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Research Article

Investigating the Microstructure, Tensile Strength, and Acidic Corrosion Behaviour of Liquid Metal Stir Casted Aluminium-Silicon Carbide Composite

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The main objective of this investigation is to study the microstructural features and evaluate the tensile strength, hardness, and acidic corrosion resistance of liquid metal stir casted aluminium-silicon carbide (Al-SiC) composite. As reinforcement for the Al alloy matrix, SiC particles were added to the matrix in the percentages of 0%, 10%, and 20%. The microstructure of Al-SiC composite was studied using optical microscope. The effect of addition of SiC particles on tensile strength and hardness of Al-SiC composite was analyzed.. There were significant improvements in tensile strength and hardness for Al–SiC composite reinforced with 20% SiC particles compared to unreinforced Al–SiC composite, and those improvements were of 14.70% and 26.88%, respectively. The evolution of harder SiC islands in the ductile matrix of aluminium alloy reinforce the Al-SiC composite which enhances the strength and hardness of Al-SiC composite. A weight loss method was used to determine corrosion rate. The samples of Al-SiC composite material were immersed in HCl, HNO_3, and H_2SO_4 solutions for immersion times of 30 hours, 56 hours, and 80 hours. It was found that the weight % of reinforcement had the largest contribution to corrosion rate with 49.86% to that of acidic solution with 29.88%, followed by immersion time with 8.85% and acidic solution with a contribution of 29.88% to the corrosion rate. The Al-SiC composite developed using 20 wt. % of SiC particles showed higher corrosion rate due to the interfacial region formed due to the addition of greater wt % SiC particles to the pure alloy.

1. Introduction

Corrosion is a critical issue in the universe and is created by the interaction between the material and the environment. The parameter of material is most critical due to the potential excellence of individual corrosion materials and the potential difference to produce corrosion value. The factor of action is induced by oxidation formation and reduction due to the standard potential difference. The environmental parameter is induced by pH deviation, concentration, humidity, and pressure [1, 2]. Environmental corrosion is the main risky factor in many industries such as the automobile industry, petrochemical factories, food processing factories, pharmaceutical industry, iron core factories, and oil refining industry [3]. One of the main reasons for industry corrosion is the liquids used in the industry. They corrode the materials and the storage containers from the inside by attacking their inner metallic surfaces, and this is called acid corrosion. This is one of the environmental issues which induce corrosion and it was caused by the running of concentrated acids such as sulfuric, hydrochloric, and nitric acid in internal regions of the acid running pipe way [4]. Nowadays, continuous working of the production process is required to overcome the complete need of the universe. This continuous production process causes corrosion and leads to high maintenance costs. So corrosion study is required to minimize the corrosion rate. So many researchers performed experiments on the engineering materials to calculate and analyse the outcome of different corrosion causing variables on the corrosion [5, 6]. Suresh et al. [7] deliberated the effect of corrosion on AISI type 304L stainless steel in nitric acid solution. The effect of acid concentration, temperature, and chloride ion concentration on the steel corrosion rate was studied using a potentiodynamic polarisation experiment. They concluded that acid concentration and the temperature had more effect on the corrosion. Desiati et al. [8] conducted a corrosion performance analysis on nickel and chromium coated carbon steel in the 37% and 25% concentrated hydrochloric acid. They choose the coating combination as FeNiCr, FeNi, FeCr, and uncoated Fe. The result showed that the nickel-coated combinations gave better corrosion resistance among all the combinations, and also higher the concentration of hydrochloric acid, the faster the corrosion rate. Widyanto et al. [9] analysed the effect of the concentration of HNO_3, H_2SO_4, and HCl on the carbon steel through an immersion corrosion test, and the result revealed that the increase in the corrosion rate was observed during the time of increasing the concentration. Aluminium composites are used in many chemical industrial applications because of their superior mechanical properties such as high tensile strength, hardness, toughness, and impact strength [10, 11]. Aluminium is an abundantly used industrial material because of its automobile and aerospace applications. Many researchers conducted various corrosion experiments to calculate and analyse the corrosion effect on aluminium composites. Bobić et al. [12] have done corrosion studies on the zinc aluminium alloy reinforced with 1, 3, and 5 wt. % SiC composites using the weight loss method. They immersed the samples in the 3.5 wt. % NaCl solution for 30 days. The result showed a lower corrosion resistance on the composite when compared with the raw alloy. Gangwar et al. [13] studied the effect of reinforcement on the corrosion behaviour of aluminium hybrid composite through various optimization techniques. The result revealed that the 4 wt. % ZrO_2 and 6 wt. % SiC reinforced aluminium hybrid composite produced enhanced corrosion performance. Ahamed and Prashanth [14] understood the effect of alkaline corrosion rate on the cenosphere-reinforced aluminium alloy by immersing NaCl solution to do the corrosion experiment. The composite samples are made to immerse in the 3.5% NaCl alkaline solution. They compared the effect of various wt. % of reinforcement and immersion time on the corrosion rate. They concluded that the increase in reinforcement did not affect the corrosion rate.

From the literature survey, it is clear that industrial corrosion prevention is very much essential to enhance the life of the respective materials. During pickling, descaling, and electrochemical etching processes, ceramic-reinforced aluminium composites frequently come in touch with acids in chemical handling industries [15–17]. So the corrosion control in aluminium composites is very much needed. However, few researchers investigated the effect of acidic immersion corrosion on aluminium composite with enhanced reinforcement percentage. Therefore, it is necessary to study the effect of reinforcement on the corrosion rate of aluminium composites. This is the novelty of the present experimental investigation. Hence, the present research is to fabricate the Al6061 aluminium alloy reinforced SiC (0, 10, and 20 wt. %) metal matrix composite through the liquid metal stir casting method and to analyse the corrosion rate behaviour using the Taguchi technique.

2. Material Fabrication and Corrosion Experimentation

2.1. Materials Employed. Aluminium Al6061 alloy was chosen as the matrix alloy. The contents of cast aluminium matrix composites are 0.63% Si, 1.08% Mg, 0.32% Cu, 0.17% Fe, 0.52% Mn, 0.01% V, 0.02% Ti, and balance aluminium. It has a great demand in aircraft and automotive structures, chemical handling equipment, fasteners, and marine frames because of its improved corrosion resistance, high strength, and better workability. For the present investigation, 23 μm average particle sized SiC particles of density 3.2 g/cm^3 was used as reinforcement.

