Corrosion Control by Using Aluminium as Sacrificial Anode Cathodic Protection (SACP) in Geopolymer Reinforced Concrete

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Abstract. This paper presents corrosion control by using Aluminium as Sacrificial Anode Cathodic Protection (SACP) in geopolymer reinforced concrete. Geopolymer concrete for this research are the combination and reaction between kaolin, which is acting as a binder, fine aggregates such as river sand, coarse aggregates and an alkaline activator which contain 12 M of sodium hydroxide (NaOH) solution and sodium silicate (Na₂SiO₃) solution with the ratio of NaOH/Na₂SiO₃ is 0.8. There are two types of sample preparation in this experiment which are the control sample without attaching with Aluminium and SACP sample that attach to Aluminium. Three testing were conducted in this research such as compressive strength, open circuit potential and gravimetric weight loss method and these results were observed after days 7 and 14. Compressive strength testing for this geopolymer concrete shows that the highest compressive strength was at sample 14 days which is 7.04 MPa while sample 7 days is 3.96 MPa. The result shows the potential values of SACP samples were lower than the control sample for both 7 and 14 days. The potential values for the SACP sample for 7 and 14 days are 0.0152 V and -0.037 V while for control sample was 0.048 V and 0.051 V respectively. From the Pourbaix diagram, the control sample was located in the passivity region while SACP sample was located in the immunity region. The corrosion rate of the reinforcement bar in concrete has been performed by the gravimetric weight loss method. Analysis of the resulting proved that the corrosion rate of SACP sample was lower than the control sample for both 7 and 14 days, which were 3.60 x 10⁻⁵ mm/yr and 1.427 x 10⁻⁵ mm/yr respectively. This is due to the presence of Aluminium which act as the sacrificial anode that protects reinforcement bar in geopolymer concrete from the corrosive agent.

1. Introduction

Geopolymer is an inorganic alumina-silicate polymer which reduces the emission of carbon dioxide (CO₂) to the atmosphere and can produce a friendly environment concrete [1, 2]. The polymerization process can occur under alkaline case which afterward constitutes a three-dimensional polymeric chain of Si-O-Al-O bonds under a quick reaction. However, for OPC or pozzolanic cement geopolymer...
utilizes the polycondensation of silica and alumina and a huge alkali content to reach compressive strength [3-6]. Geopolymer concrete exhibits superior-good mechanical strength and durability properties than ordinary Portland cement (OPC) concrete [7, 8]. Kaolin was used as a raw material or source of alumina-silicate because of its unique physical and chemical properties. Kaolin particles can easily transform into another shape or particle due to the endothermic process or dehydroxylation process which involved heat [9]. Kaolin also was selected to investigate how much kaolin can stand alone in geopolymer synthesis as well as to remove the complex interpretation of results as a result of the utilization of complex raw material with the presence of impurities [10-13].

Corrosion was the major reason for the degradation of reinforced concrete structure [14]. The main corrosion problem all over the world was the deterioration of reinforced concrete structures due to chloride-induced corrosion. Corrosion can give a big impact on to the steel with the formation of rust which is had a greater volume than the steel depends on its environment [15]. Pitting corrosion was usually occurs in the marine environment while general corrosion usually occurred due to the carbonation of the surrounding concrete [14]. Corrosion was never can be stopped but we can reduce the corrosion with a method based on technology such as Sacrificial Anode Cathodic Protection (SACP) [16]. SACP was successfully being used in embedded structures or a substructure of reinforced concrete [17]. Usually, the metal alloy in galvanic series which has more negative electrochemical potential than the steel reinforcement of the structure will be select as a sacrificial anode. A positive current will flow in the electrolyte because of the difference of potential between the anode and the protected steel. Thus, it will make the protected steel more negatively charged and become cathode. The sacrificial metal alloy will corrode instead of the protected steel because of its position in the galvanic series.

2. Experimental Methodology
This materials used in this project are kaolin, alkaline activator, fine aggregates, coarse aggregates, mild steel and aluminium. The first step in doing this project is to sieve the kaolin by using 63 micrometers size of sieve. The elemental composition of the kaolin was then determined by X-Ray Fluorescence (XRF) analysis. Alkaline activator was prepared by a mixture of the sodium hydroxide (NaOH) solution and sodium silicate (Na₂SiO₃) solution to activate the kaolin. The ratio of solid to liquid was 0.8 while the ratio between the kaolin, fine aggregates and coarse aggregates was 1:1.5:3.3. The alkaline activator needs to be stored at least one day prior to use to allow both of the solutions to achieve an equilibrium state.

