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Original Research Article

Comparison of Physical Properties and Strength of Geopolymer Mortar with White Soil Substitution and Mortar with Portland Pozzolan Cement under Corrosive Seawater Conditions

Yulita Arni Priastiwi[1*], Rudi Yuniarto Adi[1], Arif Hidayat[1], Abi Nabil Hanif[2], Bima[2]
[1] Department of Civil Engineering, Engineering Faculty, Universitas Diponegoro, Jalan Prof. Soedarto, SH, Kampus Undip Tembalang, Semarang, Indonesia 50275
[2] Department of Civil Engineering Student, Engineering Faculty, Universitas Diponegoro, Jalan Prof. Soedarto, SH, Kampus Undip Tembalang, Semarang, Indonesia 50275
* Corresponding Author, email: yulitaarnipriastiwi@gmail.com

Abstract
Construction also causes environmental pollution due to excessive cement production, so an alternative to cement is needed. Geopolymer is considered an alternative material to replace cement. This research compares three variations of mortar (PPC, geopolymer, and geopolymer with white soil) in a seawater environment. Research in the laboratory with 5x5x5 cm mortar specimens and test parameters for porosity, compressive and direct tensile strength, density, and absorption has been carried out. Microstructure due to immersion effect was also carried out but only on MGT15 mortar. The results showed that the PPC mortar had the highest compressive and tensile strength among the three variations, namely 27.80 MPa and 2.540 MPa at 28 days of age, the *most negligible* porosity and absorption were 1.124% and 76 gram/100cm2, and increased density after immersion. However, when immersing for 56 days, the decrease in strength reached 21%, while geopolymer mortar tended to be stable and even increased to 19%. Microstructure tests in the form of SEM and EDX on MGT15 showed the effect of seawater immersion, such as the presence of cracks, ettringite, and bad reactions. Soaking in seawater caused a decrease in some mortar strength supporting compounds and the appearance of 0.3% free chloride at 28 days of immersion.

***Keywords**:* Mortar geopolymer; portland pozzolan cement (PPC); corrosive

1. Introduction

Infrastructure development in Indonesia is growing rapidly. This increases the need for concrete as a construction material because until now concrete is a construction material that is widely chosen by the public. The increase in the use of concrete results in the increase in the use of cement as the main material for binding concrete. According to the *Chatham House* research institute in 2018, cement is a source of 8% of carbon dioxide (CO_2) emissions. This is a driving factor for finding other alternatives to reduce the use of cement in concrete mixes. One of the steps to reduce the use of portland cement is the use of pozzolan added to cement known as Portland Pozzolan Cement (PPC), but the existence of PPC cement is still an environmental problem so other alternative materials are needed to replace it. Geopolymer is an alternative to geosynthetic cement in which the binding reaction that occurs is a polymerization reaction. Geopolymeric mortar using rice hulk ash-derived waterglass led to reduced CO_2 emission by 63% compared to the OPC mortar (Mellado et al., 2014) and some case study geopolymer concrete mixes based on typical Australian feedstocks indicate potential for a 44–64% reduction in greenhouse gas emissions (Mclellan et al., 2011). The elements aluminum (Al) and silica (Si) have an important role in the polymerization reaction. These elements are found in many industrial waste materials such as fly ash (Saputra et al., 2018), rice husk ash (Sandya et al., 2019), and white soil (Parluhutan et al., 2018).

However currently, people's interest is still high in the use of cement, especially for construction work in corrosive environments, one example is seawater. Geopolymer concrete can be used for construction work in corrosive environments, one example is seawater. According to research (Putra, 2006), during the immersion of concrete in seawater, portland cement experienced weathering and a decrease in compressive strength of 26.6%, while the use of fly ash (Geopolymer) had a decrease in compressive strength of 10.9%. According to (Jin et al., 2020) geopolymer mortar with metakaolin content which is immersed in seawater only experiences a mass decrease of 3% -5% and does not change significantly with soaking time. These results indicate that the geopolymer has good resistance to seawater corrosion. Information related to geopolymer materials needs to be continuously developed so that air pollution can continue to be suppressed. This study aims to compare the physical properties and strength of geopolymer mortar and PPC mortar in a corrosive environment such as seawater, where geopolymer mortar is also substituted with white soil.

