus of this research.

2. Material and methods

Fly Ash was taken from PLTU Amurang, North Sulawesi, Indonesia, which has a chemical composition as shown in Table 1 based on the results of X-Ray Fluorescence (XRF) analysis.

Table 1 Chemical Composition of Fly Ash

Chemical oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	SO_3	TiO_2	SrO	BaO	MnO
% weight	36.86	8.19	34.65	14.23	0.77	3.06	0.98	0.26	0.18	0.63

The results of this XRF analysis, when compared with the ASTM C618-2019 standard [9], show that the fly ash used in this research is in class F because the amount of $SiO_2 + Al_2O_3 + Fe_2O_3$ compounds = 79.7% > 50% and the CaO content is 14.23% < 18%.

The aggregate used is sand with a fineness modulus of 3.209, and in zone 1, rock ash with a grain size of < 5 mm and coarse aggregate with a grain size of 5-10 mm. The results of the sieve analysis are shown in Figure 1.

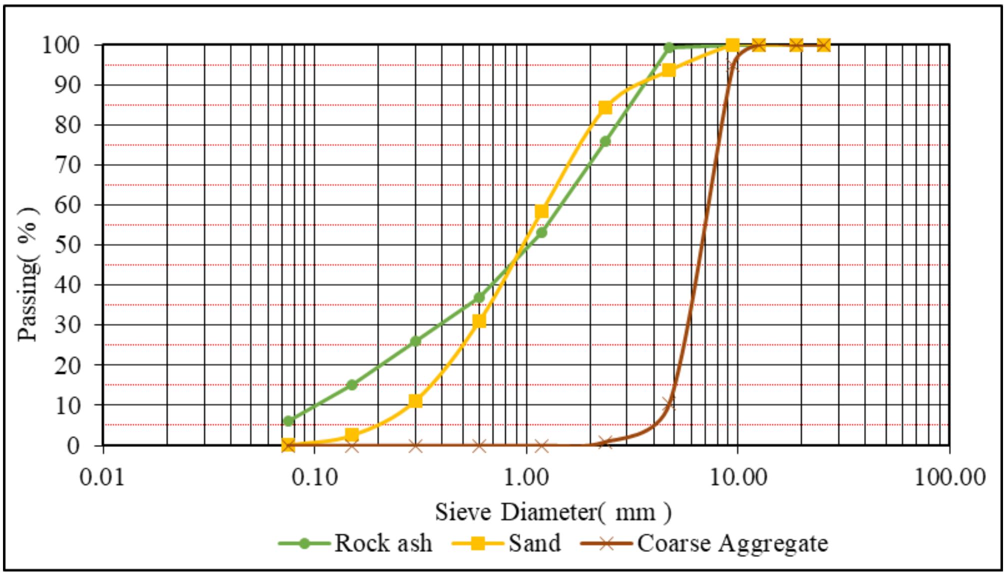

Figure 1 Aggregate sieve analysis

The alkali activator solution used is a combination of NaOH in flake form and Na_2SiO_3 with a Na_2O content of 16.2%, SiO_2 37.26% and H_2O 46.54%. NaOH is used to react the silica and alumina elements in fly ash, while Na_2SiO_3 is used to speed up the polymerization process.

The geopolymer binder was made with a NaOH molarity of 10 M, a $Na_2SiO_3/NaOH$ ratio of 2.5, an alkali activator/fly ash ratio of 0.4. This value is based on the results of previous research [10] which provides maximum strength. The design of the geopolymer paving mixture is based on the assumption that the concrete density is 2400 kg/m^3 [4], then 4 variations of the mixture composition are made as in Table 2 using mass ratio.

Table 2 Composition of Geopolymer Paving Blocks Mixture

Mixture Composition	**Sample Code**
1 Binder : 2 Sand : 1 Coarse Aggregate	1B : 2S : 1CA
1 Binder : 2 Sand : 1 Rock Ash	1B : 2S : 1RA
1 Binder : 2 Sand : 0.5 Coarse Aggregate : 0.5 Rock Ash	1B : 2S : 0.5CA : 0.5RA
1 Binder : 1 Sand : 1 Coarse Aggregate : 1 Rock Ash	1B : 1S : 1CA : 1RA

The process of making paving blocks is mixing all the dry ingredients into the mixer according to the composition of each mixture, then adding the alkaline activator solution while continuing to mix. Finally, add water and mix for 5 minutes until the mixture becomes homogeneous. Form paving blocks measuring 21 cm x 10 cm x 8 cm using a paving molding machine, then place them in a room with ambient temperature for a testing period of 7 and 28 days. Curing at ambient temperature was chosen for easy application in the field. Compressive strength testing at 7 and 28 days and absorption tests at 28 days based on SNI-03-0691-1996 [11]. The test results are the average value of 3 samples.

3. Results and discussion

3.1. Compressive Strength

The compressive strength test results of geopolymer paving blocks with variations in mixture composition are shown in Figure 2.

