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Optimization of Process Parameters of Stir Casting Technique Using Orthogonal Arrays

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***Abstract*—** Metal Matrix Composites have received substantial attention in the recent years due to their potential advantages over monolithic alloys. These materials are commonly reinforced with high strength, high modulus, and brittle ceramic phases, which may be in the form of fiber, whiskers, or particulates. The addition of ceramic reinforcement to a metal matrix improves strength and stiffness, but at the expense of ductility. Further, heat treatment has an intense influence on tribological properties of heat treated aluminum alloys and its composites. This paper describes the application of Taguchi's orthogonal array approach for optimization of parameters of stir casting technique used to process Aluminum based hybrid matrix composites. The wear behavior of the composite, which is a very important characteristic, has been selected for the analysis. Taguchi's orthogonal array has been selected considering the various control factors and levels; experimentation has been accordingly carried out and optimum process parameters have been selected. This study has resulted in improved wear properties of Aluminum based hybrid matrix composites.

Keywords— ***Aluminum matrix composite, Orthogonal array, Heat treatment, Wear properties***

1.0 Introduction

In the recent years researchers have found their attention on composite materials compared to monolithic materials in order to meet the global demands for light weight and better performance.

Metal matrix composite (MMC s) is a composite material with two constituents present in them.If there are more than two constituents then it's called Hybrid composite[1].Usually in MMCs low density metals are preferred such as Aluminium or Magnesium.
The reinforcements added to these metals will be in the form of particulates /fibres/ whiskers.

MMCs significantly possess high temperature capability, high damping capacity high transverse stiffness and strength. There are different methods which are employed to manufacture MMCs[2]. In the several methods stir casting technique is one of the widely used method.Aluminium and its alloy have magnetised their presence as base metal in MMCs.In the several series of aluminiumalloys heat treatable Al6061 and Al7075 are much considered[3]Al6061alloy is considered to be one of thehighly corrosion resistant and the strength is found to be very nominal[4]. Fabrication of aluminium is real challenge in order to eliminate a few characteristics like porosity, wettability and improper distribution og the reinforcements.To study the wear rate in the recent times has become a very important parameter in order to know that the material can withstand high temperature. Hence an attempt is made in this study to understand the dependent parameters like applied load,sliding speed, sliding distance on the dry sliding wear[5] .

The wide applications of these Aluminium Matrix composites (AMCs)[6] are in the field of construction and finds much applications in the fields of construction, automotive, aircraft and marine applications.

1.1 Hybrid Composite

Hybrid Composites are the materials which are made up by adding two or more materials or reinforcements of varying properties with the matrix as the base alloy[9]. Hybrid Composites have largepotential to replace single reinforced composites due to their improved properties. Due to the reinforcement the mechanical properties will increase. Thiscompositeis manufactured using stir casting technique and machined to a required dimension with its new characteristics like lightweight, low cost and enhanced mechanical properties.

In this study the hybrid composite which has been selected is Aluminium 6061 as the base alloy and the reinforcements are Silicon carbide (SiC)and Graphite(Gr).
The percentage of Gr has been variedfrom 3%, to 9%in steps of 3% according to our experimentation and kept 8% constant for SiC. The cast aluminium hybrid composite is subjected to micro hardness and dry sliding wear studies.

This hybrid composite is subjected to heat treatment in order to enhance the hardness.It is subjected to 3 quench medias air, water and ice for a time period from 2.5 hrs to 10.5 hrs in steps to 2 hrs and also few specimens are not heat treated.

2.0 Literature Review

N Radhika RSubrahmanian S VenkatPrasat [7] have formulated the tribological behaviour of aluminium alloy reinforced with alumina (9%) and Graphite (3%) fabricated by stir casting technique. They have conducted experiments throughtaguchi's orthogonal array L27.The analysis of the data was carried out based on the selection of orthogonal array.This showed that the sliding distance has a higher influence followed by load and sliding speed.The confirmation tests were carried out to verify the experimental results and Scanning Electron Microscopic studies were done on the wear.

