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The Effect of Bentonite and Palm Shell Ash on The Mechanical and Physical Properties of Geopolymer Concrete

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ABSTRACT

Geopolymer concrete is an alternative to obtaining environmentally friendly mortar by synthesizing materials that contain a lot of aluminum silicate. This study aims to determine the effect of bentonite and palm shell ash composition on geopolymers' physical and mechanical characteristics. All materials are mashed, mixed, and molded with a 5x5x5 cm^3 cube. Ten specimens were prepared with bentonite - palm shell ash compositions are 40/45, 45/40, 50/35, 55/30, and 60/25 wt%. Meanwhile, the composition of NaOH, Na_2SiO_3, superplasticizer and water remained at 1.3, 7.7, 2, and 5 wt%, respectively. Then the samples were dried at room temperature for 24 hrs and heated at 60 °C or 80 °C for 12 hrs. The geopolymer concrete with the best characteristics was obtained with a composition of 40 wt% bentonites and 45 wt% palm shell ash by heating at 80 °C. This specimen has a compressive strength of 11.94 MPa with a density of 2.42 g/cm^3, porosity of 8.43%, and absorption of 3.48%. The results have a chemical composition of 55.59% SiO_2, 9.45% Al_2O_3, and 8.22 Fe_2O_3 with a dominant quartz phase. Scanning electron microscope photo shows good bonding between particles, and there are no pores formed.

1. INTRODUCTION

Ordinary Portland cement-based mortar is now the most used building material in the world. The annual use of cement reaches 4 billion tons with an annual growth rate of 4% (Mineral Commodities Summary, 2014). However, Portland cement production requires much energy and produces CO_2 gas that pollutes the environment (Pavithra, 2016). Generally, for every tonne of Portland cement production, one tonne of CO_2 is released into the atmosphere (Davidovits, 1994). Under these conditions, geopolymer concrete is one of the best options to reduce global warming. It can minimize CO_2 emissions by up to 80% (Pavithra, 2016).

Geopolymers are the latest innovation in concrete manufacturing worldwide. The conventional Portland cement is completely replaced with an aluminosilicate material activated by a strongly alkaline solution as a binder. (Patankar et al., 2013). Metakaolin, fly ash, red mud, agricultural waste, and mine waste are natural and industrial products used to make geopolymer binders (Slaty et al., 2013). Silica-rich materials such as fly ash, slag, rice husks, and aluminum-rich materials such as clays, including kaolin and bentonite, are significant parts of polymerization development (Part et al., 2015).

Palm shell ash is a pozzolanic material which is not bound like cement but contains dominant SiO_2 (Graille et al., 1985). Palm shell ash is obtained from a steam power

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plant that uses palm kernel shells as fuel at temperatures from 800 - 1,000°C (Tangchirapat, 2009). Palm shell ash includes a large amount of silica dioxide and can be used as an alternative to cement. Palm shell ash is one of the pozzolanic materials found in most of the world. Palm shell ash can be used effectively to reduce cement use and waste volume, which is suitable for preserving the environment (Tangchirapat, 2009).

Some researchers used palm shell ash for an experiment. Production of geopolymer concrete using a mixture of fly ash and palm ash was well done by Islami et al. (2012). The highest compressive strength value occurs at the ratio of fly ash and palm ash 75:25, which is 20 MPa heated at a temperature of 110 °C. A higher compressive strength of geopolymer concrete can produce by mixed of ash from agro-industrial waste. The 25 MPa compressive strength was achieved from the 70:30 composition of fly ash and palm ash (Ariffin et al., 2017). Another experiment resulted from 44.57 MPa of geopolymer concrete compressive strength. This higher geopolymer compressive strength is produced from blast furnace slag and palm ash with a ratio of 0.2 (Yusuf, 2014).

Based on the previous studies, this research was conducted to see the effect of bentonite and palm shell ash on geopolymer cement's mechanical and physical properties.

2. METHODS

The parameters used for the design of the experiment are shown in Table 1. Palm shell ash is obtained from the fuel combustion process in a palm oil factory. Bentonite and palm shell ash were sieved on 100 mesh. Admixture of superplasticizer SP 200, NaOH (Merck), Na_2SiO_3 (Rofa, 58%), and water were added to the slurry according to the composition in Table 1. All materials are mixed and molded at 5x5x5 cm^3 cubes. The specimens are allowed to stand for 24 hrs and then heated in the oven at 60 °C and 80 °C for 12 hrs.

