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EFFECT OF CRAB SHELL ASH (CSA) REINFORCEMENT ON SLIDING WEAR CHARACTERISTICS OF AL-7075 COMPOSITES

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Abstract

This study examines the sliding wear behavior of aluminium 7075 composites supplemented with crab shell ash (CSA), a waste product from the seafood industry. The composites with different weight percentages of CSA (0%, 1%, 2%, and 3%) were created using the stir-casting procedure. Afterward, a pin-on-disc device was used to evaluate these composites under different sliding conditions. The primary aim of this research is to analyze the effects of CSA content and sliding parameters on composite wear performance. In the experiment, it was discovered that the stability of the composites differed depending on the amount of CSA that was present. The unreinforced aluminum 7075 alloy's wear resistance was enhanced with CSA particles, according to the data. Wear resistance is optimal at 3% CSA content and begins to decline somewhat above this concentration. As a contribution to sustainable material engineering, this study is significant since it improves metal matrix composites' properties by reusing waste materials. This research emphasizes the potential of using waste materials such as crab shell ash to enhance mechanical properties and wear resistance, to promote sustainability in material engineering approaches.

Keywords: Aluminum 7075, Crab shell ash, Metal matrix composites, Sliding wear behavior, Stir casting

I. Introduction

The structural, defense, and aerospace industries are always on the lookout for new materials with improved mechanical characteristics, reduced weight, and increased strength while simultaneously decreasing corrosion and wear [1-2]. Due to the incessant pursuit of novel materials by researchers using a wide variety of manufacturing techniques, composites have become more important in every industry [3-6]. Despite their many useful technical applications, aluminum alloys and their composites have subpar wear characteristics [7-8]. Hard reinforcements have been properly placed throughout the alloy matrix to enhance the tribological qualities [9-10]. The dispersoid particles used in aluminum matrices, like borides, carbides, and oxides, don't dissolve at very high temperatures and stay stable at high temperatures [11]. Powder metallurgy, liquid metal infiltration, squeeze casting, electro-deposition, and diffusion bonding are some of the technologies used to create metal matrix composites (MMCs) [12]. Due to its low cost, ease of use, lack of size constraints, and high quantity, the stir casting (liquid metallurgy) approach stands out among these procedures as the most promising for fabricating the composite [13-14]. Metal matrix composites (MMCs) employ a variety of metals as matrix materials, including titanium (Ti), aluminum (Al), copper (Cu), and magnesium (Mg). Composites made of aluminum are among the most affordable of these materials [15].

Wear happens when material is removed from one or both surfaces when they are exposed to relative motion to a greater or lesser degree. [16] Adhesive wear is caused when two surfaces are subjected to pressured sliding. Materials having greater ratings for hardness, strength, and toughness often have a lower rate of wear than comparable materials with lower values. The incorporation of reinforcing material particles into metal matrix composites (MMCs) has a wide variety of technological applications, including the enhancement of wear resistance, hardness, and specific strength, amongst other applications [17–18]. There are a variety of variables that determine how effectively a material resists wear. Aside from the particle size and shape, these attributes include the material's density or volume fraction, toughness, strength, malleability, and hardness, as well as the size and shape of the particles themselves. The wear resistance and fracture prevention of particle-reinforced MMC are both improved as a result of the matrix support and higher bonding strength that that material has [20].

Studies were conducted to investigate the behavior of aluminum composites depending on two or more criteria, including the kind of reinforcement, the quantity of reinforcement, the manufacturing procedure, the load, the sliding velocity, and the sliding distance. There has been a relatively small amount of research conducted on hybrid composites made of Al 7075. In light of this, the primary purpose of the current investigation is to construct hybrid composite materials composed of Al 7075 and CSA via a two-step stir casting process and to forecast the wear behavior of the composite that has been manufactured.

II. Materials and Methods

The composite material contains Al-7075 aluminum alloy, and CSA. The composites were developed through a two-step stir-casting process. Al 7075 alloy of 1.5kg was melted in an MS container by a PID-controlled electric furnace. Two-step stir casting methods have been used to ensure proper mixing of reinforcement into the molten metal. Initially, the alloy material was heated above the melting temperature. Ultimately, to preserve the slurry state, the temperature was reduced below the liquidus temperature, which corresponds to the semi-solid phase. Based on the literature, 1, 2, and 3 weight percentages of reinforcements (CSA) were selected. The preheated CSA was put in the molten aluminum alloy and mixed physically. The combination was heated to a temperature higher than its liquid state and then exposed to mechanical agitation for about ten to fifteen minutes. The molten mixture is poured in dies prepared as per ASTM Standards to prepare the specimens to estimate the sliding wear behaviour. The Raw material, equipment used, and specimens prepared to estimate the sliding wear rate of composites are shown in Figure 1.

