The effect of curing on compressive strength of geo-polymer mortar made rice straw ash, fly ash, and laterite soil

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Abstract. This study aims to analyze the effect of curing on the compressive strength of geopolymer mortar made from straw ash, fly ash and laterite soil. This research is experimental in the laboratory. Geopolymer mortar was produced using straw ash, fly ash and laterite soil with a percentage ratio of 16.67: 41.67: 41.67. The alkaline activator used is sodium hydroxide (NaOH) with a concentration of 12 M. The compressive strength test of 5 x 10 cm cylinders is used to evaluate the geopolymer mortar mixture produced at the age of 3, 7 and 28 days with curing, namely air and water curing. The results showed that the compressive strength of the geopolymer mortar increased along with the increasing age of each curing. The compressive strength values produced in air curing 3, 7 and 28 days were respectively 1.64 N/mm^2, 1.72 N/mm^2 and 3.22 N/mm^2. While water curing, the resulting compressive strength values for each curing are 1.03 N/mm^2, 1.63 N/mm^2 and 1.68 N/mm^2. At the ages of 3, 7 and 28 days, there was an increase in the compressive strength values from water curing to air curing, which were 0.37%, 5.23% and 47.82%, respectively. It can be seen that the compressive strength of the geopolymer mortar made from straw ash, fly ash and laterite soil in air curing is greater than that of water curing.

1. Introduction

Today there are many power plants that use coal as fuel. The by-product of burning coal is in the form of fly ash which is classified as a pollutant material. In Indonesia, to reduce waste, a number of cement factories mix fly ash and waste containing pozzolans with Portland cement clinker to produce Composite Portland Cement [1] with the aim of reducing energy consumption and reducing the use of non-renewable natural sources [2]. Composite Portland Cement can be categorized as CEM II according to European standard EN 197-1: 2000, in Indonesia it was only produced in 2005, but in Europe the market share for CEM II category cement is more than 50%, bigger than Portland Cement Type 1 which is only around 35% [3].

Cement is a material that is used as a binder together with aggregates to form concrete. Cement is widely used as a material for binding coarse aggregates to make concrete and mortar. Making cement will use up natural resources. One of the efforts to reduce the use of cement is the development of geopolymer materials. A number of studies have shown that a geopolymer binder can form concrete, wherein concrete made with geopolymer made from fly ash has physical characteristics similar to concrete made from cement.

Various types of materials to produce geopolymer are fly ash, straw ash and laterite soil which these three materials can bind with using alkaline activators. The use of fly ash geopolymer as a binding material has also been developed in order to provide environmentally friendly products, considering that cement factories, apart from producing cement, also produce substantial carbon dioxide emissions into the atmosphere. Fly ash is rich in silica and alumina. The silica and alumina content in fly ash can react with alkaline liquids to produce a binder. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) are used as alkaline activators [4]. Sodium silicate functions to accelerate polymerization reactions, while sodium hydroxide functions to react Al and Si elements contained in fly ash so as to produce strong polymer bonds. In addition to the activator sodium silicate (sodium silicate) and sodium hydroxide (sodium hydroxide), the strength of the fly ash geopolymer bond is also influenced by the concentration and ratio of the alkaline activator used..

Various studies have been conducted to use straw ash as a material for making geopolymer concrete. Some previous researches [5-9] found that straw ash can be used as one of geopolymer manufacturing material. In the fly ash based geopolymer binder, straw ash, laterite soil and alkaline solution react with fly ash to form an alumina-silica binder, without cement addition. The geopolymer binder then bonds the aggregate to form a mortar or concrete. Several research studies that use fly ash geopolymer as a binder to replace cement, seem to always require oven heat to develop and increase the strength of concrete. Therefore, oven heat is needed to make geopolymer concrete made from straw ash, laterite soil and fly ash, this is expected to be able to provide the heat needed for each use of fly ash geopolymer in developing concrete strength to reach normal concrete strength. In this research, geopolymer was made without using oven heat.