2.2. Fabrication of Composite. Liquid metal stir casting techniques are an efficient method to get a homogeneous form of metal. Initially, aluminium alloy Al6060 was kept in a clay graphite-made crucible and kept inside the resistance heated furnace to get the molten form of alloy. Mechanical stirring was done on the molten alloy using a dyno drive electric motor driven impeller, and the stirring speed was controlled at 350 rpm. 1% Mg was added to the molten aluminium alloy to compensate for the Mg loss due to the oxidation process. In the meanwhile, preheating of SiC particles to a temperature of 600°C was done. Then, the preheated SiC particles were added to the molten aluminium alloy maintained at a temperature of 740°C. After the addition of SiC, uniform mixing of aluminium alloy and SiC in the crucible was done with the help of a baffle, and this was performed for 15 minutes. Nitrogen gas was passed through sulfuric acid to the molten mixture to avoid hydrogen entrapment. This process is called degassing. During this process, nitrogen gas will remove the hydrogen and sulfuric acid will perform as a purifier. This is performed for a time of 15 minutes till the temperature of molten metal reaches 760°C. Finally, the molten metal mixture was poured into the permanent mould of dimension 60 mm diameter and 150 mm length. The study has been planned to find the effect of very low to high percentage of reinforcement on the mechanical and corrosion properties. Some of the literature revealed that the mechanical properties are getting down after certain percentage of reinforcement. Therefore, reinforcement ranging from 0 to 20 wt. % was elected to study the entire effect of reinforcement on the corrosion. The rule of the proportion of SiC used to examine the corrosion behaviour is Al6061 + xSiC ($x = 0$, 10 and 20 wt. %). So, the remaining composite samples were fabricated by changing the weight percentage of SiC. The microstructural evaluation was performed on the fabricated three composite samples to confirm the three different proportions and the uniform distribution of SiC particles. In addition, mechanical properties such as hardness, tensile test, density, and porosity performed on the fabricated specimens to show the variation of properties due to the addition of SiC.

2.3. Acidic Immersion Corrosion Experiment. Corrosion performance test in aluminium composite was performed on the fabricated composite specimens with three different corrosion parameters and three levels. Three sample specimens with the size of 10 × 10 × 10 mm were sliced from each fabricated composite specimen and the cut portion is shown in Figure 1.

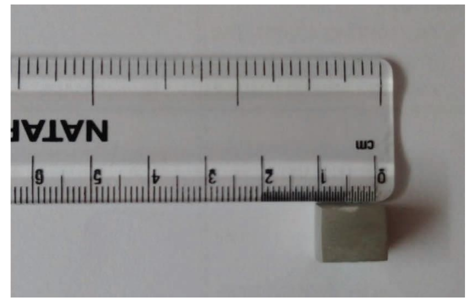

FIGURE 1: Cut portion of the composite sample for the corrosion experiment.

The initial weight of each composite sample was measured using 0.001 g accuracy electrical balance, and then the weighted specimens were washed using acetone. The test was performed by dipping the specimen into a 1 M concentrated different acid solution for different periods as per ASTM G31 standards [18]. Figure 2 demonstrates the composite specimens dipped in the different acidic solutions. Then, the composite samples were taken from the acidic solution and washed with an acetone solution. The loss in weight was measured, and the corrosion rate was found using equation (1).

$$\text{Corrosion Rate} = \frac{K \times w}{A \times d \times t}\,\frac{\text{mm}}{\text{yr}}, \quad (1)$$

where K is the corrosion parameter constant (8.76×10^4), w is the drop in weight in grams, A is the surface area ($6 \times 1\ \text{cm} = 6\ \text{cm}^2$) of the immersed aluminium composite in cm^2, d is the density of manufactured aluminium composite specimen in g/cm^3, and t is the time of duration dipped in the various acidic solution in hours [19]. Finally, the surface morphology of the corroded aluminium composite samples studied using Leica stereo zoom optical microscope (M205A).

FIGURE 2: Composite samples immersed in acidic solutions.

2.4. Methodology. Taguchi method is the optimization technique used here to find the efficient values of corrosion parameters to decrease the corrosion rate to the minimum value. The Taguchi method is used to narrow down a large number of experiments into a small number of experiments [20, 21]. Normally, acids commonly used in food and beverage industries due to their ability to act as cleaning agents to remove grease, rust, and other corrosion products from surfaces of the aluminium parts. Therefore, this study aimed to investigate the impact of these industrial acids on the fabricated aluminium reinforced with SiC composite. From the literature review, it is evident that many researchers have used three acidic solution such as HCl, HNO_3, and H_2SO_4 to analyse the effect of corrosion on aluminium composites with respect to the different immersion time. Moreover, the previous literatures reported the major corrosion rate in the early stage of immersion. Therefore, three durations of immersion (30 hours, 56 hours, and 80 hours) were selected. Along with that, the percentage of reinforcement was included in this study to investigate the effect of reinforcement on corrosion. The corrosion evaluation parameters selected for this study and their levels are tabulated in Table 1. The L_9 orthogonal array table utilized to perform the corrosion experiment. Figure 3 explains the procedure involved in the Taguchi method for the optimization of corrosion parameters graphically.

3. Result and Discussion

Microstructural observation, mechanical properties (hardness and tensile strength), and corrosion behaviour will be discussed in the following subsections.

3.1. Metallographic Observation. Microstructure plays an important role in the evaluation of the mechanical properties of particular materials. Microstructural examination confirmed the distribution of SiC particles on the aluminium alloy. Figure 4(a) shows the optical microstructure of Al6061 alloy, and it shows the existence of light dendrite primary

Table 1: Corrosion experiment parameters and their three levels.

