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COMPARATIVE ANALYSIS OF FLY ASH AND LIME ON THE COMPRESSIVE STRENGTH OF GEOPOLYMER MORTAR

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Abstract

This study aims to analyze the effect of the variation between fly ash and lime as binders on the compressive strength of geopolymer mortar at 7, 14, 21, and 28 days of testing. Using an experimental method with mortar cured at room temperature, this study produced 60 test specimens in the form of 5 cm × 5 cm × 5 cm cubes with a ratio of 2,5:1 sand to binder and using alkali activators NaOH and Na2SiO3 with ratio of 1:2,5. The results of this study prove at the maximum compressive strength was obtained at variation of 50% FA : 50% LM at a testing age of 28 days, amounting to 21.33 MPa. Conversely, the minimum compressive strength was obtained at a variation ratio of 0% FA : 100% LM, with a value af 7.33 MPa at testing age of 28 days. The use of 50% limestone can increase stable compressive strength.

Keywords: Limestone (LM), Fly Ash (FA), Geopolymer Mortar, NaOH, Na_2SiO_3

Introduction

Infrastucture that continues to develop from year to year plays an important rone in the development sector. The high demand from the community in the construction sector means that more and more buildings are needed. Concrete and mortar are highly sought after and used as structural and non-structural components in construction in Indonesia. This can lead to a significant increase in the demand for mortar and concrete (Monteiro et al., 2017 ; Wardana et al., 2025). The materials used to make concrete and mortar from nature, and if they used continuosly for construction purposes, they can cause environmental damage (Amiri et al., 2021; Xie & Wang, 2016).

In various countries, including Indonesia, fly ash from coal combustion in power plant furnaces to increase every year (Science, 2016). According to Ekaputri et al (2020), this coal waste is classified as hazardous waste due to several of its contents. This can be overcome with special treatment for use in the construction industry as an industrial waste management effort (Golewski, G. L, 2017; Rose, 2018; Shajidha & Mortula, 2025). The combustion residue can be used as an additive or substitute material in variouse applications in the construction industry (Amiri et al., 2021; Puja et al., 2025 & Sakir et al., 2020). Efforts to manage industrial waste can be transformed into a solution to address the challenges of modern industrial wate management (Zhen et al., 2020; Bahar et al., 2024; Srivastava et al., 2023).

According to Teknologi & Darma (2024) lime is made from fine sedimentary rocks that can form calcium material with potential as a geopolymer binder mixture to improve certain charactertistics (Hoy et al., 2025; M. E. Sibuea, 2025). Although there have not been many previous studies monitioning the benefits of fly ash and limistone as geopolymer binders, there are not standard requirements between the two materials, especially in the manufacture of geopolymer mortar without using portland cement (Diah Ayu Febriyanti, 2025; Sibuea, 2025; Ilyas et al., 2022).

Geopolymer mortar can be used as more eco-friendly alternative to conventional portland cement (Wardana et al., 2025; Ilmiah & Jasa, 2025; Teshnizi & Karimiazar, 2023). Its ability to reduce excess carbon dioxide emissions associated with the cement manufacturing process, as well as its role in transforming industrial waste into high-value raw materials, makes it an innovate solution (Cheng et al., 2018 ; Setiawati, 2018). The binding agent in geopolymers is the result of chemical reaction between silica and alumunium (such as fly ash) with an alkaline solution used for activation (Jegan et al., 2023 ; Hadi, 2018 & Marvila et al., 2021).

Although many studies have mentioned fly ash and lime as binding materials, there is still no ideal mixture standard for these two materials, especially in the application of geopolymer mortar without portland cement mixture.

Based on these conditions, research is needed to examine the effect of variations in the ratio of fly ash and lime on the compressive strength of mortar, particulary in a more practical curing process for laboratory scale (Adam, A. A., 2020). The results of this research should provide scientific information on the optimal binder proportion and support the development of environmentally friendly construction materials.

Thus, this study will specifically examine the effect of the FA : LM ratio with comparasion of 70%:30%, 50%:50%, 30%:70%, 0%:100%, 100%:0% and an alkali activator mixture of 8 molar. This can effect the compressive strength of geopolymer mortar at 7, 14, 21 and 28 days of testing ASTM C-109 and identify the binder composition that can be used as a reference in on going research.

