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Research Article

Investigation on Corrosion Behaviour of LM25-SiCp Composite Using Taguchi Method

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The aim of this investigation is to optimize the process parameters to obtain minimum corrosion rate and weight loss of Al/SiCp metal matrix composites. A Taguchi based grey relation analysis was carried out. The process parameters such as number of hours dipped in 3% NaCl solution, vol.% of SiCp and aging at 170°C for hours were considered. The working range of each process parameters were fixed based on minimum weight loss and low corrosion rate. The test was carried out using Taguchi based grey relationship analysis. Three factor three level L9 orthogonal array was used and output responses such as weight loss and corrosion rate were calculated. Based on the grey relationship analysis, the rank of each process parameters was calculated. Based on the F value, the vol. % of SiCp (38.42%) on the metal matrix composite followed by number of hours samples immersed in 3% NaCl solution (35.3%) and aging at 170°C for hours (25.78%) were found as influencing parameters on corrosion rate and weight loss. The surface of corroded samples was investigated and reported.

1. Introduction

In 1960, boron, graphite, and ceramic fibres were utilised as reinforcement in metal matrix composites (MMC). MMC grew in prominence when polymer matrix composites gained popularity around 1970. The potential to achieve unique property combinations and better mechanical qualities as compared to standard engineering materials is the driving force behind the development of MMC [1]. MMC has better strength and stiffness [2], as well as the capacity to withstand high temperatures and wear [3]. Hence, MMC has been widely used for many sectors such as aircraft, automobile and marine application [4]. By mixing two or more materials completely offered different physical and chemical properties [5]. The major portion is matrix and the smaller constituent which is dissolve in it, is called reinforcement. The addition of reinforcement gives additional good tribological behaviour [6]. The above properties have been achieved by adding any one or combination of two conventional reinforcement particles viz., SiC, Al_2O_3, TiC, B_4C, Fe and C [7].MMC consisting of continuous and discontinuous reinforcement such as continuous fiber whiskers or particulate in a suitable metal matrix will provide physical, mechanical in the monolithic alloy [8].

In the MMC, the properties can be changed by varying chemicals, size, shape, volume, fraction, orientation, and distribution of reinforcement. Thus, this component can have higher specific strength and modular area and fracture resistance, control thermal expansion coefficient, and used in high-temperature applications. These are new and existing materials that have significant potential for use in aerospace, such as shuttle, missile, and hypersonic vehicles, high-temperature applications in gas turbine parts and automotive components. Zakaria [9] studied the effect of particulate size and vol. % of particle in corrosion of Al/SiCp MMC. Three different sizes of particulate such as 3, 6 and 11 μm were used. The casting was produced using powder metallurgy route. Sarapure et al. [10] analysed the corrosion behaviour of AA6061/SiCp MMC using Taguchi technique. The weight percentage of SiCp varied from 0%, 2%, and 4%. Further the specimens were tested in different concentration of NaCl solution (1.0, 1.5, and 2.0) with exposure time ranging from 40 days to 80 days. Abbas et al. [11] studied the effect of corrosion in AA6061/SiCp metal matrix in 3.5% NaCl solution. It was observed that addition of SiCp to the matrix increased the corrosion rate. Pérez et al. [12] investigated the corrosion behaviour of A356 aluminum alloy with SiCp in NaCl solution. The corrosion resistance of the base material was lower than the SiCp added aluminum alloy.

