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EVALUATION OF MICROSTRUCTURE AND HARDNESS OF Al-Mg-Si ALLOY REINFORCED WITH SiCp

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Abstract: In this paper, Al-Mg-Si alloy has been used as the matrix material to develop metal matrix composites with silicon carbide particle particulates as reinforcement material. The different mesh size of SiC particles was chosen by varying wt.% (1%, 3% and 5%) and preparation was done through the stir casting method. Microstructure evaluation has been done for the formed composite material. Taguchi's technique was used to find the optimization, Analysis of Variance (ANOVA) and mathematical model were generated through regression method to validate the experimental results obtained for hardness.

Index Terms –ANOVA, Hardness, Matrix, Composite.

I. Introduction

6061 aluminum alloy, developed in 1935 and initially known as "Alloy 61S", contains magnesium and silicon, allowing it to be heat-treated to reach higher strength levels. This alloy has a high degree of formability when in its annealed, fully softened state, and it can be significantly strengthened through heat treatment. It also exhibits good weldability, making it one of the most commonly used aluminum alloys for general applications due to its strong mechanical properties.

Metal matrix composites (MMCs) are lightweight structural materials used in various aerospace applications such as aircraft, helicopters, and spacecraft. These composites consist of hard reinforcing particles embedded within a metal matrix, typically a low-density metal alloy. Common metal alloys used as matrix materials include 2024 aluminum, 7075 aluminum, and titanium-6 aluminum-4 vanadium (Ti–6Al–4V). For high-temperature applications, nickel-based superalloys may be used as the matrix phase.

To reinforce the metal matrix, MMCs often use ceramic or metal oxide materials, such as continuous fibers, whiskers, or particles. Commonly used continuous fiber reinforcements include boron (or borsic, SiC-coated boron), carbon, and silicon carbide (SiC), while silicon carbide, alumina (Al2O3), and boron carbide (B4C) are popular choices for particle reinforcement.

The reinforcement content in MMCs typically remains below 30% by volume, which is lower than the fiber content in aerospace carbon–epoxy composites (55–65% by volume). Higher reinforcement levels can be challenging due to the increased hardness and reduced ductility, complicating processing, forming, and machining.

Metal matrix composites (MMCs) are known for their low density, high strength-to-weight ratio, high temperature resistance, and impressive creep, fatigue, and wear resistance. These characteristics make them promising alternatives to cast iron and other traditional materials in automotive components like engines and brakes. Generally, MMCs designed for automotive purposes contain ceramic particles or short fibers, such as silicon carbide (SiC) or aluminum oxide (Al2O3), mixed with lightweight metals like aluminum, magnesium, or titanium.

MMCs have been developed for applications in diesel engine pistons, cylinder liners, brake drums, and brake rotors (Chawla and Chawla, 2006). They've also been tested in other automotive components like connecting rods, piston pins, and drive shafts. Despite their potential, the high cost of MMCs remains a significant barrier to broader adoption.

II. LITERATURE REVIEW

Using three different aluminum alloys (Al 7075, Al 2024, and Al 6061), the present research studied the Red Sea as a corrosive environment. Factors such as immersion time and temperatures on the corrosion behavior of aluminum alloys in seawater were studied using weight loss (WL) and potentiodynamic polarization (PDP) measurements. Change in aluminum alloy surfaces was detected at different conditions using optical photography (OP), scanning electron microscope (SEM), and electron-dispersive energy spectroscopy (EDS). (Aisha H. Al-Moubaraki et al. 2018)

In the hybrid composite we used one ceramic and a natural fibre to reduce the cost of composite. The paper examine the various factor like (a) Effect of various reinforcement (b) Mechanical behavior like tensile strength, hardness, compressive strength (c) Processing methodology and its effect (d) Application of AMC with various reinforcements. (Shipra Verma et al. 2018)

In this work, mechanical properties of Al6061 alloy was improved under different conditions by the process of optimization of heat treatment parameters (Toschi, 2018) by adopting Taguchi's experimental design and analyzing the outputs through TOPSIS methodology and optimizing the input parameters over higher tensile strength, impact strength and hardness (Mazahery and Shabani, 2014) by desirability analysis. (V. Monica et al 2019)

In the present study attempt has been made to demonstrate the mechanical and tribological characteristics of the self-healing Al6061 composite reinforced with low melting point solder alloy. The present will be of significant help to develop materials for various aerospace and automotive applications. The mechanical components such as piston skirts, driving shaft, wheels, steering knuckles, connecting rod, steering columns, cylinders liners etc fabricated using the self healing materials will be significantly benefitted as they are susceptible to frequent wear and tear due to the Sevier operating conditions. (Nitin Kumar Gupta et al. 2019)

