International Journal of Engineering Research and Sustainable Technologies
Volume 1, No.1, September 2023, P 1- 8
ISSN: 2584-1394

OPTIMIZING MECHANICAL PERFORMANCE: ALUMINUM 7075 & INCONEL ALLOY 625 HYBRID COMPOSITE WITH NANO-GRAPHENE FABRICATION

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DOI: https://doi.org/10.63458/ijerst.v1i1.57 | ARK: ark:/61909/IJERST.v1i1.57

Abstract

Due to their intrinsic characteristics, nano hybrid metal matrix composites are widely used in the automotive, aerospace, and marine sectors. The planning of trials by Taguchi method was used to conduct research on nano hybrid metal matrix composite. Predicting the more accurate factors that result in high tensile strength and toughness is the primary goal. With the goal of achieving excellent casting with the fewest possible results, the management of the processing factors was crucial. Investigating the impact of a process component on the necessary characteristics involved the use of an orthogonal array and analysis of variance. Using the Taguchi technique, the best factors are found to give composite materials their optimum mechanical characteristics. The primary goal of this study project is to identify the factors that affect flawless composite casting. The ideal values were found to be toughness 0.5% Nano graphene + 2% Inconel alloy 625, 250 rpm, 600 °C and tensile strength 1.5% Nano graphene + 6% Inconel alloy 625, 450 rpm, 650 °C. It has been determined that the most important element in improving mechanical characteristics is the composition of the reinforcement.

Keywords: Aluminium, Significant Factor, Optimum Parameter, Parameter

1. Introduction

Due to their exceptional strength-to-weight ratio, better thermal conductivity, and enhanced wear resistance, Particulate Reinforced Aluminium Metal Matrix Composites (PRAMMCs) are extensively used in the aircraft, marine, transit, and military sectors. It is primarily used in the manufacturing of car components like cam shafts, drive shafts, and pistons.[1] Many manufacturing techniques are used to create aluminium metal matrix composites, including centrifugal casting, vacuum casting, powder metallurgy, stir casting, insitu casting, compo casting, and squeeze casting. [2] Stir casting is a practical, convenient, and adaptable manufacturing technique for making things in big quantities.[3-5]. The effects of nano-sized boron carbide particles on the tensile, tribological, and microstructural properties of AA6061/B4C AMCs They discovered that introducing B4C particulates significantly enhanced the composites' mechanical and tribological properties.[6-7] After being produced by the pressure infiltration technique, the tensile characteristics of the SiC and B4C reinforced aluminium alloys were evaluated and contrasted. The strength of Al-B4C composites, they asserted, is significantly greater than that of Al-SiC composites.[8] Increasing the materials' wear resilience is the primary goal of the ceramic reinforcement. As the hardest of the three commonly used ceramic particles, B4C is the best choice for uses needing wear resilience. Gr particles act as the solid lubrication, so by adding graphite to the polymer, self-lubricating powers are added. [9] Sliding wear experiments for different particle sizes and volume fractions were performed on coated B4C particle - reinforced 2024 aluminium alloy composites created by squeeze casting [10]. The B4C distributions in the matrix were usually homogeneous, according to the study of the microstructure, and some particle clustering was advantageous for composites with relatively large particle volume percentages. It has been demonstrated that using a B4C and SiC blend improved wear resilience [11]. Since B4C particles are less dense (2.52 g/cm3) than widely used Al2O3 and SiC particles, they can be used to strengthen composites for greater specific strength and stiffness. [12] Examining the surface quality characteristics of milling mixed aluminium-B4C-SiC metal matrix composites using the Taguchi method. After input rate, chopping speed was found to be the second-most important factor. The feed velocity was found to have little to no effect on surface texture.[13] investigated how using the traditional investment casting method would affect alloys composed of an aluminium metal matrix. The studies showed that SiC reinforced MMC has a higher wear resistance than B4C reinforced MMC when comparing aluminium alloys strengthened with SiC and B4C. [14] The casting specifications for Al/RHA/RM hybrid composites were optimised in order to improve the tensile strength and hardness of the stir-cast LM 26 Al/RHA/RM hybrid composites by the Taguchi method. Taguchi's L9 orthogonal matrix is used to organise experiments. The total performance of the stir casting technique is significantly improved by combining experimental and analytical methods, with the outcome reaction acting as the most important measure.[15] explains how different stir casting process factors, such as stirring speed, time spent stirring, melt temperature, and reinforcement %, affected the casting component's quality. It was consequently tailored for the pellet-produced Al6061-NCG particulate material. The Taguchi-based RSM method was used to optimise the Al 6061 alloy process factors. The outcomes, including the alloy's hardness and tensile strength, were then submitted to an ANOVA study.[16] The S/N ratio was used as a quality measure in experiments with the L9 orthogonal array. The findings of the trial were used to determine crucial process parameters, which were then enhanced using Pareto ANOVA.[17] Grey relational analysis is used to examine the various reactions that surface texture and casting density have. The increased surface finish of the LM20 alloy is produced by the improved heat transfer rate and mould interface caused by the squeeze pressure load. The Taguchi approach was used to optimise the stir casting process parameters to reduce the wear rate of AlSiC composites and the reinforcement % of 400 mesh SiC particles. By taking into account process variables including melt temperature, stirring time, and rotation speed for composites, the L16 orthogonal array was used in optimization. The author improved the Taguchi analysis's optimal parameters for the composite, including the melt temperature of 740 C, the stirring speed of 300 rpm for 10 min, and the percentage of SiC content of 15%.[18]The importance of squeeze casting process parameter optimisation to obtain a gorgeous surface quality and interior integrity of the cast component. In this study, a compression casting process parameter was enhanced using evolutionary algorithms, particle swarms, and multi-objective particle swarm optimisation. Surface roughness and final tensile strength were used as experimental answers for alloy optimisation to characterise how squeezing pressure affected the mechanical and microstructural properties of the cast component. [19-25].

