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STUDY OF THE EFFECT OF ADDING RICE HUSK ASH, SUPERPLASTICIZER, AND HDPE PLASTIC WASTE ON THE CHARACTERISTICS OF FLY ASH-BASED GEOPOLYMER MORTAR

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ABSTRACT

Increasing infrastructure development has led to the massive use of commercial Portland cement and natural aggregates, which can threaten environmental sustainability. Commercial Portland cement production produces quite high CO₂ emissions, which can exacerbate global warming. As a solution, fly ash waste from coal combustion in steam power plants containing aluminosilicate materials can be used as raw material for geopolymer mortar, which functions as an alternative to commercial Portland cement mortar. Fly ash-based geopolymers can be modified with rice husk ash, a waste product from rice husk combustion because it contains silica, and can also be modified with High-Density Poly Ethylene (HDPE) plastic waste to reduce the use of natural aggregates. Superplasticizers can be added to geopolymers to increase their mechanical strength. This study aims to examine the effect of variations in the addition of rice husk ash, the addition of superplasticizer, and the addition of HDPE plastic waste on the compressive strength and microstructure of the resulting geopolymer mortar. The results showed that the addition of rice husk ash as a substitute for fly ash reduced the compressive strength of geopolymer mortar, where geopolymer mortar with 100% fly ash content had the highest compressive strength at 28 days of 50 MPa. The addition of 1.5% superplasticizer did not relatively affect the compressive strength of geopolymer mortar. The addition of 3% HDPE as a substitute for natural aggregates increased the compressive strength of geopolymer mortar at 28 days by 54.01 MPa. The results of SEM tests on both geopolymer mortar with 100% fly ash content, geopolymer mortar with the addition of rice husk ash, and geopolymer mortar with the addition of HDPE plastic waste showed the formation of a continuous phase of aluminosilicate gel. Meanwhile, the FTIR test on geopolymer mortar with 100% fly ash content, geopolymer mortar with the

addition of rice husk ash, and geopolymer mortar with the addition of HDPE showed the presence of dominant Si-O-Si and Si-O-Al functional groups.

KEYWORDS: fly ash-based mortar geopolymer, HDPE plastic waste, rice husk ash, superplasticizer.

1. INTRODUCTION

Economic and population growth in recent years has fueled the development of the construction industry and increased demand for building materials. The global construction industry consumes approximately 2.6 billion tons of cement annually, and with demand projected to increase by 25% over the next 10 years, there are growing concerns about a potential shortage of natural limestone reserves within the next 25 years. At the same time, other environmental impacts arising from the main building construction material, namely cement, have the potential to pollute the environment through the calcination process during its manufacturing process which releases gases such as carbon dioxide, nitrogen oxides, and sulfur dioxide as byproducts. Several studies have revealed that approximately 1 ton of carbon dioxide is emitted for every ton of cement produced, this has the potential to cause ozone depletion, global warming, and greenhouse gas emissions [1]. Meanwhile, consumption of natural aggregates reached 50 billion tons per year in 2020, and is projected to increase to 60 billion tons between 2030 and 2050. The high demand for these natural aggregates puts a lot of pressure on the surrounding ecosystem [2]. Strategies that can be used by the construction industry to increase sustainability include using recycled materials, waste, and secondary materials to replace cement, such as geopolymers [3].

Geopolymers, which are included in the category of inorganic polymers composed of Si-O-Al bonds, offer a potential cement substitute with special characteristics and an environmentally friendly manufacturing process, requiring less energy and lower emissions. Geopolymers utilize raw materials derived from industrial byproducts, such as fly ash [4]. Fly ash is a dominant byproduct of coal combustion, producing 80% of the world's fly ash production, accounting for 750 million tons annually [5]. The main components of fly ash are oxides of Si, Al, Ca, and Fe [6], [7]. However, the increasing use of coal is accompanied by an increase in fly ash production, which has negative impacts on human health and the environment in the form of dangerous air pollution when accumulated [8]. Therefore, economical and environmentally friendly fly ash processing is urgently needed. Fly ash can be processed and utilized as an adsorbent, zeolite, soil nutrient, and as a geopolymer [7], [9]. In the manufacture of geopolymers, which takes place at temperatures below 100°C, in addition to aluminosilicate material (fly ash), a chemical solution is also used in the form of an alkali activator, which is generally a mixture of Sodium Hydroxide (NaOH) and Sodium Silicate (Na₂SiO₃) solutions [10].