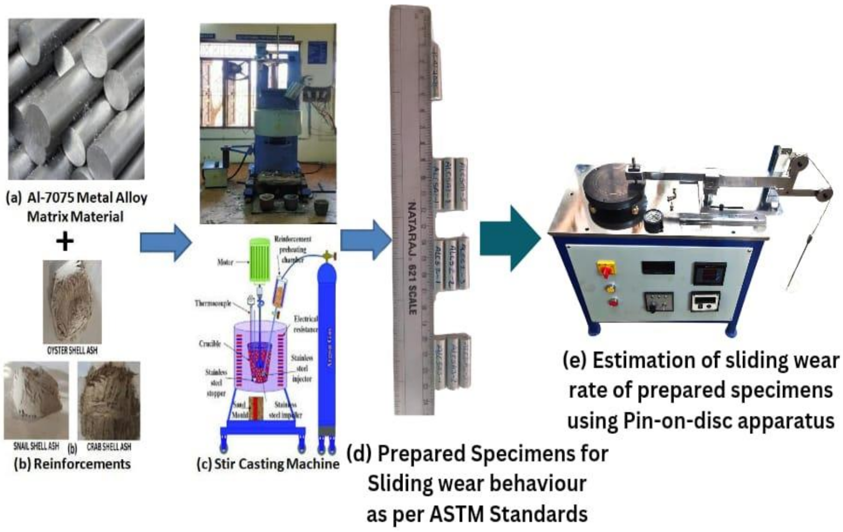

Fig. 1. Step by step Process to estimate the sliding wear behaviour

The wear experiment was conducted in accordance with ASTM standards. Using pin-on-disc friction and wear testing, G99 will be employed to analyze the wear properties of the composite material Al 7075. The samples measure 8 millimeters in diameter and 30 millimeters in height. Polishing the contact surfaces of the worn pin samples was done using a polishing machine to ensure full contact between the pin and its counterpart. At first, pin samples that had been worn were placed in the pin holder above the rotating counterpart disc, which had a diameter of 100 millimeters and was made of EN32 steel. Using a highly precise weighing machine, the pin masses were determined with an accuracy of 0.0001g. Additionally, the disc underwent thorough cleaning with acetone both before and after each test. This was done to eliminate any potential debris that might have been present. Wear testing factors such as the type of reinforcement, the amount of reinforcement, the sliding distance, the applied load, and the sliding velocity were identified from the literature, and the test conditions are summarized in Table 1. Tabular representations of the experimental predictions and the design parameter table may be seen in Table 2. The percentage of material that has been lost and the rate of wear have both been determined using the appropriate equations.

Table 1: Sliding Wear Test Conditions

Pin Material	AlCSA0, AlCSA1, AlCSA2, AlCSA3
Temperature	Room Temperature
Pin Diameter (mm)	8
Pin Height (mm)	30
Track Radius (mm)	60
Load (N)	10, 20, 30
Sliding Distance (m)	1000, 2000,3000
Sliding Velocity (m/s)	1.5, 3, 4.5

Table 2: Design parameters and experimental forecast

S. No	A-% Reinforcement	B-Applied Load (N)	C-Sliding Velocity (m/sec)	D-Sliding Distance (m)	Wear Rate (mm^3/m)	Signal To Noise Ratio Db
1	1	10	1.5	1000	0.0075328	-42.4609
2	1	20	3.0	2000	0.0041863	-47.5634
3	1	30	4.5	3000	0.0028592	-50.8751
4	2	10	3.0	3000	0.0020893	-53.5999
5	2	20	4.5	1000	0.0054367	-45.2932
6	2	30	1.5	2000	0.0037620	-48.4916
7	3	10	4.5	2000	0.0032679	-49.7145
8	3	20	1.5	3000	0.0019008	-54.4214
9	3	30	3.0	1000	0.0028798	-50.8128

III. Results and Discussion

Experiments were conducted to investigate wear loss in Al7075 CSA-filled composites, manipulating various parameters such as the percentage of reinforcement, sliding velocity, sliding distance, and applied stress and generated a Taguchi L9 design with four variables and nine runs by following the steps outlined in Table 2. Experimental data reveals that the composites containing crab shell ash exhibited an impressively low sliding wear rate of 0.0019008 mm3/m under specific operating conditions (A-3, B-20, C-1.5, and D-3000). Conversely, under different operating conditions (A-1, B-10, C-1.5, and D-1000), the composites displayed the highest sliding wear rate of 0.0075328 mm3/m. Based on the Taguchi analysis of wear rate (mm3/m) versus wt.% of the reinforcement, applied load (N), sliding velocity (V), and sliding distance (d) shown in Table 3, it is evident that the sliding distance has a greater impact on wear resistance compared to the other controlling factors.

