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Compressive Strength and Microstructural of Palm Oil Fuel Ash-Fly Ash Based Geopolymer Mortar

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Abstract. The infrastructure develops very rapidly, along with the increase of market demand for cement, but there is a problem of cement production. Cement production can produce hazardous wastes of CO₂. CO₂ can cause greenhouse effect. The amount of CO₂ produced by cement production is equal to the amount of cement produced. To overcome these problems, it needed to look for alternative materials for cement substitution. Geopolymer is an alternative material that can be a replacement or substitution for cement. Geopolymer can reduce CO₂ wastes generated by cement production and also can reduce industrial generated waste such as fly ash and palm oil fuel ash. In the manufacturing of geopolymer, this study used fly ash and palm oil fuel ash acting as precursor and also Na₂SiO₃ and NaOH as activator solution. This study aimed to examine the effects of the ratio of alkali activator in this case is Na₂SiO₃ and NaOH to microstructure of geopolymer mortar with fly ash and palm oil fuel ash precursor. This study used a variation of 75%:25%, 50%:50%, 25%:75% precursor compositions and variation of alkali activator ratios of 1.5, 2.0, and 2.5. This study used the concentration of NaOH of 14 M. The results showed that along with the increase in concentration of Na₂SiO₃ and NaOH, the structure seen on the mortar becomes denser and the greater fly ash content in the mortar precursor mixture the structure also become denser.

1. Introduction

The infrastructure development in Indonesia and even the world is growing rapidly. The development of infrastructure itself has a very close relationship with the concrete. The main material for making concrete is cement making cement actually produces waste that is very dangerous for the environment. The need for cement is 8.8 million tons per year [1] especially with the rapid development of infrastructure and the increase of incessant construction of skyscrapers that use high quality cement [2]. Carbon dioxide (CO₂) compounds produced by cement production can cause climate change in the atmosphere and cause global warming. The carbon dioxide (CO₂) produced is equivalent to the weight of the cement produced [3]. Professor Joseph Davidovits has discovered an alternative cement replacement material in 1980, the alternative material named geopolymer. Creating geopolymer uses materials containing elements such as alumina and silica. The element is often found in industrial waste. This is certainly very useful in addition to reduce the impact of cement manufactures, geopolymer can also help reduce the waste produced by the plant [4]. Geopolymer concrete is also easier to produced, like conventional cement in the manufacturing process requires temperatures up to



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800°C, enough with 60°C it can produce high quality concrete [5]. Some wastes that have elements of silicon and aluminum are fly ash and palm oil fuel ash [6].

Geopolymer is an inorganic material or material synthesized through a polymerization process. Geopolymer is a form of inorganic alumina silica synthesized from a material containing a lot of silica (Si) and alumina (Al) which comes only from nature or derived from industrial handling, the chemical composition of geopolymer material is similar to zeolite but has an amorphous microstructure [7]. At the time of the synthesis process, the silica and alumina atoms merge and form blocks that are chemically structurally similar to natural rocks.

Fly ash is the result of industrial solid waste, one of which is the result of coal combustion in an electric steam power plant. Fly ash material categorized in pozzolan material which is siliceous or aluminous material with very little or no material mixture has properties like cement. Palm oil fuel ash (POFA) is a solid waste obtained from the burning of palm shells and oil palm husk ash. In the combustion process produced its organic properties and leave Silica oxide (SiO_2) up to 58.02%, as well as other compounds which is also present in the cement [8].

The alkaline solution is a chemical liquid consisting of Na_2SiO_3 and NaOH alkali solution is useful as an activator. NaOH plays a role in the formation of zeolite. However Na_2SiO_3 plays a role in increasing the compressive strength as it accelerates the reaction in the polymerization process [9].

The variation of the precursor composition as well as the alkali mixture in the manufacture of geopolymer mortar greatly affect the workability, setting time and mortar compressive strength [10]. In this study, microstructural observation of geopolymer mortar with precursor fly ash and palm oil fuel ash, and alkaline solution with Na_2SiO_3 and NaOH were observed. This study used different ratios of alkaline solution, it aims to see the impact given by different ratios on the microstructure of geopolymer mortar.

