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RESISTANCE OF MORTAR WITH PPC CEMENT AND GEOPOLYMER MORTAR WITH WHITE SOIL SUBSTITUTION IN H_2SO_4 IMMERSION

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ABSTRACT

This study analyzes the effect of immersion of H_2SO_4 (sulfuric acid) solution with a concentration of 10% on porosity, density and compressive strength of mortar with PPC cement and geopolymer with white soil substitution mortar. The purpose of this study was to determine the resistance of mortar with PPC cement and geopolymer with white soil substitution mortar when immersed in 10% H_2SO_4 solution. The test object was 5x5x5 cm mortar with materials used including fly ash from PLTU Tanjung Jati B Jepara, white soil from Kupang, fine aggregate, water and alkaline activator in the form of a mixture of 8M NaOH and Na_2SiO_3 and also PPC cement. The composition of the geopolymer mortar mixture is 1binder: 3Fine Aggregate: 0,5Water-Binder Ratio, while the mortar with PPC cement is made with a composition of 1PPC: 3Fine Aggregate: 0,5Water-Cement Ratio. The geopolymer mortar was made in 6 variations with a white soil substitution percentage of 0-25% with an increase of 5% for each variation. Compressive strength testing using a compression test apparatus. The test results show that the variation in the percentage of white soil substitution has less effect on the size of the porosity value. As for the value of compressive strength and density, white soil substitution has an effect, the higher the white soil substitution, the higher the compressive strength and mortar density values. Geopolymer mortar was better to withstand 10% sulfuric acid solution, while mortar with PPC cement had no resistance to 10% sulfuric acid solution because it continued to deteriorate over the course of the day. The greatest compressive strength is in variation IV (15% white soil substitution) of 15,31 MPa at 28 days of age, while the smallest porosity and greatest density are in variation VI (25% white soil substitution) of 0,17% and 2,205 grams/cm^3.

Keyword: geopolymer mortar; immersion; white soil; corrosive; resistance.

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INTRODUCTION

World cement production is estimated to contribute to greenhouse gas emissions by about 7% of total greenhouse gas emissions to the atmosphere (Mehta, 2004). This of course can cause environmental damage and global warming. Considering that cement is a very large emitter of greenhouse gases, it is necessary to have an alternative as a substitute for Portland cement in a concrete mixture in order to create environmentally friendly concrete.

An alternative that can be used as a substitute for portland cement is a pozzolanic material that is produced from the binding reaction of materials that contains a lot of aluminum -silica or commonly called geopolymers. These elements are found in many industrial waste materials such as fly ash, which is the residue from burning coal in the PLTU. Geopolymers can reduce carbon dioxide (CO_2) emissions by 80% to 90% compared to using Portland cement (Davidovits, 1994). However, fly ash does not have the ability to bind like portland cement. In order for fly ash to react chemically and form polymer bonds, an alkaline solution (alkaline activator) is needed which can be a solution of sodium hydroxide (NaOH) or a solution of potassium hydroxide (KOH) and a solution of sodium silicate (Na2SiO3) or potassium silicate (K2SiO3) (Lloyd & Rangan, 2010).

An environment that contains acidic chemical elements will slowly damage the concrete starting from the edges and corners of the concrete with the release of concrete particles so that the concrete becomes porous. (Purba, 2006). Geopolymer concrete with fly ash as a binding agent has a higher resistance to acidic environments due to its phase and chemical composition (Bhutta et al., 2013). Portland cement is most susceptible to acid attack because it contains high calcium hydroxide after hydration (Hewlett, 2004). The type of cement that has resistance to sulfates and moderate hydration is Portland Pozzolana Cement (PPC Cement). (SNI 15-0302-2004). Based on research (Salain, 2007), At the age of 90 days, concrete with PPC cement produced 8% higher compressive strength and 50% lower permeability coefficient compared to concrete using PCI cement (Portland Cement Type I).

Currently, there have been many studies on geopolymer concrete and mortar made from fly ash which is substituted with other materials, such as rice husk ash, white soil, copper slag and others. Based on research (Priastiwi et al., 2020), it was found that the substitution of white soil against fly ash in the geopolymer mortar could increase the compressive strength of the geopolymer mortar. Substitution of white soil with a percentage of 15% produces the optimum compressive strength reaching 22,53 MPa at the age of 28 days compared to other percentage variations. Based on research (Wulandari et al., 2015), There was an increase of 38,87% in the compressive strength of geopolymer mortar at the age of 120 days after being soaked in peat water which predominantly contains sulfuric acid with a pH value = 4 - 5, while portland cement mortar (OPC) experienced a decrease in compressive strength. Therefore, there is a need for research on the comparison of the resistance of geopolymer mortar based on fly ash with activator NaOH and Na_2SiO_3 with white soil substitution in a certain percentage, without white soil substitution, and mortar made from PPC cement when immersed in a solution of sulfuric acid with a concentration of 10% corrosive.

