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Effects of Si Addition on the Corrosion Susceptibility of Aluminium Alloys in Different Concentrations of NaOH, and NaCl Solutions

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ABSTRACT
This study examines the effect of silicon addition at 5%, 10%, and 15% by weight on the corrosion susceptibility of aluminium alloys in 0.5 M and 1.0 M sodium hydroxide (NaOH) solutions, as well as 0.5 M and 1.0 M sodium chloride (NaCl) solutions. The aluminium was moulded and furnished, and the alloys were exposed to these corrosive environments for durations ranging from 168 to 672 hours. The corrosion behaviour of the alloy samples was assessed by measuring the weight loss, from which the corrosion rate was calculated. The results showed that the normal corrosion rate profile was observed as the reinforcement phase increased, and the samples increased in weight. This indicates continuous passivation, particularly in the 10% Si alloy content resulted in a low corrosion rate of the alloy, which was significantly lower than the other concentrations, indicating superior resistance. Based on these findings, it is recommended to optimize the silicon concentration at 10% for enhanced corrosion resistance in alkaline and salty corrosive environments. These alloys, with corrosion rates ranging from 0.01 to 0.05, are well suited for aerospace, marine, automotive, and chemical processing plant applications where materials are exposed to corrosive conditions and require durability.

Keywords:
NaOH,
NaCl,
Silicon,
Aluminium,
Corrosion rate,
Exposure time.

INTRODUCTION

Aluminium alloys have gained wide attention in various industrial applications due to their lightweight, excellent mechanical properties and corrosion resistance. The most important alloying elements for aluminium are copper, manganese, silicon, magnesium, and zinc; other elements are also added in smaller quantities to refine the grain and develop special properties (Anil, 2001; Emmanuel *et al.*, 2021). The automotive and aviation industries developed various aluminium alloys with high tensile strength. Silicon as the main alloying element in Al-Si alloys increases the fluidity of liquid aluminium, reduces volume contraction during solidification, reduces porosity and thermal expansion coefficient, and improves weldability (Alpas and Zhang, 2016; Davis, 2018).

The addition of silicon (Si) to aluminium alloys significantly affects their corrosion resistance, especially in alkaline environments such as NaOH. Silicon promotes the formation of a protective oxide film on the alloy surface, which is critical to preventing deterioration. This oxide layer acts as a barrier against aggressive ionic attacks, increasing durability under corrosive conditions (Totten, 2003; Quadri et al., 2021; Shahidi et al., 2015). In NaOH environments, corrosion behaviour is significantly improved due to passive film stabilization, as observed in experimental studies showing lower corrosion rates for Si-containing alloys compared to those without Si. Such results indicate the effective role of Si in reducing susceptibility to corrosion and highlight its potential for application in industries where aluminium alloys are routinely exposed to alkaline solutions. In addition, Si's ability to form stable intermetallic compounds further increases corrosion resistance, making it an essential element for optimizing aluminium alloys (Kosari *et al.*, 2020; Samiul *et al.*, 2020; Sieniawski, 2011; Alaneme *et al.*, 2014; Ong *et al.*, 2021).

The susceptibility of these alloys to corrosion is strongly influenced by their composition elements, particularly silicon (Si). The addition of silicon can significantly alter the electrochemical behaviour of aluminium in harsh environments, such as those containing sodium hydroxide (NaOH), sodium chloride (NaCl), and sulfuric acid (H_2SO_4) (Alaneme *et al.*, 2011; Liao *et al.*, 2011; Ikeuba *et al.,* 2024; Zuchry *et al.*, 2023, Haque *et al.,* 2023). In aggressive media such as NaOH and H2SO4, the presence of Si can promote the formation of a stable protective layer on the aluminium surface and potentially reduce corrosion rates. Conversely, increased NaCl concentrations can lead to local corrosion, exacerbated by the silicon content. Understanding the interactions between Si additives and corrosion processes in aluminium alloys is crucial for optimizing their performance in applications exposed to harsh environmental conditions (Roland et al., 2017; Ahmed *et al.*, 2024; Zehr *et al.*, 2022; Assad and Kumar, 2021; Thompson et al., 1999; Nayem *et al.,* 2023). This fundamental knowledge provides the basis for further investigations into silicon's specific effects on these alloys' corrosion susceptibility.