Rice husk ash, with its high silica content, can also be used as a geopolymer material along with fly ash. Rice husk is a byproduct of rice milling, abundantly available worldwide, at around 70 million tons per year. Burning rice husk as an energy source produces rice husk ash, which has high porosity, is lightweight, and has a large external surface area. The addition of rice husk ash as an additive can increase the compressive strength of fly ash-based geopolymer mortar [11], [12].

Meanwhile, population growth has led to increased consumption of various resources, including plastic. Over the past five decades, global plastic production has grown exponentially from 15 to 322 metric tons, a more than 200-fold increase. The extensive manufacturing and consumption of plastic products inevitably generates large amounts of plastic waste that is difficult to decompose naturally [13]. To mitigate these negative impacts, incorporating plastic waste into engineered materials is a promising way to reuse it. High-Density Polyethylene (HDPE) plastic is commonly used as filler or aggregate in geopolymer mixtures. By adding plastic to geopolymers, their properties are improved compared to conventional geopolymers, such as fire resistance, shorter curing times, and improved workability [14]. Superplasticizers are additives commonly added to concrete made from commercial cement. Superplasticizers can be derived from lignosulfonates, melamine, naphthalene, and polycarboxylates. The use of superplasticizers in concrete can reduce water content while improving workability without modifying the mix design. Superplasticizers in the cement matrix improve the mechanical and microstructural properties, as well as the durability of the concrete. Superplasticizers have also been reported to increase the compressive strength of geopolymer mortar [15], [16].

This study aims to examine the effect of variations in the addition of rice husk ash, superplasticizer, and HDPE plastic waste on the compressive strength and microstructure of the resulting geopolymer mortar. The benefit of this research is that it can contribute to the utilization of waste into useful products and have a positive impact on the environment. This research is expected to provide alternative materials to replace cement and maximize the use of fly ash and plastic waste in geopolymer production.

2. METHODS

2.1 Materials

The materials used in this study were fly ash, sand, NaOH pellets (98%), Na₂SiO₃ solution (35%), rice husk ash, Sikacim Concrete Additive superplasticizer, HDPE plastic waste. Fly ash obtained from a steam power plant in East Java was first sieved with a standard 100 mesh sieve, as were sand and rice husk ash. HDPE plastic waste in the form of bottles was chopped to a size of +5 mm. Alkali activator solution was made by mixing 10 N NaOH solution with Na₂SiO₃ solution with a mass ratio of 1:2.5.

2.2 Preparation of Geopolymer Mortar

In the preparation of geopolymer mortar, fly ash, sand, and alkali activator solution are mixed by stirring using a planetary mixer for 10 minutes. The mass ratio of fly ash to alkali activator solution is 2:1 and the mass ratio of sand to fly ash is 2.75:1. The addition of rice husk ash is varied at 5% and 10% replacing fly ash, while the addition of superplasticizer is varied at 0.5%, 1%, 1.5% of the alkali activator solution. Meanwhile, the addition of HDPE plastic waste is varied at 3%, 5%, 8% replacing sand.

After mixing, the mixture was poured into a 5x5x5 cm mold and allowed to harden for 24 hours. The geopolymer mortar was then removed from the mold and heated in an oven at 60°C for 8 hours. The geopolymer mortar was then left at room temperature until compressive strength and microstructure testing were performed.

2.3 Testing of Geopolymer Mortar

Testing of the resulting geopolymer mortar includes compressive strength and microstructure. The compressive strength test of the geopolymer mortar used a compression testing machine on samples aged 7, 14, and 28 days. The microstructure test of the geopolymer mortar was carried out using a Scanning Electron Microscope (SEM) type JEOL JSM-6510A to determine its morphology and with Fourier Transform Infrared Spectroscopy (FTIR) type Perkin-Elmer UATR Spectrum Two to determine its functional group content.

3. RESULTS AND DISCUSSION

3.1 Effect of Adding Rice Husk Ash on the Compressive Strength of Fly Ash-Based Geopolymer Mortar

The compressive strength test results of fly ash-based geopolymer mortar with various variations of rice husk ash addition at sample ages of 7, 14, and 28 days can be seen in Figure 1. The compressive strength results of geopolymer mortar with various variations of rice husk ash addition show a trend of increasing compressive strength with increasing test time with the highest compressive strength in geopolymer mortar without the addition of rice husk ash at 50 MPa. This is caused by the geopolymerization process that continues over time. Fly ash and rice husk ash are rich in silica and alumina which react with the alkali activator solution, forming an increasingly strong polymer structure. Initially, this reaction produces a product that is still in the hardening stage, but over time the chemical bonds in the geopolymer structure become stronger and tighter, thereby increasing the compressive strength value. The proper curing process also accelerates this reaction and increases the final strength of the geopolymer [10].