The addition of additives for reinforced concrete and normal concrete will increase its compressive strength. The compressive strength of concrete is also influenced by the composition of the additives contained therein. Including the composition of the amount of water added to each concrete mix (Gumilang et.al, 2021; Syaiful.S, 2020; Syaiful.S, 2021).

RESEARCH METHOD

This research was conducted at the Materials and Construction Laboratory Civil Engineering, Diponegoro University, Semarang. The time of the research was carried out for 2 months (November 2020 to January 2021).

Materials and Tools

The materials used as materials for both geopolymer and mortar with PPC cement in this research are as follows:

1. Fly Ash
   Fly ash is the residue of the coal combustion process. This material is type F fly ash originating from PLTU Tanjung Jati B, Jepara. The fly ash used must be mashed and pass sieve no.200 or have a size of less than 0,075 mm with a moisture content of 0%.

Table 1. Oxide Content of Fly Ash from PLTU Tanjung Jati B Jepara

Oxide Content	Percentage (%)
Na_2O	1,59
MgO	2,86
Al_2O_3	24,95
SiO_2	46,52
SO_3	1,13
K_2O	2,77
CaO	5,89
TiO_2	1,36
FeO	11,81
CuO	1,12

Source: (Mulyana et al., 2017)

2. White Soil
   White Soil is a naturally occurring material originating from Kupang, East Nusa Tenggara. The white soil used must be mashed and pass sieve no.200 or have a size of less than 0,075 mm with a moisture content of 0%.

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Table 2. Oxide Content of White Soil

Oxide Content	Percentage (%)
CaO	56,19
MgO	0,647
SiO2	0,433
Al2O3	0,178
Fe_2O_3	0,0875
SrO	0,0801
SO_3	0,0685
P2O5	0,0435
TiO2	0,0065
MnO	0,0060
K_2O	0,0020
LOI	41,93

Source : (Hunggurami et al., 2015)

3. Fine Aggregate
   Fine aggregate used is originating from Muntilan, Central Java. This fine aggregate must pass the filter test and have a grading that meets the requirements..
4. PPC Cement
   The PPC cement used is Semen Gresik. Chemical and physical requirements for portland pozzolana cement (PPC) including quality testing have met each type stipulated in SNI 15-0302-2004.
5. Alkaline Activator
   Alkaline Activator is used to condense the polymerization process that occurs in the geopolymer mortar. The alkaline activator used is sodium hydroxide (NaOH) 8M and sodium silicate (Na_2SiO_3).

In this research, 6 variations of the geopolymer mortar research object were used which were obtained based on trial and error from the preliminary test of variations of white soil from 0% to 25% with a difference of 5%, and 1 variation of the research object in the form of mortar with PPC cement. The composition of the mortar mixture with PPC cement that will be used for this research is 1PPC Cement: 3Fine Aggregate: 0,5Cement Water Ratio, while the composition of the geopolymer mortar mixture is 1binder: 3Fine Aggregate with a binder water ratio of 0,5. The binder is a mixture of fly ash and white soil. The alkaline activator used is a mixture of 8M NaOH and Na_2SiO_3 with a ratio of 1: 2,5. Table 3 below is the composition of the geopolymer mortar mixture in the mortar.

Table 3 . Geopolymer mortar composition for 39 specimens of each variations

No	White Soil Filler (kg)	Fly Ash (kg)	Fine Aggregate (kg)	Water (liters)	% White Soil Filler
1.	0	3,90	11,70	1,95	0%
2.	0,20	3,71	11,70	1,95	5%
3	0,39	3,51	11,70	1,95	10%
4.	0,59	3,32	11,70	1,95	15%
5.	0,78	3,12	11,70	1,95	20%
6.	0,98	2,93	11,70	1,95	25%