Research Methods

This study used an experimental method with geopolymer mortar as the research object by adding an alkali activator solution and without using portland cement (Civil et al., 2025) the lime used is limestone powder producted by grinding sedimentary limestone or chalk, chemically known as calcium carbonate (CaCO3) purchased from a Sanitas Chemical store. The mortar samples were tested at 7, 14, 21 and 28 days of age with varying proportions 70% FA:30% LM, 50% FA:50% LM, 30% FA:70% LM, 0% FA:100% LM and 100% FA:0% LM. The sample preparation process was carried out at the Addintional Building Laboratory of the Faculty of Engineering, Swadaya Gunung Jati University, with a ratio of 2,5:1 between sand and binder, and the test sample curing process was carried out at room temperature without immersion. Then, the mortar compressive strength test was carried out at the Construction Materials Technology Laboratory of Swadaya Gunung Jati University in accordance with the requirements of SNI 6825-2002 at each planned age.

Research Results and Discussion

Aggregate Analysis (Sand)

Based on graph 1, it can be seen that the distribution of the fine aggregate sample used remains in between the upper and lower limits, thus proving that the gradation obtained is quite good, the fines modulus value obtained is in zone 1 and is 2,91 where the fines modulus value ranges from 2,0-3,0 as stated in SNI 03-6825-2002.

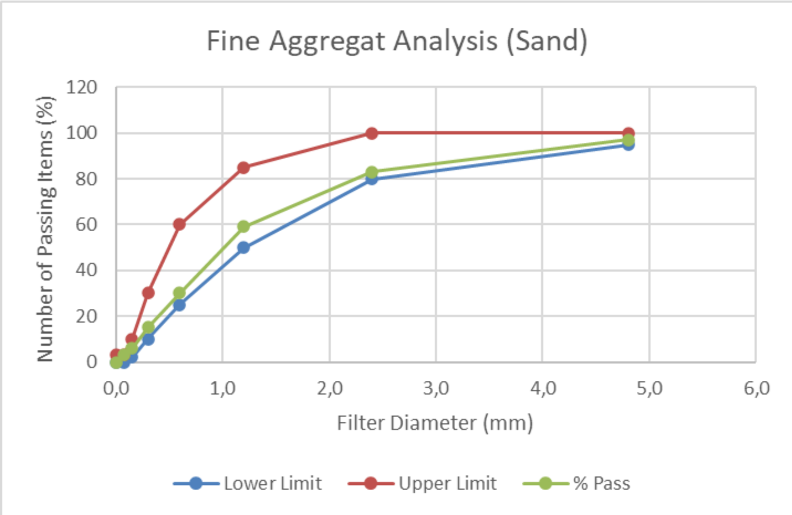

Figure 1. Fine Aggergate Gradation

Specific Grafity and Water Absorption Testing

Based on SNI 1970-2008, the result of bulk specific grafity testing obtained a value of 2,67, SSD obtained a value of 2,70, absorption percentage of 0,010 (10%) one apparet specific gravity of 2,75.

Testing Organic Matter Content

The testing of organic content conducted on this fine aggregate materials aims to determine the level of organic content in the fine aggregate. From the results of the testing that has been carried out, comparing the color of the fine aggregate with the color that is relatively the same as the color in No.1. SNI 03-2461-1991 and ASTM C-33 state that the organic content of aggregates that meet the standards has a color below No.5 on the color palette. Therefore, the organic content testing in this study meets the standards.

Table 1. Fine Aggregat Test Result

No	Description	Test Results		Testing Requirements		Description
		Sand	Testing Standards	Value	Testing Requirements Standards	
1	Grading Zone	I	-	-	-	-
2	Fines Modulus	2,91	(SNI 03-1968-1990)	2,00 - 3,00	(SNI 03-1968-1990)	Fulfill
3	Bulk Specific Grafity	2,676	(SNI 1970-2008)	2,50 - 2,90	(SNI-T-15-1990-03)	Fulfill
4	Bulk Specific Grafity SSD	2,703				Fulfill
5	Apparent Spesific Gravity	2,750				Fulfill
6	Absorption (%)	0,010		-	-	-
7	Water Content (%)	12	(SNI 1971:2011)	-	-	-
8	Sludge Content Testing	2,47%	(SNI 03-4428-1997)	≤ 5,00	(SK SNI S-04-1989-F)	Fulfill
9	Testing Organic Matter Content	No.1	(SNI 03-2816-1992)	No. 1,2 atau 3	-	Fulfill

Water Testing

The water used in this study was groundwater located in the Additional Civil Engineering Laboratory Building at Swadaya Gunung Jati University. The results of testing the water to be used for the mortar mixture in this strudy showed that it met the standard requirements based on table 2.

