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STUDY ON TRIBOLOGICAL POPERTIES OF AZ91D MAGNESIUM COMPOSITE REINFORCED WITH B_4C AND ZrO_2

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Abstract:

In present study, the tribological behavior of AZ91D Magnesium alloy matrix reinforced with 3 wt.% of B_4C and 2 wt.% of ZrO_2 was investigated. The composites were produced by the Bottom Pouring Stir Casting Process. The tribological properties were studied using Pin on Disc apparatus as per ASTM G99 standards. Percentage of reinforcement, sliding velocity and applied load have been taken as the factors/variables for evaluating wear rate and friction coefficient. The test conditions taken for conducting the test for tribological responses is designed using design of experiment. The wear test was carried out using an experiment design based on the Taguchi method. The influence of each individual element on the performance of composite wear was evaluated using the variance analysis (ANOVA). The weight percentage of reinforcements, load, and speed were found to significantly affect the wear characteristics. A mathematical model for wear and coefficient of friction was developed using the response surface methodology, and it was confirmed by conducting an experiment at the ideal level.

***Keyword*: AZ91D/B_4C/ZrO_2, Pin On Disc Apparatus, ANOVA, Taguchi method, Response Surface Methodology**

I. INTRODUCTION

Low-density composites based on magnesium have attracted attention on the automotive and aerospace industries' for the ongoing research on lighter materials. Magnesium has many benefits, including low density, increased specific strength, effective dampening, and superior dimensional stability. Magnesium's usage in piston-cylinder liners and other real-time applications has been constrained, however, by its poor wear resistance, inherent brittleness, and poor temperature stability. In order to boost the wear resistance of the magnesium matrix, reinforcing particles, especially those of nanoscales, are sought. Due to the fact that a material's wear resistance is determined by its capacity for plastic deformation, nanoparticles can get stronger and harder, increasing wear resistance. Zirconia reinforced composites offer significantly improved refractoriness, chemical resistance, and abrasion resistance when compared to composites with conventional reinforcements. In the majority of magnesium composites, plastic deformation is not possible. Nano-scale reinforcements can be used to get around this restriction. And by the addition of Boron Carbide, hardness and melting point of the composite will be increased. Hamid Raza studied that, by the addition of B_4C the hardness value of Al20%Mg2Si was increased [1]. With respect to Zirconia, Ke Qiao et al observed that, on the addition of Zirconia, the brittleness of the composite was increased and the elongation was decreased [2]. It is observed that, by the addition of ZrO_2, the hardness and strength of the material were increased [3-4]. Ravi Kumar studied that, on the addition of Tungsten Carbide as a reinforcement, the density of the AZ91D alloy was increased and elongation was decreased [5]. Nishita Anandan observed that, on the addition of small sized reinforcement to the AZ91D alloy, the particulate fracture and voids due to particulate debonding was not observed extensively [6]. Fareeha Ubaid et al fabricated the alloy of Aluminium and B_4C using Microwave sintering method and followed by hot extrusion. She observed that, on the addition of B_4C nanoparticles the yield strength and the ultimate strength were increased but the ductility behavior was opposite to the ductility of the pure Aluminium [7]. J. Udaya Prakash et al. (2018) used taguchi-based grey relation analysis approach to optimise the wear parameters of 413 Aluminium Alloy reinforced with 3%, 6%, and 9% B_4C. For the creation of composite, the stir casting method was used. Using pin-on-disc testing equipment, a dry sliding wear test was conducted. The most crucial elements in determining the friction coefficient and wear rate were the sliding distance and speed. In this work, the Taguchi L27 orthogonal array was employed. To analyse the Grey Relation Grade, ANOVA was utilised. The size of the matrix grain decreased as the weight % of reinforcement increased. The material's hardness was raised by the addition of carbides [8]. Sandeep Singh Kharb studied that the COF reduced over time, and it was discovered that base fluid containing nanoparticles significantly altered the antifrictional characteristic. The coefficient of friction (COF) value was lowest in 2wt% SiC/soluble oil nanofluids and greatest in dry sliding conditions (0.33). The wear of the AZ91D-5SiC composite pin with 2 weight percent SiC/soluble oil Nano-fluids Lubrication was reduced by 70.75% and 59.21% compared with dry condition and oil condition, respectively, at load of 40N and sliding for 180s [9]. The conditions for clustering of nanoparticles make it difficult to fabricate nanocomposite. Despite the fact that powder metallurgy is more popular, porosity is the main problem with the finished product. Spray casting and in-situ salt route methods are also frequently employed. Stir casting is becoming more and more standardised because of its adaptability, simplicity, and tremendous production capacity. This entails melting the actual metal in a furnace and combining it with the heated reinforcements. After that, the liquid slurry is poured into the desired shape. The wear qualities of AZ91D alloy are insufficient, despite its improved superior castability, and stiffness. To increase wear resistance, this alloy includes nanoparticles of zirconia and boron carbide. Few publications have been made on enhancing the wear properties of hybrid magnesium nanocomposite made by stir casting, according to a thorough examination of the literature. Therefore, it is important to optimise the wear properties of Mg-ZrO_2-B_4C produced by stir casting.