Gavgali et al. [13] studied the effect of SiCp on the corrosion characteristics of aluminum-based MMC. Compo casting method was used to produce MMC by adding weight percentage of 10%. and 20 %SiCp. The effect of corrosion was studied by potential polarization technique. Noorul Haq et al. [14] optimized machining parameters ofMMC using Taguchi based grey relationship analysis. The grey relation grade was developed and grade rank was calculated based on grade. Natrayan and Kumar [15] investigated the effect of hybrid reinforcement particles in AA2024 aluminum alloy materials. Although, the Taguchi technique was used to optimize the tribological behaviour of aluminum MMC, the result revealed that the percentage of reinforcement particles was the major contributor to wear behaviour. Kaushik and Singhal [16] used Taguchi-based GRA with weight model to find the wear rate of aluminum MMC. SiCp percentage was varied from 3.5 to 10.5%, with an increment of 3.5%. Muthu and Geethapriya [17] optimized tribological behaviour of aluminum alloy composite using Taguchi-based grey relationship analysis. Normal load, distance and sliding velocity were used as the process parameters and an L9 orthogonal array was used. Singh et al. [18] investigated the effect of SiCp addition on Al-Cu alloy corrosion in a 3.5 %NaCl solution. The introduction of 10% SiCp to the aluminum significantly improved its protection against corrosion. The addition of 25% SiCp to the aluminum alloy significantly reduces corrosion resistance. The aggregation of SiCp in the matrix was determined by microstructural tests.

From the literature survey, it is understood that lot research works has been concentrated to optimize the tribological behaviour of composite materials. Hence, an attempt has been made to optimize the corrosion behaviour in LM25-Al/SiCp composite material using Taguchi based grey relation analysis.

2. Experimental Work

2.1. Preparation of Composite Materials. In the present work, the LM 25 aluminum alloy based composites was produced through stir casting method. The aluminium was taken into resistance furnace (1400°C, 230 V, 5 kW) in the form of small blocks and heated up to 770°C (±10°C). After reaching the desired temperature, the reinforcement particles (SiCp) were added and stirredat 800 rpm using rotary stirrer. The schematic diagram of stir casting setup is shown in Figure 1. The SiCp were well mixed into the molten metal (LM25 alloy). The composite melt was taken from the furnace, and the required shape was obtained using a proper mould cavity. The chemical compositions of AA6061/SiCp are presented in Table 1.

2.2. Parameter Identification. Several methods were used to produce aluminum-based MMC, such as stir casting, extrusion, and powder metallurgy. The stir casting process is an ideal process to make defect-free casting. From the previous works, it is identified that stirrer speed, vol.% of reinforcement, melting temperature, particles size and shape were the significant parameters which affects properties of casting. The process parameters and its working range were presented in Table 2. Totally 13 specimens were prepared with a size of 10 mm × 10 mm × 10 mm for conducting immersion test (Figures 2(a) and 2(b)). Vol.% of SiCp in aluminum matrix was varied as 10 wt.%, 15 wt.%, and 20 wt.%. Number of hours immersed in 3% NaCl solution and aging time at 170°C of MMC were used as process parameters in this work.

3. Corrosion Properties of Al/SiCp

The experiment was conducted using corrosion tester and the weight of specimens before and after corrosion was calculated using electronic weighing machine. The corrosion rate was calculated using Eq. (1) and the corrosion rate is presented in Table 3.

$$W_l = \frac{(W_b - W_a)}{W_b}. \quad (1)$$

W_l is weight loss (mg), W_b is weight of specimen before corrosion (mg), and W_a is weight of specimen after corrosion (mg).

The weight loss and corrosion rate of specimens with various combinations were measured before and after corrosion at one side of each specimen. Subsequently the specimens were polished using different grade of emery sheet and etched with HCl and NaOH solution. The microstructures of corroded region under different combinations were investigated using low magnification optical microscope.

4. Grey Relationship Analysis

Taguchi method is the best suitable method to optimize single response. However, it is difficult to analyse more than one response. Grey relationship analysis (GRA) is one of the efficient methods to analyse multi-response in a process [19]. Generally, this optimization technique involved three steps: conversion of normalization, determination of grey relation grade (GRG), and grey relation coefficient (GRC).

