



Optimization of Eco-Friendly Cement Composition Based on Fly Ash in Geopolymer Concrete Mortar Production

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ABSTRACT

This study develops geopolymer cement using a dry mix method, replacing Portland cement with fly ash and utilizing solid Na_2SiO_3 derived from rice husk ash. Paste and mortar samples with three mix variations were tested for setting time and compressive strength. The initial setting time ranged from 75 minutes, while the final setting time reached up to 360 minutes. The highest compressive strength was 26 MPa for paste at 14 days and 20 MPa for mortar at 56 days. The results confirm the feasibility of producing environmentally friendly geopolymer cement with this method, though further research is needed to improve compressive strength and apply it in concrete production.

INTRODUCTION

The use of cement continues to increase every year, proving that concrete is one of the main materials in building construction. One of the impacts of concrete use is that the more concrete we use, the more CO₂ gas is produced, because every 100 tons of cement used to make concrete will produce 99 tons of carbon dioxide (CO₂). In addition to exacerbating the greenhouse effect, CO₂ gas is also one of the factors contributing to global warming. In order to reduce the negative impact on the environment caused by concrete production, it is necessary to provide alternative materials to Portland cement.

Geopolymer is a concrete mixture in which Portland cement is replaced as a binding paste with other materials such as fly ash or coal combustion residue. Geopolymers are also a new material used for coatings, adhesives, new binders for fiber composites, and new cement for concrete. Geopolymer cement has good engineering properties, such as high strength and durability and higher economic value as well. However, fly ash does not have the ability to bind like cement, which is why alkali activators are needed, namely Sodium Hydroxide (NaOH) and Sodium Silicate (Na₂SiO₃) to help the polymerization process.

In addition to not having the ability to bind itself, Fly ash also has other drawbacks such as the method of making it which is still complicated because the method of mixing the alkaline activator materials is the wet method where Sodium silicate (Na₂SiO₃) in the form of a viscous liquid or Jel and Sodium Hydroxide (NaOH) must be dissolved with water for 24 hours before use. To make this geopolymer cement practical like Portland cement, it is necessary to conduct research on making geopolymer concrete based on fly ash dry mixture method. To make this method dry Sodium silicate is needed. There have been previous studies on fly ash-based geopolymer concrete dry mix method, but the dry sodium silicate he uses is inforfor from abroad. In this study, the sodium silicate used is dry or solid sodium silicate made from rice husk.

Based on the above, Can the use of Portland cement be reduced to reduce the production of CO₂ gas that can damage the environment and Can we make eco-friendly cement based on fly ash dry mix method as an alternative material to Portland cement?

THEORETICAL REVIEW

Geopolymer Cement

Geopolymer is a concrete mixture in which the use of portland cement material as a binding material is replaced by other materials such as fly ash, rice husk ash, and others that contain a lot of silica and aluminum Davidovits (1997) The replacement of portland cement base material is considered more environmentally friendly and more effective by utilizing waste materials from industrial factories so that they care more about the environment. Geopolymers are geosynthetic concrete products where the binding reaction that occurs is a polymerization reaction. In polymerization reactions, silica (Si) and aluminum (Al) have an important role in polymerization bonds. The reaction of silica and aluminum with alkaline will produce SiO and AlO₄ as shown in the following figure :

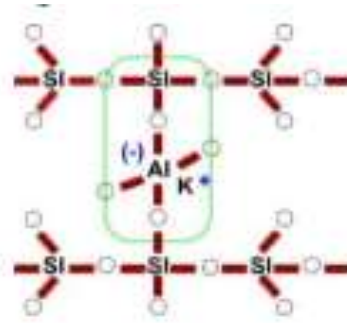


Figure 1. Polymerization Bonds That Occur in Geopolymer Concrete

In its use, geopolymer concrete has several advantages and disadvantages:

- a. Advantages of geopolymer concrete
 - Resistant to sulfuric acid attack;
 - Resistant to silica-alkali reactions;
 - Fire resistant;
 - Has small crawls and shrinkage; and
 - Can reduce air pollution.
- b. Disadvantages of geopolymer concrete
 - The manufacturing process is slightly more complicated than conventional concrete because the type of material used is more than conventional concrete;
 - Its drying period is slower than that of conventional concrete; and
 - There is no definite calculation of the design mix.

Fly Ash

Fly ash is a material derived from the remaining combustion of coal in steam power plant boilers. Fly ash has a very high cement content and has pozzolanic properties, in other words fly ash can react with free lime released by cement during the hydration process and then form substances that have binding properties at normal temperatures with the help of water (Darma and Himawan 2005).

In the application of geopolymer concrete, there are various kinds of applications that are quite potential and that already exist. Some geopolymer applications are still under development while others have already been industrialized and commercialized. The application of geopolymer technology in a wide range of properties provides technological advantages over conventional construction materials, but performance alone will not be enough to drive revolutionary changes in construction materials technology.