S. no	Corrosion parameter	Level 1	Level 2	Level 3
1	Acidic solution	1 M hydrochloric acid (HCl)	1 M nitric acid (HNO_3)	1 M sulfuric acid (H_2SO_4)
2	Immersion time (hours)	30	56	80
3	Reinforcement (Wt. %)	0	10	20

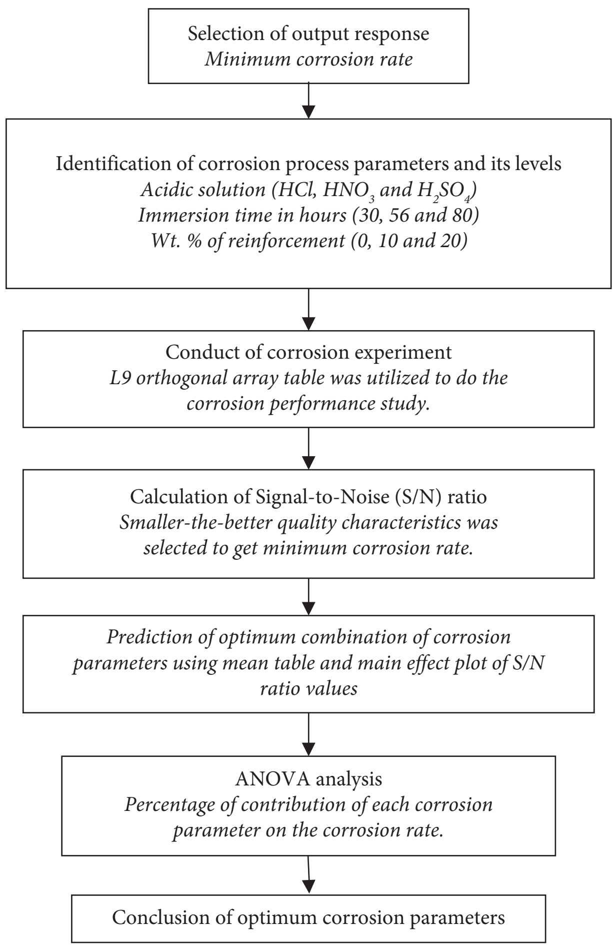

Figure 3: Taguchi procedure for optimization of corrosion parameters.

phases and dark eutectic silicon phases. Figure 4(b) shows the optical microstructure of 10 wt. % SiC-reinforced aluminium composite, and the availability of SiC in the matrix phase was confirmed through composite microstructure. Figure 4(c) shows the optical microstructure of 20 wt. % SiC-reinforced aluminium composite, and it confirmed that the SiC reinforcement was slightly higher than the second composite. However, the agglomeration effect is seen in the heavily reinforced composite. This is due to the difficulty faced during the mixing of heavier reinforcement particles on the matrix.

3.2. Hardness, Tensile Strength, and Density Evaluation. Figure 5 shows the graphical comparison of the mechanical properties of three different composites. An increase in hardness was observed due to the inclusion of rigid ceramic silicon carbide grains in the matrix phase. A maximum hardness of 118 BHN was found at 20 wt. % SiC-reinforced aluminium alloy. Similarly, an increase in tensile strength was achieved from 245 MPa to 281 MPa due to the reinforcement grains. Al-SiC composite reinforced with 10% SiC particles exhibited 7.75% and 11.82% improvement in tensile strength and hardness compared to unreinforced Al-SiC composite. Al-SiC composite reinforced with 20% SiC particles exhibited 14.70% and 26.88% improvement in tensile strength and hardness compared to unreinforced Al-SiC composite. It is mainly attributed to the harder SiC islands forming in the ductile matrix of aluminium alloy which is offering reinforcing strength and hardness.

Figure 6 shows the measured actual density of fabricated aluminium reinforced with SiC composite with their corresponding porosity values. Normally, blowholes and voids during fabrication are the cause of the porosity. The outcome inferred that the porosity values are increasing upon increasing the weight percentage of SiC particles. It is seen that the porosity is directly proportional to the density. Based on the results observed, it can be concluded that good compaction is achieved in the zero wt. % than 10 and 20 wt. % SiC-reinforced aluminium composite.

3.3. Corrosion Behaviour. The microstructural and mechanical properties confirmed the measured amount of distribution of SiC particles on aluminium during the casting fabrication process. The resultant corrosion rate of the acidic immersion corrosion experiment on the aluminium-reinforced SiC composite specimen by conducting nine experiments obtained from the L_9 orthogonal array tabulated in Table 2.

3.4. Signal-to-Noise Ratio Analysis. S/N ratio analysis was done to identify the influence of various corrosion parameters on the corrosion rate. The rank of the influencing corrosion parameter was calculated by using the delta value. The delta value is the difference between the biggest and the lowest average value of that particular corrosion parameter. The "smaller-the-better" characteristic was used to obtain the minimum corrosion rate and was calculated using equation (2). Table 3 shows the corrosion experimental results along with corresponding S/N ratios.

$$\frac{S}{N\,\text{ratio (Smaller the Better)}} = -10\log\frac{1}{n}\left(y_1^2 + y_2^2 + \cdots + y_n^2\right), \quad (2)$$

where n is the number of runs and y_1^2, y_2^2,...y_n^2 are the response values.

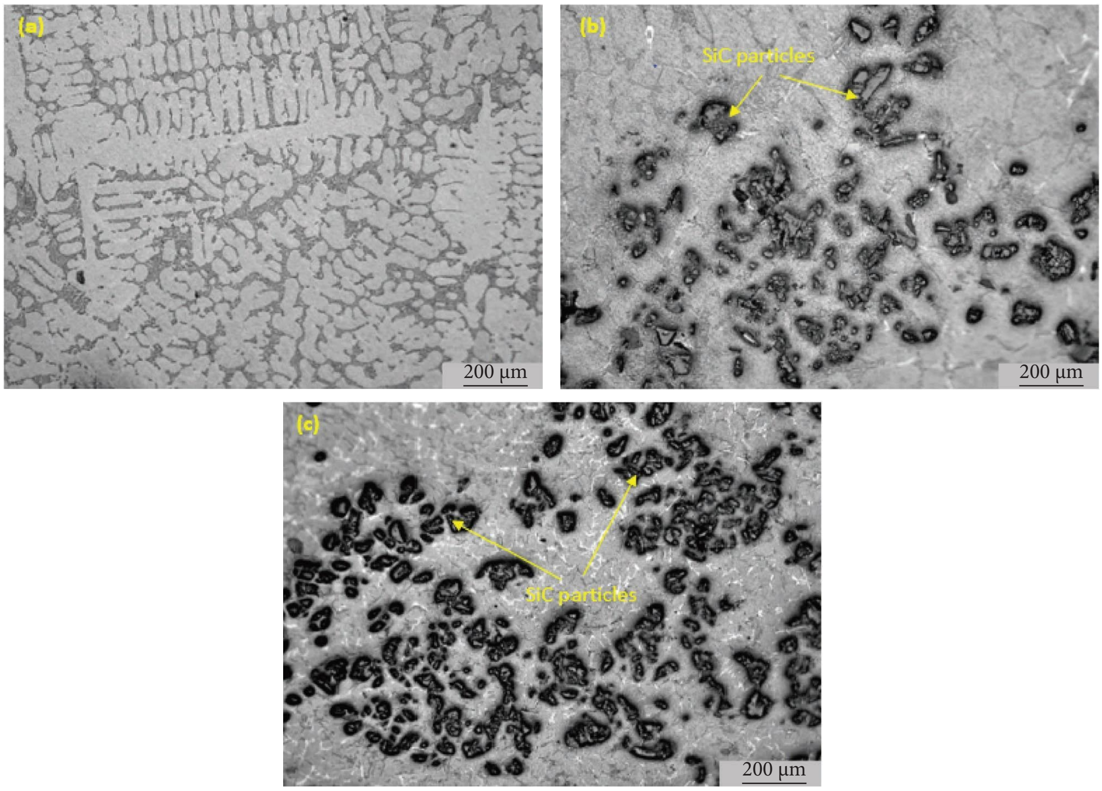

FIGURE 4: Optical micrographs of (a) Al6061 alloy, (b) Al6061-10% SiC composite, and (c) Al6061-20% SiC composite.