Table 3: Response Table for Signal-to-Noise Ratios Smaller is better

Level	wt. % of the Reinforcement	Applied Load (N)	Sliding Velocity (V)	Sliding Distance (d)
1	46.97	48.59	48.46	46.19
2	49.13	49.09	50.66	48.59
3	51.65	50.06	48.63	52.97
Delta	4.68	1.47	2.20	6.78
Rank	2	4	3	1

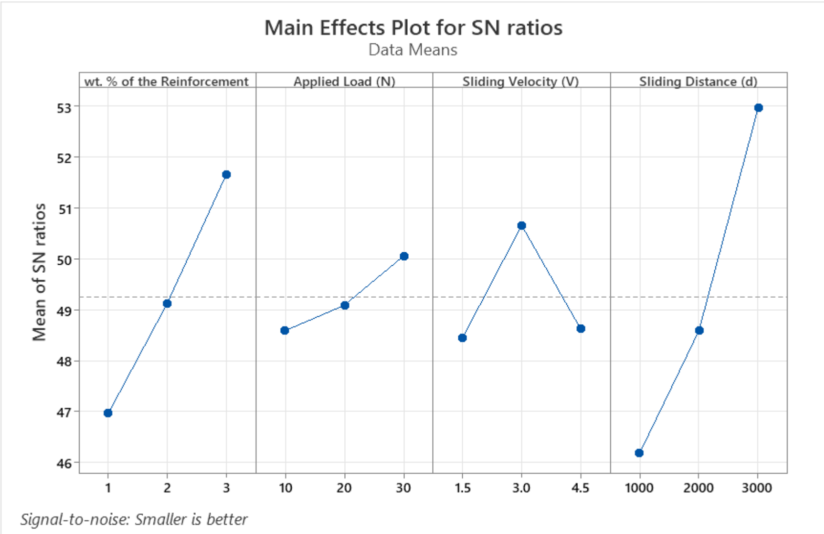

Fig. 2. Plots depicting the primary effects of CSA-filled Al-7075 composites on the signal-to-noise ratio (S/N Ratio).

Figure 2 displays the graphs illustrating the primary effects on the signal-to-noise ratio (S/N ratio) of Al-7075 composites filled with CSA. The lowest sliding wear rate for these composites is determined by the combination of the following factors: A1 (weight percent of the reinforcement: 1), B1 (pressure applied: 10 Newtons), C1 (sliding velocity: 1.5 meters per second), and D1 (sliding distance: 1000 meters). The elements sliding distance (D) and weight % (A) have a substantial impact on sliding wear resistance. On the other hand, the factors applied load (B) and sliding velocity have a less significant impact in comparison to the other parameters.