2. Materials and Methods

2.1 Physical Characteristics of Straw Ash

Straw ash is obtained from the waste of rice cutting in Gowa Regency, South Sulawesi Province and has undergone a burning process at a temperature of ± 500 degrees Celsius. The straw ash used in this study was straw ash that passed sieve number 200. Table 1 each shows the appearance and physical characteristics of the straw ash used in this study.

Table 1. Physical characteristics of straw ash

No.	Testing type	Testing standards	Testing result
1	Specific gravity	SNI 03-1964-2008	2.36
2	Fine aggregate water absorption	SNI 1970:2008	172.78%
3	Sieve analysis	ASTM C-136-06	<10% passed sieve no.100

2.2 Physical Characteristics of Fly Ash

Table 2 each shows the appearance and physical characteristics of the fly ash used in this study. Fly ash was obtained from the waste products of PLTU in Jeneponto Regency, Punagayya Village, Bangkala District, South Sulawesi Province.

Table 2. Physical characteristics of fly ash

No.	Testing type	Testing standards	Testing result
1	Specific gravity	SNI 03-1964-2008	2.65
2	Fine aggregate water absorption	SNI 1970:2008	26.42 %
3	Sieve analysis	ASTM C-136-06	> 50% passed sieve no. 50

2.3. Physical Characteristics of Laterite Soils

Based on the results of the sieve analysis test where the soil passed the Sieve No. 200 is greater than 76.03%, then the soil can be classified in group A- 4; A-5; A-6; A-7. Meanwhile, based on the results of the examination of Atterberg boundaries, the soil can be categorized as A-7-6 where the liquid limit value is > 41%, the plasticity index value is > 11% and the plastic limit value is > 30%, so the soil is classified as clay with plasticity. Table 3 shows the characteristics of laterite soils.

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Tabel 3. Characteristics of laterite soils

No.	Material Characteristics	Testing standards	Testing result
1	Soil classification	AASHTO	A-7-6
2	Sieve analysis	ASTM C-136-06, ASTM D-1140-54	> 30% pass through 200 mesh sieve
3	Atterberg limits		
	Liquid limit (LL)	ASTM D-423-66	65.46%
	Plastic limit (PL)	ASTM D-424	33.90%
	Plasticity Index (PI)	ASTM D-427	31.57%
4	Specific gravity	ASTM D-162	2.65
5	Compacting		
	γdry	ASTM D-698	1.60 gr/cm^3
	W_{opt}	ASTM D-2216-98	21.64%

2.4. Alkaline Activator

Alkaline Activator is sodium hydroxide (NaOH) obtained from one of the distributors in Makassar. NaOH is used as much as 12 molars dissolved in water. Figure 1 shows the physical appearance of the geopolymer and alkaline activator materials used in this study.

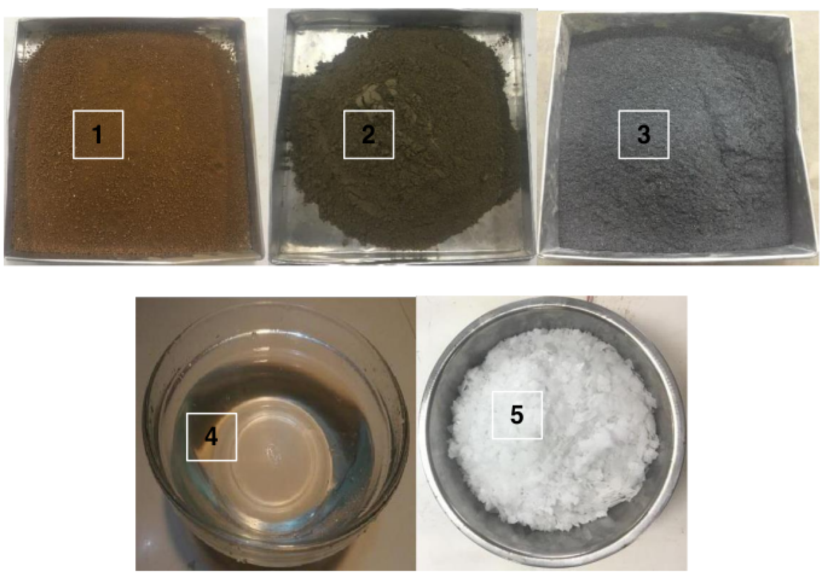

Figure 1. Geopolymer materials (1. Laterite soil; 2. Fly ash; 3. Straw ash; 4. Water; 5. NaOH)

