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THE EFFECT GRAPHITE ON THE COEFFICIENT OF FRICTION OF MAGNESIUM HYBRID COMPOSITES

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Abstract. *In the present experimental study, the coefficient of friction of magnesium matrix hybrid composites has been investigated using Taguchi technique. For the fabrication of hybrid composite simple and cost effective fabrication technique was used i.e. vacuum stir casting. Hard SiC and solid lubricant graphite particles were reinforced. Sliding wear test was carry out at Pin on disc setup at different loads (20,30,40N), graphite content (3,5,8 wt%), and sliding distance (500,1000,1500m). An L9 orthogonal array, was used for identify the effect of each control factor and their percentage contribution. It was examined that optimum value for coefficient of friction was obtained at 5%graphite (G2), 30N load (L1) and 500 m sliding distance (D1).*

Keywords: *Magnesium hybrid composite, coefficient of friction, Taguchi.*

1. Introduction

Current engineering applications demand stronger, lighter and less expensive materials. A good example is the current interest in development of new structural materials for transportation industry that have higher strength to weight ratio which can reduce overall the fuel consumption, weight and green house emissions. In recent years much attention has been paid to light weight aluminum and magnesium composite materials with broader spectrum of properties which can not be achieved using monolithic materials [1] . The important properties include: low density, high specific modulus, thermal conductivity, strength, wear resistance, good fatigue response and superior stability at elevated temperature [1-5]. Metal matrix composites (MMC's) are an important class of advance engineering materials that are fast replacing conventional metallic alloys not only in aerospace and automobile industries but also in defense, marine, sports and recreation industries due to their excellent combination of properties [6]. The MMC's combine the properties such as ductility and toughness of metallic alloys with high strength, modulus and temperature resistance of reinforcement materials to achieve desirable properties like wear resistance, high strength, light weight, self cleaning, self lubricating, high thermal conductivity and low cost for automobile applications as illustrated in Table.1. The common metallic alloys utilized for fabrication of MMC's are alloys of light metals such as Aluminum, magnesium and titanium; however another metallic alloys such as nickel, copper and stainless steel has been extensively used. Aluminum and magnesium alloys remains the most utilized metallic alloys as matrix material both in research and industrial view point [1]. Low density and high strength to weight ratio of aluminum and magnesium makes both of them a potential candidate for advanced light weight applications [1]. Aluminum and magnesium based MMC's can reduce the overall weight, fuel consumption and green house emissions in automobiles and aircrafts [1][2]. Every 10% of weight reduction from the average car or light truck can lead to reduction of fuel consumption by 6.9% [1] and as stated by W.A. Manteiro et al. [7] the reduction of 100 kgs weight in net load reduces fuel consumption by half liter per 100 kms. It causes 2000 kg less CO_2 production during the mean life of an automobile.

Many researchers have improved the wear resistance by reinforcing graphite as solid lubricant in aluminum, Copper and Zinc.N.Radhika et al. [6]stated that aluminum based hybrid MMC's with SiC and Graphite as reinforcement exhibited significantly improved mechanical and tribological properties.K.S Prakash et al. [7]revealed that SiC reinforcement in pure magnesium increased the micro hardness, COF, density and wear resistance of composite. Moreover self lubricating solid lubricant graphite was further added for lowering COF and increasing wear resistance by forming a tribo-layer between sliding counterparts.N.C Kaushik and R.N. Rao [8] found that in both As cast and T6 heat treated Al/SiC/Gr hybrid composites wear resistance was superior to that of Al/SiC composites, due to formation of tribo-layer of solid lubricant graphite. B.M Girish et al. [5]experimentally examined that SiC and Gr reinforcement in AZ91/SiC/Gr hybrid composite delayed this transition of oxidation to delamination wear and results in increase in wear resistance. B.M Girish et al. [9]further optimized the wear rate of AZ91/SiC/Gr hybrid composite using Taguchi robust design technique. It was found that the lowest wear rate was revealed at 20N load, 3wt% reinforcement and 1.047 m/s sliding speed. The normal load (34.57%) was the most significant factor followed by speed (20.75) and composition(11.70). P. Ravindran et al. [10] examined that due to self lubricating effect of graphite, wear rate and coefficient of friction of Al 2024/SiC/Gr hybrid composites were decreased upto 5wt% graphite reinforcement while further increased in graphite content wear rate was increased.

In the literature very less studies have been made to understand the wear behavior of magnesium (AZ91D) hybrid composite reinforced with SiC and Graphite and a few using taguchi parameter design approach. Hence, in this article effect of wear parameters such as applied load, sliding speed , graphite content and sliding distance on wear rate and coefficient of friction of magnesium hybrid composites have been investigated using Taguchi experimental design.

2. Experimental Details

2.1. Material and hybrid composite fabrication

The AZ91D magnesium alloy was fabricated by melting required weight percentage of Mg, manganese and Zinc with high purity in mild steel furnace at 680^{0}C under protection of SF6 and ultra pure argon. The chemical composition of fabricated AZ91D alloy chosen as base alloy for hybrid composite fabrication is shown in table 1. Preheated SiC and Graphite particulates were reinforced in molten AZ91D alloy while stirring using three blade stainless steel stirrer. The Content of SiC was kept constant at5wt% while graphite content was varied at 3, 5 and 8wt%. For 3, 5,8 wt% graphite addition, the stirring action was performed for 10 ,12 and 15 minutes respectively. After stirring melt was vacuum poured at 700^{0}C into a preheated mould of mild steel. The samples after casting in mould is shown in figure 1.