2. Methodology

In this study, a resistive heating oven heated to 700 °C to dissolve aluminium alloy 7075. The furnace's temperature was raised to 750 and held there for 25 minutes in order to achieve a homogenous boil.To avoid extra burning and oxidation, argon gas was delivered into the burner area at a rate of 4.5 L/minute. By using an exterior spure, the Inconel alloy and nano graphene were incorporated into the liquid metal at various weight percentages (2,4,6,) and (0.5,1,1.5). A 500 rpm pace was used for the entire 15-minute mechanical stirring procedure. To accomplish even dispersal of reinforcement in the melt the furnace speed and temperature has been enhanced to 600 rpm and 950 of 30 minutes stirring. A metal ultrasonic instrument was used to generate a 20 kHz signal with 2 kW of strength. Following this mechanical agitation, the hybrid composite slurry was created and poured into a die, where it was left to harden at room temperature after 10 minutes of ultrasonic stirring. To improve the liquid metal's flow and wettability, 1 weight percent of magnesium was added. Figures 1 show the tensile and hardness specimen.

Fig.1 Tensile and hardness specimen

Fig 2. Stir Casting Machine

2.1 Taguchi method Application

Taguchi technique is a most conceptual, logical methodology to analyse optimum parameter which influenced on process and performance, it neglects the necessity of frequent experiments and minimizes the processing time, material and cost. In this experimentation analyse three different parameters are selected namely weight fraction x1, stirring speed x2, and processing temperature x3, individual levels were assumed and listed in table 1.

Table 1
Design of experiments

Inputs parameters	**1**	**0**	**1**
Compositions,x1	0.5% nano graphene + 2 % Inconel alloy	1 % nano graphene + 4 % Inconel alloy 625	1.5 % Nano graphene+ 6 % Inconel alloy
Stirring speed,x2[rpm]	250	350	450
Processing temperature,x3°C	600	650	700

In factories experiment, orthogonal arrays are frequently used to assess the effects of numerous different control variables. An testing strategy in which the sections for the self-governing factors are orthogonal to one another is known as an orthogonal array. By using an orthogonal matrix, analysis is made simple and testing time is greatly reduced. The level number and variables must be determined in order to characterise an orthogonal array. Number of levels -1 x1 DOF = 3-1 = 2, x2 DOF = 3-1 = 2, and x3 DOF 3-1 = 2 were used to determine the degrees of freedom (DOF) for three factors in each of the three levels.

