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EXPERIMENTAL STUDY OF CORROSION POTENTIAL OF CONCRETE WITH VOLCANIC ASH OF MOUNT MARAPI AS PARTIAL REPLACEMENT OF CEMENT IN EXTREME EXPOSURE ENVIRONMENT

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Abstract. *Most of the damage to concrete structures is caused by corrosion of the reinforcing steel in the concrete due to chloride intrusion in the pores of the concrete, especially on structures exposed to extreme weather. The eruption of Mount Marapi in West Sumatera left a lot of volcanic ash and became waste around the affected areas. Using volcanic ash is known to make porosity tighter and inhibit the entry of chloride ions into concrete. This study aims to obtain corrosion potential in concrete with volcanic ash as a partial replacement for cement with the Half-cell potential method. A sample of 15x15x15 cm cube-shaped reinforced concrete with a thickness of 4 cm concrete blanket was made with a composition of 0%, 10%, and 20% volcanic ash. The properties of the concrete-forming material were tested to obtain the K-250 concrete mix design at 28 days. Samples were exposed to different exposure simulations, including being cured using wet cloths and other samples placed under extreme weather without treatment. The corrosion potential was tested using Ag/AgCl reference electrodes during the concrete treatment period of up to 28 days. The results showed that the use of volcanic ash gave a half-cell potential result of 0% VA substitution (extreme) on day 1 still tended to be high with a potential value of -201.61 mVvsCSE and a curing process of -200.17 mV vs CSE, a 10% VA substitution (extreme) value of -242.94 mV vs CSE and a curing process of -198.39 mV vs CSE, a 20% VA substitution (extreme) value of -215.83 mV vs SCE and curing of -221.61 mV vs CSE. On day 28 potential outcomes dropped significantly at VA 0% (extreme) -142.06 mV vs CSE and curing -99.06 mV vs CSE, substitution 10% (extreme) -209.83 mV vs CSE and curing -112.17 mV vs CSE, substitution 20% (extreme) -141.17 mV vs CSE and curing -102.61 mVvs CSE.*

Keywords: *Corrosion; Half-cell Potential; Ion Klorida; Volcanic Ash*

1. INTRODUCTION

Reinforced concrete is widely used for bridges, buildings, platforms, and underground structures such as tunnels or concrete pipes. In general, reinforced concrete is a highly durable material that can withstand a wide range of environments including marine, industrial, and mountainous conditions. Even though most of these structures show good long-term performance and high durability, there are still many concrete structure failures due to premature corrosion of reinforcement. Corrosion on the reinforcement embedded in the concrete causes most of the failure of the concrete structure. Until the 1950s, concrete carbonation was the main cause of corrosion. Since then, chloride-induced corrosion has become more important in structures exposed to chloride-containing environments (salt removal, marine climate, salt-contaminated aggregates) (Bohni, 2005).

Using volcanic ash is known to increase porosity to be tighter and inhibit the entry of chloride ions into the concrete to reach the reinforcement inside. The purpose of this study is to conduct an experimental study of K250 concrete material with the substitution of 0%, 10%, and 20% volcanic ash of Mount Marapi against corrosion potential. Concrete samples equipped with reinforcement are made to determine their corrosion potential.

2. LITERATURE REVIEW

Corrosion on the rebar can exhibit different bumps, ranging from widespread general corrosion to highly localized attacks (hole corrosion). General corrosion, mostly occurs in carbonated concrete, causing premature cracking and peeling of concrete, often with a relatively small reduction in the cross-section of the reinforcing steel rod, while local corrosion due to chloride ions results in holes, which are scattered randomly. Due to the carbonation of concrete or the ingress of chloride into the concrete, the de-passivation of the reinforcing steel occurs, causing rapid corrosion of the steel with a significant loss of cross-section. From a scientific point of view, the de-passivation of reinforcing steel and subsequent corrosion reactions are very complex due to the various interactions of environmental exposure conditions, the differences in the materials involved, as well as the design of the structure. (Bohni, 2005). The rust formation process on rebar steel is seen in Figure 1.

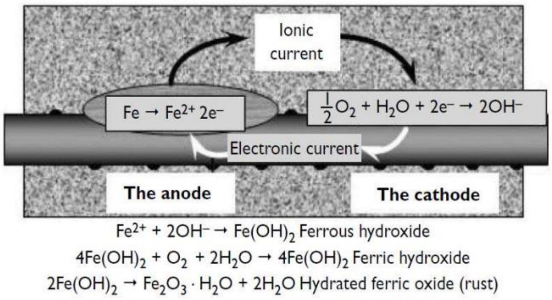

Figure 1. The process of corrosion in the reinforcement (Broomfield, 2007).

