White soil in mortar geopolymer with potassium hydroxide as the activator

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Abstract. Reducing CO$_2$ in nature is the reason for the development of alternative technologies such as mortar geopolymers. This will have an impact on reducing the use of Portland cement. Moreover, the potential of local materials is also feasible to be developed especially contains an ingredient that can support environmentally friendly alternative materials. This study aims to determine the mechanical behavior of geopolymer mortars that consist of sand, fly ash type F from Tanjungjati Jepara, white soil from Kupang NTT (as substitution of fly ash), and Potassium Hydroxide (KOH) 8M as an activator. The specimens were cube 5x5x5 cm$^3$ and molds similar to number eight. The mix proportion was 1 binder : 3 sand. Binder is a mixture of fly ash, white soil, and KOH 8M solution with w/b of 0.5. Mortar dried in the oven until 24 hours at 60 $^\circ$C. Specimens were tested for compressive and tensile strength, density, and porosity within a specified time. The results show that the substitution of white soil in geopolymer mortar can increase of the compressive and tensile strength, increase porosity, and make the weight of volume the mortar become lighter. The substitution of white soil at 10, 20, and 25% shows a trend that has a better result than the others, while the substitution of 5% has not been effected yet.

1. Introduction
Efforts to reduce CO$_2$ gas in nature are the reason for the development of alternative technologies such as mortar and geopolymer concrete. This mortar and geopolymer concrete are forms of waste utilization using fly ash, as a displace of Portland cement. Research [1] stated that portland cement has an unfavorable influence on the environment because it produces CO$_2$ emissions that affect climate change and can cause a greenhouse effect. The cement industry is estimated to contribute 5-7% of CO$_2$ emissions in the world [2].

Fly ash is a fine grain from coal combustion which contains quite high SiO$_2$, Al$_2$O$_3$, P$_2$O$_5$, and Fe$_2$O$_3$ [3]. They contain fly ash is what makes fly ash considered capable of replacing the role of cement. Utilization of local materials that have not been used optimally, such as white soil from Kupang Nusa Tenggara Timur, is also being intensified so that new alternative materials with properties that are more profitable and environmentally friendly can be obtained.

Previous research on geopolymer mortar using fly ash with a mixture of other materials was Palm Oil Fuel Ash which was activated with NaOH 14 M and Na$_2$SiO$_3$ alkaline and chemical additives superplasticizer [4]. The test results showed that the mixture of fly ash and palm ash produces compressive strength above 20 MPa. Increasing the amount of activator and treatment temperature on the test specimen can increase the compressive strength. The percentage of NaOH above 22.5% decreases the compressive strength of the mortar. Geopolymer material research with fly ash was also
investigated [5] by adding Sidoarjo Mud and trass which was activated with NaOH and Na$_2$SiO$_3$ with the addition of superplasticizer. The results showed that the maximum compressive strength was 55.6 MPa which had the composition of the combustible mud paste: fly ash: NaOH: Na$_2$SiO$_3$: superplasticizer of 33.3%: 9.52%: 23.81%: 2.5%.

A geopolymer mortar study using fly ash were also conducted [6][7] using white soil from Kupang activated with NaOH 8M, by reviewing the setting time and porosity of geopolymer mortars. The results showed that setting time for mortar with white soil substitution was not much different than a mortar with Portland cement, whereas for porosity from geopolymer mortar was lower when adding white soil by up to 20%. [8] compared mechanical properties between the use of NaOH and KOH as activators in fly ash in geopolymer mortars. The results of the study stated that NaOH has better compressive strength than KOH. The highest compressive strength for NaOH was 65.28 MPa while KOH was 28.73 MPa. Moreover, the curing process at 60°C was better than the curing process at room temperature (25°C). [9] compared the compressive strength of non-cement mortars with fly ash type C and type F with the temperature treatment parameters which were in room temperature and heating 60 °C. The test results showed that at room temperature, non-cement mortar with fly ash type C showed higher strength compared to type F non-mortar, whereas when non-cement mortar with fly ash type F was cured with a higher temperature (60 °C ), it was indicating performance higher than non-cement mortar with fly ash type C.