Nine tests on a three-level L9 orthogonal array were meticulously selected. The experiment's overall DOF is 9-1 = 8. The orthogonal matrix used in the study is shown in Table 2 for reference. Using an orthogonal array of process factors, 9 sections of hybrid composites were created as part of this experimental study project. The examples required for the tension and hardness tests were created using a milling machine in accordance with ASTM standards, which were ASTM E -8 for the tensile test and ASTM E 10 for the hardness test. In figure, the finished example is displayed.

Table 2
Orthogonal array table

Experiment number	Input paramètres x1	X2	X3
1	-1	-1	-1
2	-1	0	0
3	-1	1	1
4	0	-1	0
5	0	0	1
6	0	1	-1
7	1	-1	1
8	1	0	-1
9	1	1	0

2.2 Analysis of variance

The importance of using the signal-to-noise (S/N) ratio to calculate reaction variance is emphasised by the Taguchi technique, which minimises the amount of time that uncontrollable parameter-related behaviour changes the quality of the behaviour. Plots of the major effects of hardness and tensile strength are shown in Tables 6 to 9. The terms "signal" and "noise" in the Taguchi technique refer to the desired value (mean) and the undesirable value (standard deviation) for the product quality behavior, respectively. A greater tensile strength is wanted, so in this study project the S/N ratio for bigger is better was used to determine the ideal value. 9 examples were made in accordance with the L 9 orthogonal array, and the S/N ratios were computed using MINITAB software. Regression analysis is used to show the mechanical property values that were discovered in mentioned below.

The goal of the analysis of variance is to identify the process variables that have a major impact on the performance of the quality. MINITAB software was used to conduct an ANOVA with a threshold of significance of 5% to investigate the role of the variables. The P value is considered to be statistically significant when it is less than 0.05.According to the data, each of the three factors has a value greater than 0.05, which at a 95% confidence level indicates that the factors are highly insignificant. The percentage of contribution% Pc indicates that the composition of reinforcement is the key process parameter for increasing tensile strength and lowering hardness. It displays the overall dissimilarity and their degree of impact on the table. ANOVA tables for hardness and tension are shown in Tables 3 and 4. The graphical representation ofthe shift in performance characteristics with a process parameter deviation are called main effect graphs. The primary impact graph for three variables and three degrees of material is displayed in figures 2 to 3.

Table 3
ANOVA table for hardness strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution %
Composition of reinforcement	2	44.07	1530.18	765.088	0.054	92.31
Stirring Speed	2	44.77	27.80	13.901	0.760	1.677
Processing Temperature	2	45.35	11.53	5.764	0.884	0.695
Error	2	1.28	88.03	44.014		92.31
Total	8	2	1657.54			1.677

Table 4
ANOVA table for tensile strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution %
Composition of reinforcement	2	5766.89	2883.44	837.13	0.001	85
Stirring Speed	2	963.56	481.78	139.87	0.007	14.24
Processing Temperature	2	26.89	13.44	3.90	0.204	0.397
Error	2	6.89	3.44			
Total	8	6764.22				