Corrosion on steel rebar, in addition to causing a reduction in surface area, also causes a volume of compounds resulting from corrosion reactions that are greater than the volume of reactive steel (Rasyid et al., 2021).

3. RESEARCH METHODS

a. Material

The materials used in this study include the following.

1. Portland Cement

   Hydraulic bonding material of the milled result Together Portland cement slag and cast with one or more inorganic materials, or the result of mixing Portland cement powder with other inorganic powders. These inorganic materials include blast *furnace slag*, pozzolan, silicate compounds, and limestone, with a total organic matter content of 6%-35% of the mass of composite Portland cement. (Badan Standardisasi Nasional, 2014).

2. Aggregate

   Aggregates are natural mineral granules that serve as fillers in mortar or concrete mixtures. Approximately 60-70% of the volume of mortar or concrete is filled by aggregate. Aggregate has a great influence on the properties of mortar or concrete, so the selection of aggregate so that the selection of aggregate is an important part of the manufacture of mortar or concrete. Aggregates can be differentiated by grain size. Aggregates that have a large grain size are called coarse aggregates, while aggregates that are small grains are called fine aggregates. In the field of concrete technology, the boundary value of the area of coarse aggregate and fine aggregate is 4.75 mm or 4.80 mm. Aggregates whose grains are smaller than 4.8 mm are called fine aggregates (Bambang Sujatmiko, 2019).

3. Water

   According to Tjokrodimuljo (1996), Water is one of the most important materials in the manufacture and treatment of concrete. The function of water in making concrete is to help the chemical reaction of cement and as a lubricant between cement and aggregate so that it is easy to work.

General requirements The water used for concrete mixtures must be clean, and must not contain oils, acids, alkalis, organic substances, or other materials that can damage the concrete or reinforcement. It is best to use fresh water that can be eaten. Water used in the manufacture of prestressed concrete and concrete in which aluminum metal will be embedded, including free water contained in aggregates, must not contain harmful amounts of chloride ions (ACI 318-89:2-2). In this study, the water used as a concrete mixture is water in the Civil Engineering Laboratory, University of Muhammadiyah West Sumatra.

4. Additional Ingredients
According to Trimulyono In general, additives used in concrete can be divided into two materials, namely chemical additives and mineral additives. In this study, pozzolan material in the form of volcanic ash from Mount Marapi, West Sumatra, will be used as a substitute for cement. This volcanic ash belongs to *the N-type* pozzolan and is a natural type of *pozzolan*. The volcanic ash used passed the No. 200 sieve to avoid the effect of the difference in grain size with cement on the strength of the concrete, and then the fly ash that passed the No. 200 sieve was used in the concrete mixture to replace part of the cement.

b**.** Testing *Hardened concrete properties*
The compressive strength of concrete is one of the main performances required by concrete. Compressive strength is the ability of concrete to receive a wide union compressive force. Although there is a small tensile stress in concrete, it is assumed that all compressive stresses are supported by the concrete. Determination of compressive strength can be carried out using a compression test device with a cylindrical test piece with ASTM C-39 test procedure or a cube with BS-1881 Part 115 procedure; Part 116 at 28 days of age. (Mulyono, 2021).

Compressive strength testing is adapted to the tools in the laboratory. Then record the compressive strength test results of each test piece. The test piece is made in the shape of a concrete cube of 15cmx15cmx15cm. The formula used to find the amount of compressive strength in normal concrete is as follows:

$$f'c = \frac{F}{A}$$

Information:

f'c = Compressive Strength (N/mm2)
F = compressive force (N)
A = surface area (mm2)

c. Testing *Half-cell Potential*
According to Fonna Dkk. (2017), *half-cell potential test* It is a simple test used to measure corrosion potential without damaging the concrete surface. *Half-cell potential test* uses *a digital multimeter* and a Silver – Silver/Chloride Electrodes *or Ag/Ag* reference electrode.

The half-cell potential test is performed by ASTM C876. The half-cell potential test scheme is depicted in Figure 2. The surface of the test piece is sprayed with water and allowed to dry for 20 to 30 minutes before a potential half-cell measurement is taken (Astuti et al., 2023).

This study uses a cube-shaped mortar test piece measuring 15cm x 15cm x 15cm with one BJTP rod with a diameter of 12 mm. Furthermore, 18 cube test pieces were made and treated as controls with a layer of steel, a concrete surface layer, and without a layer of coating concrete (non-coating).

Half-cell potential *testing* is carried out periodically every 7 days to obtain a comparative value of corrosion potential on the test specimen with a concrete blanket thickness of 4 cm. Based on ASTM C876, the classification of corrosion levels can be seen in Table 1.