2.5 Geopolymer Mortar Material Mixing Method

Figure 2 shows the process of mixing all the materials to make a geopolymer mortar. This study was designed to determine the effect of age on a geopolymer mortar with a 5 x 10 cm cylinder mold. The mixing method used in this study are:

1. Prepare materials with a predetermined composition.
2. Fly ash, laterite soil and straw ash are put into the mixer bowl.

3. Stir the fly ash and straw ash using a mixer at low speed for 60 seconds then turn off the mixer machine, stirring manually the mixture until well blended.
4. Stir the fly ash and straw ash mixture using a mixer while adding the alkaline activator (NaOH) which has been previously dissolved in water, mix for 1 minute at low speed. Then turn off the mixer machine.
5. Manual stirring until evenly distributed. After that, stir the mixture using a mixer at high speed (high speed) for 1 minute.
6. The result of the mixture is molded into a 3-layer mold, each blows 25 times per layer using a slump flow pounder while pounding it.
7. Let the mixture sit for 24 hours so that the mixture can solidify in the mold;
8. Removing the test object from the mold, then curing the test object for 3, 7 and 28 days in air curing and water curing conditions.

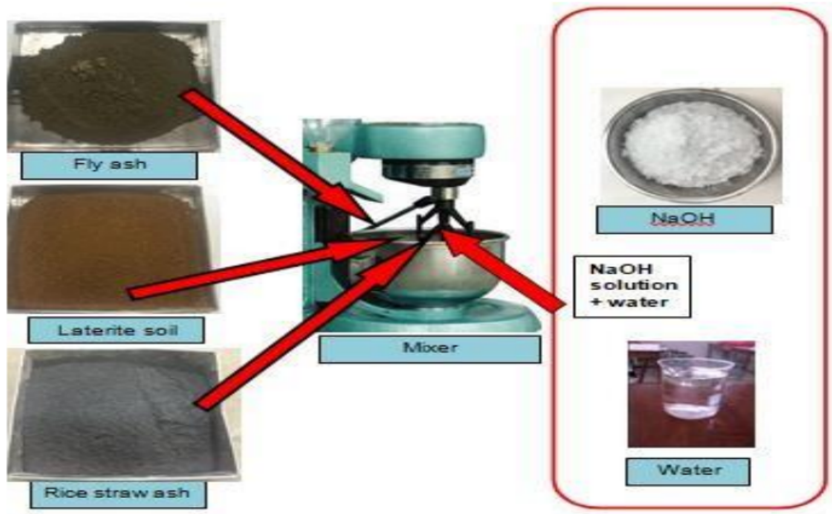

Figure 2. Mixing of geopolymer materials

2.6. Curing of Test Objects

The method used in this research is an experimental method in the laboratory. Geopolymer concrete is produced using laterite soil, straw ash and fly ash along with the alkaline activator used. The design of the concrete geopolymer mixture consists of fly ash as a substitute for cement, alkaline activator (NaOH) as a chemical that activates fly ash, laterite soil, straw ash and water. For all specimens, curing is carried out, namely water and air curing. Air curing, namely the test object is stored in the test object storage room at room temperature after printing is shown in Figure 3 (a). The test sample in air curing is left at room temperature until the sample arrives during the testing period. In water curing, the test sample after being removed from the mold, the test sample is then immersed in fresh water until the test sample arrives during the testing period shown in Figure 3 (b).

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(a) (b)

Figure 3. Curing of test objects (a. Air curing; b. Water curing)

2.7. Geopolymer Mortar Compressive Strength Testing

Figure 4 shows the position of the test object in the test of the compressive strength of the geopolymer cylinder mortar which uses the LVDT as a measuring device for horizontal displacement due to the load given.

