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Taguchi predictions on wear and heat treatment of A357 based hybrid metal matrix composites

A large range of engineering applications can be suited to hybrid metal matrix composites because of their improved mechanical properties, making them superior to conventional materials. Hybrid composites are widely used in the automotive and aerospace industries because they feature excellent wear resistance, corrosion resistance, high strength, and low density. This paper demonstrates how to use the stir casting method to create a hybrid composite. The current focus of research is on the fabrication of composites using triple particle silicon carbide (5% weight) and graphite (1.5% weight) as the reinforcements and A357 as the matrix. Wear analysis of the composite materials was conducted following the Taguchi L18 method. To obtain insight into how control factors and heat treatment parameters affect the wear rate of composites, the prescribed number of experiments was carried out. Using ANOVA, major influencing factor for the wear rate accomplished was the sliding distance of all the developed hybrid composites.

Keywords: *Hybrid metal matrix composite, heat treatment parameter, wear factor, taguchi, ANOVA, signal-to-noise ratio.*

1.0 Introduction

In recent years, hybrid composites have seen substantial growth in demand from around the world. The properties of hybrid metal matrix composites made from multiple reinforcements are excellent, making them an excellent choice for automobile and aerospace applications (Kala et al., 2014). By selecting the appropriate matrix and reinforcements, a tailored composite can be created (Lakshmikanthan et al, 2019) (Abdulmumin et al., 2015). Since aluminium and its alloys are widely used in the automotive industry, they have been given more attention. Boron carbide, fly ash, silicon carbide, graphite and other materials can be used as reinforcements to create hybrid composite materials ([a]ahin et al, 2014) (Bansal and Saini, 2015) (Kumar et al, 2017) (Sahu and Sahu, 2020). Through liquid metallurgical techniques, improved interaction between matrix and reinforced particles can be achieved, as a uniform distribution of reinforced particles.

An orthogonal array of small trials using the Taguchi technique is a statistical experimentation strategy that provides standard tests a new dimension (Kaushik and Singhal, 2017) (Kumar et al, 2013) wear studies that include variables like load, speed, and sliding distance have used the pin-on-disc approach in large-scale applications. By using an ANOVA, the most significant factor in determining wear characteristics was identified (Kiran et al., 2014) (Asha et al., 2021). According to the literature study, numerous researchers have researched the wear behaviour of MMCs. The wear parameters of heat-treated A357 reinforced with triple-size silicon carbide have been studied only to a limited extent (Balasubramanya et al, 2014).

The focus of this research is on A357 based composite materials with triple-size silicon carbide reinforcements. Taguchi design of experiments is used in the current experimental work. Solutionising temperature, soaking time, ageing temperature, ageing time, sliding distance, sliding velocity, and sliding load are input parameters and wear rate as output response. Signal-to-noise (S/N) is employed as an objective function, and arrays comprised L18 orthogonal elements are used to reduce the number of trials required.

2.0 Materials and methods

In the present research study, the major constituent A357 was chosen due to its various largescale applications pertaining to aero and automotive industries. Silicon carbide, ceramic material, and graphite are selected as reinforcements. From the chemical analysis report, the composition of A357 is shown in Table 1.

Stir casting is a simple and cost-effective method for producing hybrid castings by adding reinforcements alongside the base matrix material using a mechanical stirrer. According to the calculations, raw matrix materials were layered in a graphite crucible before being melted in an electric induction furnace. Degassing the molten metal with hexachloroethane tablets occurs once the melt temperature reaches 800°C. Simultaneously, triple-size silicon carbide (5%

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TABLE 1: COMPOSITION OF A357

Si	Fe	Cu	Mn	Ni	Pb	Zn	Ti	Mg	Sn	Al
6.775	0.16	0.02	0.027	0.03	0.022	0.04	0.15	0.48	0.012	Balance

TABLE 2: CONTROL FACTORS AND LEVELS OF THE EXPERIMENT

Control factors	Units	Level 1	Level 2	Level 3
Sliding distance (A)	m	600	1200	-
Solutionising temperature (B)	^{o}C	500	520	540
Soaking time (C)	minutes	30	60	90
Ageing temperature (D)	^{o}C	160	170	180
Ageing time (E)	hours	2	3	4
Sliding load (F)	N	20	40	60
Sliding velocity (G)	m/s	1	2	3

weight) and graphite particles (1.5 -% weight) were heated at 400^{o}C to remove the water content in a separate muffle furnace. For about 10-12 minutes, the reinforcements were continuously blended with a mechanical stirrer at 300 rpm speed. After that, the molten metal is spewed over to the already heated die available for casting.