8M NaOH Solution
Calculation of NaOH Molarity (8M)
M = 8 Molar
Water = 1,95 kg = 1,95 liters = 1950 ml
Mr NaOH = 40 gr/mol
(the sum of Ar, Na = 23, O = 16 and H = 1)

$$M = \frac{mass\ of\ NaOH}{Mr} \times \frac{1000}{Water\ volume} \qquad (1)$$

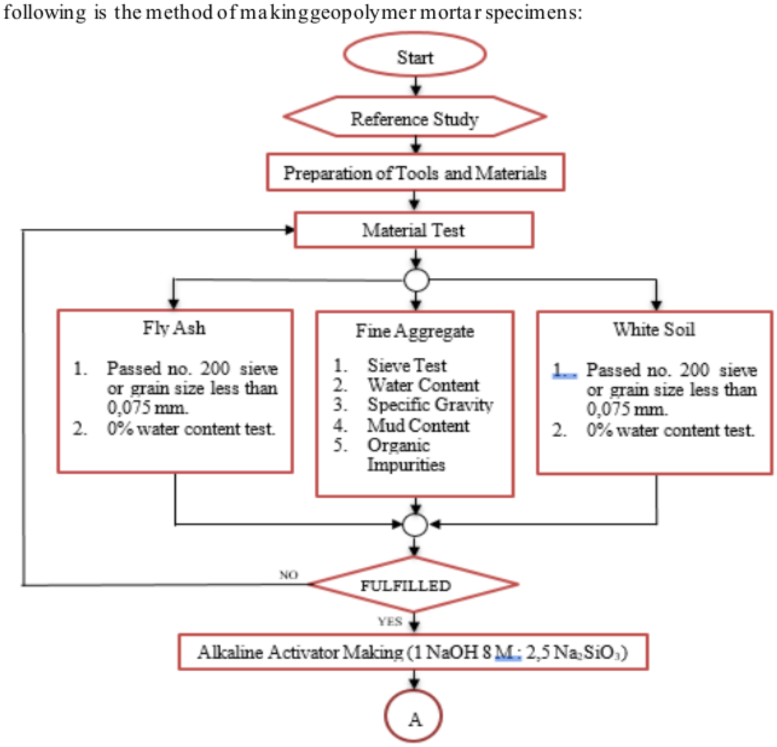
$$8 = \frac{mass\ of\ NaOH}{40} \times \frac{1000}{1950}$$

Mass of NaOH = 624 grams

Information:
M = Molarity
V = Volume
Mr = Relative Molecules (the total atomic mass of the constituents)
To determine how much the mass of sodium silicate, it can be calculated using the ratio:

$\frac{Na2SiO3}{NaOH} = 2,5$
$Na_2SiO_3 = 2,5 \times NaOH$
$Na_2SiO_3 = 2,5 \times 624$
Berat $Na_2SiO_3 = 1560$ grams

Research Flowchart
The following is the method of making geopolymer mortar specimens:



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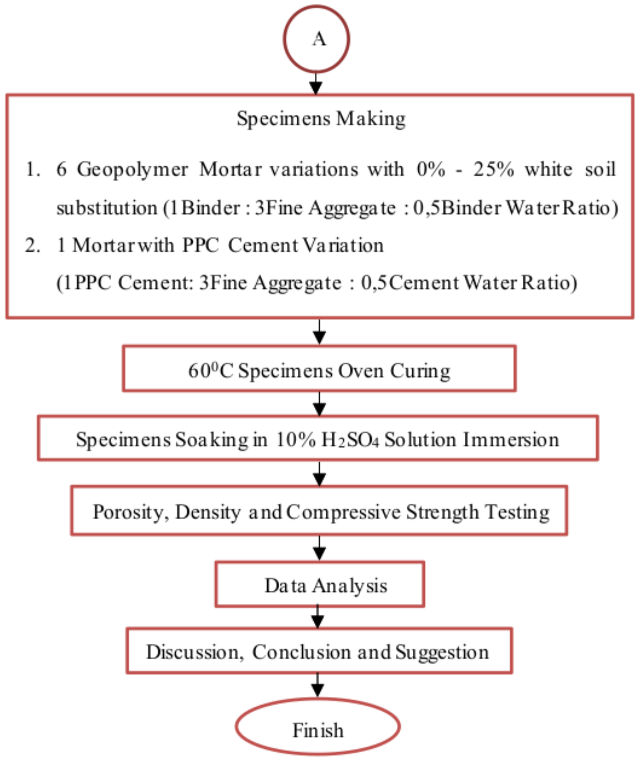