Mild steel was used as the reinforcement bar that will be embedded in a geopolymer concrete sample for corrosion measurement. The mild steel bars were lathed to remove the contaminants to make sure the result is precise. Then, the mild steel undergoes an Arc Spark Spectrometer (OES) to analysis the composition of the mild steel that used in this project. Kaolin, fine aggregates and coarse aggregates were then combined with the alkaline activator and become the geopolymers concrete. The mixture is then rapidly poured into two steel moulds. Then both moulds will be embedded with mild steel. Each mould size was 100 mm x 100 mm x 100 mm. There were two types of samples in this research; first is geopolymer concrete with embedded mild steel will act as a control sample and the second is geopolymer concrete with embedded mild steel will be attached with the Aluminium to undergo Sacrificial Anode Cathodic Protection (SACP) method [15].

After the moulding process, all samples were taken out from the moulds and will undergo a curing process in the oven with 60°C for 24 hours to achieve excellent mechanical properties. Compressive strength, Open Circuit Potential (OCP) and Gravimetric Weight Loss method testing were performed when the sample was fully hardened and completely cure after 7 and 14 days. machine.

2.1. Materials Characterization
Kaolin was supplied by Associated Kaolin Industries Sdn. Bhd., Malaysia. The general chemical composition is tabulated in table 1. Mild steel used in this experiment were locally produced steel bars.
The chemical composition of the mild steel is stated in table 2 while the chemical composition of Aluminum used in this experiment as shown in table 3.

| Compound | Concentration (%) | Compound | Concentration (%) |
|----------|-------------------|----------|-------------------|
| SiO₂     | 56.5              | MnO      | 0.042             |
| Al₂O₃    | 37.3              | ZrO₂     | 0.035             |
| K₂O      | 2.50              | CuO      | 0.031             |
| Fe₂O₃    | 2.06              | V₂O₅     | 0.028             |
| TiO₂     | 0.764             | Ga₂O₃    | 0.015             |
| CaO      | 0.284             | Cr₂O₃    | 0.012             |
| RuO₂     | 0.185             | ZnO      | 0.011             |
| Rb₂O     | 0.0782            | Y₂O₃     | 0.0099            |
| BaO      | 0.065             | Re₂O₇    | 0.007             |
| Eu₂O₃    | 0.063             | As₂O₃    | 0.004             |

### Table 1. Chemical Composition of Kaolin

| Element | Weight (%) | Element | Weight (%) |
|---------|------------|---------|------------|
| Fe      | 98.30      | P       | 0.013      |
| Mn      | 0.546      | W       | 0.019      |
| C       | 0.269      | Sn      | 0.011      |
| Cu      | 0.206      | Co      | 0.010      |
| Si      | 0.183      | Mo      | 0.010      |
| Al      | 0.127      | Nb      | 0.0050     |
| Cr      | 0.080      | Ti      | 0.0050     |
| Ni      | 0.052      | V       | 0.0050     |
| S       | 0.033      | Total   | 100%       |

### Table 2. Chemical Composition of Mild Steel

| Element | Weight (%) | Element | Weight (%) |
|---------|------------|---------|------------|
| Al      | 99.40      | Cr      | 0.0015     |
| Fe      | 0.375      | Pb      | 0.00096    |
| Si      | 0.093      | Na      | 0.00075    |
| Cu      | 0.055      | Bi      | 0.00070    |
| Mg      | 0.020      | P       | 0.00064    |
| Ti      | 0.013      | Ca      | 0.00041    |
| V       | 0.010      | Zr      | 0.00028    |
| Mn      | 0.0096     | Cd      | 0.00011    |
| Hg      | 0.0072     | Sr      | 0.00010    |
| Ni      | 0.0039     | Ag      | 0.00010    |
| Sn      | 0.0030     | Co      | 0.00010    |
| Zn      | 0.0023     | Be      | 0.00010    |
2.2. Testing

2.2.1. Compressive Strength
The samples undergo a compressive strength test after 7 and 14 days. In this research, a Universal Testing Machine (UTM) Shimadzu 1000 kN was used [19-21].

2.2.2. Open Circuit Potential
Open Circuit Potential (OCP) is a method of measuring the potential of metal. In this process, there is no flow current involved. The OCP values were measured by using a digital multimeter in units of volts [20]. The thermodynamic tendencies for the metal to corrode will be interpreted using the Pourbaix diagram. The potential of the working electrode in the cell is relative to the reference electrode. The Sanwa digital multimeter CD 771 was used to measure the potential difference between the steel in the concrete and the metal in the reference electrode [24, 25]. The positive side was connected to the reinforcement bar embedded in the geopolymer paste while the negative side was connected to the reference electrode. The potential value that gets from the OCP then will be interpreted using a Pourbaix diagram of Iron (Fe-H2O) at 25°C to determine which region the value was located. The Pourbaix diagram had a three region which is passivity region, immunity region and corrosion region.