In the context of ultra-precision machining of Al6061, it is even more important, since the heat dissipated through the chips and workpiece materials also induces the generation of precipitated phases and changes their mechanical properties, affecting the mechanisms of chip formation and surface generation. (Hailong Wang et al. 2020)

In this work, drilling studies using multi spindle drilling head were carried out on three grades of aluminum alloys i.e. Al2024, Al6064, and Al5083. The aim of this work is to evaluate and compare the effect of the cutting parameters on the generated thrust force, hole surface roughness and chip formation for the studied alloys. In addition, Analysis of variance was employed to statistically evaluate the cutting parameters and measured outputs. The studies also aim to show that multi-spindle simultaneous drilling experiments tend to increase productivity and reduce cycle time without compromising hole quality. (Muhammad Aamir ei al. 2020)

The novelty of this article shows that no study has been carried out to demonstrate the overall metallurgical property of stir cast Al-6061 MMC with optimized process parameters. In future this review article will benefit academic researchers to choose the best permutation and combination of rein-forcement and optimized process parameters to synthesize other aluminum-based alloys for achieving maximum metallurgical and functional properties. (Nagender Kumar Chandl et al. 2021)

As illustrated in the literature survey, incorporating ceramic fillers into metals can considerably enhance their properties. Furthermore, the production technique parameters could also affect the produced metal matrix composite. Consequently, the main objective of the current investigation is to evaluate the mechanical characteristics of Al6061 after adding particles of micro-TiO2 utilizing the stir casting technique. Al6061 composites were fabricated with different loading fractions of micro-TiO2, 1, 2, 3, 4, and 5 wt.%, and compared with pure Al6061, 0 wt.%. Different stirring speeds and times were applied during the production process to investigate their effects on the properties of Al6061 composites. Besides the structural and morphological characteristics of the Al6061 composite, the chemical composition was analyzed. (A. H. Badran et al. 2022)

Dissimilar FSWed joints made of AA2198 and AA2024 have already been investigated in terms of mechanical and microstructural characterizations [24–27]. To the authors' knowledge, neither pre- nor post-welding heat treatments were applied to dissimilar joints between AA2024 and AA2198 in the literature. Therefore, this research addresses the challenge of optimizing heat treatment for dissimilar joints made of AA2198 and AA2024, in order to improve the weakest as-FSWed regions without impairing the rest of the joint. (Mahdi Masoumi Khalilabad et al. 2022)

On account of this, the present investigation was conceived to incorporate locally sourced agro-waste (rice husk and palm kernel shell) and industrial waste (steel powder) as fillers in the design and development of the hybrid Al6061 via the stir casting process. The choice of rice husk, palm kernel, and steel powder is based on their abundance and availability within the purview of this research. The response surface method was employed for the design of the experiment to minimize experimental runs and for the optimization of process parameters. Experimental variables are palm kernel shell ash (PKA), rice husk ash (RHA), and stirring temperature (ST), while steel powder was introduced at a constant proportion of 4 wt.%. The choice of such wt.% of Fe was based on observations showcased by Yamasaki et al. [40] in which 3 to 5 wt.% Fe introduced into the aluminium matrix ensured improvement in the tensile performance of the developed composite. (Abayomi Adewale Akinwande et al. 2023)

III. METHODOLOGY

In the past year conventional materials used to play a significant role in the industrial applications, while the development of material has a major impact on the growth of industrial products as well on the economy of a nation. Al6061/SiC composite was prepared by using stir casting method and machining was done as per standard test size specimen. Optimization technique was used by using standard orthogonal array to find the optimization, Analysis of Variance (ANOVA) and mathematical model were generated through regression method to validate the experimental results. Tensile fracture specimen is examined through SEM images and found out that, the type of fracture is ductile fracture and silicon carbide reinforcement have good bonding with matrix material.

