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Corrosion Rate and Weight Loss of Geopolymer Mortar Coated Concrete Specimens with Different Thicknesses

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Abstract. This study is about the use of geopolymer mortar as an alternative repair material to reduce the corrosion rate of building structures. The experiment was conducted by comparing the corrosion rate and weight loss of concrete specimens with different thicknesses of geopolymer mortar coating with concrete specimens coated with Sikagrout 215M. Observations showed that the specimens with 2.5 cm thick geopolymer mortar coating cracked faster and had higher current values than the others. Corrosion rate measurements showed that the specimen with 4 cm thickness geopolymer mortar coating had the lowest corrosion rate, while the specimen with Sikagrout 215M coating had a higher corrosion rate. Visualization of the cracked specimens shows that the geopolymer mortar layer's thickness affects the reinforcement's rust formation. Geopolymer concrete with proper coating thickness can reduce the corrosion rate and weight loss of concrete structures. This research further explains the effect of coating thickness and coating type in protecting steel in concrete from corrosion.

1 Introduction

Durability or resilience in concrete is crucial for its performance throughout its service life. Concrete is deemed durable if it does not deteriorate during this period, effectively safeguarding steel reinforcement from corrosion and minimizing the risk of chemical attacks (chloride and sulfate) [1–3]. Concrete used in seawater environments may deteriorate prematurely compared to its expected service life, necessitating additional protection to reduce corrosion damage. One method for such protection is Surface Applied Protection, which involves coating the concrete to provide a protective layer. The thickness of this coating should be tailored to its specific purpose, and it plays a key role in reducing steel reinforcement corrosion. Moreover, it can prolong the service life of concrete structures exposed to water, especially in tidal areas, by preventing corrosive ions from penetrating the surface [2,4–10]

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For coatings with a thickness exceeding 5 mm, geopolymers are recommended [6,11]. According to ACI 357R-84, the recommended thickness for reinforced concrete blankets in offshore buildings is 2 inches (50 mm). However, SNI 2847-2013 specifies that the thickness of concrete blankets in direct contact with soil or exposed to weather conditions should range from 40 to 50 mm. Research on geopolymer concrete made from fly ash, which was immersed in saltwater and contained OPC (typically Portland cement). The corrosion rate of geopolymer concrete was found to be lower than that of OPC concrete. The corrosion rate of steel reinforcement is influenced by the thickness of the geopolymer concrete blanket, which can range from 4 to 8 cm. A thicker concrete blanket results in slower corrosion.[11]

Durable concrete is essential, especially in marine environments, where damage can quickly occur. To prevent corrosion and extend the service life of concrete structures, proper protection and maintenance are required. Concrete coating, with a coating thickness suitable for the purpose, is a method of protection. It is recommended that geopolymers be coated with a thickness of more than 5 millimeters. Studies have shown that geopolymer concrete experiences lower corrosion rates than OPC concrete, and the thicker the coating, the slower the corrosion occurs. Concrete blanket thickness standards vary. Therefore, it is very important to understand and apply proper protection to ensure the concrete is strong and protect the reinforcing steel during the service life of the concrete.

2 Materials and Methods

Fly ash used as a base material for geopolymer mortar were from PT Suralaya silo 1-4, Banten. The fly ash class from the XRF test results showed that it included class F criteria. The geopolymer mortar used fly ash, fine aggregate, and alkali activator. The mix ratio of geopolymer paste to fine aggregate used was 72% and 28%. The geopolymer paste is a mixture of fly ash with alkaline activator used in the ratio of 65% and 35%.

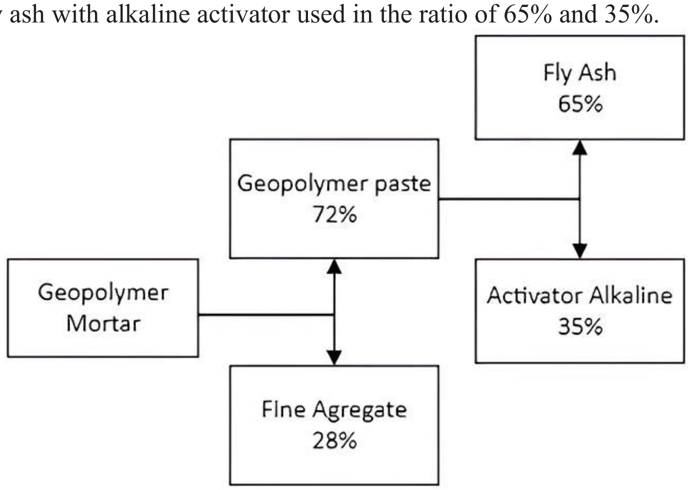

Fig. 1. Composition scheme of geopolymer mortar.