Figure 1. Research Flowchart

The mortar testing method is carried out based on existing testing standards. The mortar testing method in this research such as porosity, density and compressive strength. The following is a geopolymer mortar testing method:

1. Porosity (ASTM C 642-06)
   Porosity is the ratio of pore volume (volume occupied by fluid) to total volume (volume of specimen). The pore range generally occurs due to errors in execution and casting such as the cement water ratio which affects the adhesion between the paste and the aggregate, the size of the slump value, the choice of the type of combined aggregate grading arrangement, as well as the duration of compaction. The higher the density level, the greater the compressive strength or quality, conversely the greater the porosity, the smaller the compressive strength. The following is the equation used:

$$\text{Porosity} = \frac{B-C}{B-A} \text{ x } 100\% \qquad (2)$$

   Information:
   A = Dry mass of the mortar (grams)
   B = SSD nass of the mortar (grams)
   C = Mass of mortar in the watr (grams)

Weighing three specimens under dry mass, SSD mass, and mass in water. Testing of the test object in each variation is 3 pieces. If there is an unsuitable test value, correction will be made by ignoring it.

Figure 2. Weighing Specimens in Water

2. Density (SNI 1973:2016)
   The mortar density test is a measurement between the weight of a mortar against the volume of the mortar. The mortar density test was carried out by weighing the mortar weight and then dividing it by the volume of the mortar. The following is the equation used:

$$\text{Density } (\gamma) = \frac{\text{Mass (m)}}{\text{Volume (V)}} \tag{3}$$

   The specimens was weighed and recorded in dry conditions and had been removed 1 day before from the immersion of 10% sulfuric acid solution.

Figure 3. Specimens Weighing

3. Compressive Strength (SNI 03-6825-2002)
   The mortar compressive strength is the maximum force of unity of the surface area acting on the specimen. The test object is a cube measuring 5 x 5 x 5 cm. The following is the compressive strength formula used:

$$f'c = \frac{P}{A} \ (\text{N/mm}^2) \tag{4}$$

   Information:
   $f'c$ = Mortar compressive strength (N/mm^2 or MPa)
   P = Total maximum load (N)
   A = Mortar surface area (mm^2)

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Figure 4. Mortar Compressive Strength Testing

RESULTS AND DISCUSSION

The following are the results and discussion of the porosity, density and compressive strength tests that have been carried out in this research:

1. Porosity Test
   The mortar porosity test was carried out at 14th days. The following are the results of the porosity test for mortars immersed in 10% sulfuric acid solution:

Table 4. Mortar Porosity Percentage

Variation	White Soil Percentage	Porosity (%)
I	0%	2,37
II	5%	5,50
III	10%	9,06
IV	15%	7,15
V	20%	2,17
VI	25%	0,17
PPC	-	1,62

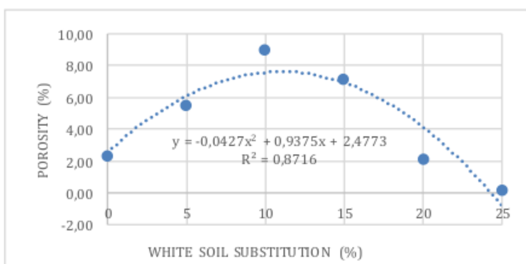

Figure 5. Geopolymer Mortar Porosity Regression Value

A regression analysis was conducted as an approach to determine the maximum porosity value of the geopolymer mortar variations I to VI. In the graph above, the correlation coefficient is 0,934 which has a non-linear relationship between the two variables. As for the coefficient of determination, it was obtained a value of 87,16% so that the porosity was strong enough to be explained by the variation in the percentage of white soil substitution. The remaining 12,84% is explained by other variables.

The calculation of the white soil substitution in the optimum geopolymer mortar to produce the maximum porosity value is as follows:

$$y = -427{,}38x^2 + 93{,}753x + 2{,}4773 \quad (5)$$

Information:
x = White soil substitution for mortar (%)
y = Mortar porosity (%)

By using a differential, the maximum y occurs at dP/dx (x) = 0. So we get the equation:

$$dP/d(x) = -854{,}76x + 93{,}753 \quad (6)$$

Obtained the value of x = 0,1097 from equation (5). By substituting x = 0,1097 into equation (4), the y = 7,62 is obtained. So that the optimum value of white soil substitution in geopolymer mortar is 10,97% which will produce a porosity value of 7,62%. From the results of the porosity test of geopolymer mortar shown in Table 2, the variation with the smallest value was then taken and compared between the porosity of geopolymer mortar and mortar with PPC cement.