After solutionising at high temperatures, the test specimens were subsequently quenched in water at room temperature. Further, the specimens were artificially aged and authorized for room temperature cooling.

The wear of engineering systems determine their life span and consistency. The material's cumulative loss and deformation are caused by the wear on the surfaces caused by friction between the contact surfaces. A pin-on-disk apparatus is the standard test instrument for assessing wear rate. The ASTM G99 standard was used to test wear samples (cylindrical pins) measuring 8 mm in diameter and 30 mm in length. The pin is loaded against a rotating EN31 steel flat disc, with a wear track diameter of 90 mm. The wear rate of 1.5% 80 microns SiC, 1.5% 100 microns SiC, 2% 120 microns SiC and 1.5% graphite aluminium hybrid composites was studied.

Testing was done with various values of solutionising temperature at 500, 520, 540^{o}C, soaking time at 30, 60, 90 minutes, ageing temperature at 160, 170, 180^{o}C, ageing time at 2, 3, 4 hours, sliding Load at 20, 40, 60 N, sliding velocity at 1, 2, 3 m/s, and sliding distance at 600, 1200 m.

3.0 Experimental results and discussion

3.1 TAGUCHI'S DESIGN OF EXPERIMENTS

Experiments designed according to this method use signal-to-noise (SN), main effects, analysis of variance (ANOVA) and orthogonal array (OA). An efficient statistical technique was chosen. The L18 orthogonal array is composed of 18 rows and 7 columns. The following input control factors are taken into account here: Solutionising temperature, soaking time, ageing temperature, ageing time, sliding load, sliding velocity each at three levels and sliding distance at two levels, as shown in Table 2. Experiments were conducted for 18 tests using the standard Taguchi method.

The present study considers wear rate as an output response. The output response of the experiments was the wear rate determined by the well-balanced combinations of input control parameters. A standard characteristic of SN quantitative is measured using Minitab-20 and then modelled from the experimental value to determine the standard characteristic.

The signal to noise ratio depicts the response of input and helps in calculating the wear rate; with a lower value indicating higher quality. The present work aims at finding the effect of controlling factors. Table 3 depicts the I/P and O/P factors, as well as the corresponding SN ratios. A statistical analysis of SN ratios points to the most significant statistical determinant. Table 4 shows the response for SN ratios, which is used to determine the most influential control factor for wear rate.

A direct representation of the main effect of control factors can be found in Figs.1 and 2, which also show how individual factors affect wear rates. Increase in wear rate was noticed with increasing sliding distance and decrease with increasing soaking time and ageing temperature. Table 5 shows the response for means.

Fig.2 depicts the effect of the seven factors on the SN ratio for the wear rate. Based on the results, the factor combined with the lowest wear rate has a sliding distance of 600m, a solutionising temperature of 540^{o}C, a soaking time of 90 minutes, an ageing temperature of 180^{o}C, an ageing time of 4 hours, a sliding load of 40N, and 1 m/s sliding velocity.

The most influential factors, as determined by the response of Table 4, are sliding distance, sliding velocity, soaking time, ageing time, solutionising temperature, ageing temperature, and sliding load. The optimal parameter variant's levels are A1B3C3D3E3F2G1.

Table 3: L18 Orthogonal Array experimental design

Ex. No.	A	B	C	D	E	F	G	Wear $(mm^3/m)*10^{-3}$	Signal to noise Ratio
1	600	500	30	160	2	20	1	1.750	-4.86076
2	600	500	60	170	3	40	2	1.670	-4.45433
3	600	500	90	180	4	60	3	1.480	-3.40523
4	600	520	30	160	3	40	3	1.949	-5.79624
5	600	520	60	170	4	60	1	1.560	-3.86249
6	600	520	90	180	2	20	2	1.590	-4.02794
7	600	540	30	170	2	60	2	1.722	-4.72066
8	600	540	60	180	3	20	3	1.542	-3.76169
9	600	540	90	160	4	40	1	1.074	-0.62009
10	1200	500	30	180	4	40	2	1.964	-5.86283
11	1200	500	60	160	2	60	3	2.210	-6.88785
12	1200	500	90	170	3	20	1	1.846	-5.32463
13	1200	520	30	170	4	20	3	2.080	-6.36127
14	1200	520	60	180	2	40	1	1.850	-5.34343
15	1200	520	90	160	3	60	2	2.250	-7.04365
16	1200	540	30	180	3	60	1	1.991	-5.98143
17	1200	540	60	160	4	20	2	2.170	-6.72919
18	1200	540	90	170	2	40	3	2.070	-6.31941