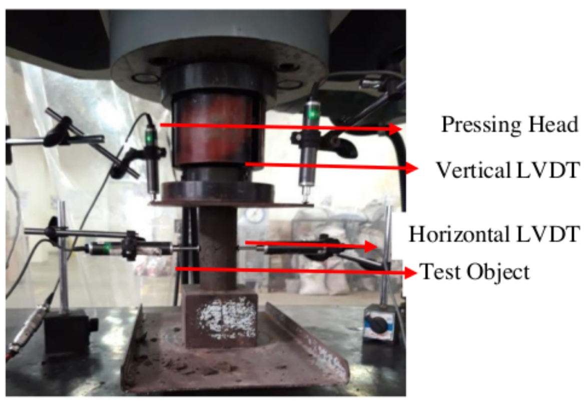

Figure 4. The position of the test object for compressive strength

3. Results and Discussion

3.1. Chemical Characteristics of Straw Ash, Fly Ash and Laterite Soils

Table 4 shows the oxide components of straw ash, fly ash and laterite soil. Fly ash used in this research is categorized as class F fly ash because the total percentage of Fe_2O_3, Al_2O_3, and SiO_2 is greater than 70%. The straw ash used in this study contained SiO_2, P_2O_5, $CaCO_3$ and K_2O.

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Table 4. Oxide components of fly ash, straw ash and laterite soil (XRF results)

Oxide components	Concentration (%)		
	Fly ash	Straw ash	Laterite Soil
Fe_2O_3	19.96	2.31	12.49
Al_2O_3	19.16	-	49.38
SiO_2	34.63	70.80	34.81
MnO	0.25	-	0.10
TiO_2	1.26	-	1.39
K_2O	1.33	15.89	0.35
CaO	12.74	5.34	0.85
P_2O_5	-	3.61	0.44
V_2O_5	-	-	0.06
ZrO_2	-	-	0.05
SrO	0.13	-	0.03
Cr_2O_3	0.07	-	0.02
CuO	-	-	0.02
ZnO	-	-	0.011
MgO	8.10	-	-
SO_3	1.80	-	-
CoO	0.05	-	-
BaO	0.21	-	-
Pr_6O_{11}	0.05	-	-
Nd_2O_3	0.07	-	-

3.2. Flow Mortar Geopolymer Test Results

Figure 5 shows a fresh geopolymer mortar flow. The flow of fresh geopolymer mortar is 112.50 mm, the specific gravity in the fresh state is 1901.3 kg/m^3. The geopolymer mortar mixture is able to bind laterite so that the fresh geopolymer mortar can flow and spread evenly without any accumulation in the middle of the circle and without bleeding.

Figure 5. Flow of fresh geopolymer mortar

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3.3. Mortar Geopolymer Mix Design

Geopolymer mix of fly ash-laterite soil ash geopolymer using straw ash, fly ash, laterite soil and activator sodium hydroxide (NaOH). In this study, the percentage of fly ash used was 41.66% of the total mixture. The ratio of laterite soil: straw ash: fly ash was 41.66: 16.66: 41.66. The best composition of the geopolymer mortar was obtained from the results of the initial mixture trials. The composition of the geopolymer mortar is shown in Table 5. Alkaline activator NaOH is used as a binder material. The total water used is obtained from the calculation of the optimum water content in the optimal compaction of the laterite soil.

Tabel 5. Composition of a geopolymer mortar mixture (1 m^3)

Water (kg)	NaOH (kg)	Straw ash (kg)	Fly ash (kg)	Laterite soil (kg)
125.690	60.392	60.392	150.979	150.979

3.4. Results of the Geopolymer Mortar Compressive Strength Test

Table 6 shows the average results of the geopolymer mortar compressive strength test of three specimens for water and air curing at the ages of 3, 7 and 28 days..