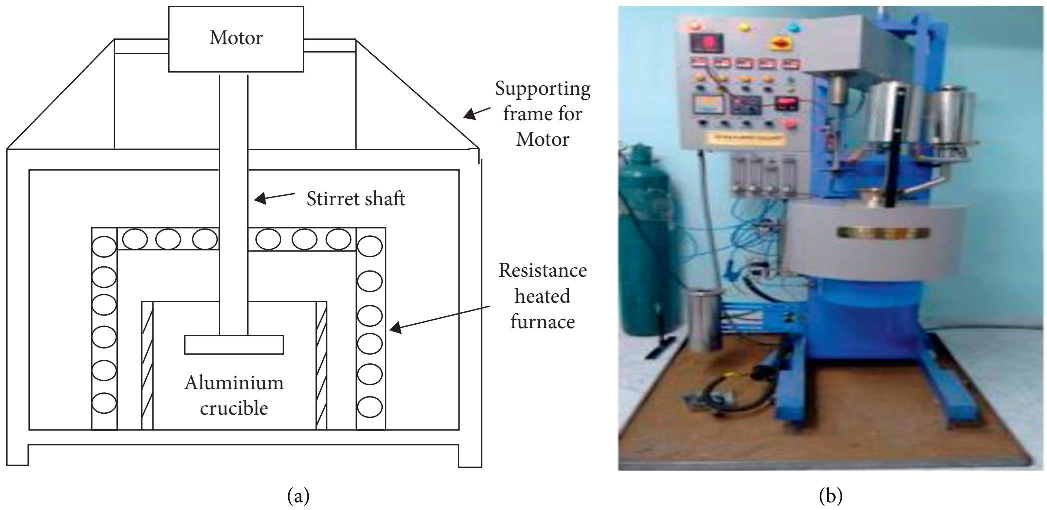

FIGURE 1: (a) Schematic diagram of stir casting equipment, (b) setup of stir casting machine.

TABLE 1: Chemical composition (Wt. %)of LM25 aluminum alloy.

Composition	Wt. %
Fe	0.4
Si	6.4–7.4
Mn	0.2
Pb	0.1
Mg	0.21–0.59
Cu	0.1
Ni	0.09
Zn	0.08
Ti	0.09
Sn	0.04
Al	Balance

TABLE 2: Working range of each process parameters.

Sl. No	Parameters	Range		
		−1	0	+1
1	No of hours specimens dipped in 3% NaCl	144	288	432
2	Vol.% of SiCp	10	15	20
3	Aging at 170°C for hrs.	8	16	24

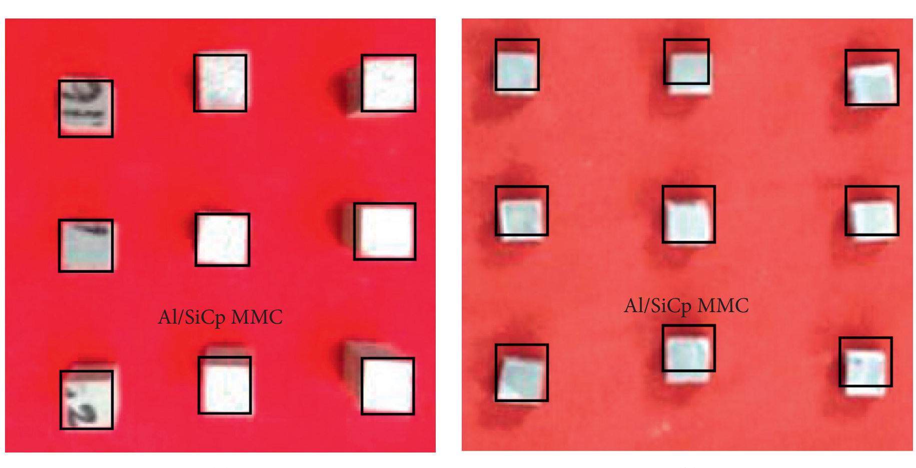

FIGURE 2: Photograph of samples prepared for corrosion test (a) before corrosion and (b) after corrosion.

Table 3: Design of experiments using Taguchi method and response (weight loss and corrosion rate).

