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The effect of white soil on geopolymer mortar porosity

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Abstract. This study analysed the effect of white soil as a filler on geopolymer mortar. The materials used were fly ash, white soil from Kupang as fillers, sand, water, and NaOH as alkaline activator. The comparison of geopolymer mortar mixture was 1 Pca: 3 Sand with water factor 0.5. The Pca was composed by white soil and fly ash with alkaline activator and water. The percentage of white soil used were 5, 10, 15, 20, 25 and 30%. The white soil chosen passed the number 200 sieve. Moreover, the dimension of mortar used was 5 x 5 x 5 cm. To remove the water content from the mortar, the oven was set at 60 °C for 24 hours until the mortar weight did not change. The result shows that porosity decreases with the increase of white soil percentage. Increase in the white soil percentage by 5, 10, 15 and 20% can reduce porosity by 0.9, 2.7, 2.5 and 2.9%. Nevertheless, the white soil, with a percentage of 25 and 30, increased porosity by 3.7 and 3.8%, respectively. This happened because in these percentages, the white soil hardens faster than the other percentages, impacting the compaction process on the mould.

1. Introduction

The geopolymers are materials that are produced from the reaction of materials containing a lot of silicon and aluminium with alkaline activators [1]. Many of these elements are found in fly ash, a waste material from the Electric power plant centre (PLTU), which is the remaining after the coal combustion. The use of geopolymers can reduce gas dioxide emissions, which is one of the causes of the greenhouse effect [2]. The use of geopolymer technology can reduce about 80% of carbon dioxide gas emissions into the atmosphere, caused by the cement and aggregate industries [3]. The other advantages are: it can reduce carbon dioxide gas emissions by reducing fly ash (the environmental pollutant waste) and can be used as building materials [4].

In the Kupang area of East Nusa Tenggara, there are natural ingredients called white soil. The white soil is a rock that has undergone changes in chemical composition, caused by weathering and the influence of underground water conditions. The white soil has brownish-white features; it is compact and rather difficult to dig with simple tools. It has chemical constituents, namely SiO₂, P₂O₅, Al₂O₃, Fe₂O₃, FeO, MnO, MgO, CaO, Na₂O, K₂O, TiO₂ and SO₃ [5]. People in Kupang use this white soil to construct pavement and light concrete by mixing it with cement [6]. The availability of white soil in Kupang area is quite abundant. Therefore, other utilisations of white soil must be done. Thus, the white soil can be used more effectively. In Kupang, there is also a Bolok PLTU, which produces fly ash from the remaining of coal combustion. However, the waste fly ash, if not properly treated will potentially be an environmental pollutant. Therefore, a study is needed to overcome this potential environmental pollution in Bolok PLTU.

To overcome the potential problem of pollution by fly ash, it can be used as a geopolymer material with the white soil as its filler. The white soil was chosen as a geopolymer filler because the majority of



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the white soil constituent material is calcium (Ca), which was carried out by the research [7] [8]. The calcium content can strengthen geopolymer specimens so that, it is expected to produce smaller porosity than the normal geopolymer mortar.

2. Research Methods

2.1. Mortar Geopolymer Composite Material

The composition of the geopolymer mortar are fly ash, white soil, fine aggregate, alkaline activator (NaOH) and water. The function of fly ash is to work as a binder and white soil as a filler. These materials, mixed with NaOH and water, formed geopolymer binders. The material used must comply with the requirements to produce good quality mortar.

2.1.1. White soil from Kupang, NTT.

The white soil is a natural product from Kupang, East Nusa Tenggara. The white soil has several chemical compounds, including calcium, magnesium, silica, alumina and iron, expressed in the form of oxides (CaO, MgO, SiO₂, Al₂O₃, Fe₂O₃ [9]. The white soil used was particles of soil with a size smaller than 0.074 mm or passed the number 200 sieve, as shown in Figure 1(a).