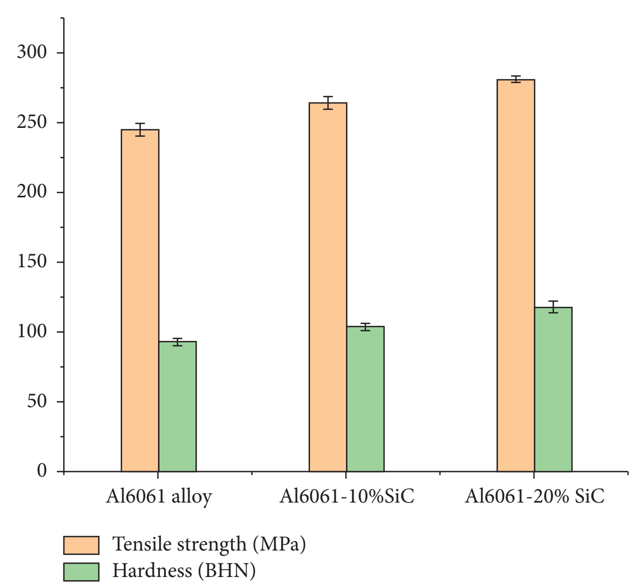

FIGURE 5: Comparison of mechanical properties of three composites.

Table 4 shows the S/N ratio table for corrosion rate. From the S/N ratio analysis, it was revealed that wt.% of reinforcement had a major influence on the corrosion rate followed by acidic solution and immersion time.

3.5. Parameters Influence on the Corrosion Rate of Composite. The S/N ratio plot for the minimum corrosion rate is displayed in Figures 7 and 8, demonstrating the plot for the mean effect of means. It used to evaluate the influence of each corrosion parameters corrosion performance. From the S/N ratio graph, it is evident that the optimum value of parameters enhancing the corrosion resistance of the composite is an acidic solution of H_2SO_4, immersion time of 56 hours, and wt. % of reinforcement of 0 wt. %. So the optimum corrosion rate found for the optimum combination of corrosion parameters was 4.83 mm/yr. This corrosion rate is lower when compared with other combinations of corrosion parameters. So, the proper identification of optimized corrosion parameters is much needed to get the long-term application of corrosion equipment through the lower corrosion rate. Therefore, the minimum optimized selection of reinforcement is much needed to avoid corrosion-forming surface imperfections, and also the reduction of chloride ions formation is necessary because it easily disables the protective aluminium oxide lining on the circumference of the aluminium reinforced with SiC composite.

3.5.1. Influence of Acidic Solution. The influence of acidic solution on the corrosion rate of the Al6061-SiC composite shown in figure 8(a), and it observed that a huge amount of corrosion has happened in a hydrochloric acidic solution when compared with a nitric and sulfuric acidic solution.

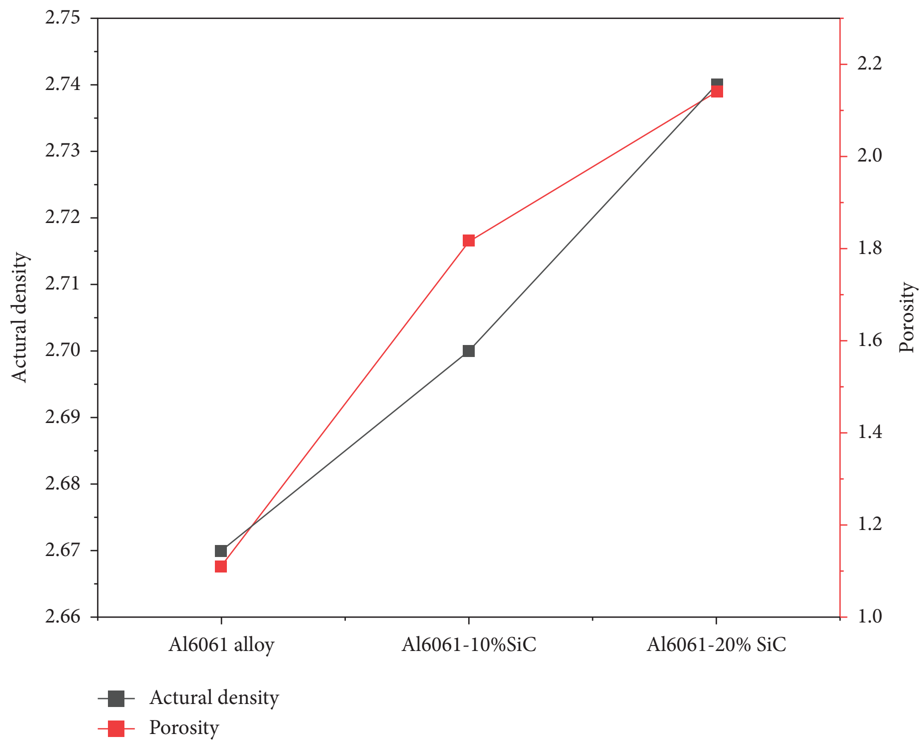

Figure 6: Density of fabricated composite with their corresponding porosity values.

Table 2: Acidic immersion corrosion experiment results.

Run	Acidic solution	Immersion time	Wt. % of reinforcement	Corrosion rate mm/yr
1	HCl	30	0	11.66
2	HCl	56	10	12.13
3	HCl	80	20	14.01
4	HNO_3	30	10	9.91
5	HNO_3	56	20	11.24
6	HNO_3	80	0	7.15
7	H_2SO_4	30	20	11.46
8	H_2SO_4	56	0	4.83
9	H_2SO_4	80	10	12.34

Table 3: Corrosion experiment values and their corresponding S/N ratios.

