Strength Performance of Sodium Hydroxide-Activated Fly ash, Rice Straw ash, and Laterite Soil Geopolymer Mortar

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Strength performance of sodium hydroxide-activated fly ash, rice straw ash, and laterite soil geopolymer mortar

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Abstract. The geopolymer of fly ash (FA), rice straw ash (RSA) and laterite soil (LS) was prepared. The strength of the geopolymer mortar with the FA/RSA/LS percentage ratio of 41.67/16.67/41.67 was tested. The geopolymer was activated with sodium hydroxide (NaOH). Effect on air curing on compressive strength as well as the optimum mix proportion of geopolymer mortar was investigated. It is possible to achieve compressive strengths of 1.64 N/mm^2, 1.72 N/mm^2, and 3.22 N/mm^2, respectively for the 12 M sodium hydroxide-activated geopolymer mortar after 3, 7 and 28 days of casting when air cured. Results indicated that the increase in the curing period increased the compressive strength.

1. Introduction

Portland cement has been widely used as a material to bind coarse and fine aggregates to make concrete and mortar. The manufacture of Portland cement will deplete the non-renewable natural resources. Now days, there are many power plants that use coal fuel where the by-products of coal combustion in the form of fly ash are classified as pollution material (pollutant). Fly ash is mainly disposed of in landfills, which causes various environmental problems. Flying ash consists of most particles having a diameter of 1-150 µm that passes from a 45 µm sieve. Generally, fly ash has the main chemical composition of silica (SiO_2), alumina (Al_2O_3) and ferric oxide (Fe_2O_3). Other chemical substances such as calcium oxide (CaO), magnesium (MgO), sulphur (SO_3), alkaline (Na_2O, K_2O), phosphorus (P_2O_5), manganese (Mn_2O_3) and titanium (TiO_2). ASTM C 618-05 [1] divides fly ash in three categories namely class N, class F and class C. Minimum content of SiO_2, Al_2O_3, and Fe_2O_3 compounds are 70% for class N and class F, while class C is between 50% - 70%. CaO content in fly ash class N and F is relatively small compared to class C where the content of CaO class C is greater than 20% [2].

Presently, using product mineral such as fly ash as cement ingredients is wide spread in practice. In Indonesia, a number of cement factories have been blended fly ash and pozzolan-containing wastes with a Portland cement clinker to produce Portland Composite Cement (SNI 15-7064-2004) [3] in order to reduce the waste, to reduce energy consumption and reduce the use of non-renewable natural resources. Portland Composite Cement can be categorized as CEM II according to European standard EN 197-1: 2000, where in Indonesia it was produced from 2005. However, based on the International Energy Agency's (IEA) report, cement production is widely recognized as one of the contributors to greenhouse gas emissions with a total of 6 - 7% of total CO_2 emissions into the Earth's atmosphere. It is estimated that about 0.9 - 1.0 tons of CO_2 is produced from the production of one ton of Portland cement clinker [4].

In this regard, efforts to reduce the use of cement have been done intensively, such as the development of geopolymer which can be produced from various kinds of industrial by products. Material rich in alumina (Al_2O_3) and silica (SiO_2) can be activated by alkali solution to produce a geopolymer without Portland cement addition. Fly ash geopolymer as a binder of material in the field of construction and building materials have been studied and developed intensively.

Indonesia is one of the rice producing countries. Every harvest, there is a lot of straw ash which is the result of burning rice straws. The abundant amount of rice straw ash (RSA) makes it a material with added value if it can be used as a building material source. Based on the related literature, rice straw ash contains silica, aluminium, and lime so that it can be used as a material to make cement. A number of studies also show that straw ash can be used in the manufacture of a geopolymer.

Several recent types of research and developments of geopolymer have expanded in the area of soil improvement. For resistance, focused [5] conducted a study related to technology associated with improving LA soil using FA geopolymer and carbide lime residue. It was found that fly ash combining curing time could provide the compressive strength. [6] conducted a study focused on technology associated with improving silty clay using FA as a precursor and calcium carbide residue as an alkali activator.

The laterite soil colour varies but is usually brightly coloured. The most common colour shades are pink, red and brown. The physical properties of the laterite soil vary according to the mineralogical composition and the particle size distribution of the soil. Granulometry may vary from the finest to the gravel according to the origin, thus affecting the geotechnical properties such as plasticity and compressive strength. One of the main advantages of laterite soil material is not easily swelling (swell) with water and not too sandy [7].

The study on FA-RSA-LS geopolymer mortars focuses on the strength performance, the mix proportions, and the manufacturing methodology. The knowledge would be instrumental and lay some foundations for future research in this field.