Sodium Silicate

Sodium silicate is the common name for a compound with the chemical formula Na_2SiO_3 . The form of this substance is available in the form of solutions and solids. Sodium silicate is generally produced by reacting alkali and silicon dioxide in solid conditions. In addition to having many functions, Sodium Silicate is also quite inexpensive. The main ingredient Sodium silicate is completely

inorganic so it is environmentally friendly because it does not have too significant an environmental impact.

Sodium Silicate is one of the alkali activators to make fly ash bind like cement. Research on how to make Sodium silicate has been carried out by previous researchers, including:

- a. Synthesis and Characterization of Sodium Silicate (Na_2SiO_3) from Rice Husks (Eti Rohaeti, Linda Trivana and Sri Sugiarti, 2015), Manado Palm Plant Research Institute, Bogor Agricultural University, Faculty of Mathematics and Natural Sciences, Department of Chemistry. This study examines how to produce silica powder from rice husk ash.
- b. the process of making water glass from silica sand with sodium hydroxide melting (Sirin Fairus, Haryono, Mas H. Sugita, and Agus Sudrajat, 2009), National Institute of Technology, Faculty of Industrial Technology, Department of Chemical Engineering,
- c. Study of the process of jelly formation and silica deposition (Eko Sulistiyono, Sumantri Sastra wiguna and Djusman Sajuti, 2004), Metallurgical Research Center (P2M) - LIPI.

The sodium silicate used in this study is dry or solid Sodium Silicate made from rice husks following the results of research by Eti Rohaeti, Linda Trivana and Sri Sugiarti, in 2015 with the title Synthesis and Characterization of Sodium Silicate (Na_2SiO_3) from Rice Husks,

Sodium Hydroxide

Sodium Hydroxide or NaOH or often called caustic soda is a chemical compound with high alkali. Its chemical properties make it ideal for use in a variety of different applications. This compound is an ionic compound in the form of a white solid composed of the sodium cation Na^+ and the hydroxide anion OH^- .

In this study, Sodium Hydroxide is also one of the alkali activators to make fly ash so it can bind like cement. The sodium hydroxide used in this study is dry or solid sodium hydroxide which is often also called caustic soda or fire soda which is widely sold in chemical stores or building stores.

Limestone

The limestone used in this study is a type of limestone, which is a sedimentary rock that is mainly composed of calcium carbonate (CaCO_3) in the form of calcite mineral, the outer term is commonly called limestone. The limestone or limestone used in this study is obtained from nature located in limestone mountains and is one of the mining materials that are widely used for industrial and construction needs.

METHODOLOGY

Type of Research

This research is experimental and will be conducted in the Civil Engineering laboratory of Bina Darma University Palembang. If you look at the nature, the type of this study is quantitative research is a process of finding knowledge that uses data in the form of numbers as a tool to analyze information about what you want

to know. So the data used in this study are data from previous research and experimental results data.

The research steps can be seen in the Flowchart/research flow scheme as follows:

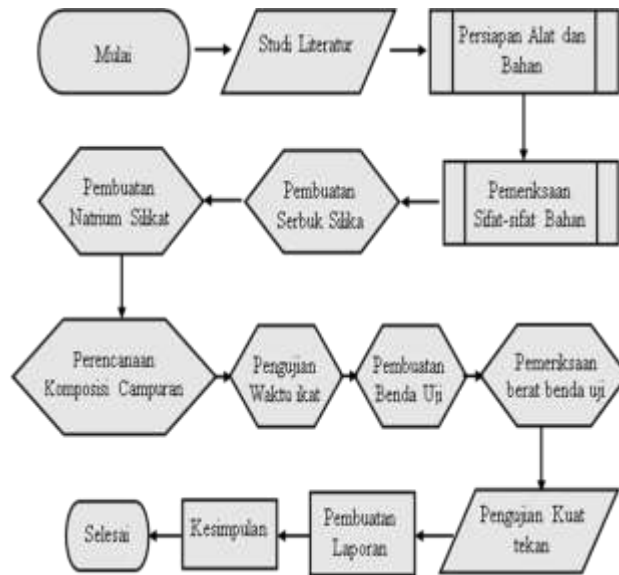


Figure 2. Flowchart/Research flow scheme

Material

- a. Flay ash;
- b. Rice husk;
- c. HCL;
- d. Aquades;
- e. PH Paper;
- f. NaOH;
- g. Limestone;
- h. Sand; and
- i. Water.