Run	Acidic solution	Immersion time (hours)	Reinforcement (Wt. %)	Corrosion rate (mm/year)	S/N ratio (dB)
1	HCl	30	0	11.66	−21.33
2	HCl	56	10	12.13	−21.67
3	HCl	80	20	14.01	−22.92
4	HNO_3	30	10	9.91	−19.91
5	HNO_3	56	20	11.24	−21.01
6	HNO_3	80	0	7.15	−17.08
7	H_2SO_4	30	20	11.46	−21.18
8	H_2SO_4	56	0	4.83	−13.67
9	H_2SO_4	80	10	12.34	−21.82

Normally, a rigid thin aluminium oxide layer act as a barrier on the external surface of the composite, and it is formed when it is in contact with atmospheric air. Chemically inert is the speciality of this rigid film and this property makes aluminium composite with high corrosion resistance. The high amount of corrosion in hydrochloric acidic solution immersed in the aluminium composite is due to the existence of corrosive chloride ions. Chloride ions are formed by the ionization reaction of water present in the hydrochloric acidic blend [22]. Initially, these chloride ions damage the

Table 4: Response table for corrosion rate.

Level	Acidic solution	Immersion time	Wt. % of reinforcement
1	−21.98	−20.81	−17.37
2	−19.34	−18.79	−21.14
3	−18.90	−20.61	−21.71
Delta	3.08	2.03	4.34
Rank	2	3	1

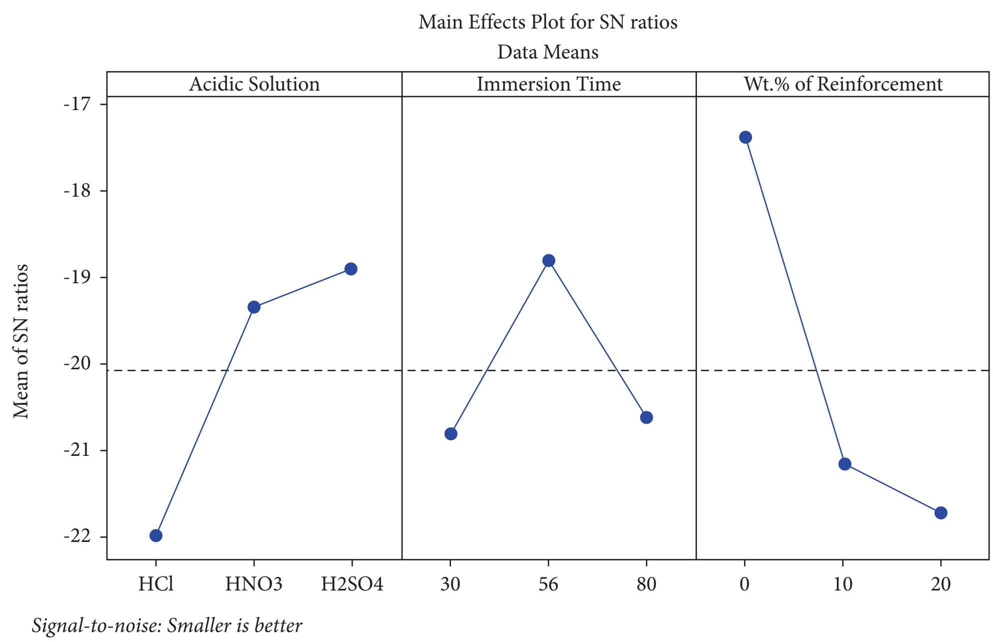

Figure 7: S/N ratio plot for minimum corrosion rate.

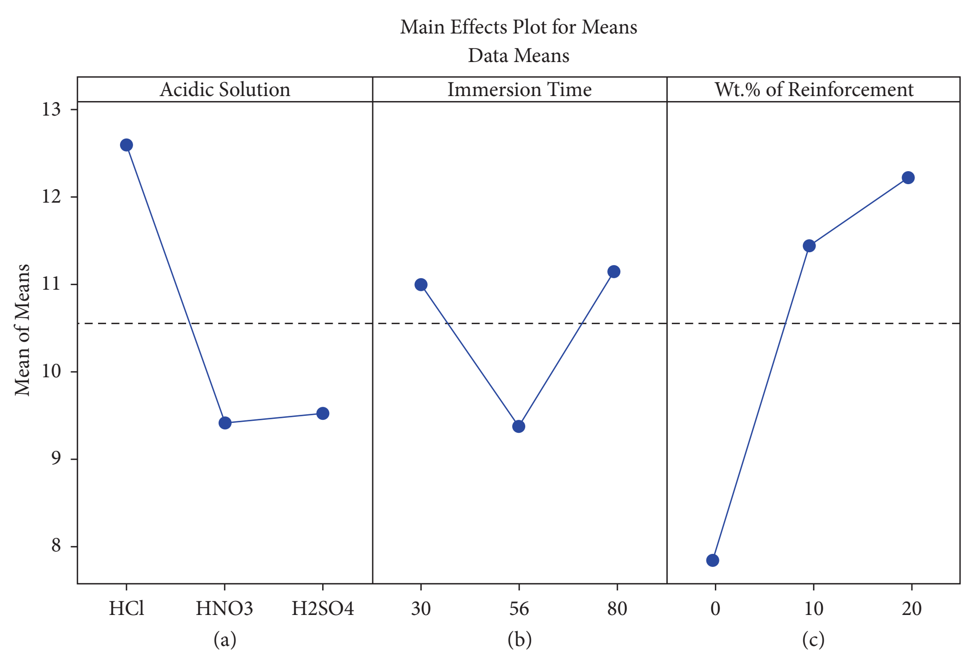

Figure 8: Plot showing the mean effect of means.

Table 5: ANOVA for corrosion rate.

Corrosion parameters	Degree of freedom	Sum of squares	Mean sum of squares	*F* value	*P* value	Percentage of contribution
Acidic solution	2	19.389	9.694	2.63	0.275	29.88
Immersion time	2	5.745	2.873	0.78	0.562	8.85
Wt. % of reinforcement	2	32.352	16.176	4.40	0.185	49.86
Error	2	7.388	3.694			11.38
Total	8	64.874				
R-sq. = 88.64%						

rigid passive metal liner formed from aluminium oxide on the Al-SiC composite surface. Once the rigid oxide liner is removed, the chloride ions spread into the fabricated aluminium composite through the available circumference microcracks and create aluminium chloride with the elimination of hydrogen bubbles. This action initiates the generation of pitting corrosion [23, 24]. However, nitric and sulfuric acidic solutions showed less amount of corrosion rate than a hydrochloric acidic solution due to the availability of a strong aluminium oxide layer on the circumference surface of the composite. This oxide layer prevents the reaction of aluminium below the protective layer with acidic solutions. The strength of the oxide lining increases as long as the composite is immersed in the acidic solution. So, the reactivity of aluminium decreases in both acidic solutions. As a result, the corrosion rate of aluminium composite decreases [25, 26].