Table 2. Water Testing

No	Description	Test Results		Testing Requirements		Description
		Value	Testing Standards	Value	Testing Requirements Standards	
1	Water Condition	Clear	(SNI 7974:2013)	Clear	(SNI 7974:2013, 2013)	Fulfill
2	Water Taste	Bland		Bland		Fulfill
3	Water Smell	Not Pungent		Not Pungent		Fulfill
4	Water Ph	8		8	Construction & Building Manual, Book 4	Fulfill

Mix Design

Table 2. Mix Design

No	Comparasion Variations FA : LM (%)	FA (%)	LM (%)	Binder Total (1 Cube) (gr)	FA (gr)	LM (gr)	Sand (gr)	T. Alkali (gr)	Na_2SiO_3 (gr)	NaOH (gr)
1	100% : 0%	100	0	1031	1031	0	2578	464	331,47	132,59

No	Comparasion Variations FA : LM (%)	FA (%)	LM (%)	Binder Total (1 Cube) (gr)	FA (gr)	LM (gr)	Sand (gr)	T. Alkali (gr)	Na_2SiO_3 (gr)	NaOH (gr)
2	70% : 30%	70	30	1031	722	309	2578	464	331,47	132,59
3	50% : 50%	50	50	1031	516	516	2578	464	331,47	132,59
4	30% : 70%	30	70	1031	309	722	2578	464	331,47	132,59
5	0% : 100%	0	100	1031	0	1031	2578	464	331,47	132,59

At the time of making the sample there are some mortar mixtures that are less homogeneous so that the addition of water. Variation 70% FA : 30% LM using water as much as 100 ml, at variation 50% FA : 50% LM using water 80 ml, at variation 30% FA : 70% LM using water 120 ml and at variation 0% FA : 100% LM using water as much as 150 ml. The amount of water added varies for each variation, depending on the weight of limistone added.

Weight Testing

Table 4. Weight Testing

No	Sample Variation	Net Weight (Gr/Cm^3)			
		7 Days	14 Days	21 Days	28 Days
1	70% FA: 30% LM	2,46	2,35	2,34	2,32
2	50% FA : 50% LM	2,53	2,54	2,55	2,57
3	30% FA : 70% LM	2,31	2,32	2,36	2,37
4	0% FA : 100% LM	2,06	2,10	2,20	2,15
5	100% FA : 0% LM	2,20	2,16	2,13	2,05

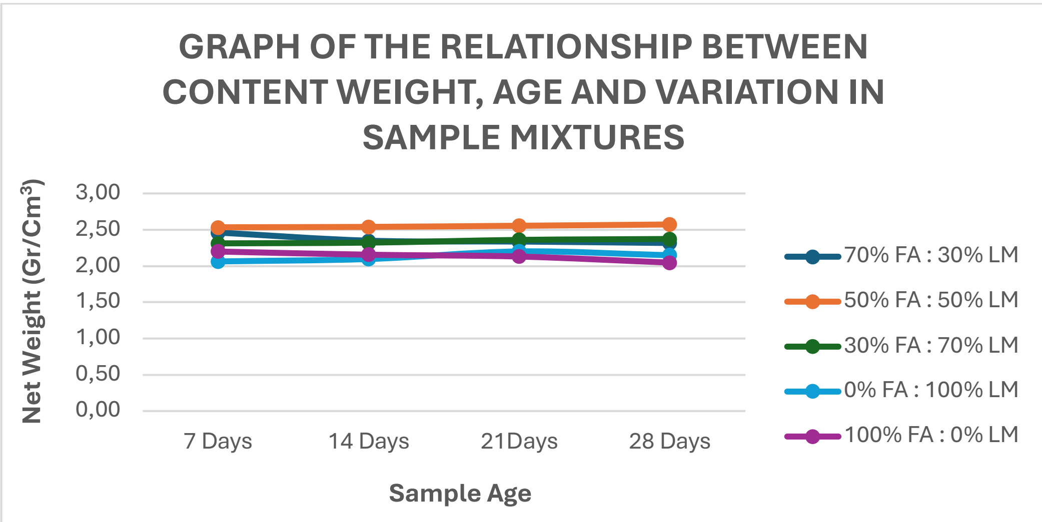

Figure 2. Weight Testing Mortar

The purpose of testing the bulk density of mortar is to determine the bulk density of the test specimen. In this study, a mixture ratio of 50% FA : 50% LM produced the highest and most stable bulk density of 2,57 gr/cm3 at 28 days of testing. However conversely, the use of FA with mixture ratio of 70% to 100% can result in a decrease in density with increasing test age.