The geopolymer concrete was characterized by compressive strength, density, porosity, and absorption test. The compressive strength test was carried used the universal testing machine model HT-2402. The chemical content was analyzed by X-ray fluorescence using Malvern Panalytical Epsilon 3 and crystal phase by x-ray diffraction using Panalytical X'Pert 3 Powder. The topography of geopolymer was obtained by SEM Phenom Pro X.

3. RESULT AND DISCUSSION

XRF characterization was carried out to determine the chemical content used to manufacture geopolymer mortar. Bentonite with high Al_2O_3 content helps form bonds between concrete particles. While the dominant palm shell ash is silica, which is 51.47%. The chemical content of bentonite and palm shell ash overall can be shown in Table 2.

Based on Table 3 shows that the sample was heated at 80 °C and 60 °C, dominated by SiO_2, Al_2O_3, and Fe_2O_3 compounds. The results of the characterization of these samples follow XRF analysis of bentonite and palm shell ash raw materials, where the results of the analysis are dominated by SiO_2, Al_2O_3, and Fe_2O_3 compounds.

Table 1. Composition of geopolymer cement manufacture

Specimen	Bentonite (%)	Palm shell ash (%)	NaOH (%)	Na_2SiO_3 (%)	Superplasticizer (%)	Water (%)
I	40	45	1.3	7.7	2	5
II	45	40	1.3	7.7	2	5
III	50	35	1.3	7.7	2	5
IV	55	30	1.3	7.7	2	5
V	60	25	1.3	7.7	2	5

Table 2. Chemical composition of raw material

Compound	Bentonite (%)	Palm shell ash (%)
SiO_2	65.20	51.47
Al_2O_3	18.10	2.00
Fe_2O_3	9.41	4.50
K_2O	0.99	15.17
TiO_2	0.33	0.39
CaO	2.79	18.36
P_2O_5	0.12	5.09
NiO	0.09	-
SO_3	0.15	-
MnO	2.94	0.37
MgO	-	2.26

Table 3. Chemical composition of geopolymer

Compound	Composition (%, wt)	
	80 °C	60 °C
SiO_2	55.59	58.54
Fe_2O_3	8.22	9.43
Al_2O_3	9.45	11.73
CaO	13.10	9.74
K2O	7.74	5.51
TiO_2	0.53	0.51
MnO	0.44	0.30
P_2O_5	2.90	2.43
MgO	1.42	1.18

Based on Figure 1, the density values decreased due to increasing the ratio value. It has happened at temperatures of 60 °C and °80 C. The confidence level of the trend formed on this graph is 98% for temperatures 60 °C and 96% for 90 °C. The polymerization process is similar when heated at 60 °C to 90 °C. The temperature is close to perfect, and fast polymerization process (Duxson et al., 2007). However, the higher the temperature, the higher the evaporation process. A temperature of 80 °C causes a higher shrinkage of water content than a temperature of 60 °C, so the density is slightly different between these two temperatures. The density value is related to the porosity value. The higher the density, the smaller of concrete porosity. It creates higher compressive strength of the mortar (Malau, 2014).

Based on Figure 2, the porosity value is directly proportional to the ratio of bentonite ash. The confidence level of the trend formed on this graph is 95% for temperatures 60 °C and 91% for °80 C. The porosity value was closely related to the density value. This is because when the water in the geopolymer mortar evaporates, the pores that were previously filled with water become empty, and when the heating temperature is higher, the geopolymer mortar will dry out and form a tight bond and close the empty hole, causing the mortar to become denser. Therefore, the increased curing temperature used in geopolymer mortar will decrease the porosity value (Amin & Suharto, 2017).

Based on Figure 3, the absorption value is directly proportional to the temperature. The confidence level of the trend formed on this graph is 98% for temperatures 60 °C and 95% for 80 °C. The large pores in the geopolymer mortar, the more cavities are made. The empty cavity can absorb much water. High temperature caused less water to absorb in the geopolymer concrete (Amin & Suharto, 2017). In addition, the higher the heating temperature, the less the geopolymer mortar will absorb water. In other words, the smaller the absorption (Amin & Suharto, 2017). The low absorption value makes a low water absorption rate in the mortar. It is made higher the density value and compressive strength, and the mortar structure is getting tighter.

Based on Figure 4, the compressive strength value is directly proportional to temperatures. The density value obtained was high because the resulting mortar structure is dense. In addition, the compressive strength value is related to the porosity value and absorption value. If the compressive strength value is high, the porosity and absorption value will be smaller. The water granules in the geopolymer mortar will evaporate due to the use of high heating temperatures. Water evaporation is formed in smaller porosity in the mortar and increases the compressive strength value of the mortar.