3.5.2. Influence of Immersion Time. The influence of the acidic solution immersion period on the corrosion rate of the Al6061-SiC composite shown in Figure 8(b), and it revealed that the corrosion rate lowered drastically up to 56 hours from the starting point for a short period and there was an immediate rise seen in the corrosion of aluminium composite after 56 hours. The main cause for the corrosion is the disarrangement of the passive layer by environmental conditions on the composites [26]. At a lower immersion time of 30 hours, the corrosion rate of the composite is high due to the absorption of chloride ions. It goes gradually to the minimum corrosion rate for 30 to 56 hours. During this time formation of the stable passive layer of aluminium hydroxide will form over the surface of the composites irrespective of the reinforcement [27, 28]. Because of this passive layer, maximum possible corrosion will happen during this period. This passive layer prevents further corrosion.

3.5.3. Influence of wt. % of Reinforcement. The influence of wt. % of reinforcement on the corrosion rate of Al6061-SiC composite shown in figure 8(c), and it revealed that the corrosion rate increases with an increase in the weight percentage of reinforcement. Normally, corrosion occurs in microcracks and near clusters of particulate reinforcements. At 20 wt. % reinforcement, the corrosion rate of the composite was high due to the interfacial region formed due to the inclusion of reinforcement particles in the pure alloy. Previous literature confirmed that no significant galvanic corrosion arises in the aluminium added with SiC composite due to the insulating nature of the SiC grains [29]. Normally, porosity, segregation of reinforcement particles on the base metal, the existence of an interfacial reaction product, voids at the reinforcement locations, and high dislocation density around the reinforcement particles are the greatest issue for corrosion [25, 30, 31]. Heterogeneous composite materials are the major cause of corrosion. Usually, 20 wt. % and 10 wt. % reinforced composite shows heterogeneous properties due to the reinforcement of SiC ceramic particles. This reason leads to a heavier corrosion rate. Moreover, homogeneity and lack of surface imperfections are present in the 0 wt. % reinforced aluminium composite is the cause for less corrosion.

3.6. ANOVA. Analysis of variance is used to evaluate the percentage significance of each corrosion parameter on the response. Here, the analysis was done to know the contribution of acidic solution, immersion time, and wt. % of reinforcement on the corrosion rate of the composite. A confidence level of 95% with a significance level of 5% was fixed during the ANOVA analysis. Table 5 shows the ANOVA analysis result for the corrosion rate, and the last column presents the percentage contribution of each corrosion parameter to the corrosion rate. According to the results of ANOVA, the wt. % of reinforcement had the highest contribution of 49.86% on the corrosion rate followed by an acidic solution, which had a contribution of 29.88% and immersion time, which had a contribution of 8.85%. The error was found at 11.38% which is less than 15%. It shows that none of the corrosion parameters was missed in the experiment.

From the above detailed study, it concluded with optimum corrosion parameters and their corresponding optimum corrosion rate and these values tabulated in Table 6. Therefore, it can be concluded that the developed conclusions are found efficient in predicting the corrosion rate of the Al6061-SiC composite, and the optimal corrosion rate was found to be 4.83 mm/yr.

3.7. Surface Morphology of the Corroded Surface. Figures 9(a)–9(d) shows the microstructure of the aluminium composite samples immersed in the acidic solutions. Figures 9(a), 9(c), and 9(d) shows the microstructure of samples immersed in HCl, HNO_3, and H_2SO_4 acidic solutions with zero weight percentage of reinforcement particles, respectively. It confirmed the presence of

Table 6: Optimum corrosion parameters and their optimum value.

Acidic solution	Optimum corrosion parameters Immersion time	Wt. % of reinforcement	Predicted optimum corrosion rate
H_2SO_4	56 hours	0 wt. %	4.83 mm/yr

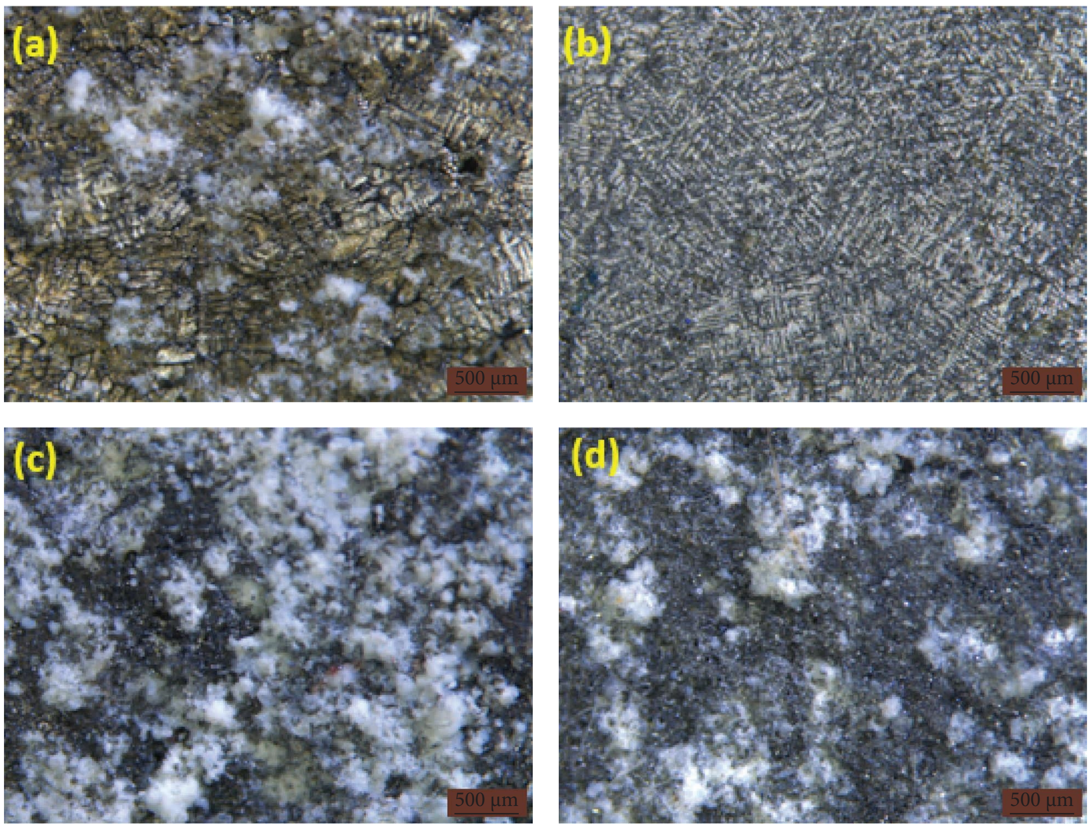

Figure 9: Surface morphology of aluminium reinforced with SiC composite at (a) exp. no 1, (b) exp. no 3, (c) exp. no 4, and (d) exp. no 7.