Shouvik Ghosh ,PrasantoSahoo, GautamSutradhar[8] have conveyed their concern to improve the tribological performance which led to the design and selection of newer variants of the composites.This investigation deals with the study of wear behavior of Al –SiCp metal matrix composite for varying reinforcement content,appliedload,,sliding speed and time.Aluminium metal matrix composites is reinforced with SiC particles prepared by liquid metallurgical route by varying the SiC %in the range of 5% to 10%.Based on L27 orthogonal array the number of experimentations are decided in order to acquire the wear data in a controlled manner. There are four controlling factors like SiC content, normal load, sliding speed and sliding time whose influence is considered on dry sliding wear of the composites. The optimal value for all these controlling factors are obtained for minimum wear.

3.0 Objective of the study

The objective of this paper is to analysethe influence of reinforcements in the hybrid matrix composite by considering the very important propertywear.Theoptimal levels for hardness is found to be Larger the better and for coefficient of frictionis Smaller the better with respect to the Aluminium based hybrid matrix composite. Considering S/N ratio concept using L 25 Taguchi 's orthogonal array approach with their control factors and levels the required results are obtained.

4.0 Taguchi Method

This is a statistical method also named as robust design method which has its wide applications in most of the fields in recent times.This is a method developed[11] by Genichi[10]Taguchi to improve the quality of all the manufactured goods in all the industries.
He introduced a unique concept known as Orthogonal Array[12] which tries to reduce the number of experimentation based on the trials by considering certain control parameters.
Orthogonal Array provides a minimum number[13][14] of experimentations and Taguchi's Signal to Noise ratio serves to give optimum results which is based on the selection of the parameter.
The main application of this Taguchi's method[15]is implemented in engineering design problems.

The Signal to Noise ratio can be calculated for three categories.
1. Larger the Better (LTB)
2. Smaller the Better (STB)
3. Nominal the Best (NTB)

LTB
$S/N = -10\log_{10} 1/n\ [\Sigma 1/y_i^2]$

STB
$S/N = -10\log_{10} \Sigma\ y_i^2/n$

NTB
$S/N = 10\log_{10}[y^2/s^2]$

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4.1 Selection of control factors and levels

To select an appropriate orthogonal array for this experiment, the total degrees of freedom should be calculated. Here there are 4 factors with 3 levels hence, the degree of freedom calculated would be 11.

Table 1.1 Control Factors and their levels

Symbol	Control factors	Levels				Unit
A	Graphite Volume	1 3%	2 5%	3 7%	4 9%	%
B	Heat	1		2		°c

	treatment	WO		HT			
C	Quench media	1	2	3			-
		Air	Water	Ice			
D	Quench duration	1	2	3	4	5	Hrs
		2.5	4.5	6.5	8.5	10.5	

Table 1.1 shows the different control factors and their levels considering the composition of Gr, heat treatment ,quench media with their respective time duration.

For this experimental L25 orthogonal array is chosen. Selection of proper orthogonal array is done based on the total number of Degrees of Freedom (DOF). The L25 OA has 25 rows corresponding to the number of tests and the degree of freedom is 11 with 4 columns. Thus, the L25 OA is chosen for the present case.

Table 1.2 L25 Orthogonal array layout

Expt	P1	P2	P3	P4	P5	P6
1	1	1	1	1	1	1
2	1	2	2	2	2	2
3	1	3	3	3	3	3
4	1	4	4	4	4	4
5	1	5	5	5	5	5
6	2	1	2	3	4	5
7	2	2	3	4	5	1
8	2	3	4	5	1	2
9	2	4	5	1	2	3
10	2	5	1	2	3	4
11	3	1	3	5	2	4
12	3	2	4	1	3	5
13	3	3	5	2	4	1
14	3	4	1	3	5	2
15	3	5	2	4	1	3
16	4	1	4	2	5	3
17	4	2	5	3	1	4
18	4	3	1	4	2	5
19	4	4	2	5	3	1
20	4	5	3	1	4	2
21	5	1	5	4	3	2
22	5	2	1	5	4	3
23	5	3	2	1	5	4
24	5	4	3	2	1	5
25	5	5	4	3	2	1

