Optimization of Tribology Properties of A356 Aluminium Matrix Composites using Grey Relational Analysis

Bheemireddy Hemanth Reddy
P.G. student,
Department of Mechanical Engineering,
KarpagaVinayaga College ofEngineering &Technology,
ChinnaKolambakam, Kanchipuram 603 308, India

S.Perumal
Assistant Professor,
Department of Mechanical Engineering,
Karpaga Vinayaga College ofEngineering & Technology,
Chinna Kolambakam, Kanchipuram 603 308, India

Abstract-*In this work,A356 Aluminium matrix composites are reinforced with $Al_2O_3$and Gr, different composite combinations are made using stir casting process. HereA356 Aluminium alloy is used as the matrix material and0%, 4%, & 8%, Alumina is used as reinforcement material along with3% Gras solid lubricant, manufacture the different composites materials. The hardness and tensile properties were also studied.The tribology behaviourof thecomposites was studied by performing dry sliding weartest using a pin-on-discTribometer using ASMT standards. Experiments were designed based on Taguchi's technique and selected L_9 Orthogonal array foranalyzing the data. The input parameters such as sliding speed, sliding distance, load and reinforcement percentages are optimized with considerations of multiple performance characteristics: wear rate, specific wear rate and coefficient of friction. The optimal levels of input parameters were selected from response table and response graph from the grey relational grade. ANOVA was used to find the significance of the wear parameters.*

Keywords-A356, Al_2O_3, ANOVA, Graphite, Grey Relational Analysis, Tribology, hardness, Pin-on-disc, Tribometer, Taguchi's technique, L_9Orthogonal array

1. INTRODUCTION

Metal matrix composites are evolved as newer materials as an outcome of a steadily growing efforts to cater to the increasing demand for lightweight, inexpensive, energy saving, stiff and strong materials in aircraft, space, defense and automotive applications. Aluminium matrix composites (AMCs) are emerging as promising materials in this direction. Addition of ceramic reinforcements to metal matrix improves hardness and thermal shock resistance. Al2O3 is one of the widely used reinforcement. But it has its own demerits like poor wettability with aluminium and more weight percentage leads to increase in porosity. Graphite particulates come handy in this direction, the addition of which improves the machining as well as wear resistance of Al composites. Al-Al_2O_3 composites reinforced with Gr particulates are referred as Al-Al_2O_3-Gr hybrid composites. The outcome of some investigations on such hybrid composites are briefed in the next few lines. Taguchi technique is a powerful tool in experimental design. It provides a simple, efficient and systematic approach for optimization of cost and quality. Taguchi-grey relational analysis is used to study the carburizing of En31 steel on the tensile strength. These investigations emphasize that the use of multiple reinforcements in aluminium matrix hybrid composites yield better tribology properties. However, efforts are scarce on parametric studies on the tribologybehaviour of aluminium matrix hybrid composites. In this context, an attempt is made to study the influence of graphite particulates, load, percentage reinforcement, sliding speed and sliding distance on the tribologybehaviour of Al– Al_2O_3–Gr hybrid composites.

2. MATERIAL SELECTION

Due to the Presence of high copper and nickel content in A356 cast alloy the ductilitydecreases and provide resistance to corrosion. The percentage of iron content decreases the strength and ductility. The Chemical Composition, Physical Properties and Mechanical Properties of Al 356 cast alloy are explained in Table 1, and Table 2 respectively.

TABLE.1.CHEMICAL COMPOSITION OF A356

Constituent	Cu	Si	Fe	Mg	Mn	Ti	Ni	Zn	Al
Weight %	0.13	7.08	0.49	0.39	0.03	0.06	0.01	0.02	Remainder

TABLE.2. MECHANICAL PROPERTIES OF A356 CAST ALLOY

Property	Tensile strength MPa	Elongation	Shear strength MPa	Hardness range HB
Value In Metric Unit	145	3%	91	40-70

The Al_2O_3 with particle size of 20µm and Solid Lubricant Particles (Graphite) are added as reinforcement