The addition of rice husk ash to geopolymer mortar results in a decrease in compressive strength. Rice husk ash contains silica, which can be used as a substitute for fly ash in geopolymer mortar. However, adding a certain amount can increase porosity and disrupt the bond between particles, thereby reducing the strength of the geopolymer mortar. In addition, fly ash generally has a higher reactivity than rice husk ash because the silica and alumina content are more soluble and react with alkali activators. Fly ash contains approximately 50-60% silica and 20-30% alumina, which makes it highly reactive in the geopolymerization process. In contrast, rice husk ash contains approximately 87-97% silica, but in a more crystalline and less reactive form than fly ash. This crystalline structure makes it more difficult for the silica in rice husk ash to react with alkali activator solutions. However, rice husk ash can still function as a good pozzolanic material when used in the right proportions [17].

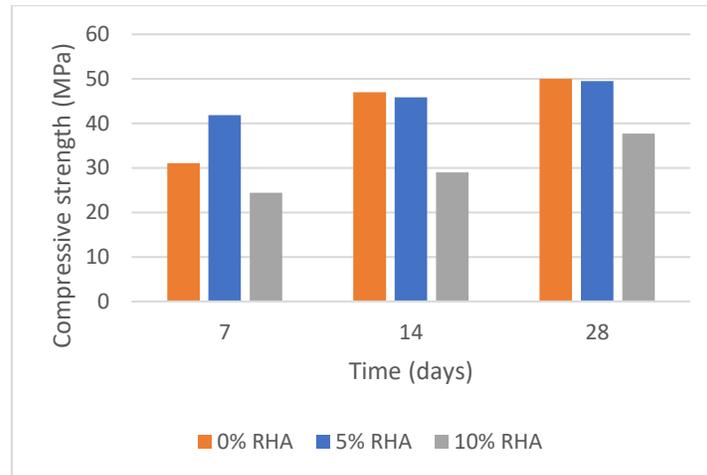


Figure 1: Results of compressive strength test of geopolymer mortar with the addition of rice husk ash

3.2 The Effect of Superplasticizer Addition on the Compressive Strength of Fly Ash-Based Geopolymer Mortar

The results of the compressive strength test of fly ash-based geopolymer mortar with various superplasticizer additions at sample ages of 7, 14, and 28 days can be seen in Figure 2. The addition of superplasticizer to geopolymer mortar resulted in fluctuations in compressive strength at each test time. This fluctuation occurs due to several factors related to the chemical reaction and distribution of materials in the geopolymer mixture. In the initial phase (day 7), the chemical reaction between the geopolymer material and the alkali activator has not reached complete stability, so the formation of a strong bond structure is not optimal. During this process, the hydration phase continues and causes variations in compressive strength. In addition, the uneven distribution of superplasticizer in the mixture also

contributes to these fluctuations. Superplasticizer acts as a water-reducing agent and improves the workability of the mixture, but if it is not mixed homogeneously, some areas in the mortar may lack superplasticizer, resulting in inconsistent quality and strength of the interparticle bond. This can result in differences in compressive strength at each test period. On the 28th day, the chemical reaction is generally more stable, but uneven distribution can still cause variations in strength [18]. The highest compressive strength of geopolymer mortar was obtained in geopolymer mortar with the addition of 1.5% SP plasticizer at 28 days at 49.05 MPa which was not much different from the compressive strength of geopolymer mortar without the addition of superplasticizer, which was 50 MPa.

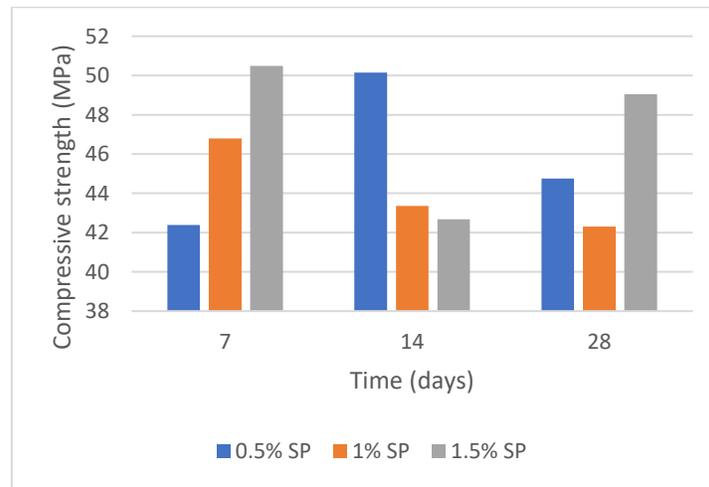


Figure 2: Results of compressive strength test of geopolymer mortar with the addition of superplasticizer