2. Materials and Methods

This study used research methods in the laboratory using mortar test objects measuring 5 x 5 x 5 cm. The test specimens are divided into geopolymer mortar and mortar with PPC cement (MPPC), where geopolymer mortar is further divided into two categories, namely mortar without white soil (MGP), and mortar with 15% white soil substitution (MGT15).

2.1 Materials

The materials used for geopolymer mortar (MGT15 and MGP) and PPC mortar (MPCC) in this study include:

1. White soil
   White soil is a material that is formed through biological and chemical weathering processes. In its original condition, white soil is a granular material that is often found in Kupang, East Nusa Tenggara. White soil is composed of chemical elements, namely calcium, magnesium, silica, alumina, and iron (Hunggurami et al., 2015). In this study, white soil was conditioned so that it had a size smaller than 0.075 mm or passed sieve no. 200 and the moisture content is close to 0%. This is so that the white soil can fill the voids in the mortar and does not increase the water content in the mortar mix.
2. Fly Ash
   Fly Ash is waste generated from burning coal in power plants. The fly ash used comes from the Tanjung Jati PLTU, Jepara. The fly ash used is conditioned to pass sieve no. 200 with a moisture content close to 0%. Table 1 shows the oxide content in fly ash and white soil.
3. Portland Pozzolan Cement (PPC)
   PPC cement is a hydraulic cement consisting of a homogeneous mixture of portland cement and fine pozzolana. The pozzolanic materials used are volcanic ash, silica fume, and fly ash. This cement is commonly used for construction work in corrosive environments such as seawater and acids.
4. Fine aggregate
   The fine aggregate used in this study is Muntilan sand. The sand used meets the requirements of ASTM C33/C33M, which has a maximum diameter of 4.75 mm. Before use, the sand must be washed to reduce the content of clay lump and organic matter.
5. Alkaline Activator
   Alkaline Activator is used in the polymerization process that occurs in geopolymer mortar (MGT15 and MGP). The alkaline activators used were 8M sodium hydroxide (NaOH) and sodium silicate

(Na_2SiO_3). According to (Saputra et al., 2018) the optimum molarity level of NaOH for geopolymer concrete is 8.18 M.

Table 1. Oxide content of fly ash and white soil

Sample	Oxide content	Percentage (%)	Sample	Oxide content	Percentage (%)
Fly Ash	Na_2O	1.59	White soil	LOI	41.930
	MgO	2.86		MgO	0.647
	Al_2O_3	24.95		Al_2O_3	0.178
	SiO_2	46.52		SiO_2	0.433
	SO_3	1.13		SO_3	0.068
	K_2O	2.77		K_2O	0.002
	CaO	5.89		CaO	56.190
	TiO_2	1.36		TiO_2	0.0065
	FeO	11.81		Fe_2O_3	0.0875
	CuO	1.12		SrO	0.0801
				MnO	0.006

Source: (Qomarrudin et al., 2018; Hunggurami, et al., 2015)

2.2. Composition object

The MGT15 and MGP geopolymer mortars were made with a mixture proportion of 1 Pca : 3Ps : 0.5 FAB with a weight ratio. Pca is a binder mixture that includes fly ash, white soil (only for MGT15), alkaline activator (NaOH 8M and Na_2SiO_3), Ps is sand, while FAB is the ratio of water and binder. The white soil substitution used is 15% because this percentage produces an optimum compressive strength reaching 22.53 MPa at 28 days of age compared to other percentage variations (Priastiwi et al., 2020). For PPC mortar it is made with a mixture proportion of 1 PPC : 3Ps : 0.5 FAS. FAS is w/c ratio and a total of 63 specimens for all variations (54 cube-shaped 5 x 5 x 5 cm and 9 dogbone-shaped). The composition of the mortar mix is shown in Table 2.

Table 2. Mortar mix composition

Variation	White soil substitution (gr)	*Fly Ash* (gr)	PPC (gr)	Sand (gr)	Alkaline Activator		Water (ml)
					NaOH (gr)	Na_2SiO_3 (gr)	
MGT15	315	1785	-	6300	336	840	1050
MGP	-	2100	-	6300	336	840	1050
MPPC	-	-	2100	6300	-	-	1050

Curing plays an important role in developing the strength and microstructural systems of fly ash-based mortars (Nurruddin, et al., 2018). In this study, curing was carried out in the form of 14 days of coating using wet gunny sacks, followed by 14 days of curing at room temperature.