Table 1.3 Physical layout for experimentation

	A	B	C	D	E	F
1	3%	WO	Air	2.5	-	-
2	3%	HT	Water	4.5	-	-
3	3%	WO	Ice	6.5	-	-
4	3%	HT	Water	8.5	-	-
5	3%	HT	Ice	10.5	-	-
6	5%	WO	Water	6.5	-	-
7	5%	HT	Ice	8.5	-	-
8	5%	WO	Water	10.5	-	-
9	5%	HT	Ice	2.5	-	-
10	5%	HT	Air	4.5	-	-
11	7%	WO	Ice	10.5	-	-
12	7%	HT	Water	2.5	-	-
13	7%	WO	Ice	4.5	-	-
14	7%	HT	Air	6.5	-	-
15	7%	HT	Water	8.5	-	-
16	9%	WO	Water	4.5	-	-
17	9%	HT	Ice	6.5	-	-
18	9%	WO	Air	8.5	-	-
19	9%	HT	Water	10.5	-	-
20	9%	HT	Ice	2.5	-	-
21	9%	WO	Ice	8.5	-	-
22	9%	HT	Air	10.5	-	-
23	9%	WO	Water	2.5	-	-
24	9%	HT	Ice	4.5	-	-
25	9%	HT	Water	6.5	-	-

Table 1.2 and 1.3 shows OA layout and Physical layout respectively.

TABLE1.4 Experimental Results Using L25 Orthogonal Array

	A	B	C	D	E	F	Sliding Distance	Hardness (VHN)	Coeffiecient of friction
1	3%	WO	Air	2.5	-	-	9.43	45	0.749
2	3%	HT	Water	4.5	-	-	12.5	70	0.744
3	3%	WO	Ice	6.5	-	-	10.2	48	0.749
4	3%	HT	Water	8.5	-	-	15.65	72	0.744
5	3%	HT	Ice	10.5	-	-	18.85	80	0.535
6	5%	WO	Water	6.5	-	-	9.84	62	0.698
7	5%	HT	Ice	8.5	-	-	22.34	78	0.454
8	5%	WO	Water	10.5	-	-	9.84	62	0.698
9	5%	HT	Ice	2.5	-	-	18.85	78	0.454
10	5%	HT	Air	4.5	-	-	22.12	65	1.707
11	7%	WO	Ice	10.5	-	-	24.83	54	0.719
12	7%	HT	Water	2.5	-	-	28.32	63	0.688
13	7%	WO	Ice	4.5	-	-	38.2	54	0.719
14	7%	HT	Air	6.5	-	-	42.8	52	0.678
15	7%	HT	Water	8.5	-	-	46.3	63	0.618
16	9%	WO	Water	4.5	-	-	54.05	50	0.734
17	9%	HT	Ice	6.5	-	-	60.35	70	1.427
18	9%	WO	Air	8.5	-	-	63.38	52	0.8
19	9%	HT	Water	10.5	-	-	64.82	68	0.856
20	9%	HT	Ice	2.5	-	-	68.33	70	1.458
21	9%	WO	Ice	8.5	-	-	71.29	49	0.754
22	9%	HT	Air	10.5	-	-	73.3	48	0.963
23	9%	WO	Water	2.5	-	-	76.7	50	0.779
24	9%	HT	Ice	4.5	-	-	82.3	70	1.519
25	9%	HT	Water	6.5	-	-	86.2	70	0.346

5.0 ANALYSIS OF THE DATA

Table 1.4 shows sliding distance ,hardness and coefficient of friction for various
trial runs for different composition of Gr, with and without heat treatment for different quench medias with their respective time duration.Based on this information, the
S/N values can be calculated for larger the better in case of Hardness and smaller the better in case of coefficient of friction. The S/N ratios of this are tabulated .The optimal conditions will be those that obtain higher hardness and lower coefficient of friction.