3.3 The Effect of Adding HDPE Plastic Waste on the Compressive Strength of Fly Ash-Based Geopolymer Mortar

The results of compressive strength tests on fly ash-based geopolymer mortar samples with the addition of HDPE plastic waste at 7, 14, and 28 days are shown in Figure 3. Geopolymer mortars with 3% and 5% plastic waste additions experienced fluctuations in compressive strength values at each test time. Fluctuations in compressive strength values in fly ash-based geopolymers with the addition of HDPE plastic waste can be caused by several factors. One is the interaction between fly ash and HDPE, where the inert nature of HDPE can disrupt the interparticle bonding process within the geopolymer matrix, causing strength variations. The distribution and size of HDPE particles also play a role, as uneven distribution can lead to gaps or weak areas that affect compressive strength. Furthermore, the microstructure of the mixture is also affected by the presence of HDPE, which can increase porosity or inhibit the formation of a strong geopolymer gel network. Finally, compatibility issues between fly ash

and HDPE, where HDPE does not participate in the chemical reaction, can create an imbalance in the mixture, leading to fluctuating compressive strength results in each test. Then, the variation of the addition of 8% plastic waste experienced an increasing trend in compressive strength values due to the ongoing hardening process, where the alkali activation reaction in fly ash is more complete over time, while HDPE acts as a stable filler, helping to increase the density of the microstructure without disrupting the main chemical bonds, thus increasing the mechanical strength gradually. The addition of 3% HDPE plastic waste to geopolymer mortar produced the highest compressive strength value at the age of 28 days compared to the addition of 5% and 8% HDPE plastic waste because in the 3% composition the distribution of HDPE plastic waste particles is more homogeneous and does not cause segregation in the mixture [19], [20].

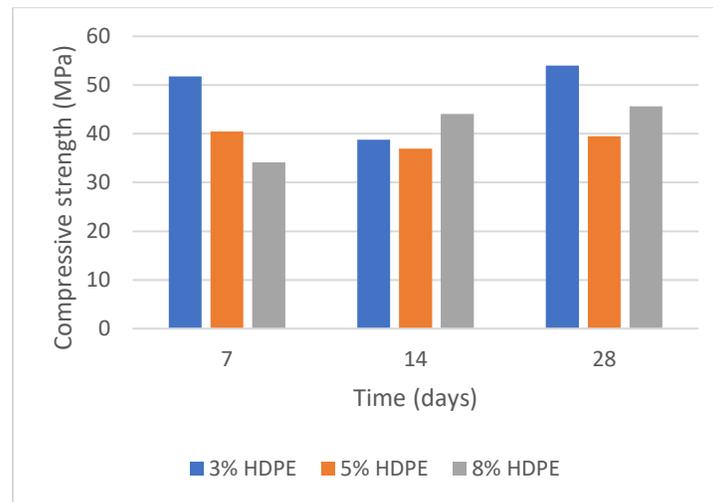


Figure 3: Results of compressive strength test of geopolymer mortar with the addition of HDPE plastic waste

3.4 Microstructure Characterization of Fly Ash-Based Geopolymer Mortar

The results of SEM testing with 1000x magnification on fly ash-based geopolymer mortar, fly ash-based geopolymer mortar with the addition of rice husk ash, and fly ash-based geopolymer mortar with the addition of HDPE plastic waste can be seen in Figure 4. In the three geopolymer mortar samples, a continuous phase originating from the aluminosilicate gel is visible. In addition, spheres originating from fly ash are also visible. In fly ash-based geopolymer mortar with the addition of rice husk ash, irregular and fragmented shapes originating from rice husk ash are visible. Meanwhile, fly ash-based geopolymer mortar with the addition of HDPE plastic waste appears to have an irregular shape with a flat and smooth surface originating from HDPE plastic waste.

