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Experimental Study of the Effect of Fly Ash and Andesite Ash Composition Variation on the Compressive Strength of Geopolymer Mortar

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Abstract

Geopolymers are one of the innovative materials currently being developed as a substitute for portland cement as a binder. CoMPared to Portland cement-based mortar, geopolymer mortar offers advantages such as relatively low carbon emissions, competitive compressive strength potential, and good chemical resistance. The method used in this study involved test specimens measuring 5 × 5 × 5 cm^3 using room temperature curing. The binder mixtures used consisted of fly ash and andesite ash, with five different ratios: 70% FA : 30% ABA; 50% FA : 50% ABA; 30% FA : 70% ABA; 0% FA : 100% ABA and 100% FA : 0% ABA. The activator solution used a ratio of Na_2SiO_3 : NaOH ratio of 2,5 : 1 with an 8 mol/L NaOH concentration. This study aimed to determine the optimum percentage ratio of fly ash and andesite ash mixture. The results showed that differences in binder composition affect the compressive strength of the geopolymer mortar. The optimum compressive strength of all test specimen variations was obtained in the 70% FA : 30% ABA variation, at 17,07 MPa at 28 days. These findings indicate that fly ash can accelerate the geopolymerization process, while andesite ash function as an additive that helps make the mortar structure denser.

Keywords: *Andesite Ash; Compressive Strength; Fly Ash; Geopolymer; Mortar*

Abstrak

Geopolimer merupakan salah satu bahan inovatif yang sedang dikembangkan sebagai pengganti semen portland sebagai pengikat. Dibandingkan dengan mortar berbasis semen portland, mortar geopolimer memiliki keunggulan seperti emisi karbon yang relatif rendah, potensi kekuatan tekan yang kompetitif, serta ketahanan kimia yang baik. Metode yang digunakan dalam penelitian melibatkan benda uji berukuran 5 × 5 × 5 cm^3 dengan proses curing pada suhu ruang. Campuran pengikat yang digunakan terdiri dari fly ash dan abu batu andesit, dengan lima perbandingan yang berbeda: 70% FA : 30% ABA; 50% FA : 50% ABA; 30% FA : 70% ABA; 0% FA : 100% ABA and 100% FA : 0% ABA. Larutan aktivator yang digunakan memiliki perbandingan Na_2SiO_3 : NaOH sebesar 2,5 : 1 dengan konsentrasi NaOH 8 mol/L. Penelitian ini bertujuan untuk menentukan persentase perbandingan campuran fly ash dan abu batu andesit yang optimal. Hasil penelitian menunjukan perbedaan komposisi bahan pengikat mempengaruhi kekuatan tekan mortar geopolimer. Kekuatan tekan optimal dari semua variasi benda uji diperoleh pada variasi 70% FA : 30% ABA sebesar 17,07 MPa pada umur 28 hari. Temuan ini mengindikasikan bahwa fly ash dapat mempercepat proses geopolimerisasi, sementara abu batu andesit berfungsi sebagai bahan tambahan yang membantu membuat struktur mortar menjadi lebih padat.

Kata kunci: Abu Batu Andesit; Fly Ash; Geopolimer; Kuat Tekan; Mortar

INTRODUCTION

The cement industry is one of the largest contributors to carbon dioxide (CO_2) emissions, accounting for 7-8% of global carbon emissions each year[1]. In this contex, there is a need for innovations regarding alternatives to cement as a binding agent that are environmentally friendly yet offer good mechanical performance[2]. An approach focused on reducing the use of cement-based materials and improving recyclability can significantly enhance sustainability[3].

Geopolymers are one of the innovative materials currently being developed as a substitute for portland cement as a binder[4]. Geopolymers can also be used in the production of various binding materials that utilize waste from construction activities[5]. Geopolymer is an aluminosilicate-based binder produced by the activation reaction of an alkaline solution with pozzolanic materials that are usually formed from volcanic activity. CoMPared to portland cement-based mortar, geopolymer mortar has advantages such as low carbon emissions, competitive compressive strength potential, and good chemical resistance[6].