Tool

- a. Large single-burner gas stove with LPG gas cylinder and iron pan;
- b. Civil Engineering Oven;
- c. Iron fist and sieve;
- d. Digital Timbangan;
- e. Mini concrete mixer machine;
- f. Vicat needle;
- g. Concrete molds,
- h. Concrete compressive strength tester;
- i. Tools;

Research Variables

A research variable is something that is determined by the researcher to be researched so that further data can be obtained to draw conclusions. In this study, the variables used are independent variables and bound variables. The independent variables in this study were variations in the content of Fly ash, Na_2SiO_3 , NaOH and lime. Meanwhile, the bound variables in this study are Water and Sand. The test specimen in this study will be made in the form of a cube with a size of $5 \times 5 \times 5$ cm. The number of samples of each mixed variation in this study will be presented in the following table:

Table 2. Research Variabel

No	Benda Uji	Variasi	FA:Aktivator	NaOH: Na_2SiO_3	(NaOH+Kapur) : Na_2SiO_3	W/C	Jumla
1	Pasta Tanpa kapur	V1	77%:23%	1 : 2,7	-	0.17	6
		V2	80%:20%	1 : 2,7	-	0.17	6
		V3	82,5%:17,5%	1 : 2,7	-	0.17	6
2	Pasta dengan kapur	V1	77%:23%	-	(2/3+1/3) : 2,7	0.17	6
		V2	80%:20%	-	(2/3+1/3) : 2,7	0.17	6
		V3	82,5%:17,5%	-	(2/3+1/3) : 2,7	0.17	6
3	Mortar Tanpa kapur	V1	77%:23%	1 : 2,7	-	0.35	8
		V2	80%:20%	1 : 2,7	-	0.35	8
		V3	82,5%:17,5%	1 : 2,7	-	0.35	8
4	Mortar Tanpa kapur	V1	77%:23%	-	(2/3+1/3) : 2,7	0.35	8
		V2	80%:20%	-	(2/3+1/3) : 2,7	0.35	8
		V3	82,5%:17,5%	-	(2/3+1/3) : 2,7	0.35	8
Jumlah							84

For Mortar: comparison of Cement Geopolymer : Sand = 1 : 2

Research Implementation

Making Sodium Silicate from Rice Husks

The first step to be taken is to make Sodium silicate (Na_2SiO_3) with rice husk ash as a base. From the results of a previous study entitled Synthesis and Characterization of Sodium Silicate (Na_2SiO_3) from Rice Husks (Sugiarti, Linda Trivana and Sri Eti Rohaeti, 2015), the following steps were obtained:

3.5.2 Silica Insulation from Rice Husks (Hikmawati, 2010).

- a. Rice husk samples are washed and then dried with sunlight,
- b. After the rice husk is dry, the authoring process is carried out until husk charcoal is formed,
- c. The husk charcoal is then roasted at a kiln temperature of 600°C for 2 hours,



Figure 3. (a) Rice husk composition, (b) rice husk charcoal is roasted at a temperature of 6000 C

- d. The rice husk ash obtained is then purified with 3% HCl (10 ml of 3% HCl for 1 g of husk ash), The mixture is heated while stirring for 2 hours
- e. samples are filtered and washed with hot aqueducts to neutral pH (tested with PH paper).
- f. The filtering results are dried at 105°C for 4 hours until white silica is obtained.

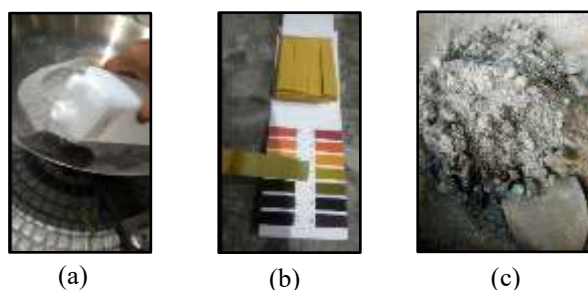


Figure 4. (a) Rice husk ash purified with HCL, (b) Neutral PH (c) Silica Powder

Synthesis of Sodium Silicate (Na_2SiO_3) or water glass (Muljiyanti 2010)

- a. Take 10 g of silica powder, put it in a cup glass.
- b. Add 82.5 ml of NaOH 4 M (stoichiometry).
- c. Bring the mixture to a boil while stirring until slightly dry.
- d. Transfer the mixture to a porcelain cup to melt at 500°C for 30 minutes.
- e. The sodium silicate obtained is then cooled at room temperature.
- f. The sodium silicate obtained is in the form of a greenish-white solid.



Figure 5. (a) Silica and NaOH Powder 4 M (b) Mixture is boiled (c) Na_2SiO_3

Manufacture of Fly Ash-Based Geopolymer Concrete Paste and Mortar, Dry Mix Method.