The addition of silicon (Si) to aluminium alloys has been shown to significantly influence their corrosion behaviour in salty and alkaline environments, especially in NaCl and NaOH solutions. Studies show that as Si content increases, the susceptibility of aluminium alloys to corrosion varies significantly depending on salt concentration. For example, the performance of Si-rich alloys in 2 M H_2SO_4 in a controlled environment showed reduced corrosion rates, especially at lower NaCl concentrations, with an impressive maximum inhibition efficiency of 90.84% at 20% SiC content. Conversely, higher NaCl concentrations generally resulted in increased corrosion rates, indicating the dual roles of environmental factors and Si in these processes (Abbas et al., 2017; Roland and Mfon 2019; Hossain et al., 2022). In addition, ongoing research illuminates the broader context of corrosion resistance technologies and highlights the application of Si-reinforced materials in a variety of areas, from daily life to the semiconductor industry, underscoring the importance of continued study of corrosion mechanisms. This investigation aims to study the effects of Silicon additives on the corrosion susceptibility of aluminium alloys in different concentrations of NaOH, and NaCl solutions.

MATERIALS AND METHODS

Experimental

Figure 1: Laboratory stir casting set up for the production of Al-Si alloys

Aluminium-silicon alloys were prepared with different weight percentages of silicon by stir casting method in a charcoal-based furnace are shown in Figure 1. The alloys were prepared by melting commercially pure aluminium (99.7%) and commercially pure silicon (99.5%) in a charcoal-based furnace and the melt was held at 720 °C and stirred for 30 s to attain homogeneous composition. Then each of the Al-Si alloys formed for the 5%Si, 10%Si, and 15%Si were poured into the required mold surrounded by fireclay bricks. The cast samples were cut using a hand saw into the required dimensions of 2 cm length, 1.8 mm breath, and 1.8 mm thickness and sanded mechanically with emery papers of rough and finish grade of 600-1200 grits, and then finally subjected for the corrosion test. The coupon is removed and cleansed with acetone after a stipulated time interval. It is then weighed to determine the final weight. From the weight loss of the coupons, the corrosion rate (CR) of mild steels was calculated using the expression (Callister, 2003).

$$\text{Corrosion Rate} = \frac{K\Delta W}{\rho A T} \quad (1)$$

Where K = Rate constant equal to 543, ΔW = Weight loss in g, ρ = Density of material in gcm^{-3}=7.86gcm^{-3}, T = Exposure time in hours, A = Exposed area of coupon in cm^2

CR = Corrosion rate, millimetre per year (mm/yr).

RESULTS AND DISCUSSION

Experimental results obtained in the course of this study include weight loss and corrosion rates used after seven (7) days intervals for twenty-eight (28) days. The graphs of corrosion rates versus exposure time at various Al-Si alloy compositions are shown in Figures 1 to 6.