Table 1. Chemical composition of the AZ91D matrix alloy.

Al	Zn	Si	Mn	Fe	Cu	Ni	Mg
8.5	1	0.10	0.15	0.005	0.03	0.002	Remaining

2.2. Wear test

Sliding wear test of magnesium hybrid composites were performed under dry condition on Pin on Disc tribometer . All specimens (8mm dia. and 40mm length) for wear test were prepared according to ASTM G99-17 standards. EN24 steel disc with 200 mm diameter was used as counter-face surface. Coefficient of friction was calculated by weighing specimen before and after the wear test[11]. After each wear test disc was cleaned using acetone and also with emery paper if needed. The main wear parameters such as applied load was varied at 30,40,50 N, and sliding distance was varied from 500,1000 and 1500m under dry condition.

2.3. Experimental Design

The experiments were conducted as per L9 orthogonal design [9]. The plan of the experiments included three variables at three levels. The three independent variables were the following: graphite content, applied load, and sliding distance. The independent variables and their levels are illustrated in Table 2.

Table 2 Control factors and their Levels

Control Factors	Units	Level 1	Level 2	Level 3
C: Graphite composition	Wt%	3	5	8
L: Load	Newton	30	40	50
D: Sliding distance	Meter	500	1000	1500

In this experimental study, L9 orthogonal array having 9 rows and 3 columns were selected, as shown in Table 3. In taguchi experimental design, signal-to-noise (S/N) ratio for each experimental data was calculated. In present investigation, the-lower-the-better quality characteristic was chosen for the coefficient of friction of the AZ91D-SiC-Gr hybrid composites.

The S/N ratio for coefficient of friction using 'the-lower-the-better' characteristic, given by Taguchi, can be obtained from eq.[1] as follow[2][12][13][14]:

$$S/_{N} = -10\log\frac{1}{n}\left(\sum y^2\right) \qquad (1)$$

where y is the response of coefficient of friction and n is the number of trail experiments. The S/N ratio values are used to calculate influence of each independent variables of coefficient of friction, while further analysis of variance is performed to observed the percentage contribution of each parameter for coefficient of friction. Moreover, which parameter is significant and their optimum value for coefficient of friction can be predicted [15].

Table 3- Taguchi experimental design for L9 orthogonal array

Trail. No.	Gr % (G)	Load (L)	Sliding Distance (D)	Coefficient of friction (*10^{-4})
1.	3	30	500	1.73
2.	3	40	1000	2.39
3.	3	50	1500	2.49
4.	5	30	1000	1.86
5.	5	40	1500	2.10
6.	5	50	500	1.70
7.	8	30	1500	1.69

8.	8	40	500	1.58
9.	8	50	1000	1.96

3. Results and discussion

3.1. Influence of control Parameters on Coefficient of friction

The influence of independent variables such as Graphite content, applied load, and sliding distance has been identified with S/N ratio analysis. The coefficient of friction and transformed S/N ratios of all combination of parameters for AZ91D-SiC-Gr composites for have been illustrated in table 2. From the response table 4. for S/N ratio, it was found that influence of variables parameters on the coefficient of friction was in following order sliding distance > Gr% > Applied load.

Table 4. Response Table for means for "Smaller is better"

Level	G	L	D
1	**2.203**	1.760	1.670
2	1.887	2.050	2.070
3	1.743	**2.050**	**2.093**
Delta	0.423	0.290	0.460
Rank	2	3	1

Fig.3. showed the main effect plots with various control factors with coefficient of friction of AZ91D-SiC-Gr hybrid composites while Fig.4 illustrated the intersection plot for coefficient of friction. It can be observed that the optimal value of independent input variables coefficient of friction was 5% Gr, 30N Load, and 500m lowest sliding distance i.e. G2 L1D1. Coefficient of friction decreases with SiC and Gr reinforcement; however, coefficient of friction increases with increase in load, and sliding distance also reported by other authors[1][16][17]. The solid lubricant graphite provides the self lubricating effect in AZ91D-SiC-Gr hybrid composite. With reinforcement of graphite content (5wt%) wear resistance of hybrid composite was improved over a wide range of applied load, and distance.

Fig.3. Main effect plot for means of different input parameters on coefficient of friction.