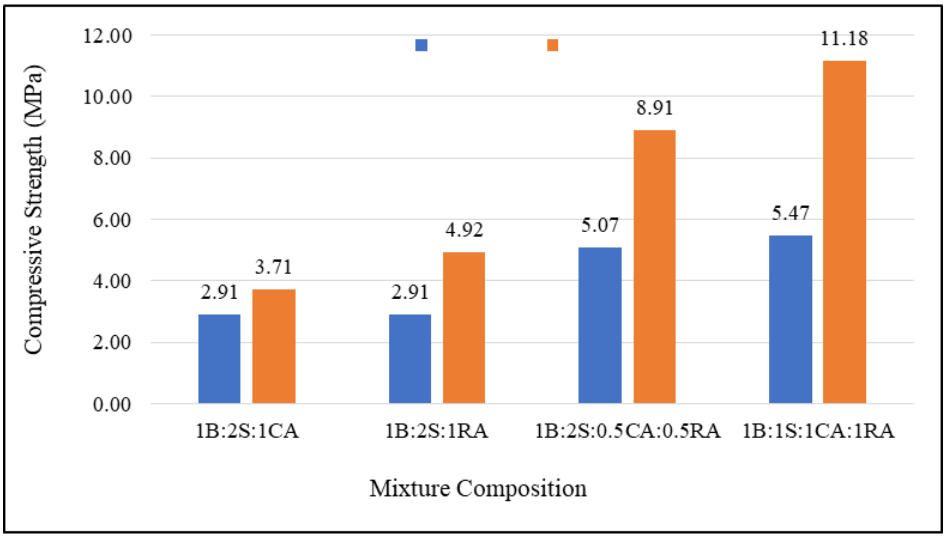

Figure 2 Compressive Strength of Paving Blocks with Varying Mixture Composition

Figure 2 shows that the highest compressive strength at 28 days was achieved with the mixture composition 1B:1S:1CA:1RA, followed by the mixture 1B:2S:0.5CA:0.5RA, then 1B:2S:1RA and 1B:2S:1CA with compressive strength respectively of 11.18 MPa, 8.91 MPa, 4.92 MPa and 3.71 MPa. The compressive strength results for the 1B:1S:1CA:1RA mixture show a combination that provides strong interlocking properties. This can be seen from the sieve analysis graph in Figure 1 which shows that the percentage passing a 5 mm sieve for coarse aggregate is around 10%, while for sand it is around 90% so that the voids between grains of coarse aggregate measuring 5-10 mm can be filled with sand. Furthermore, in Figure 1, it can be seen that the percentage passing the 0.30 mm sieve for sand is around 10%, while for rock ash it is 25%. This shows that limited fine grains of sand can be supported by rock ash. This condition causes the void size to become smaller and the paving to become denser, increasing the compressive strength of the paving. The other three mixture compositions, namely 1B:2S:0.5CA:0.5RA, 1B:2S:1RA and 1B:2S:1CA have lower compressive strength, possibly due to excess sand. Nugraha and Antoni [12] stated that if there is too much sand, the density of the concrete will decrease and the need for water will increase, which will have an impact on reducing compressive strength.

The results in Figure 2 also show the low compressive strength produced and the slow increase in compressive strength from 7 days to 28 days. This is partly due to the curing method used. The results of research on the manufacture of geopolymer materials report that the curing process at room temperature shows slow strength development, while curing at higher temperatures the strength development is very fast (significant) [13, 14, 15]. The results of research on geopolymers also state that the development of strength of geopolymer materials using class F fly ash is slower than class C fly ash when using the curing method at room temperature [13, 14]. This is because the polymerization process is very slow at room temperature. The opposite results if using the curing method at a higher temperature of around 60^{o}C [16-18].

3.2. Absorption

Absorption describes the ability of a paving blocks sample to absorb water. This ability to absorb water can be related to the pores or voids in the paving. The higher the absorption value, the greater the void volume in the paving.

The results of absorption testing of geopolymer paving blocks with variations in mixture composition are shown in Figure 3.