2.3 Method

Parameters of physical properties carried out in this study include porosity, compressive and tensile strength, density, absorption, and additional special microstructures on MGT15. Corrosive conditions are given by immersion in seawater after the mortar reaches its optimal age (28 days). Tests carried out include:

1. Porosity
   Porosity is the ratio of the pore volume to the size of the empty cavity (fluid passable) in the mortar. The greater the porosity, the lower the compressive strength, and vice versa. ASTM C-642-06 gives

the equation for porosity as in Equation (1) with A = Mass of mortar in water (gr); B = Mass of SSD mortar (gr); C = dry mass of mortar (gr).

$$\text{Porosity} = \frac{B-C}{B-A} \times 100\% \quad (1)$$

Weighing is carried out on the specimens in three conditions, namely dry weight, SSD weight, and weight in water. The test was carried out 3 times for each mortar variation.

2. Compressive strength

   The compressive strength test was carried out at 0 days of immersion (without seawater immersion), 14, 28, and 56 days after immersion. SNI 06-6825-2002 gives the compressive strength formula as in Equation (2) with f'c = Compressive strength of mortar (N/mm² or MPa); P = Maximum load (N); A = Mortar area (mm²).

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

Figure 1. Compressive strength of mortar

3. Direct tensile

   This test was conducted to determine the direct tensile strength of the three mortar variants. This test was carried out when the immersion age reached 28 days. This test was carried out on dogbone-shaped specimens. ASTM C 307 – 03 gives the direct tensile strength formula as in Equation (3) with Fct = tensile strength of mortar (N/mm²); P'= tensile force (N); A = Smallest tensile area (mm²).

$$F_{ct} = \frac{P'}{A} \text{ (N/mm}^2\text{)} \quad (3)$$

Fig 2. Direct tensile of mortar

4. Density

   Density is the ratio between the mass of the mortar to the volume of the mortar. This test is carried out by weighing the dry condition of the mortar weight and then dividing it by the volume of the mortar. SNI 1973-2016 provides a formula for density as written in Equation (4)

$$\text{Density } (\gamma) = \frac{Mass}{Volume} \quad (4)$$

5. Absorption

   Absorption *is* the condition in which something gets mixed or absorbed completely in another substance. Absorption testing was carried out to determine the relative water absorption of the three mortar variations. Absorption testing was carried out by measuring water absorption at

¼ hour; 1-hour; 4 hours; and 24- hour periods. This test was carried out when the immersion age reached 28 days. ASTM C 1403 – 05 provides a formula for absorption according to Equation (5).

$$At = (Wr - Wo) \times 10000 / L1xL2 \quad (5)$$

with At = Mortar absorption value (gr/100 cm²); Wt = Weight of the test object at time T (gr); Wo = Initial fixed weight of the test object (gr); and $L_1 \times L_2$ = Surface area of the test object (cm²)

6. Microstructure
Microstructural testing includes SEM-EDX (Scanning Electron Microscope – Energy Dispersive X-Ray) testing. SEM is a type of electron microscope that images the surface of a sample by scanning it with a high emission of electrons. EDX is an analytical technique used for the analysis of the elemental or chemical characteristics of a sample. The effect of immersing seawater on the mortar is shown by carrying out the SEM-EDX test. In this test the device is used SEM-EDX JEOL JSM-6510LA. This test was only carried out on the MGT15 variation and was carried out at 0 days of immersion (without immersion) and up to 28 days of immersion.

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3. Result and Discussion

The effect of seawater immersion on geopolymer mortars with or without white soil substitution and mortar with PPC cement will be shown in the results of physical and mechanical testing of the three types of mortar as well as the results of the SEM-XRD microstructure on mortar with white soil substitution (MGT15) produced.

1. Porosity testing
This test was carried out when the concrete soaking age reached 28 days. Table 3 shows the results of the mortar porosity test for three variations soaked in seawater.