3. FABRICATION AND PROCESS

Stir casting of Aluminium matrix composites is the most commonly used process of all fabrication methods. The following composites were fabricated:

1. Al356 + 3% Graphite
2. Al356 + 4%Al_2O_3 + 3% Graphite
3. Al356 + 8%Al_2O_3 + 3% Graphite

The fabrication of metal matrix composite used in the present study was carried out by stir casting method. 356 Aluminium alloy in the form of Ingots were melted to the desired super heating temperature of above 850°C in a graphite crucibles under a cover of flux in order to minimize the oxidation of molten metal. For each melting process 1.5 kg of alloy was used and then 0%, 4%and 8% Al_2O_3.With constant 3% Graphite particles which are preheated to 200^{o}C, were added to the molten metal. The mixture was stirred continuously by using a stirrer. The stirring time was 5 minutes. The molten material was filled in the molds. Then the mold is opened and the components are taken out of the mold easily.

The metal matrix composite material obtained from the stir casting process is machined into a cylindrical pin of size 8 mm diameter and length ranges from 50 -55 mm by using lathe.

Disc material chosen here is En 31carbon steel. It is machined to the diameter of 165 mm and a thickness of 8 mm. 4 holes of 4.5 mm diameter were drilled on the disc which are at a distance of 155mm and making an angle of 90^O with each hole from the center of the disc . So that it can be fixed onto the pin on Disc wear testing machine

4. TEST PROCEDURE

Wear Test. Prior to testing, and prior to measuring or weighing, clean and dry the specimens. Take care to remove all dirt and foreign matter from the specimens. Use non-chlorinated, non-film-forming cleaning agents and solvents. To remove all traces of dry materials with open grains, the Cleaning fluids have to be entrapped in the material. Steel (ferromagnetic) specimens having residual magnetism should be demagnetized. Report the methods used for cleaning. Measure appropriate specimen dimensions to the nearest 2.5µm or weight the specimens to the nearest 0.001g. Insert the disc securely in the holding device so that the disc is fixed perpendicular to the axis of the revolution. Insert the pin specimen securely in its holder and, if necessary, adjust so that the specimen is perpendicular to the disc surface when in contact, in order to maintain the necessary contact conditions. Add the proper mass to the system lever or bale to develop the selected force pressing the pin against the disc. Start the motor and adjust the speed to the desired value while holding the pin specimen out of contact with the disc. Stop the motor. Set the revolution counter (or equivalent) to the desired number of revolutions. Begin the test with the specimens in contact under load. The test is stopped when the desired number of revolutions is achieved. Tests should not be interrupted or restarted.

Remove the specimens and clean off any loose wear debris. Note the existence of features on or near the wear scar such as: protrusions, displaced metal, discoloration, micro cracking, or spotting. Re-measure the specimen dimensions to the nearest 2.5µm or reweigh the specimens to the nearest 0.001g, as appropriate. Repeat the test with additional specimens to obtain sufficient data for statistically significant results.

*Hardness Measurement***.**Samples were prepared as per specification of Brinell hardness Test. A ball of weight 100Kgf and diameter of 2.5mm is applied on the specimen for 1min. As the hardness of sample will not be uniform throughout, due to gravity and non-uniform distribution of the particles in the specimen, different values of hardness were observed from top to bottom. To resolve this three tests were performed at different points on sample and the average of three was taken as hardness of the sample.

5. DESIGN AND ANALYSIS OF EXPERIMENTS

A. Experimental Plan

The experimental plan is designed to find the factors influencing the wear process for achieving minimum WR, SWR and COF. The experiments were developed based on an orthogonal array, with the aim of relating the influence of sliding speed, sliding distance, load and weight percentage reinforcement of the material. The process parameters and their levels are shown in Table 3.