2.1.2. Fly Ash

The fly ash is a mineral residue in fine grains, produced from combustion of refined coal at a power plant center. The fly ash used was class F from Tanjung Jati B Jepara PLTU. The fly ash used had the particle size smaller than 0.074 mm or passed the number 200 sieve, as shown in Figure 1(b).

2.1.3. Fine Aggregate

The fine aggregate or sand used in this study was Muntilan sand. According to fine aggregate requirements based on American Standard Testing and Materials (ASTM) C33[10], the maximum diameter of sand was 4.76 mm and minimum diameter was 0.074, as shown in Figure 1(c).

2.1.4. Alkaline Activator

The alkaline activator is a compound that is used to facilitate the condensation polymerization reaction on the geopolymer mortar. The alkali activator used was sodium hydroxide (NaOH), commonly known as caustic soda, as shown in Figure 1(d)



(a) White soil

(b) Fly Ash

(c) Sand

(d) NaOH

Figure 1. Constituent material of geopolymer mortar

2.2. Making Mortar Test Objects

In conducting this research, several tools were needed to support the work process and testing, which are as follows:

2.2.1. Tools

- Mortar molds with dimensions of 5x5x5 cm,
- Measuring Cup
- Pounder
- Porcelain bowl
- Rubber Hammer
- Tray
- Scales
- Mixer
- Small spade
- Covenant, and others

2.2.2. Composition of Mortar Geopolymer

In this study, the composition of the geopolymer mortar were fly ash, white soil, fine aggregate, alkaline activator (NaOH) and water. The comparison of geopolymer mortar mixture was 1Pca: 3Ps with 0.5 water factor. The Pca is white soil and fly ash, and Ps is sand. There are 7 variations of test object with different compositions according to the percentage of white soil filler, which varies from 0% to 30%. This percentage is based on trial error methods to get the best composition. In each variation, 6 object were made. The composition of mortar mixtures as shown in the Table 1.

Table 1. Composition of mortar geopolymer mixtures

Test Object	White soil filler (kg)	Fly ash (kg)	Sand (kg)	Water (kg)	(% White soil to binder)
1.	0	3	9	1.5	0% white soil filler
2.	0.150	2.850	9	1.5	5% white soil filler
3	0.300	2.700	9	1.5	10% white soil filler
4.	0.450	2.550	9	1.5	15% white soil filler
5.	0.600	2.400	9	1.5	20% white soil filler
6.	0.750	2.250	9	1.5	25% white soil filler
7.	0.300	2.100	9	1.5	30% white soil filler

Usage of 8 M NaOH

Calculation of NaOH molarity with 8 M NaOH

M = 8 M

Water = 1.5 kg = 1.5 liters = 1500 ml

Mr NaOH = 40

$$M = \frac{\text{NaOH weight}}{\text{Mr}} \times \frac{1000}{\text{Water Volume}}$$

$$8 = \frac{\text{NaOH Weight}}{40} \times \frac{1000}{1500} \quad \text{NaOH Weight} = 480 \text{ gram}$$

2.2.3. Method for Making Test Objects

- White soil and fly ash used were particle that pass sieve no. 200. The white soil had water content of 0%, as shown in Figure 2(a), Figure 2(b), Figure 3(a) and Figure 3(b).

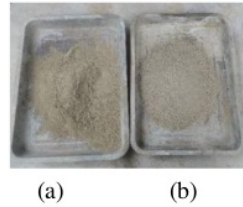


Figure 2. (a) Fine fly ash and (b) Original fly ash

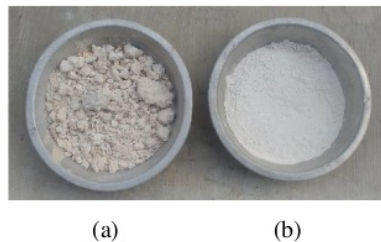


Figure 3. (a) Original condition and (b) fine condition of white soil

- The white soil, fly ash, sand, water, and NaOH were weighed as planned.
- The water and NaOH were mixed. Because of the heat produced during the mixing process, some waiting time was needed for the sample to be cold.
- The white soil, fly ash and sand were taken into the mixer.
- The engine was turned on, so that all the previous ingredients were evenly mixed for 2 minutes, then the mixer was turned off.