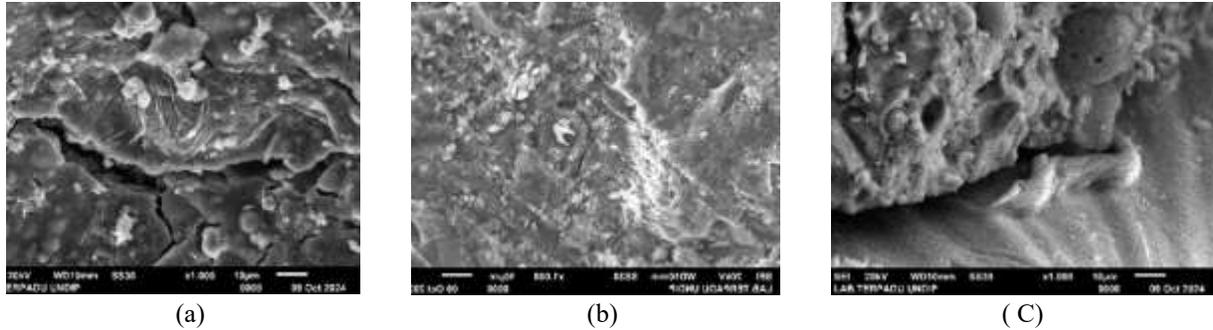


Figure 4: Results of SEM test on fly ash-based geopolymer mortar (a), fly ash-based geopolymer mortar with the addition of rice husk ash (b), and fly ash-based geopolymer mortar with the addition of HDPE plastic waste (c)

3.5 Characterization of Functional Groups of Fly Ash-Based Geopolymer Mortar

The results of FTIR testing on fly ash-based geopolymer mortar, fly ash-based geopolymer mortar with the addition of rice husk ash, and fly ash-based geopolymer mortar with the addition of HDPE plastic waste can be seen in Figure 5. The presence of peaks in the area around 1000 cm^{-1} and 450 cm^{-1} originating from Si-O-Si and Si-O-Al groups indicates the formation of geopolymers [10]. Adsorbed atmospheric water was also found around 1600 cm^{-1} . Carbonate groups which are the result of the reaction between alkali hydroxide and atmospheric CO_2 were found around 1400 cm^{-1} [21]. The addition of rice husk ash and HDPE to fly ash-based geopolymer mortar caused a slight shift in these peaks. Meanwhile, the addition of HDPE causes the formation of a peak in the area around 1380 cm^{-1} which originates from the $-\text{CH}_2$ functional group [22].

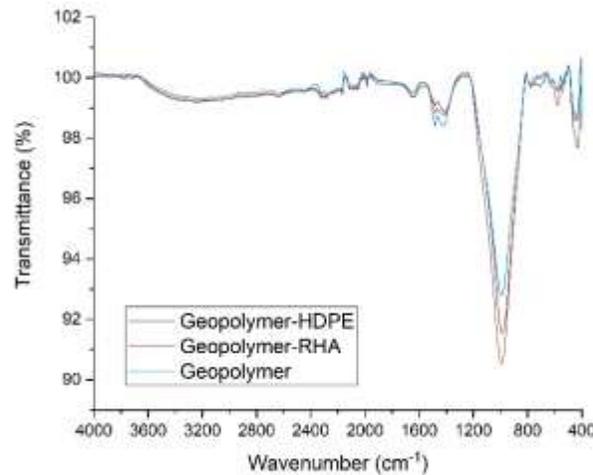


Figure 5: Results of FTIR test on geopolymer mortar

4. CONCLUSIONS

Fly ash-based geopolymer mortar has been made and modified with rice husk ash, superplasticizer, and HDPE plastic waste. The addition of 5% and 10% rice husk ash as a substitute for fly ash resulted in a decrease in the compressive strength of the geopolymer mortar. The addition of 1.5% superplasticizer to the geopolymer mortar did not change its compressive strength relatively, while the addition of 3% HDPE as a substitute for natural aggregate in the geopolymer mortar increased the compressive strength at 28 days by 54.01 MPa. Furthermore, SEM testing, both the geopolymer mortar with 100% fly ash content, the geopolymer mortar with the addition of rice husk ash, and the geopolymer mortar with the addition of HDPE plastic waste showed the formation of a continuous phase of aluminosilicate gel. The presence of fly ash can be seen from the spherical shape, rice husk ash from irregular and fragmented shapes, while HDPE from irregular shapes with flat and smooth surfaces. Meanwhile, from the FTIR test on both geopolymer mortar with 100% fly ash content, geopolymer mortar with the addition of rice husk ash, and geopolymer mortar with the addition of HDPE shows the presence of dominant functional groups Si-O-Si and Si-O-Al. The addition of rice husk ash and HDPE plastic waste causes a slight shift in the existing peaks and the presence of functional groups -CH₂ from HDPE plastic waste.

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