CHARACTERISTICS OF GEOPOLYMER USING RICE STRAW ASH, FLY ASH AND LATERITE SOIL AS ECO-FRIENDLY MATERIALS

by Parea Rusan 1
CHARACTERISTICS OF GEOPOLYMER USING RICE STRAW ASH, FLY ASH AND LATERITE SOIL AS ECO-FRIENDLY MATERIALS

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ABSTRACT: This study discusses the utilization of Rice Straw Ash (RSA), Fly Ash (FA) and alkali activator (NaOH) to bind laterite soil (LS). RSA and FA are geopolymer activated with 12M NaOH. Geopolymer mortar strength was tested, where the percentage ratio of RSA/FA/LS was 16.67/41.67/41.67. Flow testing on fresh geopolymer shows that all materials are well bound and segregation does not occur. Specimen were cured with three variations, namely immersed in water, immersed in Na₂SO₄ and immersed in H₂SO₄ solution until 28 days to evaluate its durability. The compressive strength and stress-strain relationships are analyzed to study the behaviour of hardened mortar geopolymer. Method of treatment and age of mortar can be effective for compressive strength. The geopomerization show increased strength in the immersion of sulphate solution. The XRF test results confirm that the pozzolanic from RSA can be bound by geopolymers. The results of this reactivity are very promising in terms of the potential use of ash in the cementing systems.

Keywords: Geopolymer, Rice straw ash, Fly ash, Laterite soil, Compressive strength

1. INTRODUCTION

In Indonesia, almost all of the coal used in this country was burned to produce electricity in coal-fired power plants. Fly ash is the main residue from coal combustion. The majority of fly ash is still disposed of in landfills, which creates environmental problems, where the additional cost of landfills is an urgent need in some areas. Therefore, a new recycling approach is needed to produce value-added products from fly ash instead of considering it as waste material to be disposed of. Thus, to create a more friendly environment, by conserving non-renewable materials, waste materials such as fly ash can be used. According to ASTM C 618-19 fly ash is divided into three categories namely class N, class F and class C [1]. The minimum content of SiO₂, Al₂O₃ and Fe₂O₃ compounds is 70% for class N and class F, while class C is between 50% - 70%. The CaO content in fly ash class N and F is relatively small compared to class C, where the content of CaO class C is more than 20% [2].

About 75% of organic volatile and the remaining 25% by weight of the husk are converted to ash during the burning process known as rice straw ash. RSA has a very high amount of silica and was found to be amorphous. The amorphous silica contained in RSA can react with cement binding to carry out pozzolanic activity [3]. Rice straw is an agricultural waste which causes several management problems such as field burning causing severe air pollution and natural organic decomposition supporting methane emission [4]. This last process has a strong environmental effect in terms of greenhouse gas emission, because the global warming potential of methane is much higher than CO₂ which is 25-times more for a 100-year horizon and 72-times more for 20-year horizon [5]. Therefore, it is important to treat this waste because rice production accounts for 5-10% of methane emissions worldwide. In addition, a large quantity of rice straw is produced throughout the world, where 1-1.5 kg of straw is produced for every 1 kg of paddy rice [6].

Cement production, which results in higher CO₂ levels, has a negative impact on environment [7-9]. Some recent research and developments of geopolymer has expanded the area of soil improvement. A study conducted related to technology to improve L.A soil using high calcium fly ash-based geopolymer. It was found that fly ash combining curing time could provide the compressive strength [10]. A study conducted focused on technology associated with improving silty clay using FA and high calcium alkali activator activated by NaOH dan Na₂SiO₃ [11].

The colour of laterite soil 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. Granular 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 with water and not too sandy [12]. In this case, efforts to reduce the use of cement
have been carried out intensively, such as the development of geopolymer that can be produced from various kinds of industrial by-products. Materials that are rich in alumina (Al₂O₃) and silica (SiO₂) can be activated with an alkaline solution to produce geopolymer without the addition of Portland cement [13]. Fly ash geopolymer as a binding material in the field of construction and building materials have been studied and developed intensively.

