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Research Article

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Optimizing Mechanical Properties of Metal Matrix Composites Using Taguchi's Technique

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Abstract

AA6162 alloy belongs to the Al 6000 series, renowned for its outstanding corrosion resistance and strength properties. This study aimed to determine the ultimate tensile strength (UTS) of AA6162 alloy with varying amounts of SiC (Silicon carbide) powder (3%, 6%, and 9% wt.) produced using the stir casting apparatus. The optimization of UTS was carried out using the Taguchi method, and Minitab statistical software was utilized to analyze S/N ratio and perform ANOVA (Analysis of variance) for the parameters: stir speed (SS), stir time (ST), and wt.% of reinforcements (RE). The ANOVA results revealed that stir time had the most significant impact on UTS, contributing approximately 42.3% to its improvement. The next substantial factor was the percentage of reinforcements, which contributed around 19.2%. Stir speed was identified as the least influential factor, accounting for approximately 18.5% of the variation in UTS. By considering these factors and optimizing stir time and reinforcement percentage, it is possible to enhance the UTS of AA6162 alloy particulate with SiC powder, leading to improved overall performance and mechanical properties.

Keywords

Metal matric composite, Universal testing machine, Analysis of variance, Minitab

Introduction

Metal matrix composites offer significant advantages in various specific fields [1]. AA5456 aluminum alloy is widely used due to its superior strength and corrosion resistance [2]. Metal matrix composites find applications in numerous aspects of everyday life [3], and they are extensively utilized in industries such as vehicles, aerospace, and engine machinery production [4]. The addition of Mg and Al provides additional benefits, particularly in terms of reducing weight and enhancing wet properties. Saessi et al. conducted a study on the wear rate of Al5083 alloy and Al5083-5 wt.% of B_4C composite at various temperatures and found that the hardness value increased as the boron carbide wt.% level reached around five percent [5]. Furthermore, when SiC particles (SiCp) are used as reinforcements for aluminum materials, the UTS and elastic modulus increase due to the uniform distribution of carbides [6]. Shanmugasundaram et al. [7] investigated the effect of GTA surface-melting on SiC with AA5086, revealed that the abrasion value and wear rate were improved by more than 30% compared to the base material, and no inter-metallic compounds were found. Ilangovan et al. [8] studied the use of different pin profile tools in friction stir welding of Al alloy 6061-5086. They observed variations in the tensile strength based on the shape of the pin tool. Additionally, the incorporation of Gr/SiC reinforcements in the aluminum matrix led to an enhancement in material properties [9]. The inclusion of fly ash as reinforcement in aluminum alloys improved corrosion re-

sistance by preventing the formation of pits [10]. However, it is important to highlight that these types of alloys might experience intergranular decomposition at elevated temperatures [11]. Moreover, the dispersion of particles within the matrix material during the casting process is influenced by various factors, including heating temperature, slurry viscosity, particle wetting, and stirring speed [12]. Stir casting methods offer a major advantage, as they are applicable to mass production and have lower costs (approximately 1/3rd to 1/10th) compared to other manufacturing processes for metal matrix composites [13]. The manufacturing of Al alloy metal matrix hybrid composites through casting techniques is highly attractive because of its cost-effectiveness and ability to achieve net-shape fabrication [14]. Kumar et al. [15] conducted research to enhance the mechanical performance of AA5456 alloy plates using the magnetic oscillation method. In light of the aforementioned literature reviews, this present study examines the tensile characteristics of AA6162 composites reinforced with SiC and fly ash. The experimental design for analyzing the UTS parameters was carried out using the Minitab software.

Experimentation

The stir casting method was chosen to fabricate hybrid composites using a metal matrix. The chemical weight percentages of the components are listed in table 1, where Mg has the highest proportion after Al. To prepare the testing samples, the stir casting process was performed using a fired furnace (Figure 1). Initially, both SiC powders (3%) were preheated at a specific temperature of approximately 200 °C. Then, the AA6162 material was placed inside the furnace and heated to around 750 °C for approximately 45 min. Once the Al alloy was melted, the reinforcement materials were added to the furnace. A stainless-steel stirrer was used to thoroughly mix all the materials. The molten metal was subsequently poured into a permanent mold to create specimens for mechanical behavior analysis. The same process was repeated to create the remaining samples, with variations in particle stir speed and stir time. According to the dimensional standards outlined in ASTM, the specimens were cut to perform tensile experiments table 2 presents wear input levels.

Results and Discussion

Nine wear experiments were conducted using a UTS machine, and the resulting UTS data is presented in table 3. Design of experiments was performed using Minitab-18 software, considering various input factors. The mean and S/N-ratio responses are illustrated in figure 2 and figure 3, respectively. After analyzing table 4 and table 5, it was observed that the optimum UTS was achieved at the second level of stir time (1st rank), the second level of stir speed (2nd rank), and the second level of reinforcement wt.% (3rd rank). The ANOVA results showed the contribution of each parameter on UTS: stir time had a major influence, contributing about 42.3%, followed by reinforcement percentage, which contributed approximately 19.2%, and stir speed, which had the least impact, accounting for around 18.5% in the improvement of UTS, as shown in table 6.The minimum UTS value of 156 MPa was observed for the combination of SS - 300 rpm, ST - 15 min, and RE - 3 wt.%. The maximum UTS value of 214.23 MPa was achieved with SS - 450 rpm, ST - 20 min, and RE - 9 wt.%. The regression equation for UTS, obtained from Minitab-18, is represented in equation 1.