Sl. No	No of hours specimens dipped in 3% NaCl.	% Vol of SiCp	Aging at 170°C for hrs.	Weight loss "gm."	Corrosion rate "mpy"
1	144	10	8	0.002	1.772
2	144	15	16	0.003	1.329
3	144	20	24	0.003	2.658
4	288	10	16	0.003	1.329
5	288	15	24	0.004	1.772
6	288	20	8	0.006	0.886
7	432	10	24	0.005	2.215
8	432	15	8	0.004	1.772
9	432	20	16	0.003	1.329
			Min	0.002	0.886
			Max	0.006	2.658

4.1. Normalization Process. In this process, the response of all trail, namely, weight loss and corrosion rate were first normalized ranging from 0 to 1. This step is called grey relation process. In general, three approach as are used normalization process. The target value of original sequence is infinite.

Larger the better option characterizes it [20–22].

$$X_i^* = X_i^o(k) - \frac{\min X_i^0(k)}{\max X_i^0(k)} - \min X_i^0(k). \quad (2)$$

The lower the better is used to when the objective of optimization process is minimization. The original value is normalized using the following equation.

$$X_i^* = \mathrm{Max}X_i^o(k) - \frac{X_i^o(k)}{\max X_i^0(k)} - \min X_i^0(k), \quad (3)$$

where X_i^o is the value of reference series or sequence, $\max X_i^0(k)$, $\min X_i^0(k)$ are the largest and smallest value in the series or sequence, $x_i^*(k)$ is the sequence generated after data processing, $i = 1,2,3, \ldots, m$; $k = 1,2,3, \ldots, n$; where m and n are the number of experiments and experimental data respectively.

4.2. Measurement of GRC and GRG. In order to reveal the relationship between actual and ideal experimental results were calculated using by GRC. The GRC was calculated using equations (4) and (5)

$$\Delta oi(k) = \left[x_o^*(k) - x_i^o(k)\right], \quad (4)$$

$$\zeta i(k) = \Delta\min + \frac{\zeta\Delta\max}{\Delta oj(k)} + \zeta\Delta\max, \quad (5)$$

where $\Delta oi(k)$ is the deviation series of reference series $x_o^*(k)$ and compatibility series $x_i^o(k)$; ζ is the identification coefficient, which is generally taken as 0.5 when the parameters given equal weightage.

The final stage GRG was carried out for determining corrosion behaviour between compatibility and reference series. The values are always between 0 and 1, The lower value of GRG was showed the better response (low corrosion and less weight loss) in this investigation. GRG was determined by averaging all the GRGs. Although, the GRG was calculated using

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\zeta_{ij}, \quad (6)$$

where γ_i is GRG for j^{th} experiment and n is the number of performance characteristics. Lower value suggest that the corresponding experimental value are closer to the ideal value.

5. Results and Discussion

The aforementioned Eq. (1)–(6) were used to normalise the result, according to GRA. The data was then translated into GRC to highlight the link between the real and ideal values. Table 4 shows the S/N ratio and normalized S/N ratio of weight loss and corrosion rate with GRC and GRG. Table 5 lists the GRG and their major impact, whereas Figure 3 depicts the factor effects. Because the GRG indicates the degree of correlation between the reference and comparability sequences, a higher GRG indicates that the comparability sequence is more closely related to the reference sequence. On the other hand, a higher GRG score refers to superior performance regardless of the category of performance attributes (Table 6). As a result (Table 6), the best level of process parameters was the highest GRG value and the smaller the reference value the better [9]. The comparison sequence would result in lowest weight loss and corrosion rate due to the significant importance of the GRG (Table 7). The optimal value for both weight loss and corrosion rate of Al-SiCp MMC viz., the number of hours immersed in 3 % NaCl of 288 hrs., vol. % of SiCp of 20%, and ageing at 170□C for 8 hr., as shown in Table 3 and Figure 3.

5.1. ANOVA Analysis. The analysis of variance (ANOVA) is a statistical tool for determining the influence of individual factor. The influence of each factor on the process outcomes may be determined using ANOVA. Because the Taguchi experimental approach was unable to assess the impact of specific factors on the overall process, the percentage involvement was calculated using ANOVA [23]. The overall sum of squared deviations was divided into two sections: the sum of squared deviations due to each process parameter and the sum of squared error. To measure the influence of process parameter modifications on performance metrics,

Table 4: Normalization of weight loss and corrosion rate and their deviation sequence.