2. Materials and Methods

2.1. Materials

Table 1, Table 2 and Table 3 shows the chemical contents of fly ash, rice straw ash, and laterite soil, respectively. The material is a fly ash, rice straw ash and laterite soil with a ratio of 41.67;16.67;41.67. Geopolymer used is a combination of fly ash with alkaline activator used is sodium hydroxide (NaOH). While sodium hydroxide concentrate is 12 Molar. The mortar mixture can be seen in Table 4 below.

Table 1. Chemical contents of fly ash.

Component	Content (%)	Component	Content (%)
Fe_2O_3	19.96	Cr_2O_3	0.07
Al_2O_3	19.16	MgO	8.1
SiO_2	34.63	SO_3	1.80
MnO	0.25	CoO	0.05
TiO_2	1.26	BaO	0.21
K_2O	1.33	Pr_6O_{11}	0.05
CaO	12.74	Nd_2O_3	0.07
SrO	0.13		

Table 2. Chemical contents of rice straw ash.

Component	Content (%)
Fe_2O_3	2.31
SiO_2	70.80
K_2O	15.89
CaO	5.34
P_2O_5	3.61

Table 3. Chemical contents of laterite soil.

Component	Content (%)	Component	Content (%)
Fe_2O_3	12.49	P_2O_5	0.44
Al_2O_3	49.38	V_2O_5	0.06
SiO_2	34.81	ZrO_2	0.05
MnO	0.10	SrO	0.03
TiO_2	1.39	Cr_2O_3	0.02
K_2O	0.35	CuO	0.02
CaO	0.85	ZnO	0.011

Table 4. Geopolymer mortar mixtures ($1m^3$).

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

2.2. Stage of test
This research is an experimental test and was done at Structure and Materials Laboratory of Civil Engineering Department, Universitas Hasanuddin. Table 5, Table 6 and Table 7 show the standard for testing fly ash, rice straw ash, and laterite soil, respectively.

Table 5. Standard testing for fly ash.

Type of inspection	Standard method
Specific gravity	SNI 03-1964-2008 (Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer)
Water absorption	SNI-1970-2008 (Standard Test Method For Specific Gravity And Absorption of Rock For Erosion Control)
Sieve analysis test	SNI 03-1968-1990 (Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates)

Table 6. Standard testing for rice straw ash

Type of inspection	Standard method
Specific gravity	SNI 03-1964-2008 (Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer)
Fine Aggregate water absorption	SNI-1970-2008 (Standard Test Method for Specific Gravity and Absorption of Rock For Erosion Control)

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Sieve analysis	SNI 03-1968-1990 (Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates)

Table 7. Standard testing for Laterite soil.

Type of inspection	Standard method
Specific gravity	SNI 03-1964-2008 (Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer)
Plastic limit (PL)	ASTM D-424
Liquid limit (LL)	ASTM D-423-66
Plastic index	ASTM D-427

2.3. Mixing procedure

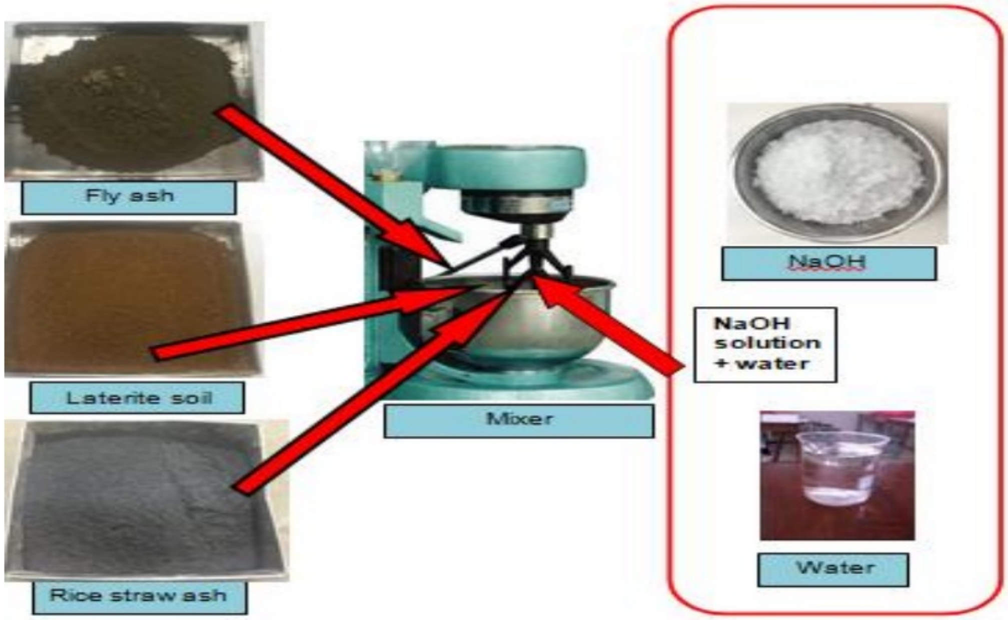

Figure 1. Mixing geopolymer materials.