Table 4: Responses table for S/N ratio for wear

Level	A	B	C	D	E	F	G
1	-3.945	-5.133	-5.597	-5.323	-5.360	-5.178	-4.332
2	-6.206	-5.406	-5.173	-5.174	-5.394	-4.733	-5.473
3		-4.689	-4.457	-4.730	-4.474	-5.317	-5.422
Delta	2.260	0.717	1.140	0.593	0.920	0.584	1.141
Rank	1	5	3	6	4	7	2

Table 5: Responses table for Means for wear

Level	A	B	C	D	E	F	G
1	1.593	1.820	1.909	1.901	1.865	1.830	1.670
2	2.048	1.880	1.834	1.825	1.875	1.763	1.894
3		1.762	1.718	1.736	1.721	1.869	1.888
Delta	0.455	0.118	0.191	0.164	0.153	0.106	0.216
Rank	1	6	3	4	5	7	2

Fig.1: Effect of control factors on the means for wear rate

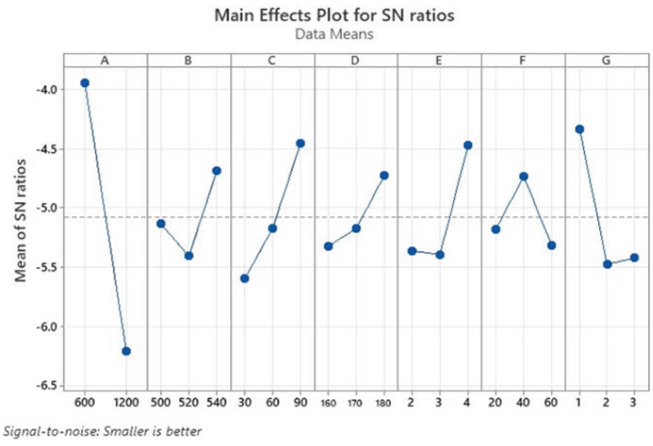

Fig.2: Effect of control factors on the SN ratios for wear rate

TABLE 6: ANOVA FOR SN RATIOS

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-value	P-value
A	1	22.994	53.87%	22.994	22.9938	25.41	0.007
B	2	1.572	3.68%	1.572	0.7859	0.87	0.486
C	2	3.987	9.34%	3.987	1.9934	2.20	0.226
D	2	1.140	2.67%	1.140	0.5699	0.63	0.578
E	2	3.267	7.65%	3.267	1.6337	1.81	0.276
F	2	1.117	2.61%	1.117	0.5586	0.62	0.584
G	2	4.984	11.67%	4.984	2.4921	2.75	0.177
Error	4	3.620	8.48%	3.620			
Total	17	42.681	100%				

3.2 Analysis of Variance

The experimental results were inferred using a statistical parametric ANOVA test. The combination of control factors that had a significant impact on the wear rate was examined using an ANOVA.

The ANOVA results for wear rate are shown in Table 6. There was a 5% significance level in the analysis (i.e., 95% confidence interval). When the corresponding p-value is less than 0.05, the factor is highly statistically significant.

According to the findings, sliding distance was the most significant factor with the highest statistical effect (53.87%), followed by sliding velocity (11.67%), and then soaking time (9.34%).

The ANOVA results for wear rate obtained using the MINITAB 20 software show that sliding distance is the most significant factor influencing wear rate, with a p-value less than 0.05.

4.0 Conclusions

The primary goal of this research was to fabricate hybrid composites and determine the wear performance of hybrid composites and the effect of control factors on it.

- Using stir casting methodology, hybrid metal matrix composites was successfully developed by the combination of various fraction (1.5% 80 microns, 1.5% 100 microns, and 2% 120 microns) of silicon carbide and 1.5 % graphite reinforcements.
- Initially, a Taguchi L18 orthogonal array was used to investigate the effects of seven variables on the wear rate: sliding distance, solutionising temperature, soaking duration, ageing temperature, ageing time, sliding load, and sliding velocity.
- Based on the SN ratio and response of means tables, the optimal set of parameters for improved wear behaviour of the hybrid composite were determined to be a sliding distance of 600m, a solutionising temperature of 540^{o}C, a soaking time of 90 minutes, an ageing temperature of 180^{o}C, an ageing time of 4 hours, a sliding load of 40N, and a sliding velocity of 1 m/s.
- The wear rate was found to increase with increasing sliding distance and decrease with increasing soaking time and ageing temperature.
- The ANOVA indicated that sliding distance was the most significant factor with the highest statistical effect (53.87%) followed by sliding velocity (11.67%) and then soaking time (9.34%).

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