Normalization						Deviation sequence	
0.004	0.004	1	0.886	1.772	0.5	0	0.5
0.003	0.004	0.75	1.329	1.772	0.75	0.25	0.25
0.003	0.004	0.75	1.772	1.772	1	0.25	0
0.003	0.004	0.75	1.329	1.772	0.75	0.25	0.25
0.002	0.004	0.5	0.886	1.772	0.5	0.5	0.5
0	0.004	0	0	1.772	0	1	1
0.001	0.004	0.25	0.443	1.772	0.25	0.75	0.75
0.002	0.004	0.5	0.886	1.772	0.5	0.5	0.5
0.003	0.004	0.75	1.329	1.772	0.75	0.25	0.25
	Min	0		Min	0		
	Max	1		Max	1		
					Delta min	0	
					Delta max	1	
					Theta	0.5	

Table 5: Grey relation coefficient, grade, and its rank.

GRC		GRG	Rank
1	1.5	1.25	5
1.25	1.25	1.25	5
1.25	1	1.125	9
1.25	1.25	1.25	5
1.5	1.5	1.5	3
2	2	2	1
1.75	1.75	1.75	2
1.5	1.5	1.5	3
1.25	1.25	1.25	5

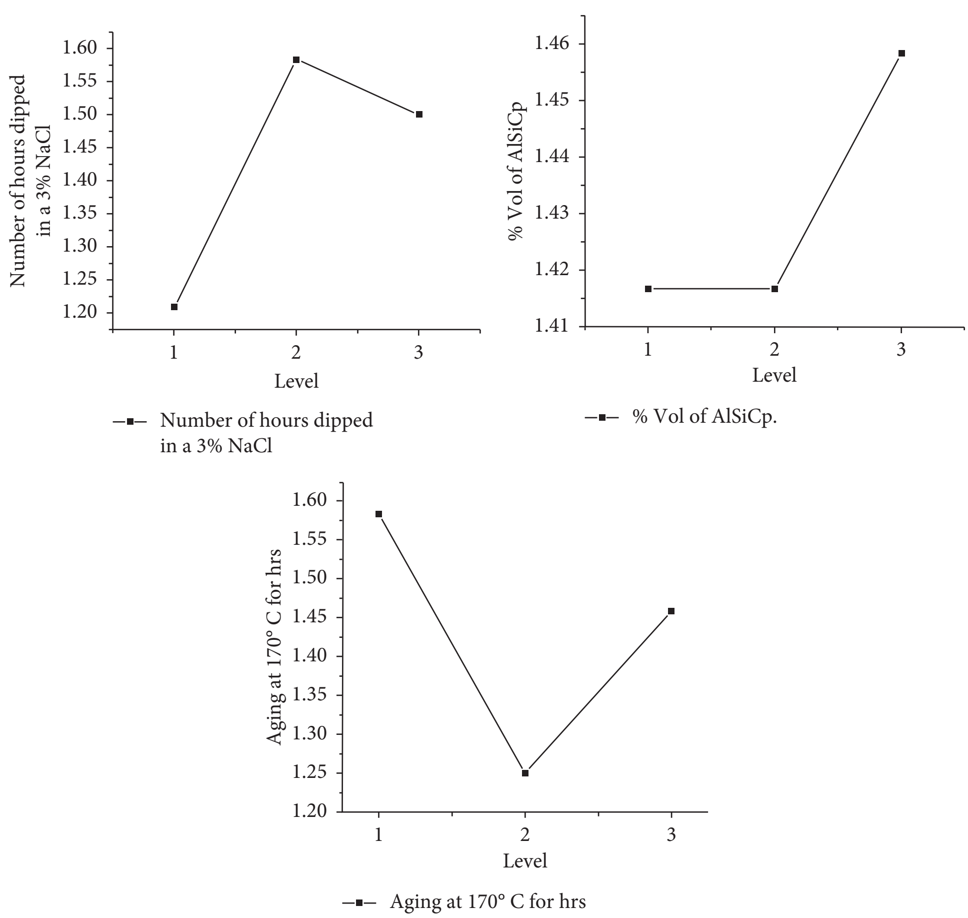

Figure 3: Main factor effects on weight loss and corrosion rate of Al/SiCp composite.