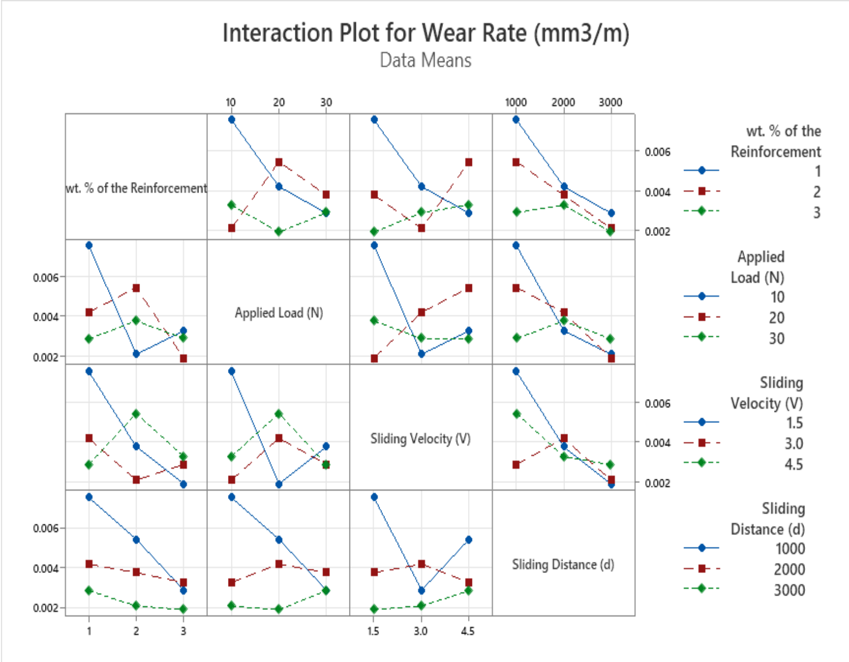

Fig. 3. Interaction plots for wear rate of CSA-filled Al-7075 Composites

The sliding wear rate of CSA-filled Al-7075 composites is most significantly affected by the relationship between sliding distance and filler content (DxA), as shown in Figure 3. The sliding wear behavior of composites filled with CSA is significantly affected by the interactions between A3XB2, A3XC1, A3XD3, B2XC1, B3XD3, B2XD3, and C1XD3, but the impact is less pronounced when A1XB1, A1XC1, A1XD1, B1XC1, B1XD1, and C1XD1 interact with one another. This study concludes that elements A, B, C, and D each have an influence on the sliding wear rate and that some of these components' interactions also have an impact. Variables A, B, C, and D, along with their interactions, are displayed in Figure 3 using interaction plots, providing insights into their respective significance. To ensure that the control parameters and their interactions have a significant impact on the sliding wear rate, an analysis of variance (ANOVA) should be conducted.

When examining the experimental findings of sliding wear rate, it is important to determine the statistical significance of parameters such as applied load, weight percentage of reinforcement, sliding velocity, and sliding distance, as well as their interactions. Analysis of variance (ANOVA) can accomplish this. The results of the ANOVA performed on composites are shown in Table 4. The final column of each task displays the P-value, and we set the level of confidence in the significance of this analysis at 5% for both the individual control variables and their interactions. It is the P-value that determines the importance of the variables and interactions that are associated with the sliding wear rate. When the P-value is lower, it shows that the factor or interaction in question is more important than the others, and then the opposite is also true.

Table 4: Analysis of Variance for S/N ratios of CSA filled Al-7075 based Composites

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	0.000023	0.000006	9.82	0.024
wt. % of the Reinforcement	1	0.000007	0.000007	12.16	0.025
Applied Load (N)	1	0.000002	0.000002	3.27	0.145
Sliding Velocity (V)	1	0.000000	0.000000	0.76	0.433
Sliding Distance (d)	1	0.000014	0.000014	23.09	0.009
Error	4	0.000002	0.000001		
Total	8	0.000025			

The findings of the analysis of variance (ANOVA) for Al-7075 composites that were filled with crab shell ash (CSA) are shown in Table 4. Several parameters were shown to have a substantial influence on the sliding wear rate. These factors include sliding distance (D) (P = 0.009), weight percent of reinforcement (A) (P = 0.025), applied load (B) (P = 0.145), and sliding velocity (C) (P = 0.433). The sliding distance (P = 0.009) has the greatest impact on the sliding wear rate, according to the findings from the previous level of significance. On the other hand, sliding velocity (C) (P = 0.433) does not have any impact whatsoever.

In any DOE approach, the last step consists of predicting and verifying the results through the use of experiments. Composite materials loaded with crab shell ash (CSA) include the following factor combinations to achieve a reduced erosion wear rate: The combination A3B3C2D3. The use of a combination of the aforementioned variables enables us to validate the results of our tests. In order to carry out a regression analysis, a combination of the aforementioned is used. Using the regression equation, one can determine the sliding wear rate and the S/N ratio for composites that have been filled with CSA compounds. Regression Equation is as follows:

Wear Rate (mm3/m) = 0.01062 - 0.001088 wt. % of the Reinforcement - 0.000056 Applied Load (N) - 0.000181 Sliding Velocity (V) - 0.000002 Sliding Distance (d)

After plugging the combined data mentioned above into the regression equation, the sliding wear rate predicted value is 0.005133 mm3/m (-42.7630 dB). The experiment is conducted utilizing a pin-on-disc test rig to determine the experimental sliding wear rate and the corresponding S/N ratio. Across the board, the experiment makes use of the same factor combinations. The combination's experimental sliding wear rate is -40.674 dB, or 0.00496 mm3/m. After calculating the percentage of error for both the regression and experimental results, a value of 3.37% was found, which is below the threshold of 5. However, taking additional measurements can reduce the error to a more acceptable level. This means that the input parameters or control variables used to verify the regression equation for sliding wear rate outcomes have been fulfilled.

V. Conclusions

The key findings from the research article are as follows:

- Successfully fabricated the specimens for sliding wear estimation as per ASTM Standards by stir casting Technique.
- A pin-on-disc apparatus is used to estimate the sliding wear rates of the specimens.
- Taguchi and ANOVA techniques are used to study the influence of operation parameters.
- We have confirmed the results from both the regression and the experiments, and the margin of error is 3.37 percent.

Conflict of Interest:

There was no relevant conflict of interest regarding this paper.

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