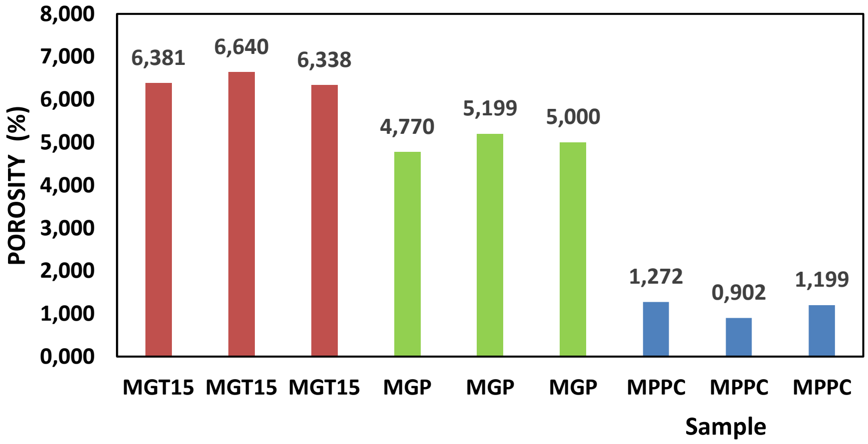

Figure 3. Mortar porosity

Obtained average porosity for mortar MGT15, MGP, and MPPC respectively 6.453%, 4.990%, and 1.124%. These results indicate that MGT15 mortar has the largest cavities and MPPC mortar has the smallest cavities. The porosity value is directly related to the mechanical properties such as impermeability, durability and even the strength of the mortar. The compressive strength of the specimen will be greater if the level of density is higher or the porosity is smaller (Chen et al., 2013) The finer grain size of PPC cement compared to geopolymer mortar with fly ash and white soil can increase the density of the mortar which causes a decrease in the percentage of porosity caused by fewer connected pores, thereby increasing compressive strength and slowing water absorption through the pores (Masdari, 2022).

2. Compressive Strength testing

The compressive strength test was carried out on the three variations of mortar at the immersion ages of 0, 7, 14, and 28 days. The tool used for testing compressive strength is a compression test apparatus. The results of the average compressive strength test of the three mortar specimens at all immersion ages are shown in Table 4 while Figure 4 shows a comparison of the compressive strength of the three variables. Figure 4 shows that at the same immersion age MPPC, mortar has the highest compressive strength compared to MGT15 and MGP mortars. During 56 days of immersion, the MPPC mortar decreased in compressive strength from 27.80 MPa at 0 days of immersion (without immersion) to 22.01 MPa on the 56th day of immersion or decreased by 20.84%. Mortar MGT15 decreased by 28 days of immersion to 17.80 MPa from 20.74 MPa before immersion or decreased by 14.17% but increased again to 21.00 MPa at 56 days of immersion, while MGP mortar experienced an increase in compressive strength of 16.12 MPa at 0 days of immersion (without immersion) to 19.15 MPa on the 56th day of immersion or an increase of 18.81%.

Table 4. Mortar compressive strength result

Mortar variation	Compressive Strength (*f'c*) (MPa)			
	Immersion age (days)			
	0 (without immersion)	14	28	56
MGT15	20.74	20.86	17.80	21.00
MGP	16.12	16.72	19.03	19.15
MPPC	27.80	26.26	27.25	22.01

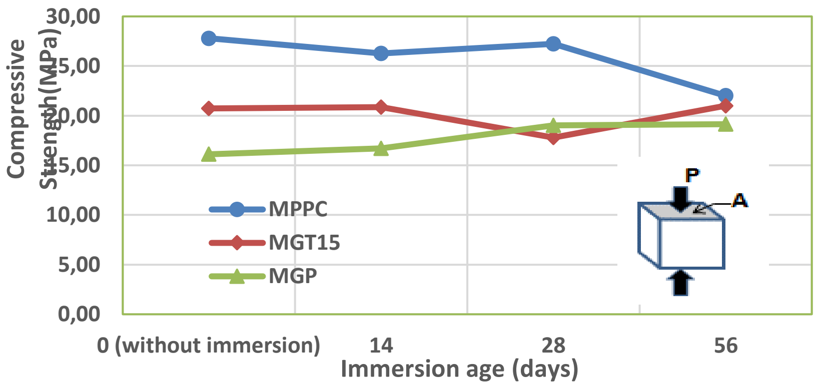

Figure 4. Mortar compressive strength comparison

From the above results, it appears that the mortar with PPC cement experienced a strength degradation of more than 20% due to seawater immersion, this is close to the results of Putra's research, 2006 which stated that there was weathering and a decrease in compressive strength due to seawater immersion in concrete with portland cement up to 26, 6%, whereas in geopolymer mortar according to research by Jin et al., 2020 it was said that there was a decrease in strength but not too significant around 10% in this study it was close to the same for MGT15 even at MGP the condition of its strength remained stable without decreasing strength due to seawater immersion.