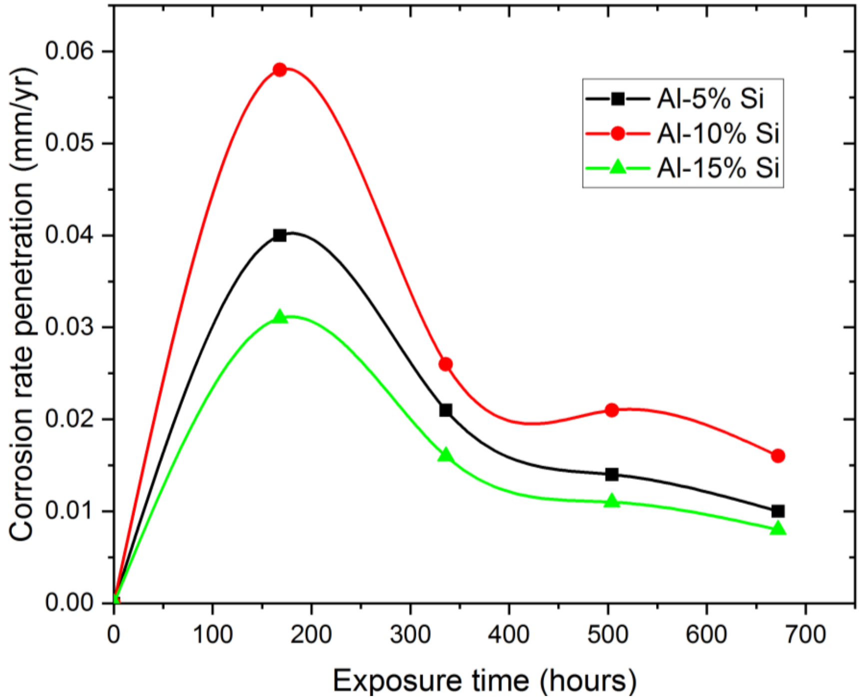

Figure 2: Variation of the corrosion profiles of Al-Si Alloy at a concentration of 0.5M NaCl medium

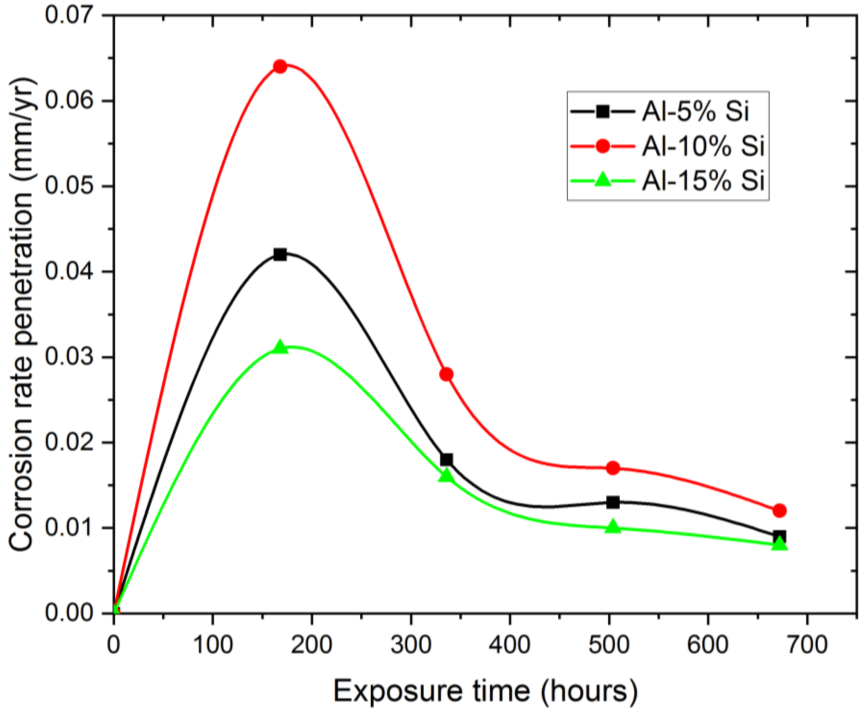

Figure 3: Variation of the corrosion profiles of Al-Si Alloy at a concentration of 1.0 M NaCl medium