The alkali activator for geopolymer mortar used a mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) with a mixture ratio of 1:2.5. The NaOH solution used with a concentration of 10 M was made from NaOH solids dissolved in distilled water. The Na_2SiO_3 used is type BE-52 which is in the form of a thick liquid or gel with a state of use produced by PT Kasmaji Inti Utama. The chemical composition of Na_2SiO_3 is Na_2O 18.5%, SiO^2 36.4%, and H^2O 45.1%. The geopolymer mortar comparison material is using Sikagrout 215 product which is produced by PT Sika Indonesia. The composition requirements of geopolymer mortar are shown in Table 1.

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Table 1. Mix Design of 1 m^3 geopolymer mortar

Materials	**Weight (kg)**
Fly ash	1039
NaOH 12M	160
Na^2SiO^3	200
Fine aggregate	621

Reinforced concrete constituent materials use reinforcing steel, cement, fine aggregate, coarse aggregate and water. The cement used is OPC (ordinary Portland cement). The reinforcing steel in this study is plain reinforcement with a diameter of 16 mm produced by PT Bhirawa Steel, Surabaya. The fine aggregate and coarse aggregate used were materials sold in local building material stores.

Before coated

After coated with Sikagard 63N

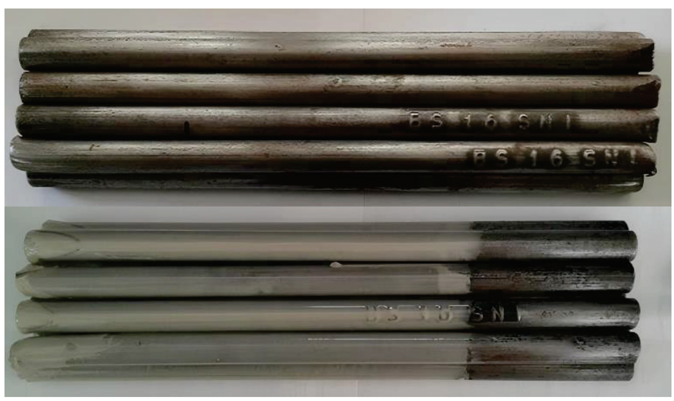

Fig. 2. Steel reinforcement coating.

Then the additional materials used to assist in the manufacture of test specimens and the execution of tests are epoxy resin with Sikagard 63N type to coat steel reinforcement that is not embedded in concrete shown in Figure 2. While Sikadur 732 epoxy resin is used to coat the outer surface of concrete that will be given a layer of geopolymer mortar or Sika mortar. Both products were obtained from PT Sika Indonesia. Figure 3 displays four types of specimen plans based on the mortar material and layer thickness utilized in normal concrete.

The normal concrete cube specimens were coated with geopolymer mortar and Sika mortar at 28 days of concrete age. Code names were given according to the thickness of the coating, namely Type A (2.5 cm geopolymer mortar), Type B (4 cm geopolymer mortar), Type C (6 cm geopolymer mortar), and Type D (2.5 cm Sika mortar). The cube specimens were then treated with moist curing until the age of 30 days. Figure 4 shows normal concrete before and after the application of geopolymer and silica mortar coating.

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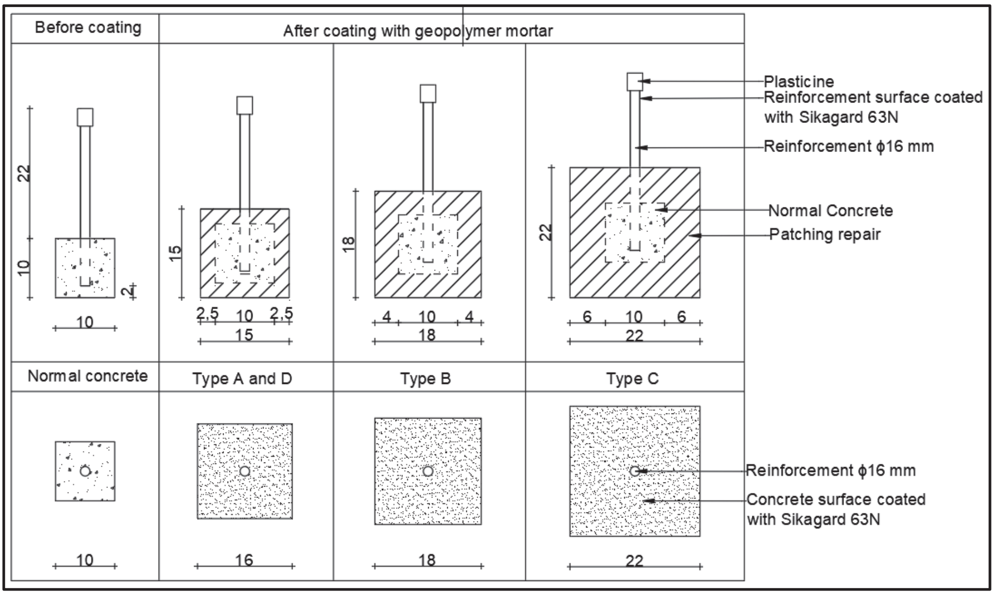

Fig. 3. 4 type cube specimen before and after geopolymer mortar coating.