From some of the studies described above, it can be said that it is possible to add or substitute other materials in non-cement mortars or geopolymer mortars using fly ash as the base material. Fly ash can be activated by using alkaline activators such as NaOH, Na$_2$SiO$_3$, or by using KOH. The use of fly ash type F is better able to provide good performance in compressive strength, and the change in temperature in the treatment conditions also affect the strength of the geopolymer mortar. The gap from previous studies can be developed to become new research. The purpose of this study is to determine the mechanical behavior of geopolymer mortar with fly ash mixed with white soil and activated with potassium hydroxide (KOH) in compressive strength, tensile strength, porosity, and density with a treatment temperature of 60 °C.

2. Research method
This study used experimental methods on a laboratory scale. The specimens used were cubes measuring 50 x 50 x 50 mm and specimens in the form of numbers eight as shown in Figure 1.

![Figure 1. Specimen mortars](image)

2.1. Materials
The material used to make geopolymer mortar was a local material consisting of sand from Muntilan, fly ash type F from Tanjung Jati power plant Jepara, white soil from Kupang East Nusa Tenggara, and potassium hydroxide (KOH) with molarity 8 solution used as an activator.

The sand had been tested and satisfied the requirements as a fine aggregate for concrete [10] with the results in Table 1, while for fly ash and white soil were conditioned to passed the sieve of 0.074 mm (sieve number 200) under dry conditions and the water content was close to zero percent. The refining and drying process was carried out on fly ash and white soil because in the original condition
the two materials were not the same size as expected. The geopolymer mortar materials are shown in Figure 2.

![Figure 2](image)

*Figure 2.* (a) Sand (b) Original Fly ash (c) Fly ash passed sieve of 0.074 mm (d) Original white soil (e) White soil passed sieve of 0.074 mm

| No | Material test                     | Result  |
|----|-----------------------------------|---------|
| 1  | Fineness modulus                  | 2.42    |
| 2  | Clay Lump                         | 0.76%   |
| 3  | Specific Gravity (native)         | 2.36    |
| 4  | Specific Gravity (SSD)            | 2.56    |
| 5  | Weight content native (loose)     | 1.36 kg/dm³ |
| 6  | Weight content native (solid)     | 1.43 kg/dm³ |
| 7  | Weight content SSD (loose)        | 1.48 kg/dm³ |
| 8  | Weight content SSD (solid)        | 1.57 kg/dm³ |
| 9  | Absorption                        | 2.50%   |
| 10 | Organic impurities                | Yellow (no.8) |

Fly ash from PLTU Tanjung Jati Jepara has 46.7% of SiO₂, 25.01% of Al₂O₃, 9.43% of Fe₂O₃, and 6.26% of CaO [11]. Thus, with these chemical conditions, the fly ash used in this study was included in class F of fly ash [12]. This fly ash has a dry weight volume ratio of 1.236 gram/cm³. Meanwhile, the white soil from Kupang East Nusa Tenggara had the X-Ray Diffraction test results composed of Magnesium Calcium Carbonate (MgCaCO₃) by 52% and Magnesium Phosphate (Mg₃P₂O₇) of 48% in [13]. The white soil has a dry weight volume ratio of 0.991 gram/cm³. The existence of an alkaline activator solution in the establishment of a geopolymer mortar is needed to bind the aggregates in the mortar because neither the fly ash nor the white soil has the binding ability like cement. Potassium hydroxide (KOH) with a molarity level of 8 M was used in this study because KOH is a strong base that can function to react Al and Si elements contained in fly ash to produce the strong polymeric bonds.

2.2. Making specimen

Geopolymer mortars with white soil substitution were made with a mixture of 1 binder: 3 sand with a water factor of 0.5. Binder is a mixture of fly ash, white soil, and KOH 8M activator solution. Mortars were made in 7 (seven) variations i.e. mortar without white soil (variation 1) and mortar with white soil substitution of 5 to 30% of the weight of fly ash with a percentage interval of 5% (Variations 2 to 7). In each variation, 27 samples were made for several test parameters. For the manufactured of 27
samples in each variation, the proportion of the mixture is needed as shown in Table 2, while the amount of KOH mixed in this geopolymer mortar could be calculated as follows:

\[
M = \frac{weight \, of \, KOH}{Mr} \times \frac{1000}{V \, water}
\]