Based on the background and on the effect of $\text{Na}_2\text{SiO}_3/\text{NaOH}$ ratio on the microorganism of geopolymer mortar with fly ash and palm oil fuel ash, the problem formulation in this study is to determine the optimum composition of geopolymer mortar mixture with fly ash and palm oil fuel ash precursor with alkaline solution to produce high performance mortar. The effects of fly ash and palm oil fuel ash on compressive strength and microstructure of geopolymer mortar also studied in this study. Na_2SiO_3 and NaOH ratio effects to compressive strength and microstructure of geopolymer mortar also observed.

Based on the existing problems, the objectives of the study on the effects of Na_2SiO_3 and NaOH ratio to microstructure of geopolymer mortar and palm oil fuel ash are to determine the optimum composition of geopolymer mortar mixture with fly ash and palm oil fuel ash precursor with alkaline solution to produce high performance mortar, to know the effects of $\text{Na}_2\text{SiO}_3/\text{NaOH}$ ratio on compressive strength of 28 days and microstructure of geopolymer mortar, to know the effects of fly ash and palm oil fuel ash on compressive strength of 28 days and microstructure of geopolymer mortar.

2. Methodology

This study conducted microstructure test with SEM on test object in the form of cubic geopolymer mortar shaped 5 x 5 x 5 cm with fly ash and palm oil fuel ash precursor as well as alkaline solution of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH). This test was also carried out on several variations of the mixture between fly ash and palm oil fuel ash with a ratio of 75%:25%, 50%:50%, 25%:75%, and also the ratio of an alkaline solution with a value of 1.5, 2.0, and 2.5. Microstructural test performed when the mortar had reached 28 days. The materials used in this study were precursors in this case are fly ash and palm oil fuel ash, water, alkaline solution as activators of Na_2SiO_3 and NaOH, and fine aggregate. In this study the equipment used were material retrieval tools, material mixing tools, molding tools, and mortar sample testing tools. The equipment used in this study included Scanning Electron Microscope (SEM), 5 x 5 x 5 cm of cube formwork, and mixer. The material used consisted of fly ash and palm oil fuel ash with the ratio of 75%:25%, 50%:50%, and 25%:75%, the ratio of alkali solution Na_2SiO_3 and NaOH of 1.5, 2.0, and 2.5, and water.

3. Result and Discussion

3.1. Compressive Strength

Figure 1(a) shows the results of mortar compressive strength test. The results obtained in mortar compressive strength test on FA75%:POFA25% mixture with Na_2SiO_3 and NaOH ratio of 1.5 obtained 17.2 MPa, Na_2SiO_3 and NaOH ratio of 2.0 obtained a compressive strength of 18.4 MPa, in the ratio of Na_2SiO_3 and NaOH ratio of 2.5 obtained a compressive strength of 22.4 MPa. The results obtained on mortar compressive strength test on FA50%:POFA50% mixture with ratio Na_2SiO_3 and NaOH ratio of 1.5 obtained 10 MPa, Na_2SiO_3 and NaOH ratio of 2.0 obtained by compressive strength of 10.4 MPa, Na_2SiO_3 and NaOH ratio of 2.5 obtained compressive strength of 12.8 MPa. The results obtained on mortar compressive strength test on FA25%:POFA75% mixture with Na_2SiO_3 and NaOH ratio of 1.5 obtained a compressive strength of 4.8 MPa, Na_2SiO_3 and NaOH ratio of 2.0 obtained a compressive strength of 6.4 MPa, Na_2SiO_3 and NaOH ratio of 2.5 obtained a compressive strength of 6.8 MPa. The above results show that the mortar compressive strength is directly proportional to the concentration of Na_2SiO_3 and NaOH, the higher concentrated activator in the mortar, the higher results of mortar compressive strength obtained.