One material that has potential for use as a mixture in the production of geopolymer mortar is fly ash. Fly ash contains large amounts of silica (SiO_2) and alumina (Al_2O_3), as well as an amorphous phase that aids in the geopolymerization reaction process[7]. In addition, andesite ash is a waste product from the process of crusing andesite rock in stone industry[8]. This material has a fairly good silica and alumina content, but its pozzolanic activity is not as high as fly ash.

Many studies have been conducted on fly ash as a mixture material in gaopolimers. However, there have not been many studies examining the combination of fly ash and andesite ash in geopolymer mortar mixtures, especially using room temperature drying methods. Therefore, this study was conducted to determine experimental data on the effect of the combination of fly ash and andesite ash as geopolymer binders on the compressive strength of geopolymer mortar.

RESEARCH METHODS

This research is an experimental study conducted at the materials Technology Laboratory, Faculty of Engineering, Swadaya Gunung Jati University, Cirebon

The following aspect will be examined in this study:

a. The dependent variable refers to national standards (SNI),
b. The independent variables include the use of various ratios of fly ash and andesite ash,
c. The control variables include testing of materials and the compressive strength of geopolymer mortar.

The test specimens used in this study were cube measuring 5 × 5 × 5 cm^3, with a sand : binder ratio of 2,5 : 1. The binder used in this study was a mixture of fly ash and andesite ash with ratio of 70% FA : 30% ABA; 50% FA : 50% ABA; 30% FA : 70% ABA; 0% FA : 100% ABA and 100% FA : 0% ABA. NaOH and Na_2SiO_3 are commonly used as activators for geopolymers because they have alkaline properties[9]. The ratio of the activator solution used was Na_2SiO_3 : NaOH = 2,5 : 1, with a NaOH concentration of 8 mol/L, and the test specimens were dried at room temperature. The test specimens used were on days 7, 14,21, and 28.

Table 1. Test Item Code

Percentage Variation	Test Object Code	Age of Test Object				Number of Samples
		7	14	21	28	
70% FA:30% ABA	AG	3	3	3	3	60
50% FA:50% ABA	BG	3	3	3	3	

30% FA:70% ABA	CG	3	3	3	3
100% FA:0% ABA	DG	3	3	3	3
0% FA:100% ABA	EG	3	3	3	3

Material testing was conducted in the initial stage prior to mixing the geopolymer mortar components. The parameters tested in this study included the gradation of fine aggregates, clay content, organic matter content, specific gravity, water pH, and moisture content.

A. Fine Agregate

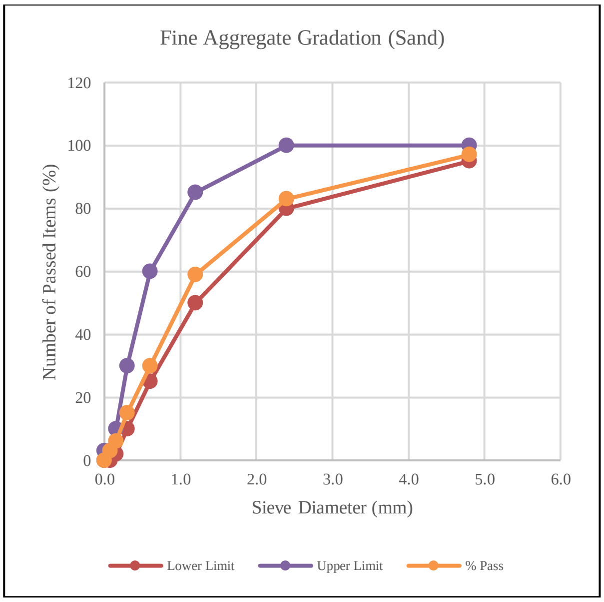
The fine aggregate used is river sand that passes through a 2,36 mm sieve[10].The testing standards used in fine aggregate testing refer to the provisions of SNI 03-6820-2002 and SK S-04-1989-F. The result of fine aggregate testing can be seen in table 2.