Where

\[
V = \text{Volume}
\]

\[
Mr = \text{Relative molecule \ (total mass of the atom molecular composer)}
\]

\[
8 = \frac{weight \, of \, KOH}{56} \times \frac{1000}{1500}
\]

Weight of KOH = 672 gram

Table 2. Composition of a geopolymer mortar mixture.

| No | White soil (kg) | Fly ash (kg) | Sand (kg) | KOH (kg) | Water (ml) | White soil substitution |
|----|----------------|--------------|-----------|----------|------------|------------------------|
| 1  | 0.00           | 3.00         | 9.00      | 0.67     | 1500       | 0%                     |
| 2  | 0.15           | 2.85         | 9.00      | 0.67     | 1500       | 5%                     |
| 3  | 0.30           | 2.70         | 9.00      | 0.67     | 1500       | 10%                    |
| 4  | 0.45           | 2.55         | 9.00      | 0.67     | 1500       | 15%                    |
| 5  | 0.60           | 2.40         | 9.00      | 0.67     | 1500       | 20%                    |
| 6  | 0.75           | 2.25         | 9.00      | 0.67     | 1500       | 25%                    |
| 7  | 0.90           | 2.10         | 9.00      | 0.67     | 1500       | 30%                    |

The manufacturing process began with made KOH 8M activator solution by mixed 672 grams of KOH into 1500 ml of water and stirred ± 3 minutes until it dissolved. The reaction from mixed KOH and water would produce the heat. After that, closed the container containing the solution to avoid evaporation and wait for the solution to cool. The sand, fly ash, and white soil mixed in a mixer until it was evenly mixed, then pour the alkaline activator solution and stirred again until evenly distributed. Subsequently, the samples were molded on the cube and number 8 mold. After 24 hours, the mortar was disassembled from the mold and treated with an oven at 60 °C temperature for 24 hours. After the treated process had been completed, the mortar was placed at normal temperature until the time of testing.

2.3. Specimen test
Tests conducted in this study include compressive strength with cube 50x50x50 mm³ specimens, tensile strength with number 8 mold specimens, porosity, and density with cube specimens. The whole test was carried out at the Materials and Construction Laboratory, Universitas Diponegoro.

2.3.1. Mortar compressive testing
Mortar compressive strength tested used the standard ASTM C109 [14] which was used Control Servo Hydraulic Concrete Compression Testing Machine, Hung-Ta HT-8391 PC series (Figure 3). Testing was done when the mortar was 3, 7, 14, 21, 28, and 90 days.

The calculation of mortar compressive strength obtained using Equation (1) where \( f'c \) was the compressive strength of mortar (N/mm² or MPa), \( P \) was the maximum compressive force (N), and \( A \)
was the compressive area (mm$^2$). The test results displayed at each age of the test were the average results of the specimens tested.

\[ f'c = \frac{P}{A} \]  

(1)

2.3.2. Mortar tensile testing.

Tensile strength was a measure of mortar strength caused by a force that tends to separate a portion of the mortar due to traction. Mortar tensile testing is based on [15] conducted when the mortar has 28 days old using the Tensile Strength Test of Briquette (Figure 4). Calculation of the tensile strength ($f_{ct}$ in N/mm$^2$ or MPa) mortar was calculated from the maximum tensile strength (P in N) divided by the smallest cross-sectional area (A in mm$^2$).

\[ \text{Porosity} = \frac{B-A}{B-C} \times 100\% \]  

(2)

where

- A = Dry of weight mortar (gram)
- B = SSD of weight mortar (gram)
- C = Weight of mortar in water (gram)
2.3.4. Density testing
Density is a measurement between the weight of mortar against the volume of the mortar. The existence of a good gradation will make the cavities or voids smaller and the density even higher. The mortar density formula is as follows:

\[ \gamma_m = \frac{B_m}{V} \text{ (kg/m}^3) \]  

where \( \gamma_m \) = Mortar density (kg/m\(^3\)), \( B_m \) = Weight of mortar (kg), \( V \) = The volume of mortar (m\(^3\)).