TABLE.3. PROCESS PARAMETERS AND THEIR LEVELS

Level	Sliding Speed, S (m/s)	Sliding Distance, D (m)	Load, L (N)	Reinforcement, R (Wt%)
1	2	500	15	0
2	4	1000	30	4
3	6	1500	45	8

B. *Taguchi Design of Experiments*

Design of Experiments is one of the important and powerful statistical techniques to study the effect of multiple variables simultaneously. This method drastically reduces the number of experiments that are required to model the response function compared with the full factorial design of experiments. The Taguchi technique is devised for process optimization and identification of optimal combination of the factors for a given response. The overall objective of the method is to produce high quality product at low cost. The L_9 orthogonal array used for this work is shown in Table 4.

TABLE.4. L9 ORTHOGONAL ARRAY

S.No	Sliding Speed, S (m/s)	Sliding Distance, D (m)	Load, L (N)	Reinforcement, R (Wt%)
1	2	500	15	0
2	2	1000	30	4
3	2	1500	45	8
4	4	500	45	4
5	4	1000	15	8
6	4	1500	30	0
7	6	500	30	8
8	6	1000	45	0
9	6	1500	15	4

C. *Grey Relational Analysis*

Grey theory is one of the important theories and can be used for analyzing the uncertainty, multi-input and discrete data. A grey system has a level of information between black and white. The grey relational analysis is a measurement of the absolute value of the data difference between sequences, and is also used to measure an approximate correlation between sequences. It is an effective means of analyzing the relationship between the sequences with less data and can analyze many factors.

D. *Analysis approach*

The experiments were conducted according to Taguchi's L_9 orthogonal array using 9 different experiments. For GRA, these 9 experiments became 9 subsystems. The influence of these subsystems on the response variables were analyzed by using GRA. The wear tests (system) were assessed by conducting 9 experiments (subsystems) and each experiment was termed as comparability sequence. The parametric conditions corresponding to the highest weighted GRG gave minimum values of the wear rate, specific wear rate and coefficient friction. In this manner, the multi-objective problem was converted into single objective optimization using GRA technique.

6. RESULTS AND DISCUSSIONS

Hardness Test, we conclude that the Hardness of the composite increases with the increase of the Al_2O_3 reinforcement.Result is shown in Table 5

TABLE.5. TOUGHNESS TESTING RESULTS

S.No.	Alumina Particle wt%	Hardness (BHN)
1	0%	67.56
2	4%	71.64
3	8%	78.68

Density Test. Density increases with increasing percentage of Al_2O_3 reinforcement the result is shown in the Table 6.

TABLE.6.DENSITY OF COMPOSITES

S.No.	Alumina Particle wt%	Density (g/cm^3)
1	0%	0.039
2	4%	0.041
3	8%	0.043

*Wear Tests,*The tests were conducted to study the effect of process parameters over the output response characteristics. The GRG of the response characteristics for each variable at different levels were calculated from experimental data. The main effects of process variables of GRG were plotted. The response graphs are used for examining the parametric effects on the response characteristics. The analysis of variance (ANOVA) of GRG is carried out to identify the significant variables and to quantify their effects on the response characteristics. The most optimal settings of process variables in terms of mean response characteristics are established by analyzing the response graphs and the ANOVA tables. The experimental results along with their Grey Relational Coefficients and GRG were given in Table 7.

TABLE.7. EXPERIMENTAL RESULTS OF COMPOSITES

S.No	SWR* E-3	WR* E-3	COF	GRC SWR	GRC WR	GR COF	GR Grade
1	1.304	19.573	0.606	0.909	0.98	0.616	0.835
2	1.636	49.093	0.673	0.454	0.535	0.333	0.441
3	1.809	81.443	0.718	0.333	0.333	0.6	0.422
4	2.083	93.771	0.593	0.339	0.337	1	0.559
5	0.804	12.063	0.706	0.919	0.98	0.338	0.746
6	1.912	57.362	0.648	0.488	0.55	0.392	0.477
7	1.189	35.673	0.692	0.549	0.59	0.459	0.533
8	2.382	107.191	0.599	0.359	0.349	0.678	0.462
9	0.915	13.731	0.637	1	1	0.479	0.826