The mixture of geopolymer cement in this study refers to previous studies such as to make paste and concrete referring to the research of Abdul Karim Yasin (2017). From the research, the following mixed composition was obtained:

Table 3. Variable composition of geopolymer cement mixture

No	Benda Uji	Variasi	FA:Aktivator	NaOH: Na ₂ SiO ₃	(NaOH+Kapur) : Na ₂ SiO ₃	W/C
1	Pasta Tanpa kapur	V1	77%:23%	1 : 2,7	-	0.17
		V2	80%:20%	1 : 2,7	-	0.17
		V3	82,5%:17,5%	1 : 2,7	-	0.17
2	Pasta dengan kapur	V1	77%:23%	-	(2/3+1/3) : 2,7	0.17
		V2	80%:20%	-	(2/3+1/3) : 2,7	0.17
		V3	82,5%:17,5%	-	(2/3+1/3) : 2,7	0.17

Then to make concrete mortar, still refer to the research of Abdul Karim Yasin (2017) combined with the results with the research of Fiki Riki Tambingon, Marthin D. J. Sumajouw, Steenie E. Wallah (2018)

Table 4. Comparison of mass values in the design of geopolymer mortar mixtures

No	Benda Uji	Variasi	FA:Aktivator	NaOH : Na ₂ SiO ₃	(NaOH+Kapur) : Na ₂ SiO ₃	W/C	Semen Pasir
1	Mortar Tanpa kapur	V1	77%:23%	1 : 2,7	-	0.35	1 : 2
		V2	80%:20%	1 : 2,7	-	0.35	1 : 2
		V3	82,5%:17,5%	1 : 2,7	-	0.35	1 : 2
2	Mortar Tanpa kapur	V1	77%:23%	-	(2/3+1/3) : 2,7	0.35	1 : 2
		V2	80%:20%	-	(2/3+1/3) : 2,7	0.35	1 : 2
		V3	82,5%:17,5%	-	(2/3+1/3) : 2,7	0.35	1 : 2

Geopolymer concrete samples based on Fly Ash dry mixture method will be compressed as an indication of the success or not of this research and as an analysis and comparison material for future research. This means that this research only focuses on the manufacture of Fly Ash-based Geopolymer concrete mortar dry mix method has not yet reached the achievement of concrete quality.

Concrete Treatment

Concrete treatment is carried out at room temperature where the test specimen that has been printed in the form of a cube size of 5x5x5 cm, is left for 1 day, then the concrete is removed from the mold and left at room temperature.

Compressive Strength Testing

Compressive strength testing is carried out by means of a compressive test using a test standard according to ASTM C 496 - 11 for compressive strength testing paste is carried out at the age of 3 days, 7 days and 14 days while for mortar testing is carried out after the concrete mortar is 7 days, 14 days, 28 days and 56 days old.

RESULTS AND DISCUSSION

Setting Time Test

Setting time testing is a test that is carried out to find out the time it takes for cement to bind or harden starting from the initial setting time to the end of binding (final setting time). This test is used for binders (pastes). The setting time testing process standard refers to ASTM C191-2019.

The steps for testing cement setting time are as follows:

Pasta making

- a. Prepare the mixing bowl and mixing tool;
- b. Prepare Geopolymer cement with a mixed formula as presented in the following table;

Table 5. Formula of Lime-free Geopolymer cement mixture

Variasi	FA (gr)	Binder	Aktivator	NaOH	Na ₂ SiO ₃	Air
V1 (77:23)	400	519.48	119.48	32.3	87.2	88.31
V2 (80:20)	400	500.00	100.00	27	73	85
V3 (82.5:17.5)	400	484.85	84.85	22.9	61.9	82.42

Table 6. Formula of mixture of Geopolymer cement with lime

Variasi	FA (gr)	Binder	Aktivator	NaOH	Kapur	Na ₂ SiO ₃	Air
V1 (77:23)	400	519.48	119.48	21.5	10.8	87.2	88.31
V2 (80:20)	400	500.00	100.00	18	9	73	85
V3 (82.5:17.5)	400	484.85	84.85	15.3	7.6	61.9	82.42

- c. Put the Fly ash and Activator in a mixing bowl then stir until evenly distributed;



(a)



(b)

Figure 6. (a) Fly ash, NaOH and Na₂SiO₃ before stirring, (b) Geopolymer cement (Fly ash, NaOH and Na₂SiO₃ after stirring)

- d. Once flat, add water and let it sit for 30 seconds so that the water is absorbed into the mixture;



Figure 7. Geopolymer Cement + water

- e. Stir the mixture until completely smooth for approximately 60 seconds.
- f. Once flattened, collect the pasta that is attached to the wall of the bowl and let it sit for 15 seconds.



Figure 8. Geopolymer Cement after stirring

- g. Then stir again for 1 minute.

Test Piece Printing

- a. Immediately shape the paste into balls with both hands (use gloves). Throw from one hand to the other with a distance of about 15 cm 6 times.



(a) (b)
Figure 9. Geopolymer cement paste balls

- b. Press the paste ball into the conical ring on the vicat tool with one hand.



Figure 10. The balls of geopolymer cement paste are inserted into the conical ring

- c. Flatten the pasta on the conical ring, place it on a glass base, remove the excess pasta, then place the pasta on the vicat tool in the position provided on the tool.