3. Result and discussion
Geopolymer mortars with white soil substitution are visually lighter in color than geopolymer mortar without white soil substitution (variation 0%). The lime (CaO) content in white soil makes the geopolymer mortar lighter in color. When removed from the mold, the whole mortar looks more fragile, but oven at 60 °C within 24 hours after it removed from the mold makes the mortar harden and become stronger. Drying enhances the geopolymeration process and develops the compressive strength of the mortar, as in the research of [9]. The result of the geopolymer mortar compressive strength tested at the age of 3, 7, 14, 21, 28, and 90 days with variations of white soil from 0; 5; 10; 15; 20; 25; and 30% are shown in Figure 5. The tensile and compressive strength of mortar at 28 days are shown in Table 3.

In Figure 5, it is shown that the compressive strength value of geopolymer mortar with white soil substitution is higher than mortar without white soil (variation 0%). In mortar with white soil substitution of 5% by weight of fly ash, there was not much effect on increasing the compressive strength of the mortar, but with the addition of the percentage of white soil, it showed an increase in the compressive strength of the mortar. Mortar stiffness appears to be higher when the percentage of white soil is 10 to 25%. For the strength of 28 days of age, the substitution of white soil by 10, 20, and 25% showed an increase in compressive strength of up to 45% compared to the strength of mortar without white soil, while in substitution of 15 and 30%, it increased by 29 and 22%, respectively. After 28 days of age, it is also shown that the compressive strength of mortar with white soil is still increasing, although less significant than that of a mortar without white soil, so it can be said that after 28 days of age, the strength of mortar with white soil is stable and does not experience a decrease in strength.
Apart from compressive strength, the substitution of white soil in the geopolymer mortar also increases its tensile strength. In Table 3, it is shown that the highest tensile strength value of mortar at the age of 28 days is obtained from 10% white soil substitution, which has an increase of 50.91% compared to mortar without white soil (variation 0%). For variations of 10, 20, and 25% white soil also has a higher tensile strength than other percentages such as compressive strength, which increases respectively 50.91; 36.73; and 20.97% compared to mortar without white soil. The bond between fly ash and white soil with KOH activator in a certain proportion increases the compressive strength and tensile strength of the geopolymer mortar.

Table 3. Comparison of tensile and compressive stress of geopolymer mortar

| Condition               | Percentages substitution of white soil |
|------------------------|----------------------------------------|
|                        | 0  | 5  | 10 | 15 | 20 | 25 | 30 |
| Tensile, fct (28days)  | MPa| 0.83| 0.91| 1.25| 0.84| 1.13| 1.00| 0.95 |
| to 28 days ↑%          |    | 1.00| 10.55| 50.91| 1.45| 36.73| 20.97| 15.15 |
| Compressive, f'c (28 days) | MPa| 7.41| 7.50| 10.80| 9.59| 10.76| 10.76| 9.04 |
| to 28 days ↑%          |    | 1.00| 1.17| 45.79| 29.37| 45.18| 45.18| 22.01 |
| fct/f'c                | %  | 11.13| 12.17| 11.52| 8.73| 10.49| 9.28| 10.51 |

The results of porosity and density testing of geopolymer mortar with and without white soil substitution are shown in Figure 6. It can be seen that the density graph has decreased with the substitution of white soil in the mortar, with a density value between 2143-2170 kg / m3 while mortar without white soil (variation 0 %) has a higher average density value at 2198 kg / m3. The dry of weight volume of white soil which is smaller than fly ash makes the density of mortar with the substitution of white soil lower even though the maximum grain size of fly ash and white soil is made the same. The decreasing density of the white soil substitution is inversely proportional to the increase in the porosity of the geopolymer mortar. Mortar without white soil has a porosity value of 7.93% and the porosity increases with the substitution of white soil with values ranging from 9.71 to 12.42%. The increase in porosity value is related to the number of pores or spaces in the mortar which are partially filled with white soil, however, the unevenly distributed pore structure makes the strength of the mortar unequal.

4. Conclusion
The substitution of white soil in the geopolymer mortar increases the compressive strength and tensile strength of the geopolymer mortar. Significant increases in the compressive strength and tensile strength of geopolymer mortar occurred in mortars with white soil substitution of 10, 20, and 25% of
the weight of the fly ash. The compressive strength of mortar with white soil substitution remains at
the age of more than 28 days and still increases, although it is not significant. The presence of white
soil also affects the porosity of the mortar, which tends to increase with the addition of the percentage
of white soil and vice versa, its density tends to decrease compared to mortar without white soil.

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