The mixing method used in this research as shown in Figure 1, as follows:
1. Laterite soil + fly ash + rice straw ash, mix in dry conditions for 1 minute (slow speed).
2. Enter the activator alkali (NaOH) that has been dissolved in water, mix for 2 minutes.
3. Blend manually for 1 minute and afterwards laterite soil, fly ash and rice husk ash, activator solution, and water, mix with mixing machine with high speed for 10 minutes. The total mixing time is 11 minutes.

2.4. Flow testing (Consistency)

The flow or consistency of the mixture is important to know in order to obtain an indication showing the ability to use fresh geopolymer mortar in. In this case, there is a tendency of flow or consistency of each addition of water resulting in a decrease in consistency. Flow testing is done based on SNI 03-

6825-2002. In this research used water to solid ratio of 0.20 (water weight divided by total weight of mixture) with flow equal to 110 ± 5% of fresh mortar. The value of flow or consistency is then maintained for each mix design performed as an indication that the mixture used has the same condition.

2.5. Compaction and curing method

This study was designed on a mortar geopolymer with a cylinder mould with a size of 5 x 10 cm. For all specimens performed the treatment (curing) that is the cooling in the room. There are 2 types of treatment of the specimen after removal from the cylinder mould, the first is the air treatment that is the test object is stored in the storage space of the specimen with the room temperature. The test specimen treated at room temperature is a standard test object. The second treatment is cooled to room temperature for 24 hours, the specimen is air curing, where the sample is left at room temperature until the age of compressive strength testing is carried out. The test piece was treated until the age of compressive strength testing was carried out.

2.6. Compressive strength and modulus of elasticity

Based on SNI-03-6825-2002 [8], a compressive strength test is to provide a continuous monotonic static load at a constant rate on the test specimen that creates compressive stress. Two test specimens were used for the compressive strength test, the results obtained were then averaged. A compressive strength test was performed using a Universal Testing Machine, two vertically mounted LVDT 10 mm and a set of data logger tools connected to a set of computers. LVDT is placed to measure the displacement that occurs when receiving a compressive load, the value of change or decrease that is analyzed to obtain strain due to the compressive load.

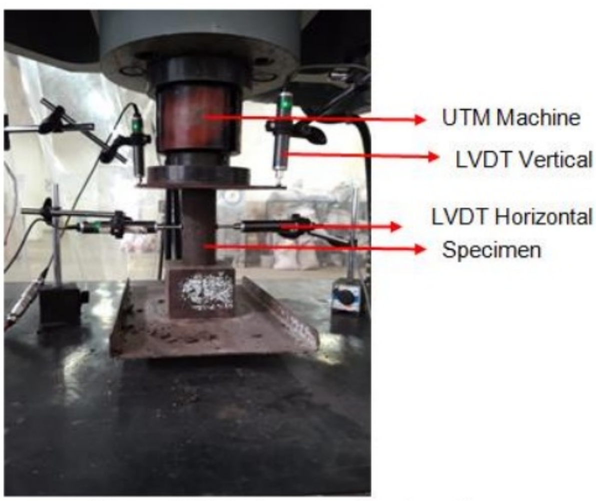

Figure 2. Test of compressive strength.

3. Results and Discussion

3.1. Physical characteristics of fly ash, rice straw ash, and laterite soil

Table 8, Table 9 and Table 10 shows the physical characteristics of fly ash, rice straw ash, and laterite soil, respectively.

Table 8. Physical properties of fly ash.

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Type of testing	Result of testing
Specific gravity	2.65
Water absorption	26.42 %
Sieve analysis test	> 50 % pass sieve No. 50

Table 9. Physically characteristic of rice straw ash.

Type of testing	Result of testing
Specific gravity	2.36
Fine Aggregate water absorption	172.78%
Sieve analysis	< 10 % pass sieve No.100

Table 10. Engineering properties of laterite soil.

Type of testing	Result of testing
Specific gravity	2.65
Plastic limit (PL)	33.90 %
Liquid limit (LL)	65.46 %
Plastic index	31.57 %