Table 2. Recapitulation of Fine Aggregate Testing

No	Description		Test Results	
			Sand	Testing Standards
1	Grading Zone		I	SNI 03-1968-1991
2	Finnes Modulus		2.91	
3	Bulk Specific Gravity		2.676	SNI 1970-2008
4	Bulk Specific Gravity SSD		2.703	
5	Apparent Spesific Gravity		2.750	
6	Absorption	%	0.010	
7	Moisture Content	%	11.994	SNI 03-1971-1990
8	Mud Content	%	2.47	SNI 03-4428-1997
9	Organic Matter Content	%	No.1	SNI 03-2816-1992

Table 3. Recapitulation of Fine Aggregate Testing

Testing Requirements		Description
Value	Testing Requirements Standards	
–	–	–
2.0 - 3.00	SNI 03-1968-1991	OK
		OK
2.50 - 2.90	SK SNI T-15-1990-03	OK
		OK
–	–	–
–	–	–
≤ 5.00	SK SNI S-04-1989-F	OK
No. 1,2 or 3	–	OK



Graph 1. Fine Aggregate Sieve Analysis

1. Fine Agregate Sieve Analysis
   The grading zone is in zone I, and the fine modulus value obtained is also in accordance with the applicable provisions, which is 2.91, were the standard fine modulus rages from 2.0 to 3.0 in accordance with SNI 03-1968-1991.

2. Mud Content
   The mud content in fine aggregates was found to be 2.47%. According to SNI 03-

4428-1997, the maximum mud content limit is 5%.

3. Organic Matter Content
The organic content was measured in fine aggregate in the from of river sand to determine the organic content in the sand. It can be concluded that the river sand has a color that is quite similar to the color in No. 1. Referring to SNI 03-2816-1992, the organic content in aggregates that meet the criteria must be in the color palette below No. 5.

4. Specific Gravity
Referring to SNI 1970-2008, the results obtained show that the dry specific gravity (bulk specific gravity) reaches 2.676, the surface dry specific gravity (SSD) is 2.703, the apparent specific gravity is recorded at 2.75, and the absorption rate is 0.010.

B. Water Testing

The water used in the production of geopolymer mortar comes from groundwater located at the Lab GT of Swadaya Gunung Jati University. The water used meets the requirements in table 3.

Table 4. Water Testing Summary

No	Description	Test Results	
		Value	Testing Standards
1	Water Conditions	Clear	
2	Taste of Water	Freshwater	SNI 7974:2013
3	Water Smell	Does not sting	
4	Water pH	8	

Table 5. Water Testing Summary

Testing Requirements		Description
Value	Testing Requirements Standards	
Clear	SNI 7974:2013	OK
Freshwater		OK
Does not sting		OK
8	Construction and Building Manual, Book 4	OK

C. Geopolymer Mortar Mix Design

During the mixing preparation stage, the resulting binding properties depend on the raw materials used[11]. The variations in this mixture were designed to see how changes in the proportions of fly ash and andesite ash could affect the compressive strength of geopolymer mortar.

Table 6. Geopolymer Mortar Mix Design

Variation	Binder	FA (g)	ABA (g)	Sand (g)
100% FA : 0% ABA	1031.25	1031.25	0	2578.13
70% FA : 30% ABA	1031.25	721.88	309.38	2578.13
50% FA : 50% ABA	1031.25	515.63	515.63	2578.13
30% FA : 70% ABA	1031.25	309.38	721.88	2578.13
0% FA : 100% ABA	1031.25	0	1031.25	2578.13

Table 7. Activator Alkali Solution Requirements

Variation	Total Alkali (g)	Na2SiO3 (g)	NaOH (g)
100% FA : 0% ABA	464.06	331.47	132.59
70% FA : 30% ABA	464.06	331.47	132.59
50% FA : 50% ABA	464.06	331.47	132.59

30% FA : 70% ABA	464.06	331.47	132.59
0% FA : 100% ABA	464.06	331.47	132.59

D. Preparation and Maintenance of Test Specimens

The preparation and maintenance of the geopolymer mortar test specimens in this study were conducted in a systematic and controlled manner. Each procedure followed the requirements and provisions of SNI 03-6825-2002 regarding the test method for the compressive strength of portland cement mortar for civil engineering works. There were adjustments in the use of geopolymer binders. This is because geopolymers are produced through the interaction between silicate and aluminosilicate base materials and an acid or alkaline solutions[12].

The initial stage in the preparation of test specimens begins with weighing the mortar components according to the specified proportions, followed by the mixing of the dry materials, consisting of fine aggregate and various binders.