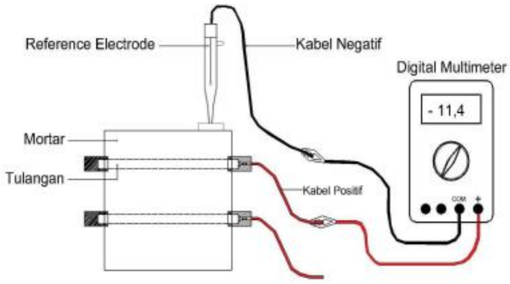

Figure 2. Test sketch *half-cell potential*

The reference electrode used for the half-cell potential test in the marine environment is SCE (silver-silver chloride electrode), so it must be converted to CSE (copper-copper sulfate electrode) to know the classification of corrosion levels according to ASTM C876-15 (ASTM, 2015) which can be seen in table 1 with equation 3.1.

Table 1. Corrosion classification (ASTM C876)

Table 1. The ASTM C876 criteria for corrosion risk of reinforced concrete [2].

Reference electrode $Cu/CuSO_4$	Reference electrode Ag/AgCl	Corrosion risk
≥ -200 mV	≥ -106 mV	Low (10% risk of Corrosion)
-200 to -350 mV	-106 to -256 mV	Intermediate corrosion risk
≤ -350 mV	≤ -256 mV	High (<90% risk of corrosion)
≤ -500 mV	≤ -406 mV	Severe corrosion

$$\text{Potential CSE} = \text{Potential SCE} - 74{,}5 - 1{,}66\,(t-25^{o}) \quad (3.1)$$

Information:
Potential CSE = Value Potential CSE (mV)
Potential SCE = Value Potential SCE (mV)
T = Air Temperature When Testing HCP Done (^{o}C)

d**.** Concrete Treatment or *Curing*

To avoid evaporation of water from the unhardened concrete, close the test specimen immediately after the final work, preferably with a non-absorbent and non-reactive plate or a strong, durable, and waterproof plastic sheet. Wet burlap can be used to close, but care must be taken to keep the burlap wet until the test piece is opened from the mold. Placing a plastic sheet on top of the burlap will protect the burlap from staying wet (SNI 2493, 2011).

The test piece that has been printed for 24 hours is removed from the mold and a curing process is carried out. The test piece was soaked for 28 days.

4. RESULTS AND DISCUSSION

a. *Aggregate properties*

This study used Padang Cement (PCC), gravel, and sand from Palembayan and Mount Marapi volcanic ash taken from Batang Aia Katiak.

Volcanic ash contains silica sand (SiO2) which is harmful to health, the greatest impact of volcanic ash occurs on the lungs and eyes. The dominant composition in Merapi volcanic ash is silica, alumina, iron, and calcium, so it is a material that can be used as a mixture or as a cement substitution material. (Girsang, 2017). Until now, Mount Marapi, West Sumatra's volcanic ash has economic value for the community, so it still has not utilized volcanic ash to its full potential. The following are the results of the aggregate property test in Table 2.

Table 2. Aggregate property test results

Cement	1. Specific Gravity	2.830
Fine Aggregate	1. Specific Gravity 2. Aggregate Volume Weight 3. Modulus of Fineness 4. Sieve Passing Material No. 200 5. Sludge Content	2.798 1.371 3.261 3.080 4.950
Coarse Aggregate	1. Specific Gravity 2. Aggregate Volume Weight 3. Modulus of Fineness 4. Moisture Content	2.594 1.609 4.548 1.237
Abu Vulkanik	1. Specific Gravity of Ash	1.498

Source: Personal Data, 2024

b. Property-hardened concrete

The compressive strength of concrete (fc') identifies the quality of a structure, meaning that the higher the level of strength of the desired structure, the better quality of concrete will be demanded. Concrete must be designed proportionately to the mixture to produce the average compressive strength required. At the construction implementation stage, the concrete that has been designed and mixed must be produced in such a way as to minimize the frequency of concrete with a compressive strength lower than fc' as required, that is, the concrete acceptance criteria must be by the applicable standards or accordance with the SNI 2847: 2013 (Mulyono, 2021).

The compressive strength of concrete will increase with the increase in the age of concrete. The strength of concrete will increase rapidly (linearly) until the age of 28 days, but after that, the increase will be small. The compressive strength of concrete in certain cases will continue to increase for several years in advance. Usually, the compressive strength of concrete plans is calculated at the age of 28 days. The rate of increase in the age of concrete is highly dependent on the use of cement materials because cement tends to directly improve its pressing performance (Bambang Sujatmiko, 2019).