Figure 1(b) shows the results of mortar compressive strength test according to the precursor composition. The results obtained on mortar compressive strength with ratio of Na_2SiO_3 and NaOH 1.5 and composition of FA75%:POFA25% was equal to 22.4 MPa, on FA50%:POFA50% composition with same Na_2SiO_3 and NaOH ratio was 12.8 MPa, at FA25%:POFA75% with the same ratio of Na_2SiO_3 and NaOH was 6.8 MPa. The results obtained on mortar compressive strength with the ratio of Na_2SiO_3 and NaOH 2.0 and the composition of FA75%:POFA25% was equal to 18.4 MPa, at FA50%:POFA50% composition with the same Na_2SiO_3 and NaOH ratio was 10.4 MPa, on the composition of precursors FA25%:POFA75% composition with the same Na_2SiO_3 and NaOH ratio was 6.4 MPa. The results obtained on mortar compressive strength with ratio of Na_2SiO_3 and NaOH 2.5 and composition of FA75%:POFA25% was 17.2 MPa, on FA50%:POFA50% precursor with the same Na_2SiO_3 and NaOH ratio obtained 10 MPa, on the composition of FA25%:POFA75% with the ratio of Na_2SiO_3 and NaOH the same obtained result of 4.8 MPa. The above results show that the more concentrated fly ash on the mortar mixture, the higher results of mortar compressive strength obtained.

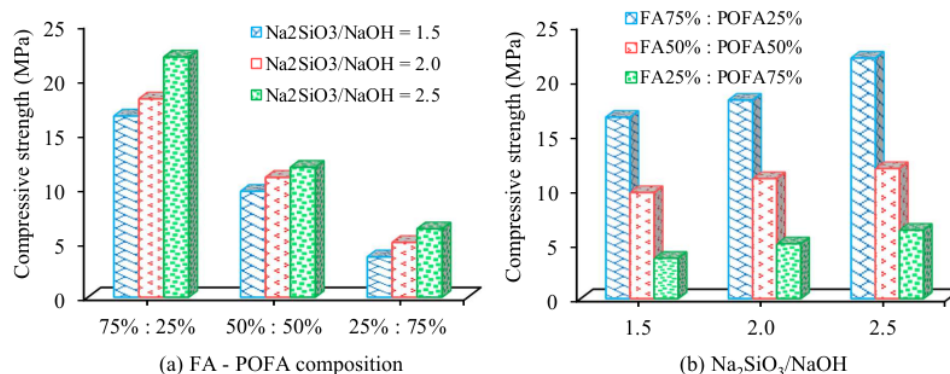


Figure 1. Compressive strength

3.2. Microstructural

The results of microstructure mortar test can be seen in Figures 2 to 4. Figure 2 shows the mortar with the composition of FA75%:POFA25%, in Figure 3 shows the composition of FA50%:POFA50%, in Figure 4 shows the composition of FA25%:POFA75%. Figure 2 shows the mortar with the

composition of FA75%:POFA25%, Figure 2(a) shows a less dense structure, then seen also fly ash and intrigued that has not reacted, but also seen there is a crack that has a length of more than $20\text{ }\mu\text{m}$ and also pores that has a size not more than $1\text{ }\mu\text{m}$. Figure 2(b) has a much denser structure than Figure 2(a), Figure 2(b) also has a smaller crack than Figure 2(a), Figure 2(c) shows the most solid structure between two previous figures, as well as it can be seen intrigued that has not reacted perfectly and cracks that had a length of more than $30\text{ }\mu\text{m}$. Figure 3 shows the SEM test results on FA50%:POFA50% composition. Figure 3(a) shows the most distant structures among other figures, then it can be seen intrigued that had not reacted and also seen some pores of a fairly large size. Figure 3(b) shows a denser structure than the previous figure and also shows several pores that are larger than $1\text{ }\mu\text{m}$. Figure 3(c) shows the most solid structure among the other figures, then it can be seen several cracks and also intrigued almost finished reacting. Figure 4 shows the SEM test results on the composition of FA25%:POFA75%. Figure 4(a) shows a distant structure, then intrigued reacting and also seen several cracks. Figure 4(b) shows a denser structure compared to the previous figure and also seen some pores and intrigued being reacted. Figure 4(c) shows the most solid structure among the other figures and also looks intrigued almost reacting. The above results show that along with the increase of $\text{Na}_2\text{SiO}_3/\text{NaOH}$ ratio, the mortar structure becomes more solid.