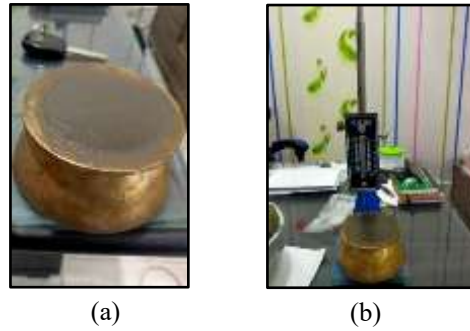


Figure 11. (a). Geopolymer cement paste that has been flattened on the conical ring, (b). Geopolymer cement paste and conical rings are laid on the Vicat tool

Determining Consistency

- a. Center the ring of paste-filled just below the press rod. Stick the tip of the needle on the surface of the paste and lock;
- b. Place the indicator on the number zero;



Figure 12. Geopolymer cement paste ready for binding time testing

- c. Remove the press rod and the needle into the paste
- d. Normal consistency occurs when the press rod and needle penetrate the 40 mm limit below the surface within 30 seconds of being left



Figure 13. Geopolymer cement paste at normal coexistence

- e. Remove the press rod and needle once every 15 minutes and record the number of drops that occur.
- f. The initial setting time occurs when the vicat needle is 25 mm deep.



Figure 14. The condition of the vicat device at the time of initial binding or initial setting time

- g. The final binding time or final setting time occurs when there is no decrease in the vicat needle is indicated by the indicator fixed at zero. When the press rod is released.



Figure 15. The condition of the vicat device at the time of final binding or final setting time

Create a Tie Time Testing Graph

Glue Time Testing Graph Chalk-Free Geopolymer Cement Paste

After testing the binding time and recording every decrease in the decrease in the vicat needle every 15 minutes, the following results were obtained:

Table 7. Bonding Time Test Results of lime-free geopolymer cement paste

Waktu	Jam	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75
	menit	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
penurunan	V1	4	3.4	3	2.8	2.7	2.5	2.3	2.2	1.9	1.8	1.6	1.6	1.5	1.5	1.4	1.3
jarum vicat (cm)	V2	4	3.8	3.6	3.5	3.3	2.9	2.5	2.5	2.4	2.3	2.3	2.3	2.1	2	2	1.9
	V3	4	3.4	3.3	3.2	2.9	2.7	2.6	2.5	2.4	2.3	1.9	1.8	1.7	1.6	1.5	1.5
Waktu	Jam	4		4.25	4.5	4.75	5	5.25	5.5	5.75	6	6.25					
	menit	240	255	270	285	300	315	330	345	360	375						
penurunan	V1	1.1	0.8	0.6	0.4	0.3	0.3	0									
jarum vicat (cm)	V2	1.9	1.8	1.7	1.3	0.8	0.8	0.7	0.5	0							
	V3	1.5	1.3	1	1	0.6	0.3	0									

From the table of Time Results of Bonding Time of lime-free geopolymer cement above, the graph can be described as follows:

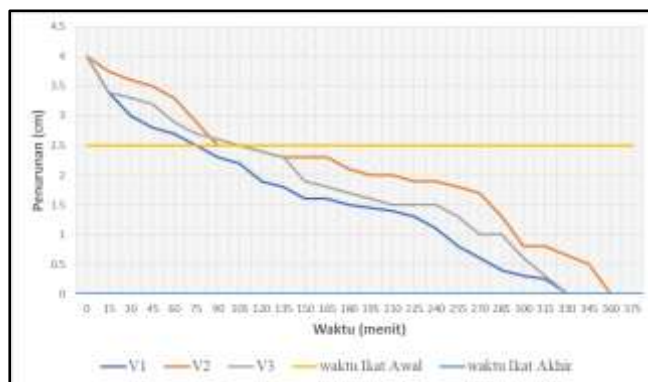


Figure 16. Glue Time Testing Graph Chalk-free geopolymers cement paste

Based on the table and graph of the results of the binding time test above, it can be seen that the fastest initial binding time occurs in the V1 mixture which is 75 minutes and the longest final binding time occurs in the V2 mixture which is 360 minutes. based on ASTM C191-2019 that the earliest permissible cement initial bonding time is 45 minutes and the latest permissible final bonding time is 375 minutes, thus all V1, V2 and V3 lime-free geopolymers cement mixture segmentation are still categorized according to the standard. However, of the three mixed pairings, V1 is the most optimal because the initial binding time and the final binding time are the fastest.