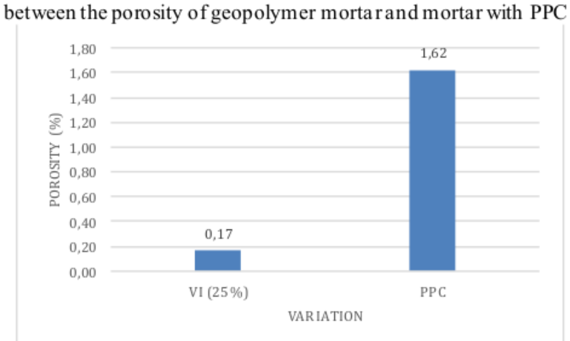

Figure 6. Porosity Comparison between Variation VI Mortar and PPC Mortar

25% white soil substitution (variation VI) resulted in the smallest porosity value of all variations, namely 0,17%. This is due to the higher percentage of white soil substitution, the drier the condition of the mortar will be at the time of dismantling (Priastiwi et al., 2020) which can facilitate dismantling of the mortar and minimize defect to the mortar.

Mortar with PPC cement has a greater porosity value than the variation VI mortar with a porosity value of 1,62%. This is because the mortar with PPC cement underwent a continuous erosion of the surface of the mortar so that the pores in the mortar were getting bigger and made the sulfuric acid solution enter the cavities of the mortar which then damaged the inside of the mortar.

2. Compressive Strength Test
The compressive strength test was carried out at the age of 7, 14 and 28 days using a compression test apparatus. There are 3 test objects in each variation of the test. The following are the results of the compressive strength test according to the predetermined age and variation:

Table 5. Mortar Compressive Strength Recapitulation

Age	Variation	Average Compressive Strength MPa	Information
7		8,894	
14	I	12,419	Increase
28		14,200	
7	II	7,459	Decrease

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14		7,367	
28		6,395	
7		11,249	
14	III	10,687	Decrease
28		10,421	
7		14,740	
14	IV	13,998	Decrease then Increase
28		15,308	
7		15,053	
14	V	12,329	Decrease then Increase
28		13,372	
7		14,116	
14	VI	15,031	Increase then Decrease (a Little Bit)
28		15,024	
7		9,149	
14	PPC	6,941	Decrease
28		6,313	

From the test results, a graph of the compressive strength of the mortar is made with the x-axis being the age (days) and the y-axis being the compressive strength (MPa). Then the following results are obtained:

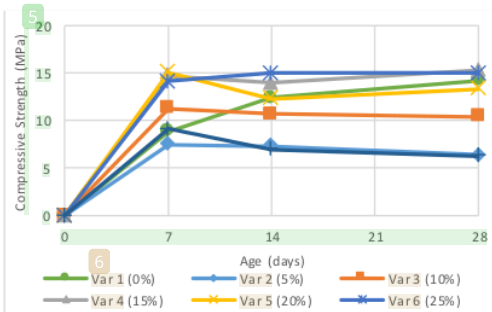

Figure 7. Mortar Compressive Strength Recapitulation Graph

The greatest compressive strength of all variations is found in variation IV geopolymer mortar (15% white soil substitution) at the age of 28, which is 15,31 MPa. This shows that the percentage of 85% fly ash and 15% white soil substitution is the best mixture for geopolymer mortar when immersed in 10% sulfuric acid solution.

Mortar with PPC cement has the smallest compressive strength among all variations because mortar with PPC cement has a continuous decrease in compressive strength from the 7th day to the 28th day due to the grinding of the mortar surface which is experienced continuously over the course of the day. This shows that mortar with PPC cement does not strong against attack from 10% sulfuric acid solution, while geopolymer mortar especially with 15% white soil substitution is able to withstand 10% sulfuric acid solution.