3.2. Flow testing

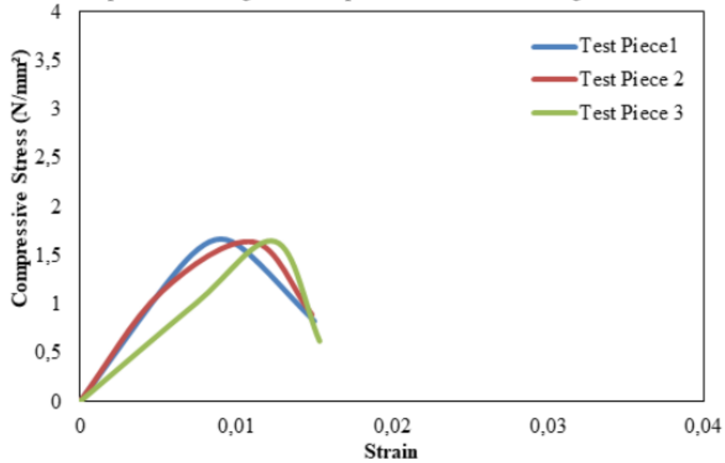
The flow of fresh mortar geopolymer is 112.50 mm, the specific gravity when it is fresh is 1901.3 kg/m^3. Mixed geopolymer mortar is able to bind the laterite so that the fresh mortar geopolymer can flow and spread evenly without any accumulation in the middle of the circle and without any bleeding.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

Figure 3. The flow of fresh mortar geopolymer

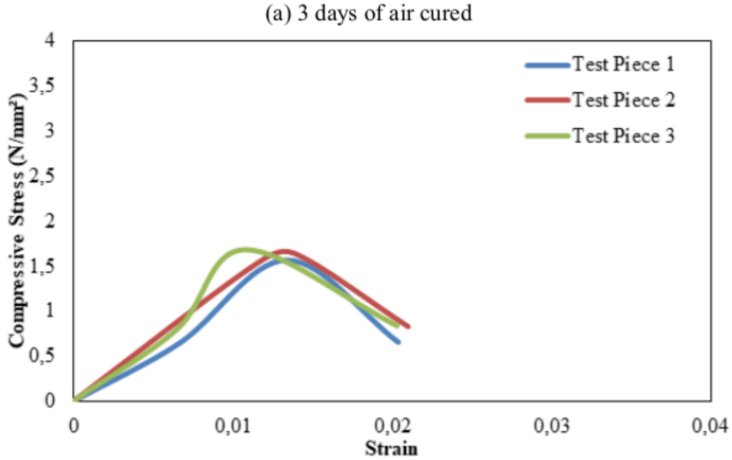
3.3. Effect of air curing on stress strain relationship of geopolymer mortar containing rice straw ash and laterite soil

Figure 4 shows the stress strain of the relationship of specimen cured in the air remains linear until it reaches the stress and compressive strength evolution to avoid environmental degradation. Based on figure 4, it can be seen that sample of 3 days air curing has average compressive strength value of 1.64

N/mm^2 and the average strain of 0.0160 while 7 days air curing arise 1.72 N/mm^2 of average compressive strength corresponding to 0.0180 of average strain and 28 days curing has average compressive strength value of 3.22 N/mm^2. Compressive strength at 7- and 28-days air curing increase 4.87% and 96.34%, respectively as compared with the compressive strength at 3 days air curing. This result shows that the compressive strength developed without oven curing.



(a) 3 days of air cured



(b) 7 days of air cured

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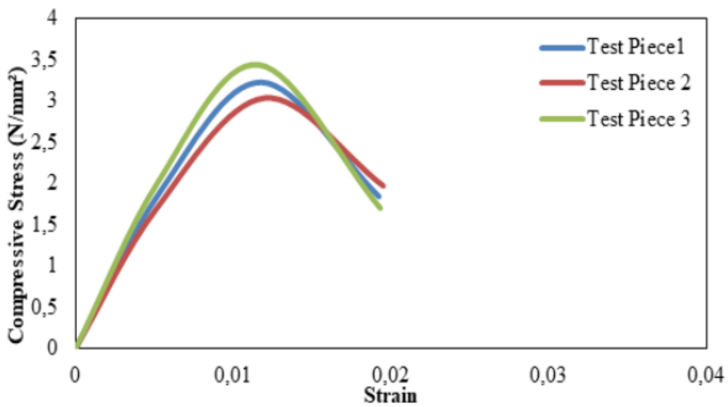

(c) 28 days of air cured

Figure 4. Stress-strain of geopolymer.

Similar to the samples those cured in air, the presence of rice straw ash in mortar mixture, hence without the curing of oven temperature, the fly ash geopolymer mortar with this laterite soil material can still provide strength. This caused by the presence of rice straw ash in this mortar mixture contributes to the heat, hence without the curing of oven temperature, the fly ash geopolymer mortar with this laterite soil material can still provide strength. This result also indicated that compressive strength increased without oven curing similar because of the oxide content of rice straw ash, laterite soil and fly ash SiO_2 able to bind well and produce amorphous silica.

4. Conclusion

Based on the results and discussion, it can be concluded as follow:

1. In fresh conditions, the mortar geopolymer is able to bond well without segregation and bleeding.
2. The sodium hydroxide (NaOH) leaches the silica and alumina in the amorphous phase and acts as a binder.
3. The compressive strength of geopolymer increases with time.

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