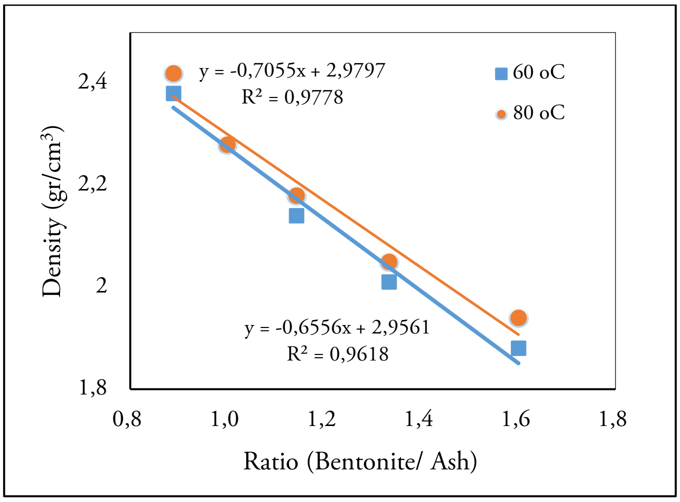

Figure 1. The graph of density vs ratio

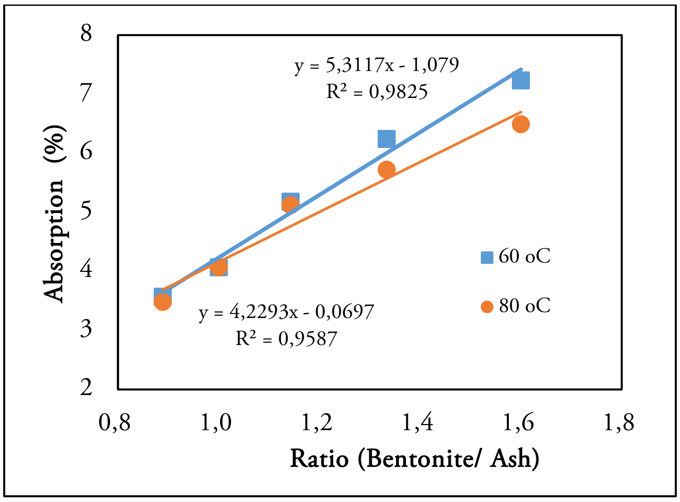

Figure 3. The graphic of absorption vs ratio

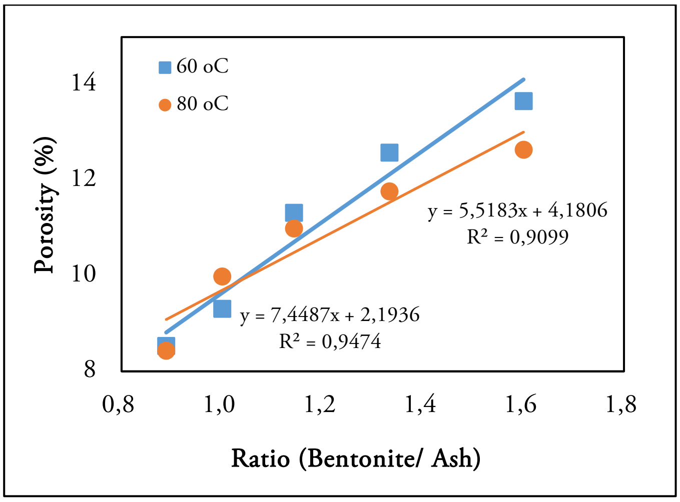

Figure 2. The graphic of porosity (P) vs ratio

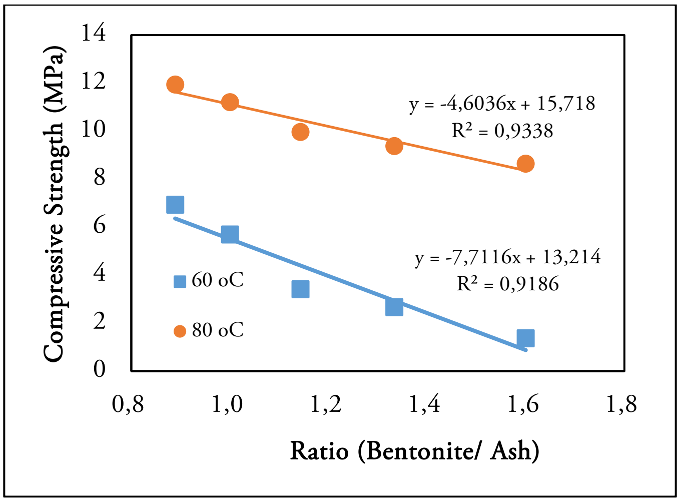

Figure 4. The graphic of compressive strength vs ratio

Geopolymer concrete made using geopolymer will bind with high alkaline NaOH to form a polysilicon-aluminate gel. It will harden due to the crystallization process and will increase the compressive strength of the mortar (Amin & Suharto, 2017). The increase in the percentage of bentonite causes a decrease in the compressive strength value due to an increase in porosity and changes in the microstructure. The addition of bentonite to the geopolymer increases the number of pores and pore size and widens the pore size distribution because bentonite contains much water (Yang et al., 2020).