2.2.3. Gravimetric Weight Loss Method
In this method, the contrast weight of the mild steel before and after were prioritized to calculate the weight loss. The reinforced geopolymer concrete was immersed in a 3% sodium chloride solution. Usually, this process will take 15 days to be done. After 15 days, the mild steel in the geopolymer concrete is taken out and cleansed followed by the method in ASTM G1 [26]. Then, the final weight was obtained. The corrosion rate was assessed from the difference in weight loss values between the initial and final exposure period, as reported elsewhere. The corrosion rate was calculated using the following equation (1).

\[
\text{corrosion rate (mmpy)} = \frac{87.6 \times W}{D \times A \times T}
\]  

Where,
- \(W\): The weight loss in milligrams (mg)
- \(D\): The density of the material used
- \(A\): The area of the specimen (cm²)
- \(T\): The test period in hours (h)

3. Results and Discussions

3.1. Compressive Strength
The compressive strength results of this research as shown in figure 1. From figure 1, it is clearly showing that the compressive strength at 14 days was higher than the 7 days sample which the results are 7.04 MPa and 3.96 MPa respectively. Based on previous research, the compressive strength was directly proportional to the curing time. Which means, the strength will increase when the curing time was increased [24]. The same goes for the concentration of NaOH, the strength will increase upon the concentration increase. However, there is a limit for it. The strength will only increase until 12 M concentration of NaOH. 12 M was the optimum concentration for activating the kaolin thus will increase its strength [28]. If the concentration was more than 12 M the strength will slightly decrease because of excess Na⁺ ion. The function of Na⁺ ion in geopolymerization was for balanced the negative charge created by the formation of Si-O-Al bond or non-bridging oxygen ion remained in the system. While OH⁻ ion is consumed during hydrolysis of kaolin.
3.2. Open Circuit Potential

Open Circuit Potential (OCP) is used to determine the corrosion in reinforced geopolymer concrete. Figure 2 shows the graph of time (days) versus the potential (volts) of reinforced geopolymer concrete for both samples. Clearly shows on the graph below that the potential value of the SACP sample for both days is lower than the control sample. The potential value of the control sample for 7 and 14 days was 0.048 V and 0.051 V respectively. While the potential value of the SACP sample for 7 and 14 days was 0.0152 V and -0.037 V. Analysis was continued by interpreting the value in the Pourbaix diagram to determine the region of the value. To enable interpreting the value used by the Pourbaix diagram, the pH of the geopolymer concrete for both samples must be determined by using pH paper. The pH of the geopolymer determined was 12. From the Pourbaix diagram, all potential values for the control sample were located in the passivity region while the SACP sample located in the immunity region.

![Figure 1. The compressive strength analysis for 7 and 14 days](image)

![Figure 2. Graph of redox potential versus time (day) in both samples reinforced geopolymer concrete with and without SACP](image)
3.3. Gravimetric Weight Loss Method
The corrosion behaviour of mild steel in geopolymer concrete was determined by using the Gravimetric Weight Loss method. This test revealed that the SACP sample had a lower corrosion rate than the control sample for 7 days and 14 days curing time. The corrosion rate of the SACP samples for 7 and 14 days were $3.600 \times 10^{-5}$ mm/yr and $1.427 \times 10^{-5}$ mm/yr respectively. However, for control sample corrosion rate for both 7 and 14 days stated a value of $3.315 \times 10^{-4}$ mm/yr and $1.162 \times 10^{-4}$ mm/yr respectively. The corrosion rate of SACP sample was low because of the Aluminium that had been attached to mild steel in the geopolymer concrete. It helps the mild steel from being attacked by the corrosive agents. Aluminium was chosen as the sacrificial anode because it is more reactive and had higher electronegativity compared to mild steel in the galvanic series. Hence, it will give up its electron instead of mild steel and starting to corrode.

4. Conclusions
Research to solve the corrosion problems in concrete had been done successfully as the result also had been very promising. Referring to the results and discussion part, it seems reasonable to conclude as below:

i. Compressive strength testing for this geopolymer concrete shows that the highest compressive strength was at 14 days which is 7.04 MPa while 7 days is 3.96 MPa.

ii. Open Circuit Potential (OCP) test methods shows that the potential value of the SACP sample was lower than the control sample for both 7 and 14 days. By referring to the Pourbaix diagram, the potential value of the SACP sample was located in the immunity region while the potential value of the control sample was located in the passivity region.

iii. Gravimetric Weight Loss method proves that the corrosion rate of the SACP sample is lower than the control sample for both 7 and 14 days. The results for SACP sample for 7 and 14 days was $3.600 \times 10^{-5}$ mm/yr and $1.427 \times 10^{-5}$ mm/yr while for Control sample was $3.315 \times 10^{-4}$ mm/yr and $1.162 \times 10^{-4}$ respectively.

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