Glikhovskiy classified the alkaline activators in six groups based on their chemical composition: Caustic alkalies (MOH), Non-silicate weak acid salts: (M₂CO₃, M₂SO₄, M₂PO₄, MF etc), Silicates: M₂O₃Si₂O₆, Aluminates: M₂O₃Al₂O₃, Aluminosilicates: M₂O₃Al₂O₃·(2·6)SiO₂, Non-silicate strong acid salts: (M₂SO₄) [14].

Often water from swamps or estuaries that contain sulfates flows during high-intensity rain. Water containing sulfate compounds such as Na₂SO₄, H₂SO₄ is inundated in a region containing laterite soils. Sulfate compounds have the potential to affect laterite soil resistance.

This research uses rice straw ash and fly ash geopolymer-based to bind laterite soil. The composition of geopolymer from rice straw ash, fly ash and laterite soil was made, then was conducted slump flow test and resistance to immersion, both freshwater and sulfate solution (Na₂SO₄ and H₂SO₄) at 28 days. Also, compressive strength and stress-strain relationship will be discussed.

2. EXPERIMENTAL PROGRAM

Laboratory studies were carried out to analyze the oxide content of fly ash, rice straw ash and laterite soil by using XRF. Also, compressive strength test was conducted.

2.1 Materials

Rice straw is collected from open fields in locally small heaps, in Tonja, South Sulawesi, Indonesia. Then the rice straw is burned in a tin box furnace under controlled conditions (temperature 800 - 900 °C). After that, the fine ash is crushed in the ball mill until the average particle size passes in sieve No. 50 (0.3 mm) (100%) and 10% passing sieve No. 100 (0.15 mm).

Fly ash used in this research was collected from Jeneponto coal-burning power plant in South Sulawesi, Indonesia. All fly ash particles pass the sieve No. 200. Table 1 present physical properties of rice straw ash and fly ash.

Table 1. Physical characteristic of RSA and FA

| No. | Characteristics | RSA     | Fly Ash |
|-----|----------------|---------|---------|
| 1   | Specific gravity | 2.36    | 2.65    |

Laterite soil was obtained from the field in Gowa, South Sulawesi, Indonesia. Laterite soil is processed until it passes the sieve No. 8 (2.36 mm). Engineering properties of laterite soil is shown in Table 2. This soil is classified as heavy clay (CH) according to the Unified Soil Classification System (USCS) (ASTM D2487-17) and A-7-5 according to the AASHTO (ASTM 2009).

Geopolymer mortar mixture is activated with an alkaline solution, namely sodium hydroxide (NaOH) solution with a concentration of 12 Molar. Fig. 1 show the geopolymer materials.

Table 2. Engineering properties of laterite soil

| No. | Characteristics | Laterite Soil |
|-----|----------------|--------------|
| 1   | Specific gravity | 2.65         |
| 2   | Plastic limit (PL) | 33.90%     |
| 3   | Liquid limit (LL) | 65.46%     |
| 4   | Plastic index   | 31.57       |

Fig 1. Geopolymer mortar materials

2.2 Specimens

Geopolymer mortar is formed from a mixture of Soil Laterite - RSA - FA with sodium hydroxide as an activator. The ratio between RSA: FA: LS is 16.67: 41.67: 41.67. From preliminary research, the composition of mortar geopolymers was obtained, as presented in Table 3. NaOH solution was used as an alkaline binder. The amount of water used is carefully calculated to get optimum compaction of laterite soil.

Table 3. Geopolymer mortar mix (1 m³)

| Water (kg) | NaOH (kg) | Rice straw ash (kg) | Fly Ash (kg) | Laterite Soil (kg) |
|------------|-----------|---------------------|--------------|---------------------|
| 125.690    | 60.392    | 60.392              | 150.979      | 150.979             |

The specimen is cylindrical in diameter 50 mm and height 100 mm. There are 3 variations of curing namely immersed in water, immersed in 2% Na₂SO₄ solution and immersed in 2% H₂SO₄ solution until the age of the testing.