To prepare the alkali activator solution, an 8 M NaOH solution was mixed with Na_2SiO_3 and allowed to stand for 24 hours to ensure a stable reaction[13], with a NaOH to Na_2SiO_3 ratio of 1 : 2,5. The alkaline activator solution was gradually added to the dry material mixture until the mixture became homogeneous. The final step involves molding the mixture into a 5 x 5 x 5 cm^3 cube-shaped mold that has been greased and coMPacting it.

After molding, the test specimens were stored at room temperature until the mold hardened, and a curing process was conducted for 7, 14, 21, and 28 days.

In this study, the curing method was performed at room temperature, although previous studies have indicated that geopolymers harden at high temperatures. Temperature during the curing process significantly affects the improvement in geopolymer durability in the early stages, but does not have a significant iMPact on compressive strength after 28 days[14]. CoMPared to curing under specific conditions, curing at room temperature can certainly reduce costs and simplify the geopolymer production process[15].

RESULT AND DISCUSSION

A. Geopolymer Mortar Weight Test Result

Table 8. Recapitulation of Mortar Weight Testing

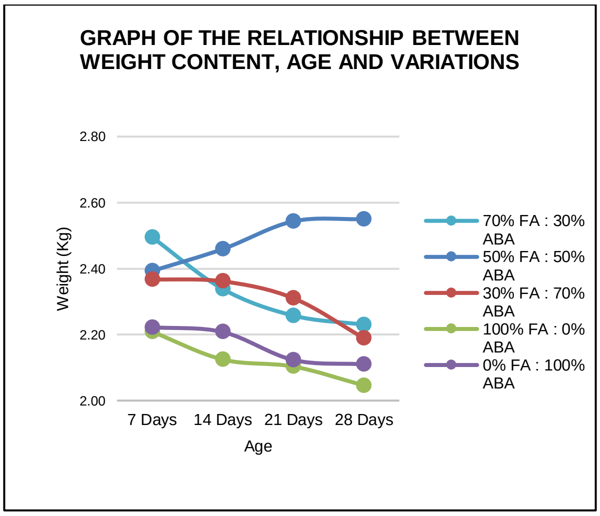
Mortar Density (g/cm3)				
Variations	**7 days**	**14 days**	**21 days**	**28 days**
70% FA : 30% ABA	2.49	2.34	2.26	2.23
50% FA : 50% ABA	2.39	2.46	2.54	2.55
30% FA : 70% ABA	2.37	2.36	2.31	2.19
0% FA : 100% ABA	2.22	2.21	2.12	2.11
100% FA : 0% ABA	2.21	2.12	2.10	2.05

Table 9. Recapitulation of Compressive Strenght Result

RECAPITULATION OF STRONG RESULT (MPa)				
Variations	**7 Days**	**14 Days**	**21 Days**	**28 Days**
70% FA : 30% ABA	9.47	11.33	14.27	17.07
50% FA : 50% ABA	10.00	11.07	11.87	13.87
30% FA : 70% ABA	8.13	10.00	10.53	12.80
0% FA : 100% ABA	1.87	3.87	7.20	9.33
100% FA : 0% ABA	11.33	10.67	12.00	13.33

1. Analysis of Bulk Density Test Result on Geopolymer Mortar Compressive Strength Test Result

Several variations show that the waight is inversely proportional to the compressive strength produced. However, the 50% FA : 50% ABA variation shows result that differ from the average variation, where the weight is directly proportional to the compressive strength produced. The lower the porosity and water absorption of the mortar, the higher its density making the mortar more coMPact, this higher density increase the mortar's compressive strength[16].