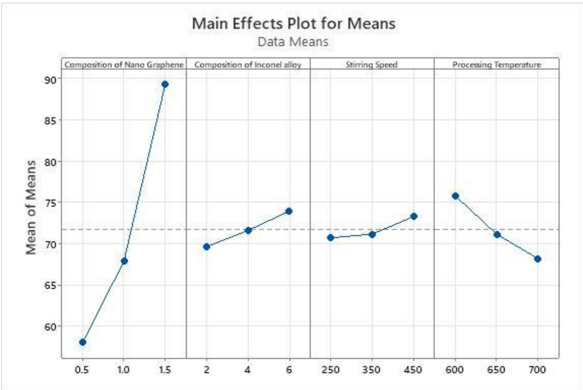

Fig.2 Main effects plot for means to hardness

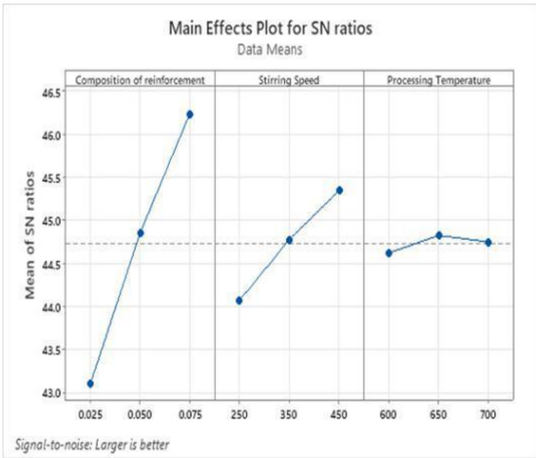

Fig. 3 Main effects plot for S/N ratio of tensile strength

3. Results and Discussions

A common test for determining the Brinell hardness of ferrous objects is ASTM E -10. The load employed in this experimental study project is 250 kg, and a 5 mm indenter ball was used, resulting in an indention diameter that ranges from 2.5 to 6 mm. Without shaking, the load was delivered for 10 to 15 seconds at maximum force. The test object was held to the two extremities of the universal testing device for the tensile test. Until the specimen fractured, load was given to it using the moveable cross head. Results of the toughness and tension tests are shown in Table 5.

Table 5
Hardness and tensile test results

Experiment number	Input parameters			Output parameters	
	Composition of reinforcement	**Stirring speed r.p.m**	**Processing temperature °C**	**Hardness (BHN)**	**Ultimate tensile strength Mpa**
1	0.5 % Nano graphene + 2 % Inconel alloy 625	250	600	59	130
2	0.5 % Nano graphene + 2 % Inconel alloy 625	350	650	56.8	145
3	0.5 % Nano graphene + 2 % Inconel alloy 625	450	700	58.3	155
4	1 % Nano graphene + 4 % Inconel alloy 625	250	650	61.7	165
5	1 % Nano graphene + 4 % Inconel alloy 625	350	700	73.4	175
6	1 % Nano graphene + 4 % Inconel alloy 625	450	600	68.5	185
7	1.5 % Nano graphene + 6 % Inconel alloy 625	250	700	88.2	190
8	1.5 % Nano graphene + 6 % Inconel alloy 625	350	600	84.6	205
9	1.5 % Nano graphene + 6 % Inconel alloy 625	450	650	95.0	221

3.1 Confirmation test

The final step in the DOE is a confirmation test. It was identified that the optimum parameters for tensile strength were 1.5 % Nano graphene + 6 % Inconel alloy 625, 450 rpm , 650 °C and for hardness 0.5 % Nano graphene + 2 % Inconel 625 , 250 rpm , 600 °C . Best results (Maximum 221MPa concluded Hardness and tensile strength measured experimentally and computed using the regression equation are virtually identical with a 4% maximum error. Regression equation is used to determine mechanical properties at a degree of accuracy that is adequate.

Table 6
Response table for S/N ratio of hardness

Level	Composition of reinforcement	Stirring speed r.p.m	Processing temperature °C
1	-35.27	-36.71	-36.89
2	-36.61	-36.98	-36.82
3	-39.00	-37.19	-37.18
Delta	-35.27	0.48	0.36
Rank	-36.61	2	3

Table 7
Response Table for means of hardness

Level	Composition of reinforcement	Stirring speed r.p.m	Processing temperature °C
1	58.03	-36.71	-36.89
2	67.87	-36.98	-36.82
3	89.27	-37.19	-37.18
Delta	31.23	0.48	0.36
Rank	1	2	3