XRD characterization was performed on samples with the highest compressive strength value (80 °C). The results of the X-Ray Diffraction test show that the higher the intensity, the higher the crystallinity level (Latif et al., 2014). The crystal phases formed are quartz. The crystal structure is hexagonal and is the highest peak on the chart, with its highest intensity at 2θ= 26.654°, as evidenced by the ICDD result 01-085-0795. Subsequently formed a sillimanite phase (Al_2SiO_4) with an orthorhombic crystal structure, its highest intensity at 2θ= 27.584°. The sillimanite phase showed conformity with the ICDD reference 01-089-0888. In the anorthite phase ($Ca(Al_2Si_2O_8)$) with the anorthic crystalline structure, its highest intensity at 2θ= 31.310°, the anorthite phase shows conformity with the ICDD reference 01-089-1460. In addition to the quartz, sillimanite and anorthite phases are formed, namely magnetite (Fe_3O_4) with an orthorhombic crystal structure, the highest intensity of which is at the position of 2θ= 19.791° with ICDD reference 01-076-0958. The intermediate microcline phase ($KAlSi_3O_8$) at position 2θ= 36.646° with an anorthic crystalline structure.

The dominant phase formed is a quartz mineral group with the chemical formula silicon oxide (SiO_2), which indicates that the mortar has a lot of SiO_2, so it acts as a filler that fills the pores of the mortar and causes the mortar to have the highest compressive strength. The results are under the sample XRF test, where the compound produced is dominated by SiO_2.

X-ray diffraction analysis for two specimens has higher and lower compressive strength values. From the results of the XRD diffractogram obtained from the XRD analysis carried out in the study, the analysis is qualitative research, where the low peak does not indicate the number of crystals contained in the sample (Jefry, 2019). XRD analysis of specimen one at a temperature of 80 °C is shown in Figure 5.