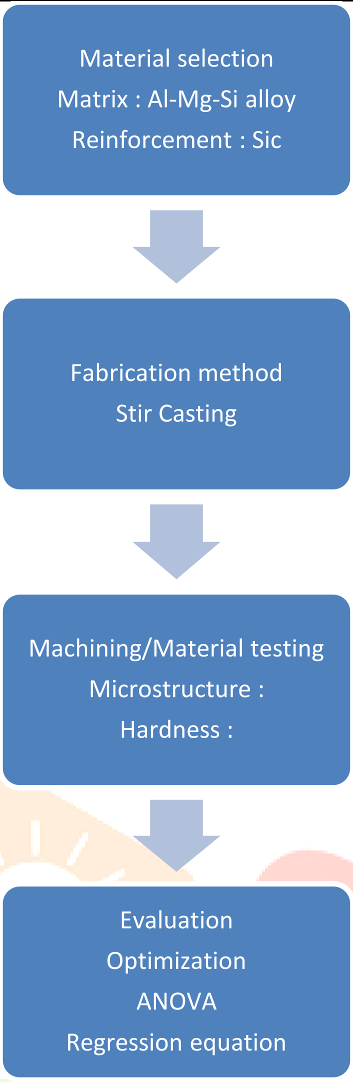
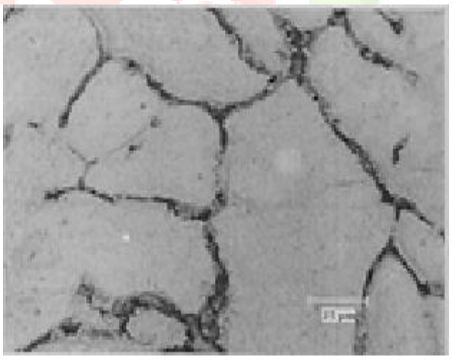
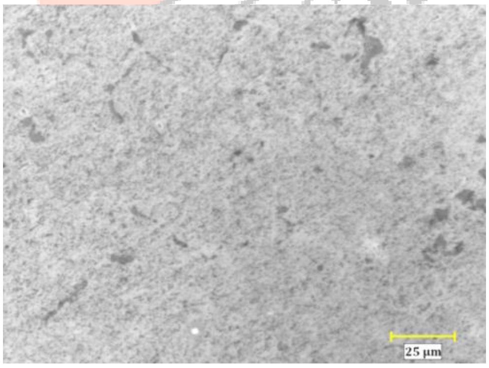


FIG 1: Flow chart of current work.

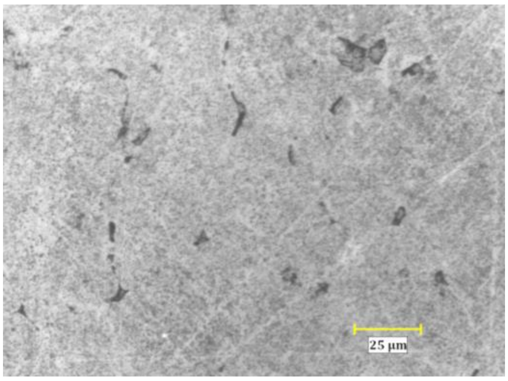
IV. RESULTS AND DISCUSSION



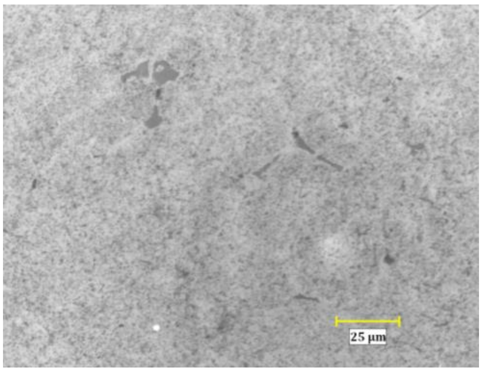
(a) Al-Mg-SiC alloy without heat treatment



(b) Al6061+5% SiC+1 hr. Heat Treated



(c) Al6061+5% SiC+3 hr. Heat Treated



(d) Al6061+5% SiC+5 hr. Heat Treated

Figure 1: (a) Microstructure of Al6061 alloy; (b-d) Microstructure of Al6061/SiC composite material

Figure 1(a): Untreated Al-Mg-SiC Alloys
This figure represents an alloy composed of aluminum, magnesium, and silicon carbide (SiC) in its natural state, typically exhibiting moderate strength, good formability, and corrosion resistance. Despite these positive traits, heat treatment processes like quenching and ageing are used to increase strength and hardness.

Figure 1(b): Al6061 + 5% SiC with 1-Hour Heat Treatment
This configuration combines Al6061 with 5% silicon carbide and undergoes heat treatment for 1 hour. The SiC particles boost hardness and wear resistance, while the heat treatment improves the composite's overall strength.

Figure 1(c): Al6061 + 5% SiC with 3-Hour Heat Treatment
This variant of Al6061 with 5% SiC undergoes a 3-hour heat treatment. This process builds upon the properties of the 1-hour heat treatment by potentially providing additional strength and durability.

Figure 1(d): Al6061 + 5% SiC with 5-Hour Heat Treatment
This setup consists of Al6061 alloy with 5% SiC, heat treated for 5 hours. The extended heat treatment aims to maximize the material's mechanical properties, potentially yielding greater durability, strength, and hardness compared to shorter heat treatments.