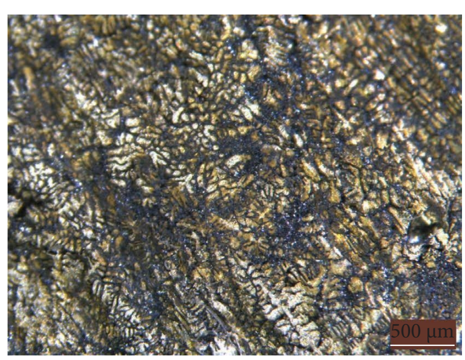

Figure 10: Microstructure at optimum corrosion rate.

aluminium oxide layer over the surface of the fabricated aluminium alloy. This oxide layer prevents the contact of corrosion causing ions with the alloy. Moreover, the less porosity is the one of the cause for minor corrosion in the aluminium alloy than composite due to the comparative less amount of holes, voids, and cracks. Figure 9(b) shows the microstructure of aluminium composite immersed in the HCl acidic solution for 80 hours. It observed that the removal of the top layer from the aluminium composite with the maximum corrosion rate of 14.01 mm/yr and it is due to the presence of microcracks and reinforcement particles. Figure 10 shows the optimum microstructure with zero wt. % of SiC aluminium composite sample immersed in H_2SO_4 acidic for 56 hours. Furthermore, this pitting corrosion can be decreased and maintained by giving proper painting and surface treatments that form a coating on the aluminium surface [32–34]. Corrosion can also be controlled by cleaning the surface of the aluminium using mild alkaline and acidic detergents. Finally, the experimental conclusions confirmed that the corrosion rate was highly impacted by chloride ions, intermetallic phase region, immersion time, and surface irregularities on the composite.

4. Conclusions

The following conclusions are drawn from the research on microstructural and corrosion properties of Al6061 aluminium alloy reinforced with SiC composite:

(1) Al-SiC composite reinforced with 20% SiC particles exhibited 14.70% and 26.88% improvement in tensile strength and hardness compared to unreinforced Al-SiC composite

(2) The greater strength and hardness of 20 wt.% Al-SiC-reinforced composite is mainly attributed to the harder SiC islands forming in the ductile matrix of aluminium alloy which is offering reinforcing strength and hardness

(3) The wt. % of reinforcement had the highest contribution of 49.86% on the corrosion rate followed by an acidic solution, which had a contribution of 29.88% and immersion time, which had a contribution of 8.85%

(4) At 20 wt. % reinforcement, the corrosion rate of the composite was high due to the interfacial region formed due to the addition of reinforcement particles to the pure alloy, and this confirmed through the surface morphology of the aluminium samples.

Data Availability

All the data used to support the findings of this study are included within the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] M. G. Fontana, *Corrosion Engineering*, McGraw-Hill Book Company, Singapore, 1987.

[2] P. Prabhuraj, S. Rajakumar, T. Sonar, M. Ivanov, I. Rajkumar, and E. D. Raja, "Effect of retrogression and reaging (RRA) on pitting and stress corrosion cracking (SCC) resistance of stir zone of high strength AA7075-T651 alloy joined by friction stir welding," *International Journal of Lightweight Materials and Manufacture*, vol. 6, no. 2, pp. 264–277, 2023.

[3] Inco-Sterling Forest, *The Corrosion Resistance of Nickel-Containing Alloys in Sulphuric Acid and Related Compounds*, Inco-Sterling Forest, New York, NY, USA, 1983.

[4] V. S. Sugur, "Problems in storage and handling of red fuming nitric acid," *Defence Science Journal*, vol. 33, no. 4, pp. 331–337, 1983.

[5] P. N. Sudha, K. Sangeetha, A. V. Jisha Kumari, N. Vanisri, and K. Rani, *Corrosion of Ceramic Materials, Fundamental Biomaterials: Ceramics*, Woodhead Publishing Series in Biomaterials, New York, NY, USA, 2022.

[6] K. Alaneme, "Corrosion behaviour of heat - treated Al-6063/SiCp composites immersed in 5 wt% NaCl solution," *Leonardo Journal of Sciences*, vol. 18, pp. 55–64, 2011.

[7] G. Suresh, V. R. Raju, U. K. Mudali, and R. K. Dayal, "Corrosion assessment of type 304L stainless steel in nitric acid," *Corrosion Engineering, Science and Technology*, vol. 38, no. 4, pp. 309–312, 2003.

[8] R. D. Desiati, E. Sugiarti, and K. A. Z. Thosin, "Effect of cloric acid concentration on corrosion behavior of Ni/Cr coated on carbon steel," *AIP Conference Proceedings*, vol. 1964, 2018.

[9] B. Widyanto and S. W. S. Putri, "Corrosion behavior of ASTM A1008 carbon steel in mixtures of HNO_3, H_2SO_4, and HCl using immersion and polarization methods," *Materials Transactions*, vol. 60, no. 5, pp. 732–736, 2019.

[10] M. Sambathkumar, R. Gukendran, T. Mohanraj, D. K. Karupannasamy, N. Natarajan, and D. S. Christopher, "A systematic review on the mechanical, tribological, and corrosion properties of Al 7075 metal matrix composites fabricated through stir casting process," *Advances in Materials Science and Engineering*, vol. 2023, Article ID 5442809, 17 pages, 2023.

[11] S. Suresh Pungaiah, K. Kumar Sahu, R. Yuvaraja et al., "Investigation on mechanical behaviour of lm6 aluminum alloy hybrid composites processed using stir casting process," *Advances in Materials Science and Engineering*, Article ID 4116843, 2022.