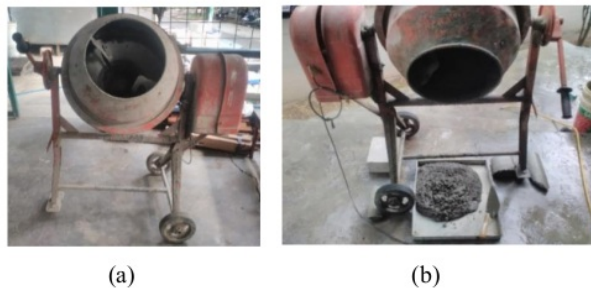


Figure 4. (a) Mini mixer for stirring mortar and (b) dough pouring process into baking pan

- The water and NaOH were taken into the mixer.
- The mixer was turned on, so that all ingredients were mixed evenly for 5 minutes.
- The mixture was poured into a baking pan.
- The mortar mixture was added into the oil-coated mould. The mixture was put into 2 layers of mould, each layer was crushed evenly 32 times, and the top surface of the mortar was flattened (Figure 5)

- The test items were stored for 24 hours.



Figure 5. Mortar mould

2.2.4. Porosity Test on Mortar

The porosity is the ratio of pore volume (volume occupied by fluid) to the total volume of mortar (volume of the test object). The purpose of this test is to determine the percentage of the mortar pores to the volume of geopolymer mortar. The porosity affects the durability and compressive strength of the mortar. Reduced porosity leads to higher durability and compressive strength of the mortar. The porosity test stages are as follows:

- The mortar was removed from the mould after it is 1 days old.
- The mortar specimens were put into an oven with a temperature of 60 °C, as per the research in another study [11]. The test material in the oven was tested until the weight of the mortar became unchanged. The temperature of 60 °C was considered so that the mortar does not experience a shaking, resulting in increased mortar porosity.



Figure 6. Mortar covenant

- The test object was removed from the oven and waited until it is cold
- The weight of dry mortar (A) was weighed.
- The mortar was soaked until no bubbles were coming out of the mortar.
- The weight of mortar in water was considered as C.
- The mortar was lifted, and the surface of the mortar was wiped with a cloth to get the saturated surface dry (SSD) condition.
- The weight of the mortar in SSD condition was considered as B.

The mortar conditions are shown in Figure 7 to Figure 9.

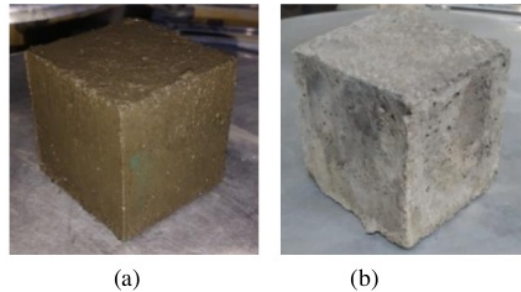


Figure 7. The condition of mortar (a) after unloading and (b) after the oven



Figure 8. Soaking the mortar

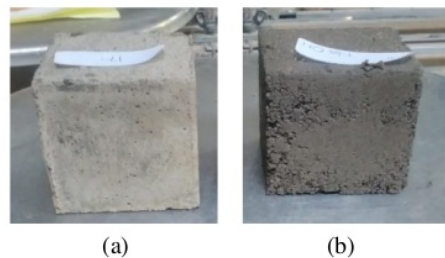


Figure 9. (a) Mortar in dry conditions and (b) mortar in SSD condition

Porosity of mortar can be calculated using the formula (1):

$$Porosity = \frac{B-A}{B-C} \times 100\% \quad (1)$$

with:

A = the weight of dry mortar (kg)

B = the weight of mortar in SSD condition (kg)

C = the weight of mortar in water (kg)

3. Result and analysis

The results of porosity testing on the 7 variations, according to percentage of white soil in the mortar, are shown in Table 2.