3. Density Test

Before testing the compressive strength at 28th days, the weight of the mortar specimen was measured using a digital scale. This data is used to calculate the density in this study. The following is the average result of the mortar density calculation:

Table 6. Density Calculation Results

Variation	Density (grams/cm^3)
I	2,039
II	2,062
III	2,064
IV	2,110
V	2,125
VI	2,205
PPC	2,138

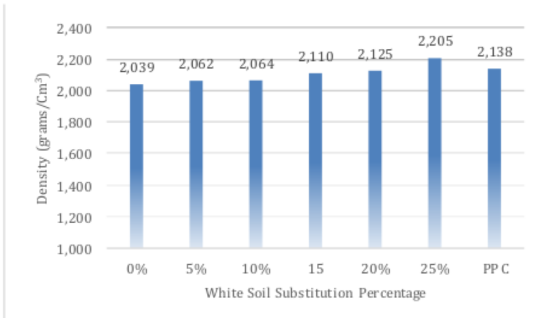

Figure 8. Mortar Density Graph

From the graph above, it can be seen that the lowest density value is in the variation I geopolymer mortar with a value of 2,039 grams/cm³ and variation II with a value of 2,062 grams/cm³. The graph above also shows that the more the substitution of white soil, the higher the density value.

The density of mortar with PPC cement is 2,138 grams/cm³ where this value is the second highest after the variation VI geopolymer mortar with a value of 2,205 grams/cm³, this is because the grain size of white soil is able to function as a filler in geopolymer mortar. However, the mortar with PPC cement experienced a decrease in mass and the change in dimensions was smaller, from 5 x 5 x 5 cm to 4 x 4 x 4 cm after soaking for 2 days. This was due to the very strong 10% sulfuric acid attack on the PPC cement mortar.

4. The Relationship between Porosity and Compressive Strength
   The porosity test and the compressive strength test results were compared on the 14th day of immersion. The following is the data on the results of the porosity test and the compressive strength of the mortar at the age of 14 of soaking 10% sulfuric acid solution.

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Table 7. Compressive Strength and Porosity Test Results at the Age of the 14th Day of Immersion

Variation	White Soil Percentage	Porosity (%)	Compressive Strength (MPa)
I	0%	2,37	12,42
II	5%	5,50	7,37
III	10%	7,63	10,69
IV	15%	7,15	14,00
V	20%	2,17	12,33
VI	25%	0,17	15,03
PPC	-	2,22	6,94

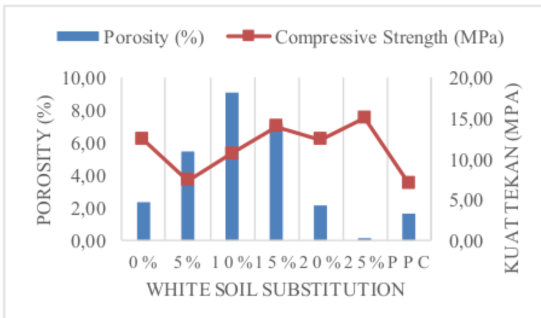

Figure 9. The Relationship between Porosity and Compressive Strength Graph

From the graph above, it can be seen that in the geopolymer mortar with a mixed activator of NaOH and Na_2SiO_3 has a pattern that the lower the porosity, the higher the compressive strength. This can be seen in variation VI geopolymer mortar (25% white soil substitution) which has the highest compressive strength value of 15,03 MPa and the lowest porosity value of 0,17%. These results are in accordance with previous studies (Priastiwi et al., 2020) which examined the relationship between porosity and compressive strength of geopolymer mortars with KOH and Na_2SiO_3 activators. From this research, it was found that the Na_2SiO_3 activated geopolymer mortar had a pattern that the lower the porosity, the higher the compressive strength.

However, this pattern does not applied to mortar with PPC cement because mortar with PPC cement has a relatively small porosity value and a small compressive strength value. This is caused by the surface of the mortar with PPC cement which continues to be damaged by the 10% sulfuric acid solution over the course of the day, thus decreasing the quality of the mortar and resulting in low compressive strength.

CONCLUSION

Geopolymer mortar has better resistance when immersed in 10% H_2SO_4 solution because it has higher compressive strength and density values as well as smaller porosity values than mortar with PPC cement. Meanwhile, mortar with PPC cement experienced a decrease in mass and the change in shape became smaller with increasing age of the mortar. Mortar with PPC cement also has very low compressive strength and has experienced a continuous decline from 7th days to 28th days. This shows that the mortar with PPC cement does not able to withstand the attack of 10% H_2SO_4 solution.

In geopolymer mortar, the size of the porosity value depends on the density of the mortar and the perfection of the mortar form when unloading the mortar from the mold. As for the compressive strength and density values, the resulting value is influenced by the substitution of white soil. The higher the percentage of white soil substitution, the higher the density of the geopolymer mortar.

15% white soil substitution in geopolymer mortar is the best mixture because it has the highest compressive strength when immersed in 10% H_2SO_4 solution.

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