Table 1: Composition AA6162 (Wt.%).

Elements	Si	Cu	Fe	Mg	Cr	Mn	Zn	Al
%	0.65	0.10	0.32	0.12	0.12	0.09	0.19	Balance

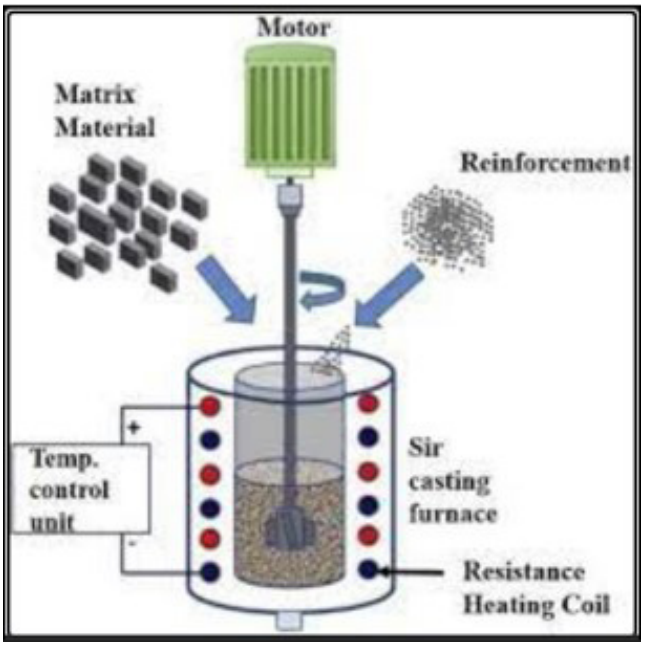

Figure 1: Stir casting furnace.

Table 2: Wear input levels.

Factors	Level 1	Level 2	Level 4
SS (rpm)	300	450	600
ST (min)	015	020	025
RE (Wt.%)	003	006	009

Table 3: Observation results.

Exp. No.	SS	ST	RE	UTS (MPa)	S/N Ratio
1	300	15	3	156.25	-43.8764
2	300	20	6	198.60	-45.9596
3	300	25	9	201.65	-46.0920
4	450	15	6	198.25	-45.9443
5	450	20	9	214.23	-46.6176
6	450	25	3	189.26	-45.5412
7	600	15	9	178.26	-45.0211
8	600	20	3	210.60	-46.4692
9	600	25	6	201.36	-46.0795

$$UTS = 150.01025 - 2.000125\,SS + 5.000253\,ST - 0.000314\,RE \quad (1)$$

The contour plot for UTS performance against all parameters are drawn. It was noticed that rate or value of UTS was increased when increased stir time and decrement of stir speed in figure 4, at the same way wear value slightly comes down due to increase of reinforcement and stir speed in figure 5 and finally wear rate was changed while changing of reinforcement percentage and stir time in figure 6.

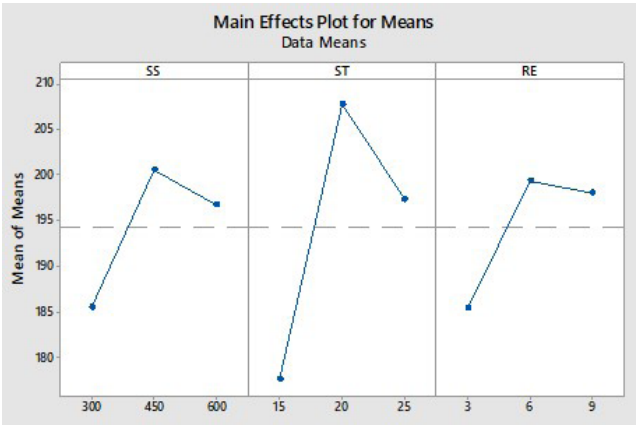

Figure 2: UTS-Means plot.

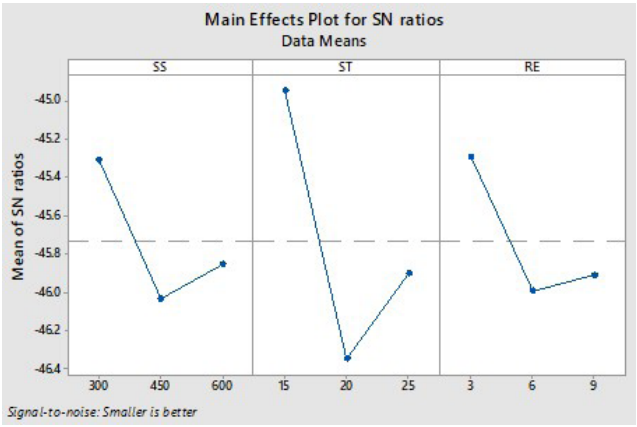

Figure 3: UTS-S/N plot.