3. Tensile Strength testing

The direct tensile strength test was carried out using a dogbone mortar with an effective square area of 26.5 mm x 26.1 mm = 691.65 mm2 (Wang et al., 2019). Table 5 contains the results of the mortar tensile strength test for the three variations tested at 28 days of immersion age.

Table 5. Tensile strength test result

Dogbone variation		Tensile Max (P)	Area (A)	Tensile strength (ft)	Average		ft/f'c
		N	mm²	N/mm²	MPa	kg/cm²	%
MGT15	1	470.00	691.65	0.68	0.66	6.69	3.68
	2	500.00	691.65	0.72			
	3	390.00	691.65	0.56			
MGP	1	330.00	691.65	0.48	0.63	6.46	3.33
	2	490.00	691.65	0.71			
	3	495.00	691.65	0.72			
MPPC	1	1580.00	691.65	2.28	2.54	25.91	9.32
	2	1800.00	691.65	2.60			
	3	1890.00	691.65	2.73			

In Table 5 it is found that the MPPC dogbone has a much higher average tensile strength reaching 2.54 MPa or 25.91 kg/cm² compared to geopolymer mortar (MGT15 and MGP) with an average tensile strength of 0.66 MPa and 0.63 MPa. This proves that the results of the tensile strength test will be directly proportional to the results of the compressive strength, where MPPC has the highest compressive strength value. MPPC also has the highest ratio compared to its compressive strength of 9.32%, whereas mortar MGT15 and MGP have a ratio of 3.68% and 3.33%. The test results obtained on the MPPC mortar following previous studies where according to (Asmara et al., 2021), the tensile strength has a ratio of around 9% - 15% of the compressive strength.

4. Density testing

Density testing was in the form of weighing on a cube mortar with a size of 5 x 5 x 5 cm and was carried out before and after seawater immersion in the three mortar variations. No change in volume occurred during immersion in seawater. Figure 4 shows a graph of the relationship between density and immersion time.

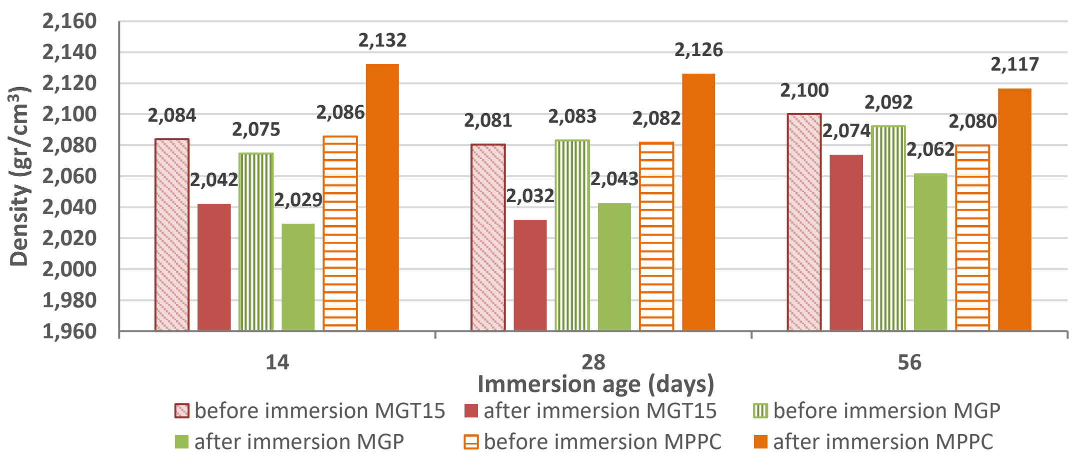

Figure 5. Comparison of Density before and after Immersion

Based on Figure 5, the development of decreasing and increasing density of the three mortar variations is obtained. The MGT15 and MGP geopolymer mortars decreased, while the MPPC mortars increased in density as the bath age increased. The increase in the mass of the MPPC mortar is due to the difficulty in removing the water in the mortar because the mortar has a small porosity value, so the hydration reaction continues and increases the mass of the mortar. Mortar MGT15 and MGP did not increase in mass because there was no continuous reaction. The MGT15 and MGP mortars which experienced a mass loss of around 2% were lower than the research by Jin et al., 2020 which indicated a decrease in the mass of geopolymer mortar in the range of 3-5%.