Mortar Compressive Strength Testing

Table 3. Mortar Compressive Strength Testing

No	Sample Variation	Compressive Strength (MPa)			
		7 Days	14 Days	21 Days	28 Days
1	70% FA: 30% LM	16,00	10,00	10,00	13,33
2	50% FA : 50% LM	14,00	17,33	17,33	21,33
3	30% FA: 70% LM	9,33	5,33	10,67	13,33
4	0% FA : 100% LM	2,00	2,67	4,67	7,33
5	100% FA : 0% LM	11,33	10,67	12,00	13,33

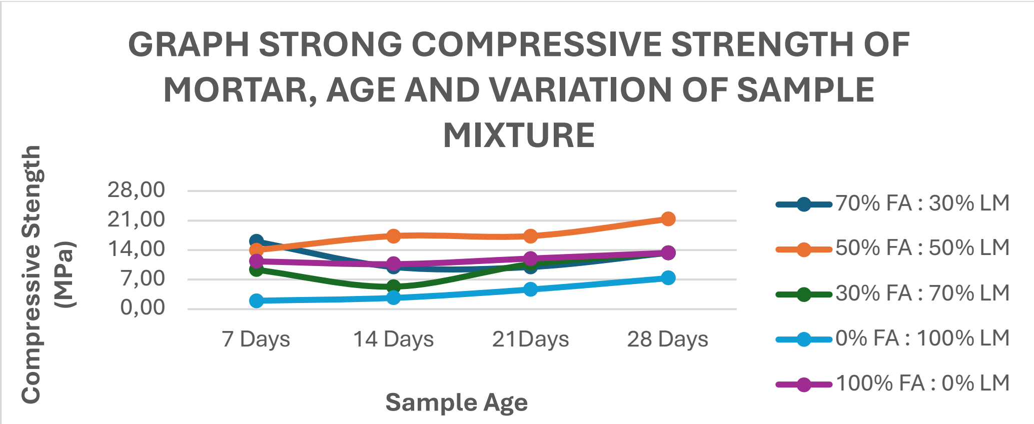

Figure 3. Summary of Mortar Compressive Strength Result

Table 3 shows that the 50% FA : 50% LM variation ratio demonstrates consistent performance with the highest compressive strength value of 21,33 MPa at 28 days of testing, indicating a stable increase in compressive strength starting from 7 days of testing, which was 14.00 MPa. However coversely, test speciments with a variation ratio dominated by limestone (0% FA : 100% LM) prosucted the lowest compressive strength values at each testing age, although they showed a gradual upeard trend, resulting in a compressive strength value at 7,33 MPa at a testing age of 28 days. There was an interesting phenomenon in the mixture proportions of 70% FA : 30% LM and 30% FA : 70% LM, which experienced a decrease in compressive strength at 14 days of testing, but increased again at 28 days of testing the same compressive strength result of 13,33 MPa. Test Specimens with a variation ratio of 100% FA : 0% LM demonstrated low mechanical perfomance, with a compressive strength of 13,33 MPa at 7 days of testing, which increased only slightly to 13,33 at 28 days of testing.

Conclusion

Based on the experimental research that has been conducted, it has been proven that the proportion of variation in the mixture between fly ash and limestone and the testing age has a significant effect on the compressive strength value increases with increasing test age from 7 days to 28 days, indicating that the polymerization process and pozzolanic reaction work well and effectively to strength the 50% FA : 50% LM ratio was the most optimal and produced a maximum compressive value of 21,33 MPa at a test age of 28 days. However conversely, the proportion dominated by limestone, 0% FA : 100% LM, produced the minimum compressive strength value throughout the testing period, which was 7,33 MPa at 28 days. Variations in proportions of 70%

FA : 30% LM, 30% FA : 70% LM and 100% FA : 0% LM limestone produced compressive strength in the range of 13,33 MPa but did not reach the maximum compressive strength. This event proves that a balanced composition ratio between fly ash and limestone is crucial a trigger a significant increase in compressive strength at room temperature.

A mixture of 50% FA : 50% LM demonstrated the most optimal perfomance due to the achievement of a aluminosilicates from the fly ash and the supplye simutaneous formation of dual gels in the form of N-A-S-H and C-(A)-S-H, which fill the pore spaces and producted a very dense mortar matrix. The density of this macrostructure allowa compressive strength to develop consistently and stably without decline, reaching a peak value of nearly 21,33 Mpa at 28 days. Meanwhile, the sharp decline in compressive strength on day 14 in the 70% FA : 30% LM and 30% FA : 70% LM variation was caused by an imbalance in the binder proportions, which triggered the formation of microcracks. Under these conditions, the accumulation of unreacted free calcium or a lack of calcium binders triggers internal stress due to chemical shrinkage, along with a phase of reorganization of the gel structure that is temporally unstable. Nevertheless, by 28 days, compressive strength increase again because secondary pozzolanic reactions and continued polymerization proceed slowly, allowing newly formed hydration products to re-consolidate these micro-cracks.

Based on the research and experiments that have been conducted, there are several suggestion that can be applied if this research is to be planned for furter study or development. Continuous research is needed on the interaction between fly ash and limestone and the long-term impact on the properties of mortar, both structurally and environmentally. In-depth research in needed on the physical and chemical properties of the binder used and molarity testing should be conducted on the use of alkali activators.

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