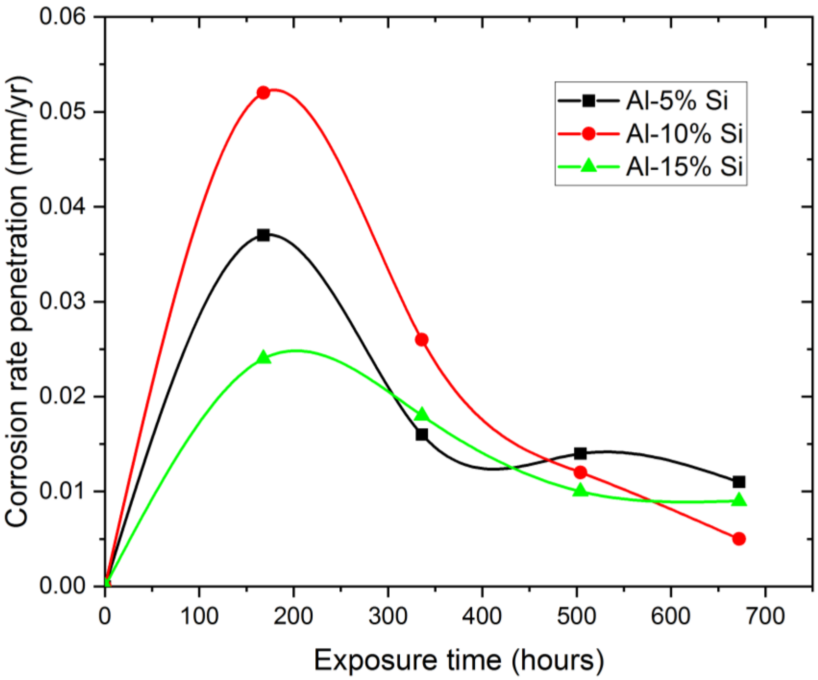

Figure 4: Variation of the corrosion profiles of Al-Si Alloy at a concentration of 0.5 M NaOH medium

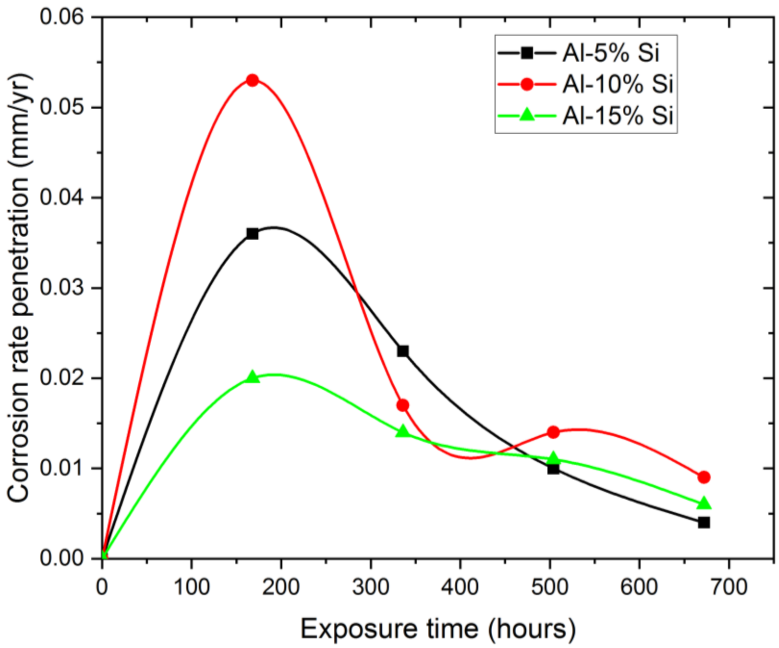

Figure 5: Variation of the corrosion profiles of Al-Si Alloy at a concentration of 1.0M NaOH medium

From Figure 2, the normal corrosion rate profile for passivating metal can be observed at the intermediate concentrations and for all alloy samples. There was a progressive increase in corrosion rate, peaking after an average of 168 hours of exposure before decreasing over time. This means that the rate of ion adsorption on the metal surface was high within the first 168 hours, but as ion migration to the metal surface increased, the passivation rate decreased due to the competition of the ions for the available surface area. In terms of alloy composition, the Al-10%-Si alloy showed the highest values of corrosion rates and was therefore the most passivated and, by extension, the most affected. This suggests that Al-10% Si may well represent the maximum solid solubility of Si in Al; corresponding to the maximum grain boundary concentrations. Therefore, increased kinetics of the corrosion reaction is expected since grain boundaries are known to be favorable sites for corrosion attacks (Ekuma and Idenyi, 2006; Kisasoz et al., 2018).