The testing of this test piece is carried out at the age of 28 days or after passing the curing process period, including a compressive strength test on normal concrete with a variation of 0%. The results are shown in table 2.

Sample Name	Heavy (kg)	Broad (mm2)	Load (KN)	Load (N)	Compressive Strength (MPa)	Kg/cm2	SD	∑	fc' (Mpa)
a	b	c	d	e = (d) x 1000	f = (d) / (c) x 10	g = (g) x 0.83 x 10	h	i = (g) + (h)	j = (i) x 0.083
1	7,321	225000	460	460000	20,44	246,32	9,117	255,44	21,201
2	7,013	225000	470	470000	20,89	251,67	9,117	260,79	21,645
3	7,327	225000	480	480000	21,33	257,03	9,117	266,15	22,090

4	7,128	225000	435	435000	19,33	232,93	9,117	242,05	20,090
5	7,250	225000	445	445000	19,78	238,29	9,117	247,40	20,534

Average compressive strength = 21,11 MPa
Source: Personal Data, 2024

The results of the study on normal concrete with a 0% variation were obtained at 21.11 MPa.

c. *Mix Design*

The mixing method to determine the proportion of materials (*mix design*) is determined through a concrete design (mix design). This is intended so that the proportion of the mixture can meet the strength requirements and can meet the economic aspect. This design method determines the composition of the constituent materials of concrete for a certain expected performance. (Mulyono, 2021).

After getting the design mix with maximum compressive strength, the mixture is used to mix normal concrete designs with fc' 20.75 MPa. The results of the design mix can be seen in Table 3.

Table 3. Normal concrete design mix results/1m^3 fc' 20,75 MPa

1	Cement	1.268	kg
2	Water	0.685	kg
3	Fine Aggregate Field Conditions	1.859	kg
4	Gross Aggregate Field Conditions	3.154	kg

Personal Data, 2024

Concrete can contain several trapped air cavities, or it can also contain air cavities that are deliberately inserted through the addition of additional materials. Chemical additives are often used to accelerate, slow down, improve workability, reduce mixing water, increase strength, or change other properties of the resulting concrete. Some cementitious materials such as fly ash, natural pozzolan/tras, high kiln slag flour, and silica powder can be used together with hydraulic cement to reduce the price or to impart certain properties such as reducing the heat of initial hydration, increase the development of final strength, or increase resistance to alkali-aggregate reactions or sulfate attack, increase density, and resistance to the ingress of destructive solutions. (Mulyono, 2021).

Mix fc' 20.75 MPa concrete design with an additional mixture of volcanic ash of 10% and 20% of the weight of cement. The results of the design mix are Table 4 and Table 5.

Table 4. Design mix results/1m3 composition of ash substitution elements 10%

1	Cement	1.268	kg
2	Water	0.685	kg
3	Fine Aggregate Field Conditions	1.859	kg
4	Gross Aggregate Field Conditions	3.154	kg
5	Abu Vulkanik 10%	0.126	kg

Personal Data, 2024

Table 5. Design mix results/1m3 composition of ash substitution elements 20%

1	Cement	1.268	kg
2	Water	0.685	kg
3	Fine Aggregate Field Conditions	1.859	kg
4	Gross Aggregate Field Conditions	3.154	kg
5	Abu Vulkanik 20%	0.253	kg

Personal Data, 2024

e. *Corrosion probability of half-cell potential testing*

The half-cell potential test in this study is divided into two parts: the immersion phase and extreme conditions. The test is carried out for 28 days during the treatment period after the test piece is removed from the formwork to compare the potential value of the test piece with the prevention of steel coating and the control test piece (non-coating) (Astuti et al., 2023).

During the treatment period, the potential test results are more than -200 mV vc. CSE, it can be interpreted that the reinforcement is still in a 90% corrosion-free condition. On the first day, the potential value of corrosion is still high, around -200 mV vs CSE, but the potential value drops significantly on the next day. It can be seen in the following table 7:

Table 7. Half-cell potential test results

	mV, CSE					
	VA0%		VA10%		VA20%	
day	**EKSTRIM**	**RENDAM**	**EKSTRIM**	**RENDAM**	**EKSTRIM**	**RENDAM**
1	-201.61	-200.17	-242.94	-198.39	-215.83	-221.61
3	-204.72	-179.28	-218.17	-190.06	-164.72	-165.94
7	-172.17	-138.28	-145.28	-161.61	-169.28	-141.28
14	-149.61	-133.83	-138.17	-141.17	-135.06	-136.50
21	-125.17	-118.39	-128.61	-115.50	-119.94	-110.94
28	-142.06	-99.06	-209.83	-112.17	-141.17	-102.61

The results of corrosion testing using half-cell potential can be seen in the following figure.