Table 6: Results of process parameters and their GRG.

	Input		GRG
144	10	8	1.25
144	15	16	1.25
144	20	24	1.125
288	10	16	1.25
288	15	24	1.5
288	20	8	2
432	10	24	1.75
432	15	8	1.5
432	20	16	1.25

Table 7: significance level of each process parameters.

Levels	No.of hrs dipped in 3% NaCl	% Vol of Al/SiCp.	Aging at 170°C for hrs
Level I	1.208333	1.416667	1.583333*
Level II	1.583333*	1.416667	1.25
Level III	1.5	1.458333*	1.458333
Delta	0.333	0.042	0.375
Rank	2	3	1

*Optimum value.

Table 8: ANOVA test results on GRG.

Source	Df	Adj. SS	Adj. MS	F-value	*P* value	% Contribution
No of hours specimens dipped in 3% NaCl	2	0.232639	0.116319	0.92	0.021	35.3
% vol of SiCp	2	0.253472	0.126736	0.01	0.056	38.42
Aging at 170 for hours	2	0.170139	0.085069	0.67	0.059	25.78
Error	2	0.003472	0.001736			0.5
Total	8	0.659722				100

the relative contributions of each process parameter to the overall sum of squared deviations can be employed. Table 8 shows the ANOVA results of Al/SiCp MMC. From the test results, the significance factor for this analysis (based on F value) is the vol. % of SiCp (38.42%) on the MMC followed by number of hours samples immersed in 3% NaCl solution (35.3%) and aging at 170°C for hours (25.78%).

5.2. Confirmation Test. A confirmation experiment was conducted to predict and verify the improvement of quality attributes using the optimal level of design parameters. The predicted GRG value is verified with optimum level of weight loss and corrosion rate calculated using

$$\gamma_e = \gamma_m + \sum_{i=1}^{a} (\gamma_i - \gamma_m). \quad (7)$$

Where "m" denotes the overall mean GRG, "i" represent the grey relationship at its best, and "a" denotes the number of primary factors that substantially impacted weight loss and corrosion rate. Table 9 compares the predicted GRG with actual GRG produced in tests using the best process parameters. The optimal data received from the confirmation test was presented in Table 9. The experiment demonstrated good agreement with the predicted model when the level setting parameters of immersion duration in NaCl (288 hrs.), weight % of SiCp (20%wt.) and aging at 170°C for hours (8 hrs) were used. As a result, the GRA based on the Taguchi model for multi-response problem optimization is a highly effective tool for predicting weight loss and corrosion rate of LM25 Al-SiCp MMC.

6. Effect of Process Parameters on Weight Loss and Corrosion Rate

The corrosion rate and weight loss of Al/SiCp MMC varied by varying process parameter viz., aging time, vol. % SiCp and immersion time in 3% NaCl solution [24]. Typical optical micrographs of Al/SiCp composites with different vol. % percentages of SiCp and aging hours at 170°C are shown in Figure 4. Figures 4(a)–4(c) depicts the corrosion rate of Al/SiCp composites as a function of immersion time in a 3% NaCl solution at room temperature. In general, the Al/SiCp composites outperformed when compared to pure Al matrix in corrosion resistance. The corrosion resistance of Al/SiCp composites improved when the vol. % of SiCp particles increased in matrix [25, 26].This finding implies that when the immersion for prolonged, the corrosion resistance of the materials under consideration rises. With increasing the immersion time of Al/SiCp in the 3% NaCl solution causes less corrosion rate and lower weight loss. It may be attributed due to the formation of passivation in MMC [27]. The SiCp resist the severity of corrosion attack to some extent. There is evidence for grain boundary corrosion and pitting corrosion in MMC. The interface between aluminum and SiCp, which can also influence the corrosion rate and weight loss. During

Table 9: Result of conformation experiments.