Table 8
Response Table for Signal to Noise Ratios

Level	Composition of reinforcement	Stirring speed r.p.m	Processing temperature °C
1	43.10	44.07	44.62
2	44.85	44.77	44.82
3	46.23	45.35	44.75
Delta	3.13	1.28	0.20
Rank	1	2	3

Table 9
Response table for means of tensile strength

Level	Composition of reinforcement	Stirring speed r.p.m	Processing temperature °C
1	143.3	161.7	173.3
2	175	175	177.0
3	205.3	187	173.3
Delta	62.0	25.3	3.7
Rank	1	2	3

3.2 SEM Morphology

Using SEM images of the sample, the dispersion of Inconel alloy particles in the matrix and the existence of nano graphene in the microstructure were investigated.. 50mm x 50mm x 10mm specimens with a mirror finish were polished to create micro graphs. The microstructure specimen was polished using several types of emery paper. We wiped, dried, and cleaned with a velvet cloth following each polish cycle. Using a scanning electron microscope, the composite was inspected to look at the cast structure. In the matrix material of aluminium 7075, Inconel and nanographene are uniformly scattered and diffused in SEM Figures 4 to 7.

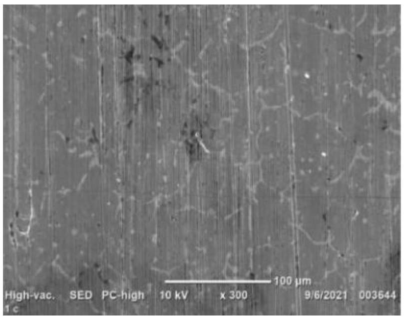

Fig.4 Aluminium alloy 7075

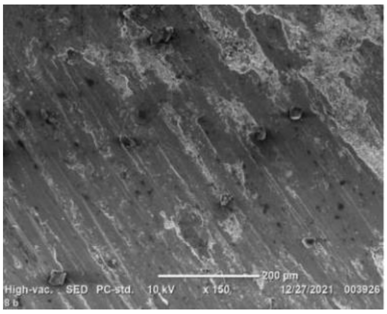

Fig.5 SEM image of 2 wt % inconel alloy 625 and 6wt %Nano grapheme

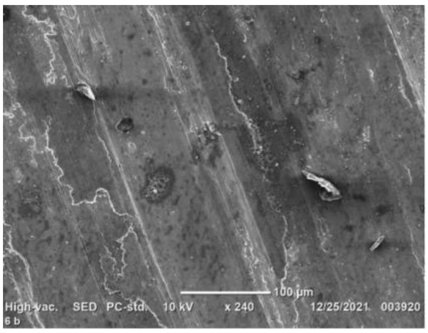

Fig.6 SEM image of 4 wt % inconel alloy 625

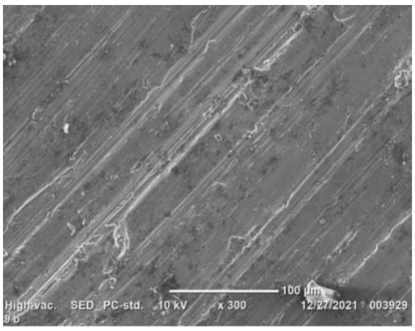

Fig.7 SEM image of 4 wt % inconel alloy

and 1wt %Nano grapheme 625 and 1wt %Nano grapheme

4 Conclusion

A composite MMC made of aluminium 7075 Nano graphene and Inconel metal was found to be affected by the weight percentage of reinforcement, swirling speed, and stirring temperature. The test assessment reveals that string speed and reinforcement weight percent were the two most important factors. Tensile strength 1.5% Nano graphene + 6% Inconel alloy 625, 450 rpm, 650 °C and hardness 0.5% Nano graphene + 2% Inconel alloy 625, 250 rpm, 600 °C were found to be the ideal values. The quantity of particle size and the percentage of reinforcement by weight affected the mechanical characteristic.

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