In this study all the designs, plots and analysis have been carried out using Minitab statistical software. Figure 1show that the GRG increases with increase in sliding speed, sliding distance and reinforcement and, decreases with increase in load. When the pin is sliding over the disc the pin wears initially and then a mechanically mixed layer is formed and this resists the wear rate of the composite pin. The response Table8 shows the average of each response characteristic for each level of each factor. The table includes ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor. Ranks are assigned based on delta values; rank 1 to the highest delta value, rank 2 to the second highest, and so on. The ranks indicate the relative importance of each factor to the response. The ranks and the delta values show that sliding distance has the greatest effect on GRG and is followed by sliding speed, percentage of reinforcement and load in that order. It can be seen from Figure 3 that the 2 level of sliding speed, 3 level of sliding distance, 1 level of load and 2 level of reinforcement provide maximum GRG.

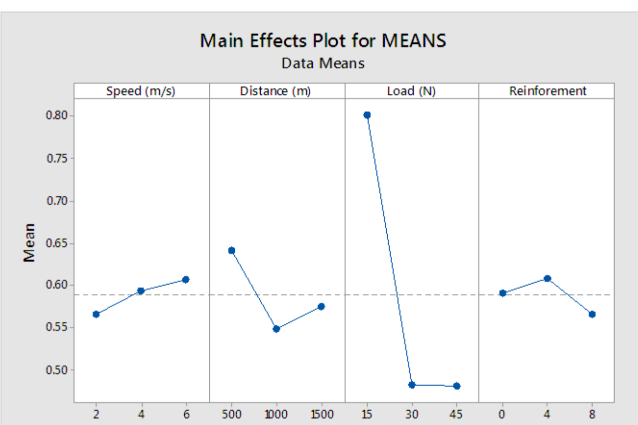

Figure.1. Response Graphs

TABLE.8. RESPONSE TABLE

Level	Sliding Speed, S (m/s)	Sliding Distance, D (m)	Load, L (N)	Reinforce ment, R (wt %)
1	0.566	**0.642**	**0.802**	0.591
2	0.594	0.549	0.483	**0.609**
3	**0.607**	0.575	0.481	0.567
Delta	0.041	0.093	0.321	0.042
Rank	4	2	1	3

In order to study the significance of the process variables towards GRG, analysis of variance (ANOVA) was performed. From ANOVA table 8 we see that Sliding speed and Sliding distance were most influential for obtaining maximum GRG. Whereas load and reinforcement has less significance on GRG.

TABLE.9.ANOVA OF GRG

Source	DOF	Sequence sum of square	Mean sum of square	Contribution
Sliding Speed	2	0.003	0.001	1.18%
Sliding Distance	2	0.014	0.007	6.17%
Load	2	0.205	0.102	91.46%
Reinforce ment	2	0.003	0.001	1.19%
Total	8	0.224		100.00%

Confirmation Experiment

Experimental results are analyzed for identifying the optimum parameters. From Figure 1 and response Table 8 the factors at level S3, D1, L1, R2 that is Sliding Speed 6 m/s, Sliding Distance 500 m, Load 15 N and 4% Al_2o_3 reinforcement are the optimum parameters for obtaining minimum wear rate, specific wear rate and coefficient of friction. The optimum parameters are used for conducting the confirmation experiment and also for predicting the wear rate, specific wear rate and coefficient of friction using Taguchi Design of Experiments. The predicted GRG and experimental value of GRG were same. So the optimization technique holds good for this research work.

7. CONCLUSION

The following conclusion can be drawn from the analysis of tribological behavior of these composites.

(1) Load is the parameter that has the highest statistical influence on GRG values of the

composites (91.46%) followed by sliding distance (6.17%), reinforcement (1.19%), and sliding speed (1.18%).

(2) Optimum values of sliding speed is 2m/s, sliding distance is 500m, load is 15 and reinforcements is 0% Al_2O_3 added hybrid composites.

(3) The tribology properties of 356/0%Al_2O_3/3%Gr composites are better than 356/4% Al_2O_3/3%Gr and 356/8%Al_2O_3/3%Gr composites.

(4) Al_2O_3improves the hardness and density of materials. Graphite is improves the machinability.

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