Figure 3 shows the variation of corrosion rate with duration of corrosion of Al-Si alloy in 1.0 M NaCl media. It can be seen from the figure that the normal corrosion profile for passivating metals was observed. This involves a sharp increase in corrosion rate followed by a gentle decrease with increasing duration. The decrease in corrosion rate was very high in the first six days of the experiments and then slowed down. This is due to the formation of a thin oxide film on the surface of the coupon, which acts as a barrier between the surface of the coupon and the medium itself. The figure also confirmed that the loss of corrosion rate of the alloy decreases as the composition of Al-Si solution increases, indicating good corrosion inhibition performance of the alloy used in this study. This is consistent with the results of current research (Alaneme and Bodunrin, 2011; Kharitonov *et al.*, 2020).

Figure 4 shows the variation of the corrosion rate with the exposure time for the corrosion of an Al-Si alloy at a concentration of 0.5 M NaOH solution. The result shows that the corrosion rate of Al-Si alloy in 0.5 M NaOH was lower than that of Al-15% Si alloy. The figure shows that the corrosion rate of Al-Si alloy decreases with increasing contact time, but decreases with increasing alloy composition, indicating that the Si actually inhibits the corrosion of Al-Si in NaOH solution. As the composition of the alloy increased, the corrosion rate decreased exponentially. This observation may be due to the formation of a continuous passive film on the surface of the metal, which is due to the higher composition of the alloy in the alkali (MacKenzie, 2018).

Figure 5 shows the variation of corrosion rate with exposure time for the corrosion of an Al-Si alloy in 1.0 M NaOH solution. The calculated corrosion rate values for the Al-Si alloy samples in 1.0 M NaOH at different immersion times are shown in Figure 4. The result shows that the corrosion rate of the Al-Si alloy samples in 1.0M NaOH was lower in 0.5M NaOH solution. The figure shows that the corrosion rate of mild steel decreases with increasing contact time, but decreases with increasing Al-Si alloy composition. Si is effective in slowing the corrosion rate of metals exposed to an alkaline environment. However, with a higher Si alloy composition, the corrosion rate decreased with increasing exposure time in alkali. As the Si composition increased, the corrosion rate decreased exponentially. This observation may be due to the formation of a continuous passive film on the surface of the metal due to the higher composition of Si in the NaOH. This film serves as a strong barrier that prevents alkali solution from penetrating the metal surface, thereby preventing corrosion of the metal in the alkaline medium in the presence of higher Si composition (Shahidi *et al.*, 2015; Deepa *et al.*, 2017)

In comparison, the different compositions of the Al-Si alloy in the different concentrations of NaOH solutions at different exposure times showed that the Al-10% Si alloy had the best inhibitory effect in all test solutions compared to the Al-5% Si alloy and Al-15%Si alloys. In this case, we can say that for a reasonable degree of corrosion inhibition of the test sample in alkali (NaOH), Al-10% Si alloy should be used instead of Al-5% Si and Al-15% Si alloy.

CONCLUSION

In this study, the corrosion behaviour of Al-Si alloys in acid, base, and salt environments was investigated. The results show a general trend of decreasing corrosion rate with exposure time for the alloy compositions used in this study. In particular, the decrease for Al-10% Si alloy was quite exponential in all environments used in the study. The study further concludes that this observation is an indication that these conditions can be exploited to achieve minimal corrosion effect on Al alloys in alkaline and saline media under the influence of such Al-Si alloy. These findings underscore the importance of optimizing Si content to achieve the desired balance between mechanical properties and corrosion resistance. Future research should further explore the synergistic effects of other alloying elements alongside Si to enhance the performance of aluminium alloys in aggressive environments. It is therefore recommended that further research be carried out to determine the minimum composition of the alloy used in the acidic environment.

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