Time Testing Graph Bonding Geopolymer Cement With Lime

The same is also done for geopolymers cement with lime substitution and the result as a:

Table 8. Results of Bonding Time Geopolymer cement paste with lime substitution

Waktu	Jam	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75
	menit	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
penurunan jarum vicat (cm)	V1	4	3.8	3.5	3.5	3.1	3	2.9	2.7	2.6	2.5	2.3	2.1	2	1.8	1.6	1.4
	V2	4	3.9	3.4	3.3	3.2	3.1	2.7	2.5	2.4	2.2	2.1	2	1.9	1.7	1.5	1.4
	V3	4	3.6	3.2	2.9	2.6	2.4	2.2	1.9	1.7	1.5	1.5	1.4	1.3	1	0.9	0.8

Waktu	Jam	4	4.25	4.5	4.75	5	5.25	5.5	5.75	6	6.25
	menit	240	255	270	285	300	315	330	345	360	375
penurunan jarum vicat (cm)	V1	1.3	1.1	0.9	0.7	0.5	0.4	0.3	0.2	0	
	V2	1.3	1.2	1.1	0.7	0.2	0				
	V3	0.6	0.3	0.1	0						

From the table of Time Test Results of bonding geopolymers cement with lime above can be depicted as follows::

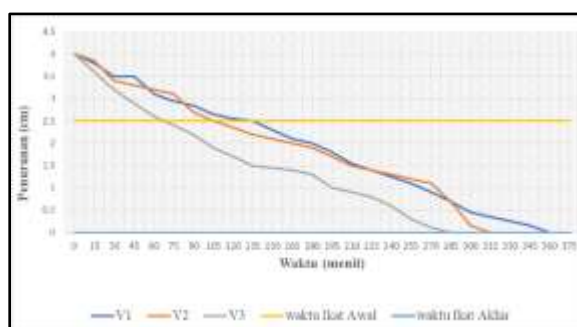


Figure 17. Bonding Time Testing Graph Geopolymer Cement Paste with Lime Substitution

Based on the table and graph of the results of the binding time test above, it can be seen that the fastest initial binding time occurs in the V3 mixture which is 75 minutes and the longest final binding time occurs in the V1 mixture which is 360 minutes. based on ASTM CI9I-2019 that all variations of geopolymers cement mixtures with V1, V2 and V3 lime substitutions are still categorized according to the standard. However, of the three mixed variations, V3 is the most optimal because the initial binding time and the final binding time are the fastest.

Compressive Strength Testing

The compressive strength of concrete is the ability of concrete to withstand compressive forces in every unit of concrete surface area. The concrete compressive strength test is an effort to obtain the estimated compressive strength value of the test piece by applying pressure to the concrete. The sample tested in this study was in the form of a cube with a size of 5 cm x 5 cm x 5 cm. This compressive strength test is performed using the ASTM C 496 - 11 standard. For Compressive Paste testing is carried out at the age of 3 days, 7 days and 14 days while for mortar testing is carried out after the concrete mortar is aged 7 days, 14 days, 28 days and 56 days. The stages of the implementation of compressive strength testing in this study are as follows:

- a. Making test specimens with molds with a size of 5 cm x 5 cm x 5 cm according to the mixed formula of each variation in this study.
- b. Leave it on for 24 hours.
- c. After 24 hours, open the mold and remove the test piece.
- d. Place the tester in a safe place and allow it to dry at room temperature until the age specified for performing the pressure test.
- e. After reaching the planned life, weigh to determine the specific gravity of the test object.
- f. Placing the test specimen on the press machine centrally.
- g. Run pressure test equipment with an additional load of between 2 and 4 kg/cm² per second.
- h. Apply pressure until the test piece is destroyed.
- i. Record the maximum load that occurs.
- j. Drawing/ documenting while performing Tests.
- k. Record the condition of the test object.
- l. Calculating the compressive strength of concrete wide unity with formula

$$f_c = \frac{P}{A}$$

where: f_c = Compressive strength (MPa)

P = Maximum force/load (N)

A = Cross-sectional Area of the press field (mm²)

Based on the results of testing at the Civil Engineering laboratory of Bina Darma University, the following results were obtained:

Paste

Lime-Free Geopolymer Cement Paste Compressive Strength Test Results Of Cement Paste

Lime-free geopolymers in this study are presented in the following table:

Table 9. Test Results Compressive Strength Chalk-Free Geopolymer Cement Paste

Variasi	Umur 3 hari			Umur 7 hari			Umur 14 hari		
	tekanan (N)	Berat (g)	Kuat tekan (Mpa)	tekanan (N)	Berat (g)	Kuat tekan (Mpa)	tekanan (N)	Berat (g)	Kuat tekan (Mpa)
V1	17,000	290	6.8	29,000	260	11.6	65,000	260	26
V2	8,000	280	3.2	27,000	249	10.8	63,500	240	25.4
V3	5,000	270	2	19,000	243	7.6	63,000	240	25.2

From the table of the results of the compressive strength test of Geopolymer cement paste above, the compressive strength graph can be described as follows:

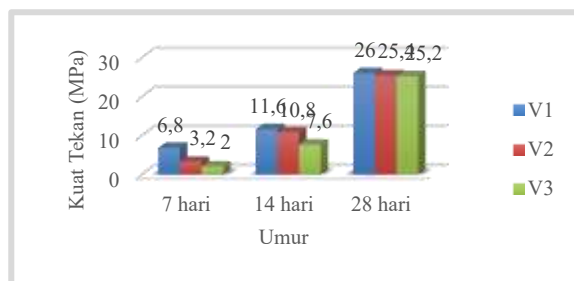


Figure 18. Testing Graph Compressive Strength Carbonate geopolymer cement paste Without lime

Based on the table and graph of the compressive strength test results above, it can be seen that the highest compressive strength occurs in the V1 mixed non-lime geopolymer cement paste, which is 26 MPa after 14 days of age. Thus the V1 mixed lime-free Geopolymer Cement Paste is the most optimal.