Graph 2. Relationship Between Weight, Age, and Mix Variation

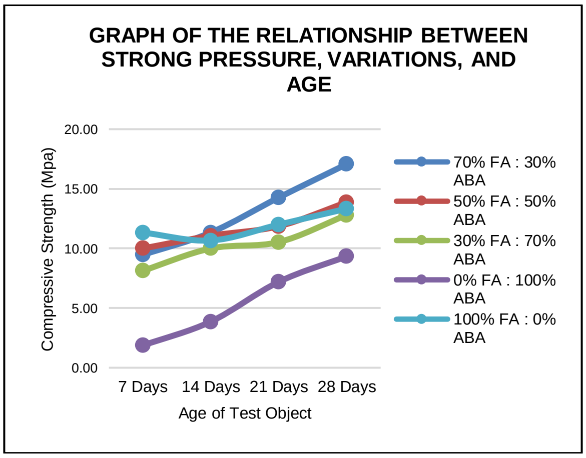
In some variations, the bulk density is influenced by the hydration process, geopolymerization reaction, and water evaporation. High bulk density does not always correlate directly with high compressive strength, as compressive strength is more strongly influenced by the quality of the internal structure, porosity, and the formation of the geopolymer gel during the alkali activation reaction[17]. In the 50% FA : 50% ABA mixture, there was a stable increase in bulk density, reaching 2.55 g/cm^3 at 28 days. The combinations of 70% FA : 30% ABA and 30% FA : 70% ABA tended to experience a decrease in bulk density as the test specimens aged. The variations of 100% FA : 0% ABA and 0% FA : 100% ABA showed relative changes, althought these changes were not extreme.

B. Geopolymer Mortar Compressive Strength Test Result

Compressive strength tests were conducted when the test specimens had reached 7, 14, 21 and 28 days of age after the room temperature curing peocess using a compressive strength testing machine. The compressive strength result are presented in table 8.

Table 10. Recapitulation of Mortar Compressive Strength Result

RECAPITULATION OF STRONG RESULT (MPa)				
Variations	**7 Days**	**14 Days**	**21 Days**	**28 Days**
70% FA : 30% ABA	9.47	11.33	14.27	17.07
50% FA : 50% ABA	10.00	11.07	11.87	13.87
30% FA : 70% ABA	8.13	10.00	10.53	12.80
0% FA : 100% ABA	1.87	3.87	7.20	9.33
100% FA : 0% ABA	11.33	10.67	12.00	13.33



Graph 3. Recapitulation of Geopolymer Mortar Compressive Strength Result

Graph 3. shows that each variation secquentially produced compressive strength of 17.07 MPa, 13.87 MPa, 12.8 MPa, 9.33 MPa, and 13.33 MPa at 28 days of age. Helmy

[18] observed that the increase in compressive strength in geopolymer mortar is significantly influenced by the level of alkalinity. The ratio of the binder to the alkali solution also plays an inportant role. The maximum compressive strength produced in the graph above is in the variation of 70% FA : 30% ABA at 17.07 MPa, while the minimum compressive strength is in the variation of 0% FA : 100% ABA at 9.33 MPa.

CONCLUSION

The use of fly ash and andesite ash waste can increase the compressive strength of geopolymer mortar mixtures. The binder ratio can affects the compressive strength of geopolymer mortar. A ratio of 70% FA : 30% ABA shows maximum compressive strength and consistent improvement, creating a balance of physical stability. The 50% FA : 50% ABA variation showed a fairly stable increase in compressive strength. The 30% FA : 70% ABA variation was dominated by 70% andesite ash, resulting in sub optimal geopolymerization reactions. The 0% FA : 100% ABA mixture recorded the lowest compressive strength, indicating that fly ash significanly influences the geopolymerization reaction. The 100% FA : 0% ABA mixture showed a good reaction, but the absence of andesite ash resulted in a suboptimal mortar structure in term of density.

From the result of compressive strength test on geopolymer mortar obtained at 7, 14, 21, and 28 days of age, in each variation. The 70% FA : 30% ABA variation showed values of 9.47 MPa, 11.33 MPa, 14.27 MPa, and 17.07 MPa. For the 50% FA : 50% ABA mixture, the values obtained were 10 MPa, 11.07 MPa, 11.87 MPa, and 13.87 MPa. In the 30% FA : 70% ABA variation, the values obtained were 8.13 MPa, 10 MPa, 10.53 MPa, and 12.8 MPa. The values obtained for the 0% FA : 100% ABA variation are 1.87 MPa, 3,87 MPa, 7.20 MPa, 9,33 MPa. For the 100% FA : 0% ABA variation, the values were 11.33 MPa, 10.67 MPa, 12 MPa, and 13.33 MPa.

The 70% FA : 30% ABA variation resulted in the optimum compressive strength of the composite geopolymer mortar of fly ash and andesite ash, with a compressive strength reaching 17.07 MPa at 28 days.

All mix variations showed a gradual increase in compressive strength that continued to develop until reaching 28 days at room temperature. This indicates that the geopolymer reaction occurs gradually at every age of the test specimen.

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