Sl. No	Initial value	Initial testing factor	Optimal parameters	
			Predicted	Expected
1	Combination of testing	$A_2B_3C_1$	$A_1B_3C_2$	$A_1B_3C_2$
2	Corrosion rate "mpy"	0.886	0.8981	0.9122
3	Weight loss "mg"	0.002	0.0122	0.0221
4	GRG	1.125	0.889	1.1221

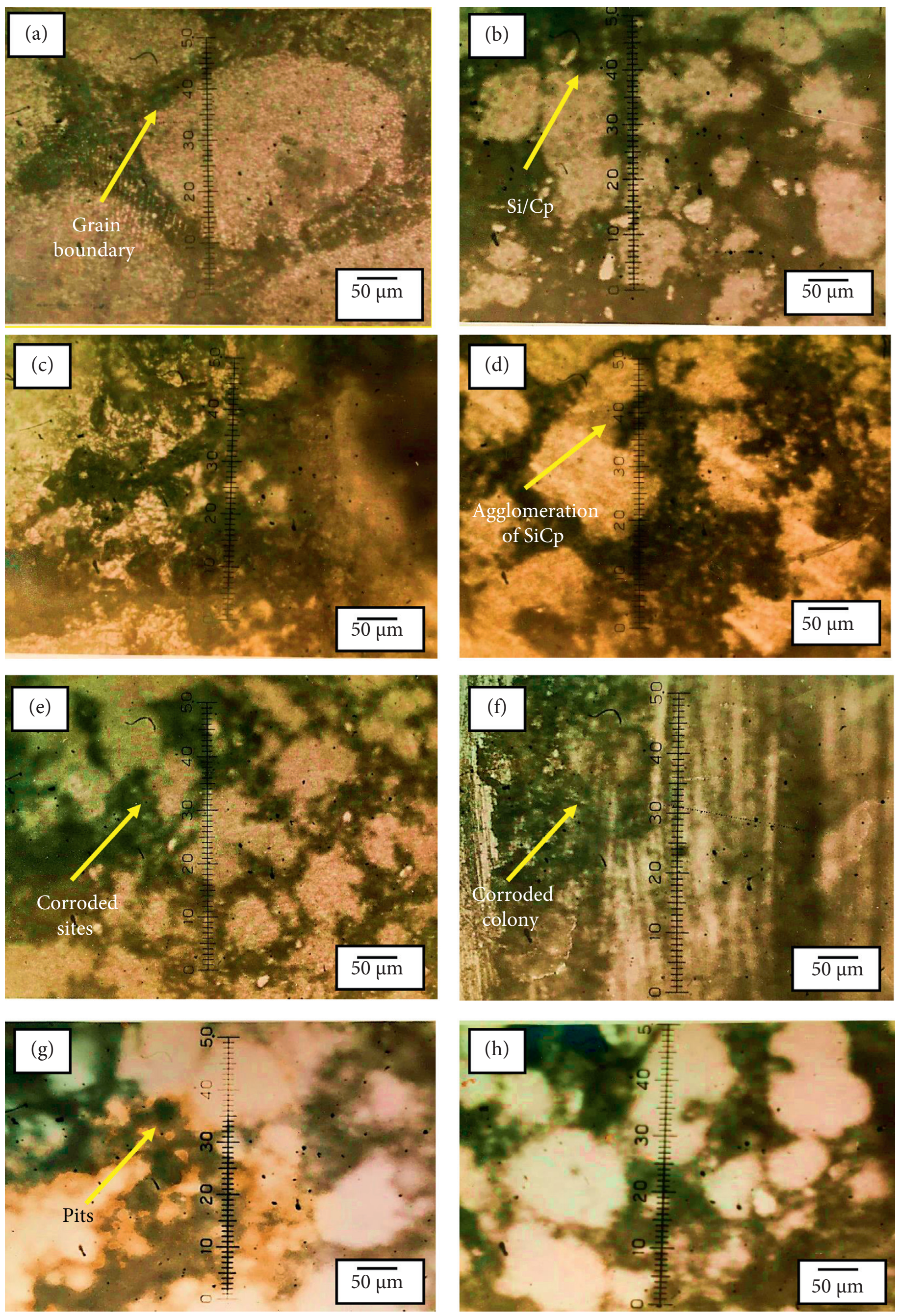

Figure 4: Micrograph of Al/SiCp composite with respect to process parameters.