Geopolymer Cement Paste with Lime Substitution

The results of the compressive strength test of geopolymer cement paste with lime substitution in this study are presented in the following table:

Table 10. Test Results Compressive Strength Geopolymer Cement Paste with Lime Substitution

Variasi	Umur 3 hari			Umur 7 hari			Umur 14 hari		
	tekanan (N)	Berat (g)	Kuat tekan (Mpa)	tekanan (N)	Berat (g)	Kuat tekan (Mpa)	tekanan (N)	Berat (g)	Kuat tekan (Mpa)
V1	9,000	265	3.6	30,000	253	12	35,000	235	14
V2	8,000	265	3.2	29,000	253	11.6	35,000	235	14
V3	8,000	262	3.2	20,000	253	8	27,000	235	10.8

From the table of the results of the compressive strength test of Geopolymer cement paste above, the compressive strength graph can be described as follows:

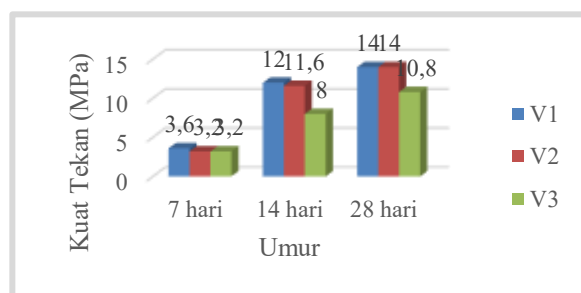


Figure 19. Testing Graph Compressive Strength Geopolymer cement paste with lime substitution

Based on the table and graph of the compressive strength test results above, it can be seen that the highest compressive strength occurs in geopolymmer cement paste with the substitution of mixed lime V1 and V2, which is 14 MPa after 14 days of age, but still below the mixed mixture of mixed geopolymmer cement paste without lime. Thus the V1 mixed lime-free cement cement paste is still the most optimal.

Lime-Free Geopolymmer Concrete Mortar

The results of the compressive strength test of lime-free geopolymmer concrete mortar in this study are presented in the following table:

Table 11. Test Results Compressive strength of lime-free geopolymmer concrete mortar

Variasi	Umur 7 hari			Umur 14 hari			Umur 28 hari			Umur 56 hari		
	tekanan (N)	Berat (g)	Kuat tekan (Mpa)	tekanan (N)	Berat (g)	Kuat tekan (Mpa)	tekanan (N)	Berat (g)	Kuat tekan (Mpa)	tekanan (N)	Berat (g)	Kuat tekan (Mpa)
V1	20,000	276	8	40,000	270	16	47,000	270	18,8	50,000	270	20
V2	20,000	275	8	40,000	270	16	47,000	270	18,8	47,000	270	18,8
V3	15,000	280	6	22,000	280	8,8	32,000	280	12,8	32,000	280	12,8

From the table of the results of the compressive strength test of Geopolymmer concrete mortar above, the compressive strength graph can be depicted as follows:

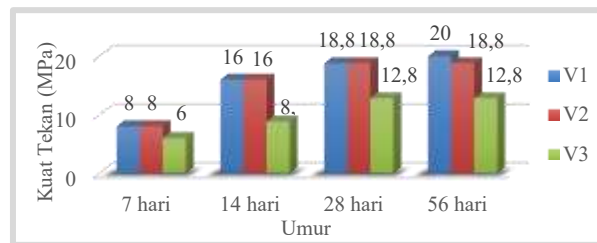


Figure 20. Testing Graph Compressive Strength of Chalk-Free Geopolymmer Concrete Mortar

Based on the table and graph of the compressive strength test results above, it can be seen that the highest compressive strength occurs in the V1 mixed lime-free geopolymmer concrete mortar, which is 20 Mpa after 56 days of age. Thus the V1 mixed limeless geopolymmer concrete mortar is the most optimal.