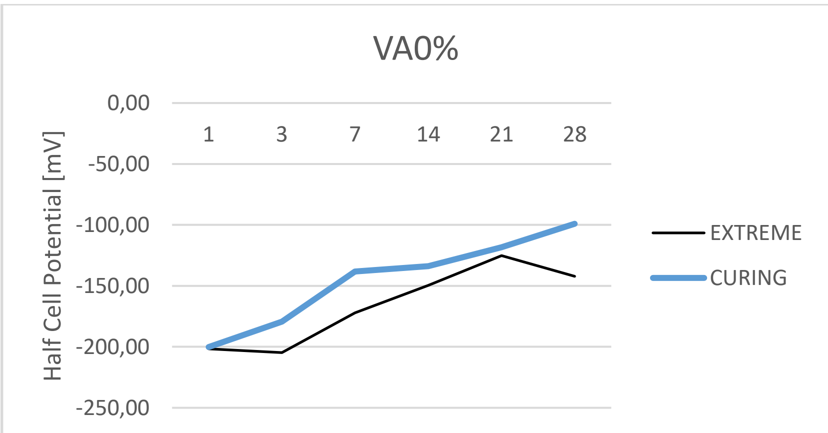

Figure 3. Corrosion test results using half-cell potential VA 0%

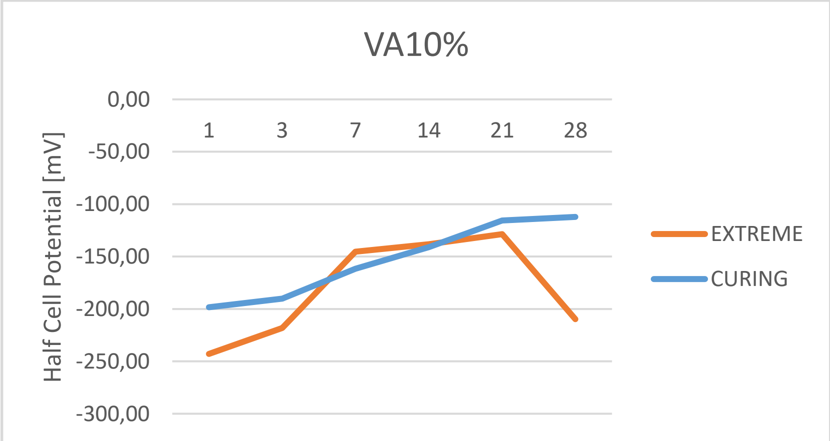

Figure 4. Corrosion test results using half-cell potential VA 10%

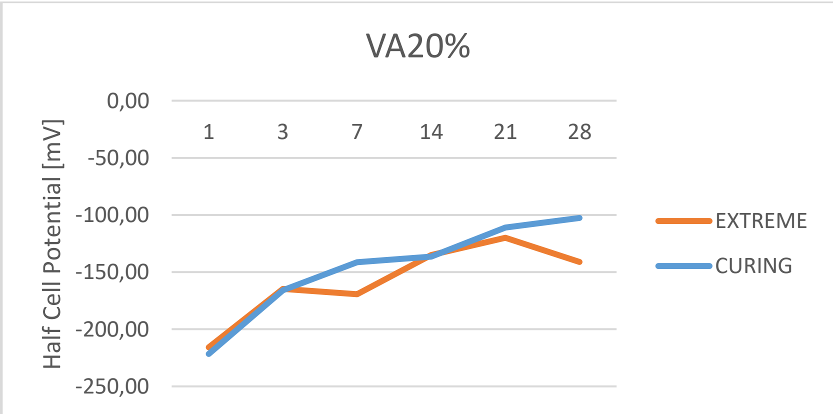

Figure 5. Corrosion test results using half-cell potential VA 20%

CONCLUSION

1. The difference between curing and extreme based on research conducted on the cured concrete process that produces corrosion is lower than concrete that is left in extreme weather without maintenance.
2. The effect of adding VA during the corrosion process is longer and can increase the porosity to tighter and inhibit the entry of chloride ions into the concrete.
3. Meanwhile, the effect of adding extreme VA is faster and the value is higher than the cured VA.
4. the addition of VA to concrete can increase porosity to be tighter and inhibit the entry of chloride ions into the concrete to reach the reinforcement inside.
5. Since there are some fluctuating results for further testing, it is considered to use a 20% VA >%.
6. The measurement time was extended to> 28 days, this was done to obtain more detailed data.

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