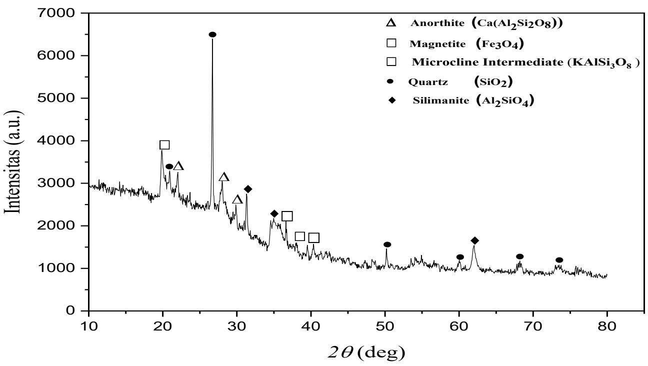

Figure 5. X-ray diffraction of temperature at 80 °C

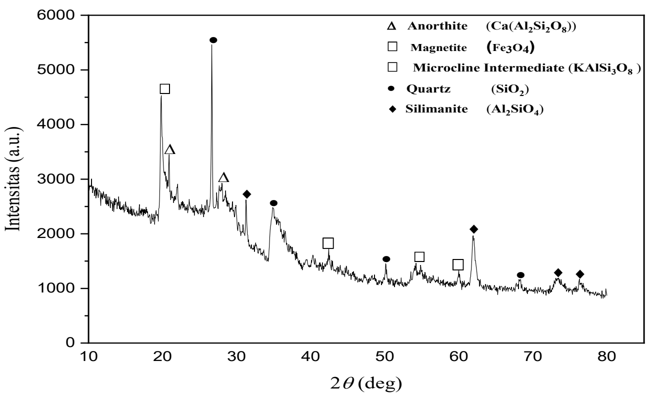

Figure 6. X-ray diffraction of temperature at 60 °C

XRD characterization was carried out on samples with the lowest compressive strength value (composition V at 60 °C). The results of the X-Ray Diffraction test show that the higher intensity, the higher the crystallinity level (Latif et al., 2014). The crystal phases formed are quartz. The crystal structure is hexagonal and is the highest peak on the chart, with its highest intensity at 2θ= 26,644°, as evidenced by the ICDD result 01-085-0504. Subsequently formed a sillimanite phase (Al_2SiO_4) with an orthorhombic crystal structure, its highest intensity at 2θ= 27,584°. The sillimanite phase showed conformity with the ICDD reference 01-089-0888. The anorthite phase ($Ca(Al_2Si_2O_8)$) with the anorthic crystalline structure, its highest intensity at 2θ= 27,836°, the anorthite phase shows conformity with the ICDD reference 01-089-1461. In addition to the quartz, sillimanite and anorthite phases are formed, namely magnetite (Fe_3O_4) with an orthorhombic crystal structure, the highest intensity of which is at the position of 2θ= 19,791° with ICDD reference 01-076-0958. And the intermediate microcline phase ($KAlSi_3O_8$) at position 2θ= 42,423° with an anorthic crystalline structure.

The dominant phase formed is a quartz mineral group with the chemical formula silicon oxide (SiO_2). The results are under the sample XRF test, where the compound produced is dominated by SiO_2.

The results of the XRD diffractogram obtained from the XRD analysis have been carried out in the study. The analysis is qualitative research, where the low peak does not indicate the number of crystals in the sample (Jefry, 2019). XRD analysis of specimen 5 at 80 °C is shown in Figure 6.

Figure 7 depicts the morphology of the particle size SEM with a magnification of 2000X. The surface does not produce many pores (Jiminez et al., 2004). The distribution of constituent elements has a distribution of dominant elements in the form of Si, Al, and Fe.

The results of the EDS analysis are shown in Figure 8 where in the spectrum 0-2 KeV contains elements of carbon (C), oxygen (O), potassium (P), potassium (K), magnesium (Mg), aluminum (Al) and silicon (Si). In the energy spectrum of 2-4 KeV, there are elements of potassium (K) and calcium (Ca), and in the energy spectrum of 4-7 KeV, there are elements of iron (Fe).

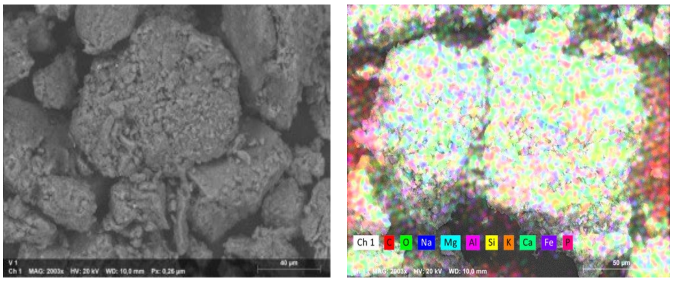

Figure 7. Micro photo of SEM for specimen 1 (temperature 80 °C)

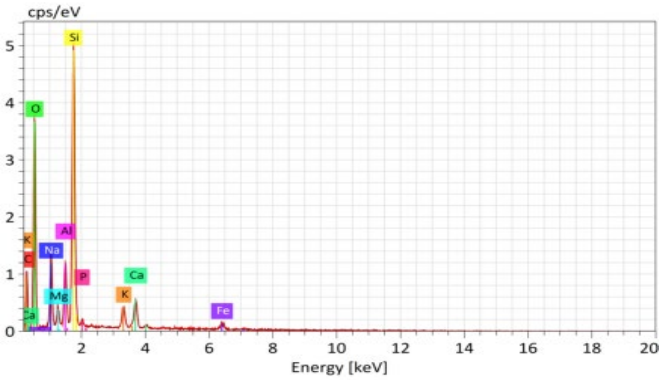

Figure 8. The result of EDS for specimen 1 (the temperature at 80 °C)

4. CONCLUSION

The high palm shell ash content and higher temperature increase the geopolymer compressive strength. This higher strength only used small content of bentonite. The best value obtained of 11.94 MPa with a density of 2.42 g/cm^3, porosity of 8.43%, and absorption of 3.48%. The chemical contained 55.59% SiO_2, 9.45% Al_2O_3, and 8.22% Fe_2O_3, with the phases formed in the form of quartz, sillimanite, anorthite, magnetite, and microcline intermediate. SEM results show that the surface does not produce many pores, so it has the highest compressive strength value. The lowest compressive strength value was obtained from the specimen with low content of palm shell ash. The low compressive strength was 6.94 MPa, with porosity and absorption value were 13.66% and 7.23%, respectively. The chemical contains 58.54% SiO_2, 11.73% Al_2O_3, and 9.43 Fe_2O_3, with the phases formed not different from the high compressive strength specimen. The SEM results show that the surface has many pores, so it has the lowest compressive strength value. This research shows that bentonite and palm shell ash waste is feasible and can be used in geopolymer cement manufacture.

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