[12] B. Bobić, I. Bobić, A. Vencl, M. Babić, and S. Mitrović, "Corrosion behavior of compocasted ZA27/SiCp composites in sodium chloride solution," *Tribology in Industry*, vol. 38, no. 1, pp. 115–120, 2016.

[13] S. Gangwar, P. Arya, and V. K. Pathak, "Optimal material selection for ship body based on fabricated zirconium dioxide/silicon carbide filled aluminium hybrid metal alloy composites using novel fuzzy based preference selection index," *Silicon*, vol. 13, no. 8, pp. 2545–2562, 2021.

[14] A. Ahamed and T. Prashanth, "Evaluation of corrosion behaviour of Aluminium 6061- cenosphere composites," *Journal of Manufacturing Engineering*, vol. 13, no. 1, pp. 055–058, 2018.

[15] N. K. Bhoi, H. Singh, and S. Pratap, "Developments in the aluminum metal matrix composites reinforced by micro/nano particles- A review," *Journal of Composite Materials*, vol. 54, no. 6, pp. 813–833, 2020.

[16] S. Prathap Singh, K. Arun Vasantha Geethan, D. Elilraja, T. Prabhuram, and J. Immanuel Durairaj, "Optimization of dry sliding wear performance of functionally graded Al6061/20% SiC metal matrix composite using Taguchi method," *Materials Today: Proceedings*, vol. 22, no. 4, pp. 2824–2831, 2020.

[17] S. Gangwar and V. K. Pathak, "A critical review on tribological properties, thermal behavior, and different applications of industrial waste reinforcement for composites," *L: Journal of Materials: Design and Applications*, vol. 235, no. 3, pp. 684–706, 2021.

[18] J. Zhu and L. H. Hihara, "Corrosion of continuous alumina-fibre reinforced Al-2wt.% Cu-T6 metal matrix composite in 3.15 wt.% NaCl solution," *Corrosion Science*, vol. 52, no. 2, pp. 406–415, 2010.

[19] A. Gnanavelbabu, K. S. Surendran, P. Loganathan, and E. Vinothkumar, "Effect of ageing temperature on the

corrosion behaviour of UHTC particulates reinforced magnesium composites fabricated through ultrasonic assisted squeeze casting process," *Journal of Alloys and Compounds*, vol. 856, pp. 158173–173, 2021.

[20] D. Sandiri, R. Malkapuram, and S. Balasubramaniyan, "Experimental investigation of textured inserts on machining performance of Al-mmc using Taguchi method," *Tribology in Industry*, vol. 44, pp. 54–63, 2022.

[21] K. Ramesh, K. Gnanasekaran, S. Prathap Singh, and M. Thayumanavan, "Optimization of turning process parameters in machining of heat-treated ductile iron bar using tic/ticn/al2o3-coated tungsten carbide tool," in *Proceedings of the ICDMC 2019, Lecture Notes in Mechanical Engineering*, New York, NY, USA, June 2022.

[22] M. S. B. Selamat, "Corrosion behavior of SiCp/6061 Al metal matrix composites in chloride solutions," *Advanced Performance Materials*, vol. 3, no. 2, pp. 183–204, 1996.

[23] S. Narayanan, G. G. Sozhamannan Hemalatha, K. Velmurugan, and V. S. K. Venkatachalapathy, "Corrosion and hardness behaviour of Al/GO nanocomposites processed by the ultrasonic gravitational stir casting method," *International Journal of Corrosion*, vol. 2021, Article ID 6658186, 8 pages, 2021.

[24] S. Yadav, S. Gangwar, P. C. Yadav, V. K. Pathak, and S. Sahu, "Prabhat chand yadav, vimal kumar pathak, sandeep sahu, mechanical and corrosion behavior of SiC/graphite/ZrO_2 hybrid reinforced aluminum-based composites for marine environment," *Surface Topography: Metrology and Properties*, vol. 9, no. 4, Article ID 045022, 2021.

[25] K. K. Alaneme and M. O. Bodunrin, "Corrosion behavior of alumina reinforced aluminium (6063) metal matrix composites," *Journal of Minerals and Materials Characterization and Engineering*, vol. 10, no. 12, pp. 1153–1165, 2011.

[26] K. K. Alaneme, B. O. Fatile, and J. O. Borode, "Mechanical and corrosion behaviour of Zn-27Al based composites reinforced with groundnut shell ash and silicon carbide," *Tribology in Industry*, vol. 36, no. 2, p. 195-203, 2014.

[27] J. Bienia, M. Walczak, B. Surowska, and J. Sobczak, "Microstructure and corrosion behaviour of Aluminum Fly ash composites," *Journal of Optoelectronics and Advanced Materials*, vol. 5, no. 2, pp. 493–502, 2003.

[28] L. F. Cabeza, J. Illa, J. Roca et al., "Immersion corrosion tests on metal-salt hydrate pairs used for latent heat storage in the 32 to 36 8°C temperature range," *Materials and Corrosion*, vol. 52, no. 2, pp. 140–146, 2001.

[29] A. J. Trowsdale, B. Noble, S. J. Harris, I. S. R. Gibbins, G. E. Thompson, and G. C. Wood, "The influence of Silicon Carbide reinforcement on the pitting behaviour of Aluminium," *Corrosion Science*, vol. 38, no. 2, pp. 177–191, 1996.

[30] M. S. N. Bhat, M. K. Surappa, and H. V. S. Nayak, "Corrosion behaviour of silicon carbide particle reinforced 6061/Al alloy composites," *Journal of Materials Science*, vol. 26, no. 18, pp. 4991–4996, 1991.

[31] W. Neil and C. Garrard, "The corrosion behaviour of Aluminium silicon carbide composites in aerated 3.5% sodium chloride," *Corrosion Science*, vol. 36, no. 5, pp. 837–851, 1994.

[32] I. Gusti Ayu Arwati, "Effect of chitosan on the corrosion protection of aluminum in H_2SO_4 medium," *World Chemical Engineering Journal*, vol. 2, no. 1, pp. 1–5, 2018.

[33] H. M. Hajar, F. Zulkifli, M. G. Mohd Sabri, and W. B. Wan Nik, "Protection against corrosion of aluminum alloy in marine environment by lawsonia inermis," *International Journal of Corrosion*, vol. 2016, Article ID 4891803, 5 pages, 2016.

[34] J. Yue and Y. Cao, "Corrosion prevention by applied coatings on aluminum alloys in corrosive environments," *International Journal of Electrochemical Science*, vol. 10, pp. 5222–5237, 2015.