fabrication of MMC using liquid metallurgy process, Al_4C_3 intermetallic was formed between matrix and SiCp by the formation of this intermetallic in MMC, it causes sever rate of weight loss and corrosion [28]. The SiCp particles, it should be mentioned, play a significant function as a physical barrier. The beginning and growth of corrosion pits are slowed by the presence of a SiCp. The strong interfacial connection between the aluminium and SiCp is thought to be responsible for the improved corrosion resistance of Al matrix [29].It is discovered that increasing the vol.% causes the SiCp to agglomerate. Many researchers reported similar observations [8, 30]. The size of agglomerations was determined between 10 μm and 35 μm. Figures 4(d)–4(f) depicts the change in density of Al/SiCp composites with vol.% at various SiCp sizes. The thickness of Al/SiCp composites was greater than that of the pure Al matrix. The measured densities of Al/SiCp composites were around 97–98% of predicted density. In Al/SiCp composites with 10 vol.%, 15 vol.%, and 20 vol.% SiCp, the densities were 2.581 g/cm^3, 2.685 g/cm^3, and 2.709 g/cm^3, respectively. The density of aluminum alloy was 2.785 g/cm^3. The weight of composites increased when the vol.% of SiCp increased in matrix. Many researchers have reported increase in aluminum alloys density due to the inclusion of SiCp [18, 31, 32]. The reinforcements increased the density of MMCs, according to the findings. Furthermore, when the particle volume fraction increased, the weight of the composites also increased. The increased density of reinforcing particles is the reason for the increased in density [33].

The microstructure development with respect to aging hours is shown Figures 4(g)–4(h). Another important factor is aging time at 170°C. The sample treated with immersion time during aging process. Generally, the aging process is carried out in aluminium alloy for improve the mechanical properties by changing aging hours. The aging hour is direct relationship to corrosion rate and inversely proportioned to the strength. Hence, Al/SiCp composite yields higher corrosion resistance and lower weight loss by the reinforcement of coarse SiCp in aluminum matrix. During artificial aging time, the reformation of dissolved SiCp in the matrix and formation of SiCp in bulk size. As a result, the influence of temperature on Al/SiCp MMC corrosion depends on the energy activation of corrosion [9]. The rate of corrosion rises as the activation energy rises. Corrosion resistance is improved by increasing the vol.% of SiCp in the aluminium matrix, which reduces weight loss.

7. Conclusions

Aluminium alloy based SiCp composites was successfully produced by stir casting process. Three major process parameters such as immersion time, vol.% of SiCp and aging hour at 170°C were used to analyse the corrosion behaviour of composites. A multi-objective response technique, Taguchi based GRA were used to optimize corrosion rate and weight loss. From this investigation, the following major conclusions were derived and presented as follows:

(i) Based on the F value, the vol. % of SiCp (38.42%) in MMC followed by number of hours samples immersed in 3% NaCl solution (35.3%) and aging at 170°C for hours (25.78%) were found as significant factor in corrosion rate and weight loss.

(ii) In a 3%NaCl aqueous solution, Al/SiCp composites showed superior corrosion resistance than pure aluminum.

(iii) By increasing vol.% of SiCp increased the corrosion resistance of the Al/SiCp composites. Similarly, raising the duration of immersion increases the corrosion rate. On the other hand, increasing the volume fraction of SiCp reduced the corrosion rate of MMC.

Data Availability

The data used to support the findings of this study are included within the article.

Disclosure

The publication is only for the academic purpose of Addis Ababa Science and Technology University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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