Flow or consistency tests indicate the ease of fresh geopolymer mortar mixtures to be formed,
with reference to SNI 03-6825-2002. The ratio of water to solids is 0.2 with a flow target of 110 ± 5%. The flow value is then maintained for each mixed design.

3. RESULTS AND DISCUSSION

3.1 Oxide Content of Rice Straw Ash, Fly Ash and Laterite Soil

From the XRF analysis results was obtained oxide content of rice straw ash, fly ash and laterite soils as presented in Table 4. Rice straw ash contain SiO₂, P₂O₅, CaCO₃ and K₂O. Fly ash used in this study is categorized as class F because it has a total content of Fe₂O₃, Al₂O₃, and SiO₂ greater than 70%. The density of fly ash is 2.65 g/cm³ and the weight of the laterite soil type is 2.65 g/cm³.

Table 4. Oxide content of fly ash, rice straw ash and laterite soil

| Oxide Content | Fly ash | Rice straw ash | Laterite soil |
|---------------|---------|----------------|--------------|
| Fe₂O₃         | 19.96   | 2.31           | 12.49        |
| Al₂O₃         | 19.16   | -              | 49.38        |
| SiO₂          | 34.63   | 70.80          | 34.81        |
| MnO           | 0.25    | -              | 0.10         |
| TiO₂          | 1.26    | -              | 1.39         |
| K₂O           | 1.33    | 15.89          | 0.35         |
| CaO           | 12.74   | 53.4           | 0.85         |
| P₂O₅          | -       | 3.61           | 0.44         |
| V₂O₅          | -       | -              | 0.06         |
| ZrO₂          | -       | -              | 0.05         |
| SrO           | 0.13    | -              | 0.03         |
| Cr₂O₃         | 0.07    | -              | 0.02         |
| CuO           | -       | -              | 0.02         |
| ZnO           | -       | -              | 0.011        |
| MgO           | 8.1     | -              | -            |
| SO₃           | 1.80    | -              | -            |
| CO₂O₂         | 0.05    | -              | -            |
| BaO           | 0.21    | -              | -            |
| Pr₆O₁₇        | 0.05    | -              | -            |
| Nd₂O₃         | 0.07    | -              | -            |

3.2 Flow Testing

The flow of fresh mortar geopolymer is 112.61 mm with specific gravity in fresh conditions is 1901.3 kg/m³. Geopolymer mortar mixes can bind laterite soil well, therefore fresh mortar geopolymers can flow and spread evenly without segregation and bleeding in the center of the circle. Fig 2 shows the flow of fresh mortar geopolymers.

3.3 Stress-Strain Behavior

The relationship of stress-strain geopolymer mortar with curing variation is shown in Fig 3-5. As shown in the figure, the linear stress-strain relationship is 78%, 80% and 82% of the peak stress in each specimen which is cured by immersion in water, Na₂SO₄ solution and H₂SO₄ solution, respectively. Also, it appears that all specimens have elasticity, this indicates that shrinkage that occurs after being immersed in water keeps the specimen elastic. After reaching the peak stress, the stress decreases but the strain continues to increase. This shows that the geopolymer mortar, although fragile, is not destroyed suddenly.

Fig 2. The flow of fresh mortar geopolymer

Fig 3. Stress-strain relationship of specimens immersed in the water

Fig 4. Stress-strain relationship of specimens immersed in Na₂SO₄ solution
The compressive strength values for various curing variations are presented in Figure 6. There is a decrease in the strength of 31% and 44%, if the geopolymer mortar is immersed in the solution of Na$_2$SO$_4$ and H$_2$SO$_4$. This shows that the binding process between materials is disturbed by the sulfate environment, resulting in a significant decrease in strength. Although visually, it does not appear to be defective in the test specimen.

4. CONCLUSION

From the results and discussion, it can be concluded as follow:
1. In fresh condition, the mortar geopolymer can bond well without segregation and bleeding.
2. The sodium hydroxide (NaOH) releases the silica and alumina in the amorphous phase and act as a binder.
3. Compressive strength development of geopolymer mortar using RSA, FA and LS remain steady at 2% Na$_2$SO$_4$ and H$_2$SO$_4$ immersion.

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