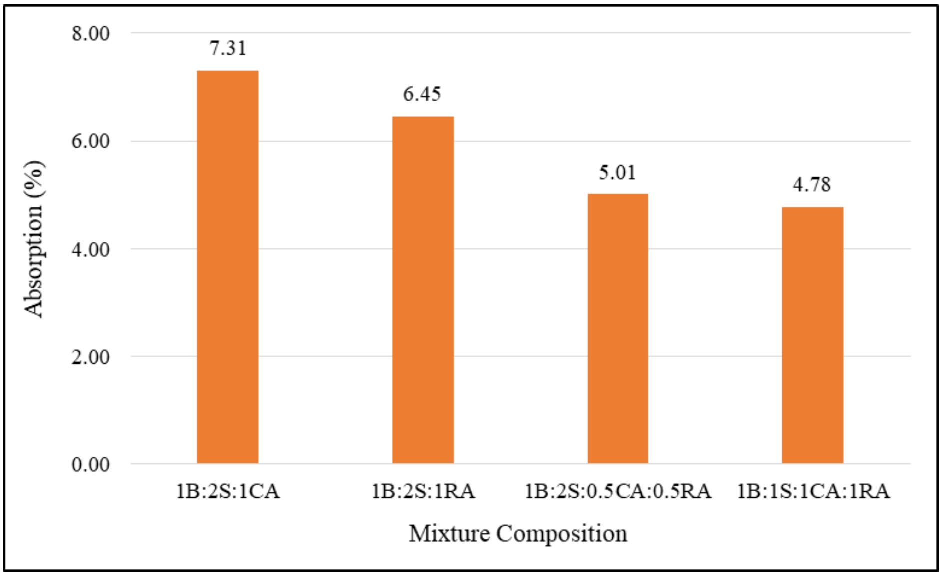

Figure 3 Absorption of Geopolymer Paving Blocks on Varying Mixture Composition

In Figure 3, it can be seen that the lowest absorption of geopolymer paving blocks was achieved in the mixture composition 1B:1S:1CA:1RA, followed by the mixture 1B:2S:0.5CA:0.5RA, then 1B:2S:1RA and 1B:2S:1CA with values respectively of 4.78%, 5.01%, 6.45% and 7.31%. The level of paving blocks absorption can provide an idea of the size of the void volume in the paving blocks. The higher the absorption indicates the greater the void volume that can be filled by water, and vice versa. The absorption value can also provide an idea of the density of a sample. The denser the sample, the lower the absorption. The results shown in Figure 3 show the influence of mixture composition on the absorption of geopolymer paving blocks. Based on the distribution of aggregate grain sizes in Figure 1, it can be seen that the combination of coarse aggregate measuring 5-10 mm with sand and rock ash in the ratio 1B:1S:1CA:1RA can provide interlocking properties and make the mixture denser. Fine sand and rock ash can fill the voids between coarse aggregate grains. This makes the void volume smaller which has an impact on the lower absorption of geopolymer paving blocks.

The higher absorption in other mixture compositions, namely 1B:2S:0.5CA:0.5RA, 1B:2S:1RA and 1B:2S:1CA, is probably due to excess sand so that the density of the paving blocks decreases and absorption increases.

3.3. Relationship between Compressive Strength and Absorption

Based on the results of testing the compressive strength and absorption of geopolymer paving blocks, the relationship shown in Figure 4 can be obtained.

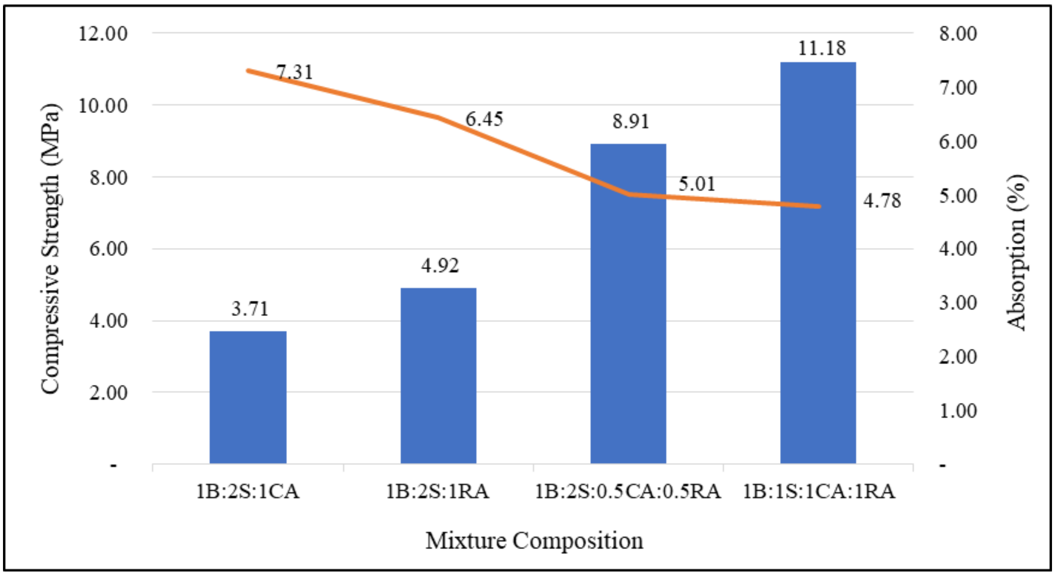

Figure 4 Relationship between compressive strength and absorption of geopolymer paving blocks

In Figure 4 it can be seen that the 1B:2S:1CA mixture has the highest absorption value and the lowest compressive strength, whereas the 1B:1S:1CA:1RA mixture has the lowest absorption value and the highest compressive strength. The mixture composition 1B:1S:1CA:1RA provides interlocking properties in the mixture, creates a strong bond between the aggregate grains, and the mixture becomes denser, thus providing a higher compressive strength value. As the mixture becomes denser, the void size becomes smaller, which results in a smaller absorption value. Based on this graph, it shows that there is an inverse relationship between compressive strength and absorption, where the lower the absorption value, the higher the compressive strength value and vice versa.

4. Conclusion

The research results concluded that the composition of the mixture, especially the aggregate, had an effect on the compressive strength and absorption of geopolymer paving blocks. The grain size distribution of each aggregate plays a role in producing interlocking properties in the mixture, thereby influencing the void size and density of the paving, as well as having an impact on the compressive strength and absorption capacity of the paving.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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