Table 6. Test results of the compressive strength of water and air curing geopolymer mortar

No.	Geopolymer mortar age (days)	Weight (gram)	Height (cm)	Diameter (cm)	Compressive strength (N/mm^2) Curing	
					Water	Air
1		504.00	11.56	5.27	1.03	1.65
2	3	494.00	11.49	5.19	0.93	1.64
3		499.00	11.52	5.16	1.14	1.64
	Average	**499.00**	**11.52**	**5.20**	**1.03**	**1.64**
1		515.00	11.43	5.09	1.57	1.74
2	7	513.00	11.50	5.09	1.65	1.71
3		520.00	11.49	5.09	1.68	1.72
	Average	**516.00**	**11.47**	**5.09**	**1.63**	**1.72**
1		492.40	11.72	5.88	1.63	3.22
2	28	491.50	11.63	5.73	1.73	3.03
3		499.40	11.74	5.66	1.69	3.44
	Average	**494.40**	**11.69**	**5.75**	**1.68**	**3.22**

Based on Table 6, it can be seen that the average compressive strength of 3 (three) specimens of water curing geopolymer mortar at the age of 3, 7 and 28 days is 1.03 N/mm^2, 1.63 N/mm^2 and respectively. 1.68 N/mm^2 while the specimens for the air curing geopolymer mortar were 1.64 N/mm^2, 1.72 N/mm^2 and 3.22 N/mm^2 respectively.

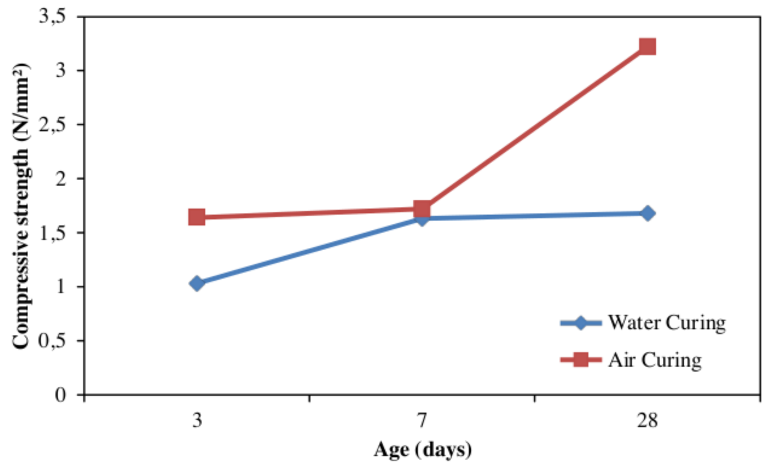

Figure 6. The relationship between the age of the geopolymer mortar and the average compressive strength

Figure 6 shows the relationship between the age of the geopolymer mortar and the resulting average compressive strength. It can be seen that the compressive strength value increases with increasing age of the geopolymer mortar. The increase in the compressive strength value in water curing was 58.25% and 63.10% at 7 and 28 days against 3 days of age, while in air curing it was 4.87% and 96.34%, respectively. At the ages of 3, 7 and 28 days, there was an increase in the compressive strength values from water curing to air curing, which were 0.37%, 5.23% and 47.82%, respectively. This is due to the presence of straw ash in this mortar mixture which contributes to heat, so without oven temperature, fly ash geopolymer mortar with laterite soil material can still provide strength. These results also indicate that the compressive strength increases without a similar curing oven because the oxide content of straw ash, laterite soil and fly ash, namely silica (SiO_2), is able to bind well and produce amorphous silica and contribute positively to the increase in compressive strength values. The cause of the higher value of compressive strength in water curing than the compressive strength value of air curing on the test object with a concentration of 12 Molar is because the test sample mixture can no longer be bound perfectly because the higher the NaOH concentration, the use or water content used is also reduced. With less water needed in the sample mixture, the mixture does not mix properly. In addition, because the sample did not mix well and was immersed in water, the test object was quickly destroyed.

4. Conclusion

Straw ash can be used as a geopolymer mortar material. Straw ash can be an alternative chosen of fly ash geopolymer mortar material. The value of the compressive strength of the geopolymer mortar increased with increasing age at each curing. The compressive strength of the water curing geopolymer mortar at the age of 3, 7 and 28 days was 1.03 N/mm^2, 1.63 N/mm^2 and 1.68 N/mm^2 respectively, while the test specimens of the air curing geopolymer mortar were respectively amounting to 1.64 N/mm^2, 1.72 N/mm^2 and 3.22 N/mm^2.

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