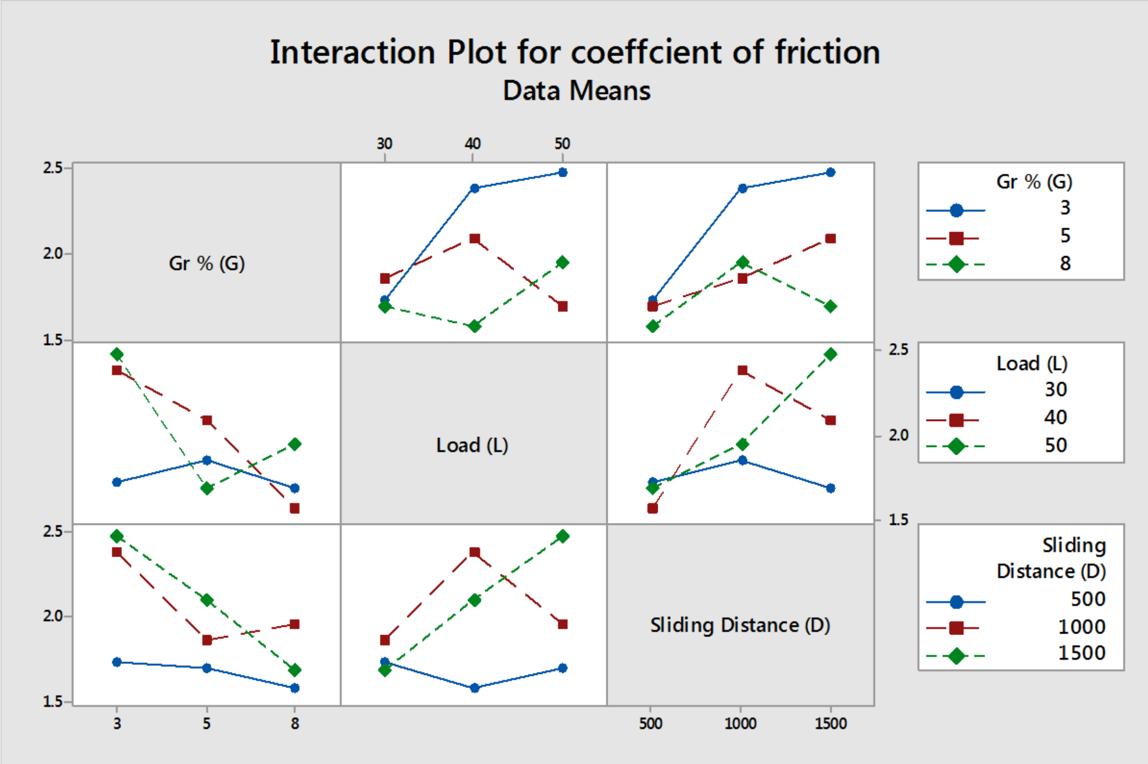

Fig. 4. Interaction plot for various input parameters on coefficient of friction of hybrid composites.

3.2. ANOVA

ANOVA is a statistical technique that predict the influence and parentage contribution of control factors, based on the analysis of experimental results [18][19]. Computed F ratio is used for finding significance control factors and by dividing sum of squares of a factor by total sum of squares, percentage contribution can be calculated. The results of ANOVA for coefficient of friction of AZ91D-SiC-Gr hybrid composites are presented in table 5. The ANOVA was performed at 95% confidence interval, where factor is considered as significant effect on coefficient of friction if its P value is < 0.05[20].

From the Table 5, it was figured out that a sliding distance (40.88%) have the strongest influence on the coefficient of friction of AZ91D-SiC-Gr magnesium hybrid composites followed by applied load (40.00%) and graphite content (18.55%).

Table 5. Analysis of Variance of mean value for coefficient of friction

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
G	2	0.332422	40.00%	0.332422	0.166211	70.90	0.014
L	2	0.154156	18.55%	0.154156	0.077078	32.88	0.030
D	2	0.339756	40.88%	0.339756	0.199878	72.46	0.014
Error	2	0.004689	0.56%	0.004689	0.002344		
Total	8	0.831022	100.00%				

3.3 Multiple Linear Regression Models

Multiple linear regression model that linked the control input and output response variable was developed as shown in eq. 2 [21].

Coefficient of friciton = 1.9444 + 0.2589 Gr % (G)_3 - 0.0578 Gr % (G)_5 - 0.2011 Gr % (G)_8
- 0.1844 Load (L)_30 + 0.0789 Load (L)_40 + 0.1056 Load (L)_50
- 0.2744 Sliding Distance (D)_500 + 0.1256 Sliding Distance (D)_1000
+ 0.1489 Sliding Distance (D)_1500 (2)

The Eq. [2] specified that the coefficient of friction decrease with graphite reinforcement, while it increase with increase in applied load, and sliding distance.

3.3 Conclusion

The main conclusions derived from above experimental study of MMHCs using taguchi techniques are illustrated below:

1. AZ91D-SiC-Gr hybrid magnesium composites can be successfully fabricated via vacuum stir casting with homogenous distribution of SiC and graphite.

2. Coefficient of friction of the AZ91D-SiC-Grmagnesium hybrid composites decreases with SiC and graphite reinforcement while it increases with increment in sliding distance and normal load.

3. From the response analysis of S/N ratio, the optimal value of independent input variables for minimum coefficient of friction of hybrid composite is 5wt% Graphite, 30 N applied load, and 500m sliding distance.

4. The sliding distance has the highest influence on coefficient of friction of fabricated hybrid magnesium composite (40.88%) followed by applied load (40.00%) and graphite content (18.97 %).

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