Normal concrete | Concrete coated with geopolymer mortar and sika mortar

Fig. 4. Cube specimen before and after geopolymer mortar coating.

After that, the accelerated corrosion test with electric current was started. The specimens were immersed in 5% NaCL solution as shown in Figure 2. The test specimens were accelerated corrosion using the Accelerated Corrosion Test method, where the test specimens were immersed in 5% NaCl solution and then exposed to a certain electric current to initiate and accelerate corrosion of the reinforcement. Tests were conducted until cracks occurred on the surface of the concrete coated with a width of 0.4 mm. To calculate the corrosion rate using the corrosion rate equation according ASTM G1-90 Reapp. 99.

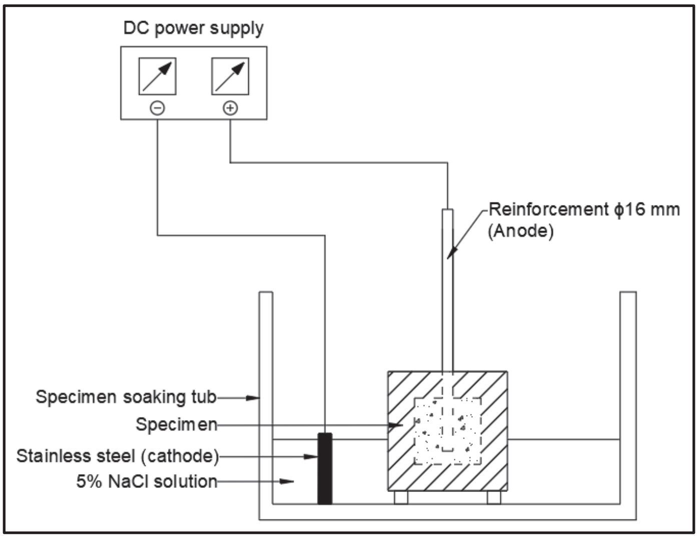

Fig. 5. Accelerated Corrosion Test ilustration

3 Results And Discussion

3.1 Weight Loss of Reinforcement steel

The calculation of the weight lost in the corrosion test is shown in Table 2. The most weight lost is at type D which is 194.3 gr/year. While the least weight lost in Type B amounted to 9.5 gr/year. The determination of the weight lost on the reinforcement is reviewed on the reinforcement embedded in concrete along 8 cm. Pictures of the corroded rebar before and after cleaning from rust are shown in Figures 6.

Table 2. Weight Loss of reinforcing steel

Name	Time	weight of reinforcing steel		weight loss		
		Initial	Final			
	(days)	(gr)	(gr)	(gr)	gr/days	gr/year
Type A	33	115.58	108.90	6.68	0.20	73.93
Type B	30	114.68	113.90	0.78	0.03	9.52
Type C	18	114.76	113.90	0.86	0.05	17.39
Type D	12	117.99	111.60	6.39	0.53	194.27

After 14 days, the reinforcement embedded in Sikagrout 215 OPC concrete rusted more than the reinforcement embedded in concrete with geopolymer mortar of 4 cm and 6 cm thickness in more than 20 days, and the geopolymer mortar of 2.5 cm thickness produced rust in a considerable time. This shows that the thickness of the geopolymer mortar layer is very high.