5. Absorption testing
This test uses a 50 x 50 x 50 mm cube mortar test object (2500 cm² surface area) with absorption time variables of 0.25 hours; 1 hour; 4 hours; and 24 hours. The results of the absorption test are shown in Figure 6. Based on the absorption test, it was found that after 15 minutes (0.25 hours) of testing, the geopolymer mortar (MGT15 and MGP) had produced high absorption values with an average of 82.40 gr/100cm² and 71.60 gr/100cm², where the PPC mortar only produced an average absorption value of 18.13 gr/100cm². After 24 hours of testing the MPPC mortar experienced a significant increase in average absorption value to 78.53 gr/100cm². However, this value was still below the MGT15 mortar of 98.93 gr/100cm² and the MGP mortar of 89.33 gr/100cm². The high absorption is also directly proportional to porosity and inversely proportional to density, this can be proven because MGT mortar has the highest porosity of 6.453% and has the greatest decrease in density at 28 days of age.

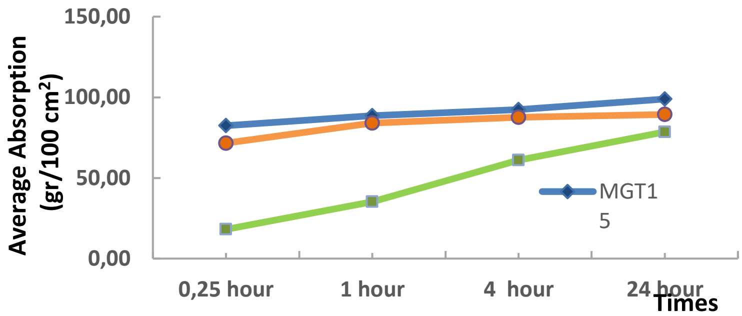

Figure 6. The average absorption value of 3 variation mortars

6. Microstructures testing
In microstructural testing, two types of tests were carried out, namely testing using SEM (Scanning Electron Microscopy) and EDX (Energy Dispersive X-Ray). To see the microstructure of the mortar due to the influence of seawater immersion, this study only tested the MGT15 mortar without immersion and 28 days of immersion.

A. SEM (*Scanning Electron Microscopy*)
SEM testing was carried out on MGT15 samples under conditions without immersion and 28 days of immersion. The conditions without immersion at 5000x and 1000x magnification are shown in Figure 7.

1. Mortar MGT15 without immersion
Figure 7 shows that there are fly ash particles that do not react in the mortar without immersion. In addition, relatively few mortar pores were also found. Although found in small quantities, the pores of the mortar can affect the density and compressive strength of the mortar. Small amounts of micro-cracks were also found but assisted by the formation of a dense matrix in the mortar. This condition indicates that this mixture has a high density which affects the compressive strength test results of the mortar itself, which is 20.74 MPa.

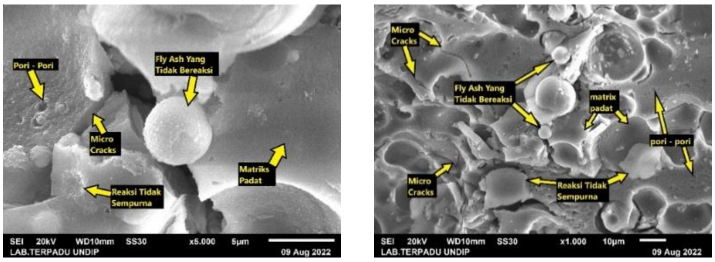

Figure 7. SEM results of mortar gt without immersion with magnification 5000x and 1000x

2. Mortar MGT15 with seawater immersion

Conditions with immersion with a magnification of 5000x and 1000x are shown in Figure 8.

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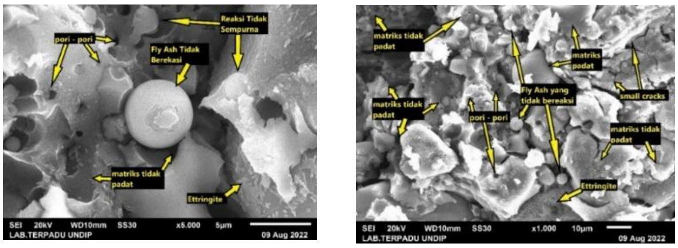

Figure 8. SEM results of mortar gt with seawater immersion

In Figure 8 it is found that the mortar immersion in seawater has larger pores and a large number of cracks occur. When compared with unsoaked mortar, the particles making up the soaked mortar have a lot of loose matrices and contain more imperfect reactions. The effect of immersing seawater on this mortar is shown in the appearance of ettringite which can be seen in Figure 9.