Trail No.	SiC (wt.%)	Heat Treatment (hrs.)	Mesh Size	Hardness (BHN)	Predicted Value	Error	Error %
1	1	1	100	64.21	66.56245	3.45	5.3729949
2	1	3	200	70.64	66.5296	0.28	0.396376
3	1	5	300	73.04	66.49675	1.15	1.5744797
4	3	1	200	67.81	66.4639	1.27	1.8728801
5	3	3	300	77.27	66.43105	7.46	9.6544584
6	3	5	100	83.97	66.3982	1.04	1.2385376
7	5	1	300	61.57	66.36535	3.84	6.2368036
8	5	3	100	83.41	66.3325	4.87	5.8386285
9	5	5	200	75.87	66.29965	5.92	7.8028206

Table 1: Comparison of experimental and predicted hardness using standard orthogonal array

Regression equation for hardness of Al6061/SiC composite material is shown below:

BHN = 66.5953 + 1.08 Silicon Carbide (wt.%) + 3.27417 Heat Treatment (hrs.) - 0.03285 Mesh Size……………..(Eq. 1)

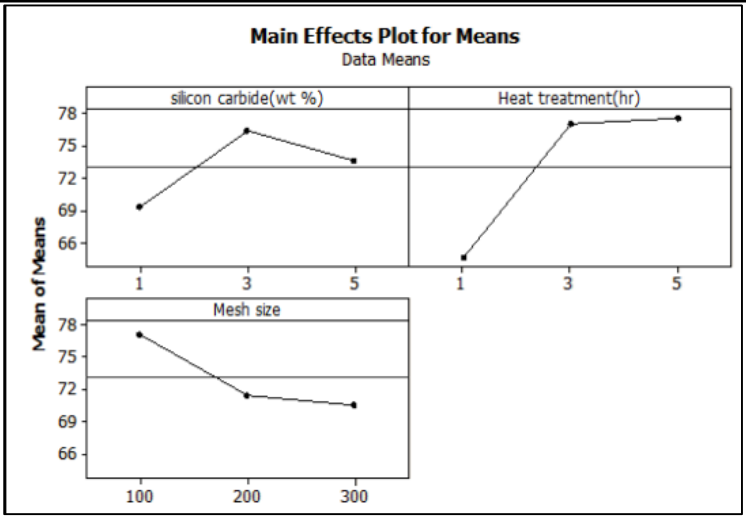


Figure 2: Optimization of hardness of Al6061/SiC composite.

Figure 2 represent the main effect plot for means is a graphical representation used to illustrate the impact of three factors on a response variable in an experiment or statistical analysis. In the above graph silicon carbide (wt.%) is higher for A2, heat treatment (hr) is higher for B3 and for mesh size is higher for C1. Hence, optimal condition is A2B3C1 for hardness of Al6061/SiC composite.

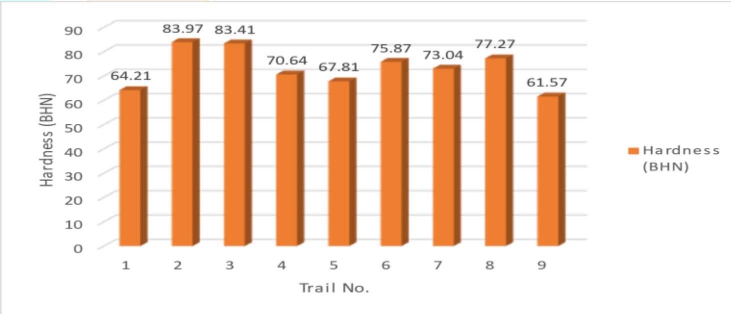


Figure 3: Plot of hardness of Al6061/SiC composite.

ANOVA

To determine the percentage contribution of different factors to their output responses, analysis of variance (ANOVA) is employed. This method quantifies the influence of each factor on the outcome, presenting it as a percentage of the total effect. ANOVA also allows for examination of the interaction between various parameters and their levels in experiments, providing a clear view of how these factors influence each other.

Factors used	Percentage contribution for Hardness	Rank
Silicon carbide (wt.%)	15.31%	3
Heat treatment (hr)	66.58%	1
Mesh size	15.53%	2

Table 2: Percentage contribution of each parameter on hardness of Al6061/SiC composite.

Regression Analysis

To ensure the accuracy of experimental results, regression analysis is utilized to create mathematical models. These models are derived from the output response values, the number of variables, and the corresponding levels used in the experiments. The Taguchi standard orthogonal array table guides the structure of the analysis. This study employs General Linear Regression Models to verify that the experimental results fall within a ±10% margin of error.

V. Conclusion and Future Scope

- Formulated composites exhibits increased hardness and tensile strength with increase in SiC particles.
- Al6061/SiC composites shows better hardness when compared to Al6061 alloy alone.
- Experimental results are validated through regression equation by using Minitab software.

VI. REFERENCES

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