Table 1.5 Speed to Noise Ratio for the controlling factors considering Hardness

SNR for A	SNR for B	SNR for C	SNR for D
50.17305	54.46444	48.43918	49.88514
50.80645	60.21481	56.04593	49.87689
49.15769		56.41524	49.69695
55.63872			50.07364
			50.01907

The Speed to Noise (S/N) ratio for hardness Larger the better (LTB) considering the control factors and their levels is calculated using the respective formula is as shown in the table 1.5.

Table 1.6 Speed to Noise Ratio for the controlling factors considering Co-efficient of friction

SNR for A	SNR for B	SNR for C	SNR for D
2.983804	2.608673	-0.41543	0.998442
0.654522	0.212534	3.322008	-1.3548
3.281103		0.300555	1.350224
-0.25445			3.278851
			2.290751

The Speed to Noise (S/N) ratio for Co efficient of friction Smaller the better (STB) considering the control factors and their levels is calculated using the respective formula is as shown in the table 1.6.

Fig 1.1 Signal – Noise ratio Ratio Graph for Hardness

The S/N ratio for hardness is as shown in the above fig 1.1 with respect to the composition of Gr , Heat treatment ,quenching media and their duration.

Table 1.7 Optimal Levels for Hardness

Control Factor	Symbol	Optimal level	Value
Graphite Volume	A	9%	55.63
Heat treatment	B	HT	60.21
Quench media	C	Ice	56.41
Quench duration	D	8.5	50.07

From fig 1.1 the optimal levels with respect to hardness are 9% of Gr heat treated and quenched in ice for a duration of 8.5 hrs.

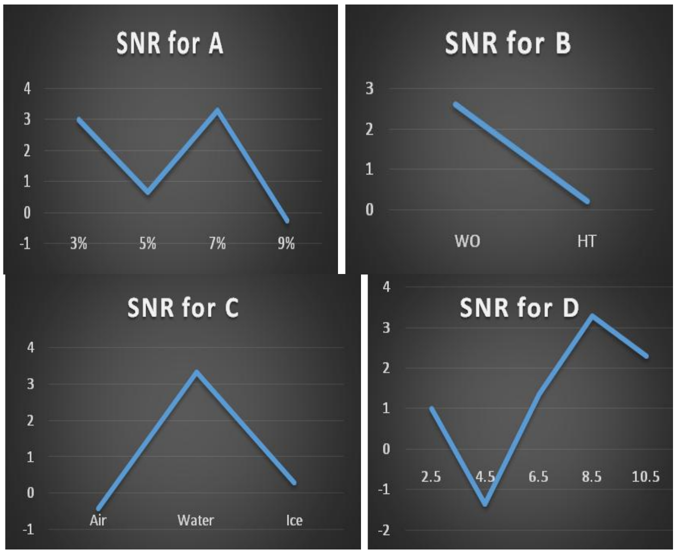

Fig 1.2 Signal to Noise Ratio Graph for Coefficient of friction

The optimum levels for Co efficient of friction is as shown in the fig 1.2 with respect to the composition of Gr , Heat treatment ,quenching media and their duration.The optimal levels for Co efficient of friction is shown in table 1.8.

Table 1.8Optimal Levels for Coefficient of friction

Control Factor	Sym bol	Optimal level	Value
Graphite Volume	A	7%	3.2811
Heat treatment	B	WO	2.608
Quench media	C	Water	3.322
Quench duration	D	8.5	3.278

From fig 1.2 optimal levels with respect to Co-efficient of friction are 7% of Gr without heat treated and quenched in water for a duration of 8.5 hrs as per the figure and table.

6.0 Conclusion

The approach of taguchi 's robust design methodto wear study led to conclude the following :

- By using Taguchi's design the numbers ofexperiments were reduced from eighty one to Twenty five.
- The optimal Heat treatment condition with respect to the hardness(LTB) of Al 6061-SiC- Gr composites is 9% of Gr under ice quenching for a duration of 8.5 hrs.
- The optimal Heat treatment condition with resect to the Coefficient of friction (STB) of Al 6061-SiC-Gr composites is 7% of Gr under water quenching for a duration of 8.5 hrs.
- Hence the composite with the larger percentage of soft reinforcement quenched for a moderately larger period of time will yield to improve the wear properties.

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