Geopolymmer Concrete Mortar With Lime Substitution

The results of the compressive strength test of geopolymmer concrete mortar with lime substitution in this study are presented in the following table:

Table 12. Test Results Compressive Strength of Geopolymmer Concrete Mortar with Lime Substitution

Variasi	Umur 7 hari			Umur 14 hari			Umur 28 hari			Umur 56 hari		
	tekanan (N)	Berat (g)	Kuat tekan (Mpa)	tekanan (N)	Berat (g)	Kuat tekan (Mpa)	tekanan (N)	Berat (g)	Kuat tekan (Mpa)	tekanan (N)	Berat (g)	Kuat tekan (Mpa)
V1	15,000	284	6	20,000	277	8	48,000	277	19,2	48,000	277	19,2
V2	15,000	288	6	20,000	280	8	37,000	270	14,8	45,000	270	18
V3	16,000	301	6,4	16,000	277	6,4	37,000	277	14,8	45,000	277	18

From the table of the results of the compressive strength test of Geopolymmer concrete mortar above, the compressive strength graph can be depicted as follows:

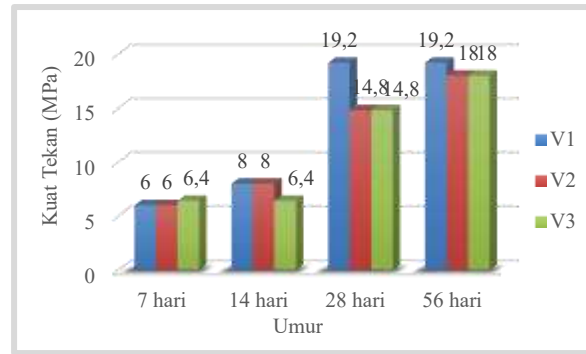


Figure 21. Testing Graph Compressive Strength of Geopolymer Concrete Mortar with Lime Substitution

Based on the table and graph of the compressive strength test results above, it can be seen that the highest compressive strength occurs in geopolymer concrete mortar with V1 mixed lime substitution, which is 19.2 Mpa after 28 days of age and does not change after 56 days but is still below the V1 mixed lime without lime mortar. Thus the V1 mixed lime-free geopolymer concrete mortar is still the most optimal.

CONCLUSION

From the results of the research that has been carried out, the following conclusions can be drawn:

- Environmentally friendly cement based on fly ash dry mixing method can be used as an alternative material to Portland cement, so that the production of carbon dioxide (CO₂) gas due to the use of Portland cement can be reduced;
- Dry Na₂SiO₃ made from rice husk ash can be used as one of the alkali activators of geopolymer cement ;
- Based on the results of the binding time test, it was found that the fastest initial binding time was 75 minutes in the mixture of V1 lime-free geopolymer cement and the longest final binding time was 360 minutes in the V2 lime-free geopolymer cement mixture and the mixture of geopolymer cement with V1 lime substitution;
- Referring to ASTM C191-2019 that the earliest permissible cement initial binding time is 45 minutes and the latest permissible final binding time is 375 minutes, it can be concluded that dry mixed method of fly ash sandy geopolymer cement with Na₂SiO₃ made from rice husk ash has standard workability;
- From the results of the compressive strength test, it was found that the highest compressive strength for the paste was 26 MPa occurring in the V1 Lime-free Geopolimer Cement mixture after the paste was 14 days old, and in the highest compressive strength concrete mortar of 20 MPa also occurred in the V1 mixed non-lime geopolymer mortar after the concrete mortar was 56 days old;
- The drying time of fly ash-based geopolymer cement concrete mortar is longer than that of conventional concrete, this can be seen in the compressive

- strength test where the compressive strength of the concrete mortar is still increasing at the age of 56 days;
- g. Based on the results of this study, it can be concluded that in the manufacture of fly ash-based geopolymer cement, the dry mixture method with Na_2SiO_3 made from rice husk ash with lime substitution will reduce the compressive strength of both the paste and the concrete mortar; and
 - h. Overall, the V1 mixed lime-free geopolymer cement, both paste and mortar, is the most optimal.

RECOMMENDATION

- a. This research still needs to be optimized, especially in the manufacture of Na_2SiO_3 from rice husk ash where this process is a chemical process that should be carried out in a chemical laboratory and accompanied by a chemist;
- b. For the next time, it is necessary to test the compressive strength and tensile strength with concrete test pieces; and
- c. It is necessary to optimize the mixture variety to get the maximum results and analyze the cost of making environmentally friendly cement based on fly ash or dry mixed method geopolymer cement so that a clear efficiency value for Portland cement is obtained.

FURTHER STUDY

Further studies are suggested to optimize the mechanical and durability properties of fly ash-based geopolymer cement using the dry mixing method with Na_2SiO_3 from rice husk ash. Future research could explore variations in curing conditions, substitution ratios, and additional pozzolanic materials to enhance compressive strength and long-term performance.

Comparative analysis with conventional Portland cement under different environmental exposures would also provide deeper insights into the sustainability and practicality of geopolymer cement applications in construction. Moreover, large-scale experimental trials and life-cycle assessments are recommended to validate its feasibility as a mainstream alternative to conventional cement.

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