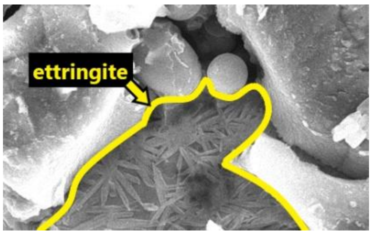

Figure 9. *Ettringite* in mortar

Ettringite is the result of the reaction of calcium elements in the mortar with sulfate salts from seawater. Ettringite causes excessive volume development until the mortar breaks down. Ettringite also causes the condition of the mortar particles soaked in seawater which are not as dense as the mortar that is not soaked, and the condition of the particles which are not as homogeneous as the mortar without immersion indicates that the mortar mixture has a lower density. This is indicated by the results of the compressive strength of mortar immersed in seawater of 17.80 MPa, 16% lower than that of mortar without immersion of 20.7 MPa. Yuan et al., 2021 stated that the presence of fine limestone interspersed with cement and aggregates made it possible to produce mono carbonate ($C_3A.CaCO_3.11H_2O$) which is the basis for the formation of ettringite.

B. EDX (Energy Dispersive X-Ray)

The EDX test aims to determine the oxide compounds contained in the MGT15 mortar before and after immersion. The EDX results from the two conditions are shown in Table 6.

In Table 6 it was found that several oxide compounds experienced an increase and decrease after 28 days of immersion. The FeO compound experienced the most significant decrease from 14.25% to 5.04%. Each compound contained in the MGT15 mortar has a different function; Na2O and K2O compounds function as lowering the melting point of the raw material mixture or commonly called flux, MgO compounds function as cement fluxes and dyes, TiO2 compounds are coloring substances contained in white soil, SiO_2, Al_2O_3, CaO, and FeO compounds play a role in the process bonding and set in mortar and concrete. There are chemical elements that are not present in the MGT15 sample without immersion, namely Chloride (Cl) of 0.30%. Chloride is a compound that attacks mortar when it is immersed in seawater. The high levels of SiO2, Al2O3, CaO, and FeO compounds have an important role in accelerating the bonding and hardening process in concrete (Sorrentino et al., 2021). This can also be proven by the compressive strength of MGT15 mortar which decreased after 28 days of immersion from 20.74 MPa to 17.80 MPa.

Table 6. Result text EDX

Test Parameter	White soil without immersion (%)	White soil after 28 days of immersion (%)
Na_2O	5.46	6.65
MgO	3.17	1.2
Al_2O_3	11.19	11.06
SiO_2	37/32	36.7
K_2O	1.49	1.19
CaO	4.85	7.96
TiO_2	0.56	0.48
FeO	14.25	5.04
Cl	-	0.3

From all the results of tests carried out both on mortar with a cement binder (MPPC) and on geopolymer mortar (MGT15 and MGP) it appears that geopolymer mortar has the potential to be used as part of building structures that are in corrosive conditions such as seawater such as for building materials. making coral reefs, building block binders, filling joints between river stones in a waterproof layer, or making paving blocks. Development towards wider use when it will be applied to geopolymer concrete by adding strength from the presence of coarse aggregate in a mortar mix with a certain composition.

4. Conclusion

Based on 5 variables testing the physical properties and strength of mortar, it can be concluded that MPPC mortar has better quality than geopolymer mortar (MGT15 & MGP) with the highest compressive and tensile strength results of 27.80 MPa and 2.540 MPa, the smallest porosity and absorption of 1.124% and 76 gr/100cm2, and the density increased after immersion. However, MPPC mortar has lower resistance in seawater immersion than geopolymer mortar (MGT15 and MGP) after 56 days of immersion in seawater. Geopolymer mortar has a compressive strength that tends to be more stable even when MGP mortar increases by 19%, while the compressive strength of MPPC mortar decreases by up to 21%. Microstructural tests in the form of SEM and EDX on MGT15 showed the effect of seawater immersion on mortar such as the presence of cracks, ettringite, and incomplete reactions. Soaking in seawater also caused a decrease in some of the mortar strength supporting compounds and the appearance of 0.3% free chloride when the immersion was 28 days old.

5. Acknowledgments

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