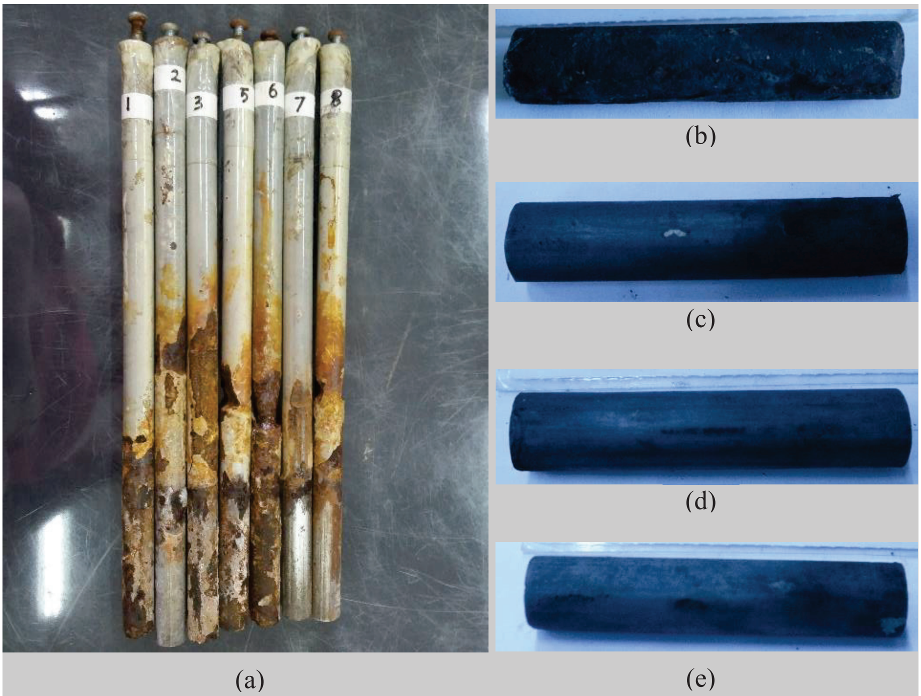

Fig. 6. (a) corroded rebar before cleaning from rust, (b) Reinforcement steel from type A after cleaning rust, (c) Reinforcement steel from type B after cleaning rust, (d) Reinforcement steel from type C after cleaning rust, and (e) Reinforcement steel from type D after cleaning rust

3.2 Corrosion rate

The acceleration of the current entering the reinforcement embedded in the concrete specimen to provide faster cracking until cracks appear on the surface. Observations were made every day in the form of reading the current entering each specimen which was then recapitulated in table 3.

Table 3. Observation of electric current on the cube specimen

Day to	Electrical current (mA)				Description
	Type A	Type B	Type C	Type D	
14	0.02	0.01	0.01	***0.12***	*Type A has been cracked*
21	0.04	0.05	***0.01***		*Type C has been cracked*
33	0.04	***0.10***			*Type B has been cracked*
36	***0.11***				*Type A has been cracked*

Specimen Type D cracked more quickly compared to another type specimen. Incoming electric current has a higher value than types A, B, and C. This is because of the various coating materials employed. Concrete coated with geopolymer mortar has lower inflow values and is more durable than Sikagrout 215M coatings.

To determine the corrosion rate of the specimen, the corroded reinforcement will be calculated based on the accelerated corrosion. The reinforcement will be weighed before and after corrosion to determine the weight lost. The corrosion time and the area of the reinforcement under review will be used to calculate the weight lost. Figure 7 shows the results of the corrosion rate measurements.

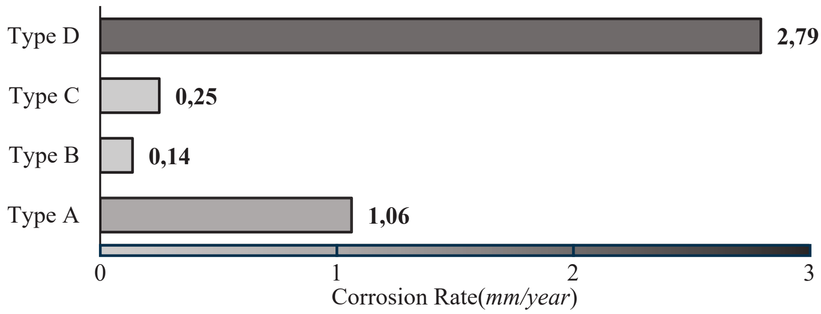

Fig. 7. Corrosion rate of specimen type A, B, C, and D

This illustrates the impact of the geopolymer mortar layer's thickness on rust formation on the reinforcement. The thinner the OPC concrete layer, the faster chloride ions penetrate and react with iron, compromising the passive layer of steel reinforcement. Subsequently, the exposed steel reinforcement reacts with oxygen, leading to the formation of rust on its outer surface. This indicates that a greater quantity of chloride ions infiltrates the OPC concrete at a layer thickness of 2.5 cm.

Chloride ions enter OPC concrete faster and react with iron, damaging the passivation layer of steel reinforcement. After the steel reinforcement is exposed, the reaction with oxygen causes rust on the outer layer. This shows that chloride ions enter more into the OPC concrete with a thickness of 2.5 cm. Fly ash is high in silica and aluminium, while alkaline activators use Na^+ to form stable Si-O-Al bonds in brine. This increases the compressive strength of the geopolymer. Although geopolymer concrete has more chloride ions, the corrosion rate is lower because the Na^+ in the concrete binds free Cl, reducing the potential damage to steel reinforcement. The ability of geopolymers to bind chloride is also related to the compressive strength of concrete in a salt water environment. [5,11–15]

4 Conclusion

The geopolymer mortar coating with a thickness of 2.5 cm cracked longer than the Sikagrout 215M coating. The geopolymer coating had a higher corrosion rate, but the 4 cm thick geopolymer mortar coating had the lowest corrosion rate.

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