Table 2. Mortar geopolymer porosity

Test object	Weight (kg)			B-A	B-C	Porosity (%)
	Dry Oven (A)	SSD (B)	In Water (C)			
1	0.25403	0.27327	0.12438	0.01923	0.14888	12.9
2	0.26500	0.28393	0.12697	0.01893	0.15696	12.1
3	0.27284	0.28947	0.12675	0.01662	0.16272	10.2
4	0.29838	0.31668	0.14053	0.01829	0.17614	10.4
5	0.28904	0.30617	0.13504	0.01712	0.17113	10.0
6	0.26350	0.28903	0.13504	0.02552	0.15398	16.6
7	0.26599	0.29222	0.13572	0.02623	0.15650	16.8

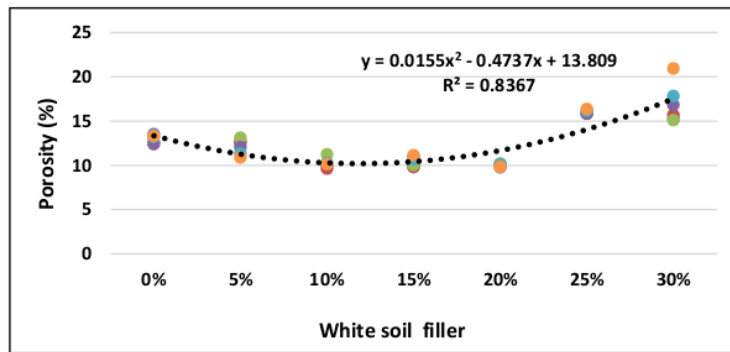


Figure 10. Regression of porosity value with white soil filler variations

Figure 10 shows the value of $R^2 = 0.8367$, which means that the white soil filler affects geopolymer porosity. The porosity of 83.67% is influenced by the white soil and the rest ($100\% - 83.67\% = 16.33\%$) is influenced by other variables.

The equation to calculate optimum percentage of white soil to produce a minimum porosity value is as follows formula (2):

$$P = 0.0155x^2 - 0.4737x + 13.809 \tag{2}$$

with:

P = Mortar porosity (%)

x = White soil filler in mortar geopolymer (%)

P minimum occurs on $dP/d(x) = 0$

Then, $dP/d(x) = 0.031x - 0.4737$

From the above equation, the x and P values are obtained as follows:

$$x = \frac{0.4737}{0.031} = 15.28$$

By entering the value of x into the initial equation, it is obtained:

$$P = 0.0155x(15.28)^2 - 0.4737x(15.28) + 13.809$$

$$P = 10.19$$

From the result of the equation above, the value of $x = 15.28$. It means that the optimum value of white soil filler in geopolimer mortar is 15.28%, which will result in a minimum mortar porosity value of 10.19%.

4. Conclusion

Based on the results of the analysis, the following conclusions can be made in this study:

1. There is a reduction of porosity with the increment of white soil percentage of 5, 10, 15 and 20. The reduction are 0.9, 2.7, 2.5 and 2.9%, respectively. However, 25 and 30% of white soil have increased porosity by 3.7 and 3.8%. From the results of the analysis, it was concluded that the white soil is suitable to be used as a filler, with the percentage of filler being 5 to 20 of the binder. The white soil filler of 20% produced the smallest porosity.
2. The increase in white soil easily hardens the dough, making the compaction difficult. This is considered as the cause of higher porosity in the type of mortar with 25% filler and 30% white soil.

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