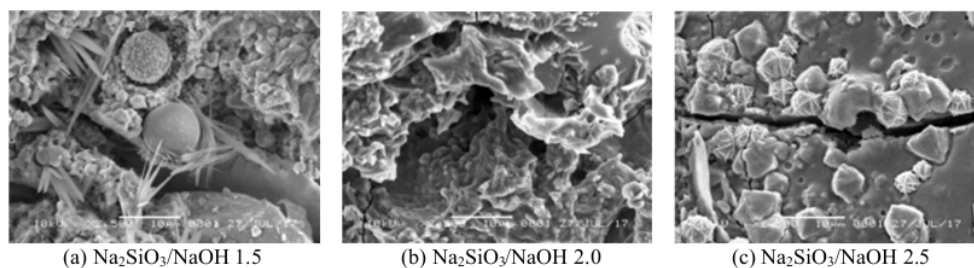


Figure 2. Microstructural of FA75%:POFA25%

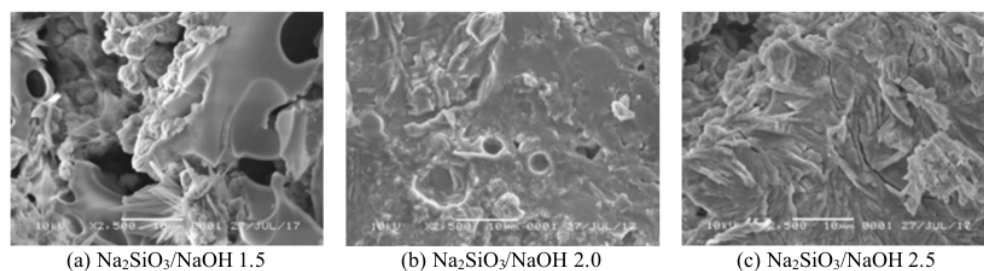


Figure 3. Microstructural of FA50%:POFA50%

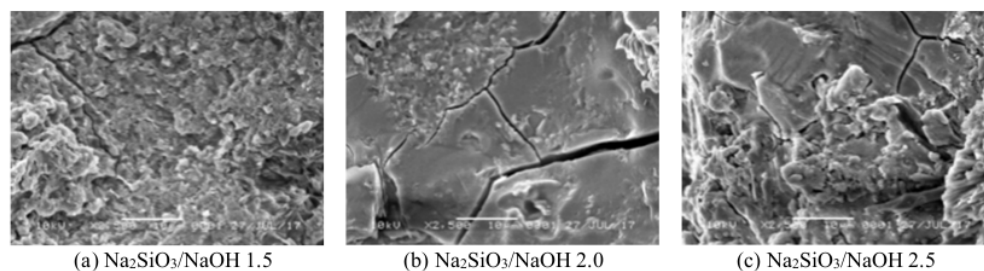


Figure 4. Microstructural of FA25%:POFA75%**4. Conclusion**

The optimum composition of geopolymer mortar mixture with precursor fly ash and palm oil fuel ash with alkaline solution showed the best performance on FA75%:POFA25% mixture composition and $\text{Na}_2\text{SiO}_3/\text{NaOH}$ ratio 2.5. The more concentrated alkaline ratio produces the higher mortar strength, along with the decrease in the concentration of $\text{Na}_2\text{SiO}_3/\text{NaOH}$, the mortar compressive strength also decreases. This can be seen in FA75%:POFA25% mixture where the maximum result occurred in $\text{Na}_2\text{SiO}_3/\text{NaOH}$ 2.5 ratio of 22.08 MPa, at a ratio of $\text{Na}_2\text{SiO}_3/\text{NaOH}$ 2.0 of 18.23 MPa and the minimum occurred in the ratio $\text{Na}_2\text{SiO}_3/\text{NaOH}$ 1.5 was equal to 16.6 MPa.

The addition of fly ash content causes the compressive strength becomes stronger. It can be seen that at the time of test of compressive strength of $\text{Na}_2\text{SiO}_3/\text{NaOH}$ ratio of 1.5, on FA75%:POFA25% precursor mixture was 16.66 MPa, on FA50%:POFA50% precursor mixture was 9.74 MPa, on FA25%:POFA75% precursor mixture was 3.70 MPa. The addition of fly ash content causes the mortar structure becomes denser. This can be seen in microstructure test, FA75%:POFA25% precursor mixture has a denser structure, the mortar density decreases, along with the decrease of fly ash content.

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