Table 4: Response reading - Means.

Level	SS	ST	RE
1	185.5	177.6	185.4
2	200.6	207.8	199.4
3	196.7	197.4	198.0
Delta	015.1	030.2	014.0
Rank	002.0	001.0	003.0

Table 5: Response reading – S/N ratio.

Level	SS	ST	RE
1	-45.31	-44.95	-45.30
2	-46.03	-46.35	-45.99
3	-45.86	-45.90	-45.91
Delta	00.73	01.40	00.70
Rank	02.00	01.00	03.00

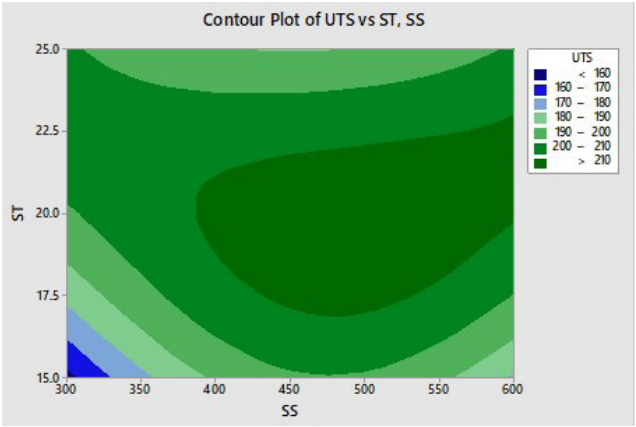

Figure 4: Contour plot SS vs ST.

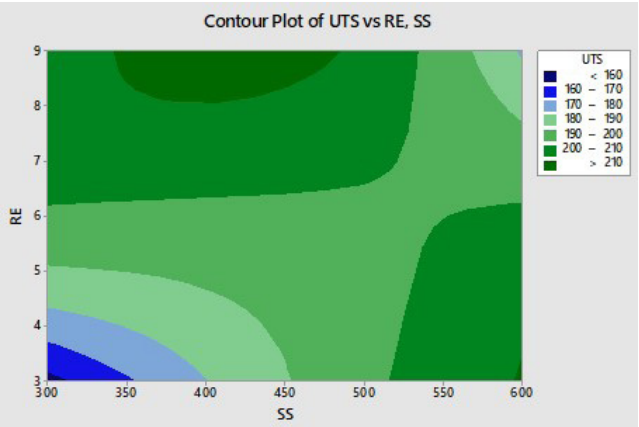

Figure 5: Contour plot SS vs RE.

Conclusion

AA6162 alloy serves as the primary material reinforced with SiC, and a total of nine specimens were prepared following the ASTM standard using the stir casting technique for conducting tensile tests on a UTS. The Design of Experiments for UTS parameters was analyzed using Minitab software. Based on the ANOVA results, the contribution of each parameter was calculated, and it was observed that stir time had the most significant influence on UTS, accounting for approximately 42.3%. The next substantial parameter was the reinforcement percentage, contributing around 19.2%, followed by stir speed, which was the least influencing factor, contributing approximately 18.5% to the improvement of UTS. The minimum UTS of 156 MPa was obtained at the combination of SS - 300 rpm, ST - 15 min, and RE - 3 wt.%. On the other hand, the maximum UTS of 214.23 MPa was detected at SS - 450 rpm, ST - 20 min, and RE - 9 wt.%.

Acknowledgements

None.

Table 6: ANOVA - UTS.

Source	DF	Seq SS	Adj MS	F	P	Contribution (%)
SS	2	0.8568	0.4284	1.01	0.0499	018.5
ST	2	3.0777	1.5389	3.61	0.0217	042.3
RE	2	0.8733	0.4366	1.02	0.0494	019.2
Residual error	2	0.8522	0.4261			019.6
Total	8	5.6599				100.0

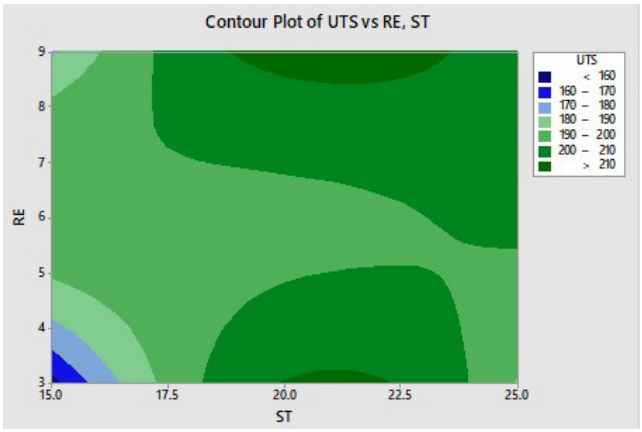

Figure 6: Contour plot ST vs RE.

Conflict of Interest

None.

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