II. EXPERIMENTAL DETAILS

A. *Work piece material*

The base metal used in this study is an AZ91D magnesium alloy, while the reinforcement elements used are nanosized zirconia (ZrO_2) and boron carbide (B_4C). The size of a nanoparticle is typically 100mm on average. The AZ91D magnesium alloy's composition is displayed in Table 1.

Table 1

AZ91D Mg alloy Composition in Weight percent

Al	Mn	Zn	Si	Cu	Fe	Ni	Others	Mg
8.3 - 9.7	**0.15-0.5**	**0.3 - 1**	**0.1**	**0.03**	**0.005**	**0.002**	**0.02**	**Remainder**

The procedure of bottom pour stir casting is used to create the composite. The AZ91D material is placed in the furnace and heated to a temperature of 750°C in a steel crucible. The reinforcement materials are currently being weighed before being added to the small furnace that is attached to the main furnace. The reinforcement material will be preheated for at least an hour at a temperature of 350 °C before being added to the molten AZ91D alloy in the furnace. The composite mixture will then continue to be stirred while the furnace is heated continuously to a temperature of 750°C to ensure that the reinforcement and base alloy are well blended. The liquid will then be added to a permanent mould. Three weight percentages of B_4C — 0%, 3%, and 5%—along with 2% of ZrO_2 are used in this approach. The casting furnace is depicted in Figure 1. Table 2 provides information on the various reinforcement combinations used.

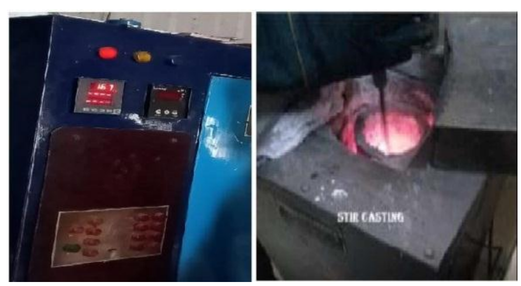

Figure 1: Bottom Pour Stir Casting Furnace

Table 2
Reinforcement Combination

Sl.No.	AZ91D (%)	B_4C (%)	ZrO_2 (%)
1.	98	0	2
2.	95	3	2
3.	93	5	2

B. ***Design of Experiments***

The design of experiments aims to produce the most conclusive knowledge from the least quantity of data. The statistical strategy prepares the details of the experiment in order for adequate data to be gathered, assessed, and a valid conclusion to be drawn. This technique assists in identifying the fewest parameter combinations and levels necessary to ascertain the primary and interaction effects of selected parameters on the outcome. There are numerous DOEs, including Taguchi, Grey Relational Analysis, Response Surface Approach, and others. Depending on the situation, researchers will choose an acceptable experiment design. In this work, the Taguchi method of experiment design was used. In this scenario, three input factors were taken into account at three levels. They are summarised in Table 3.

Table 3
Input Parameters and their levels

Input Parameters	Levels
Reinforcement % of B_4C	0, 3, 5
Loads in N	4.905, 9.81, 14.715
Speed in rpm	200, 300, 400

C. ***Experimental Setup***

A Pin-on-Disk type triboteter was used to conduct a dry sliding wear test of the produced Mg-B_4C-ZrO_2 composites at room temperature. (JNTU UCESTH ,Hyderabad). The Pin-on-Disk tribotester is shown in working order in Figure 2. On samples measuring 12 mm in diameter and 120 mm in length, a wear test was performed. To guarantee that the experiments were carried out in a dry atmosphere, the samples were painstakingly cleaned. A steel disc serves as the test's counter surface because the disc's substance has a far higher degree of hardness than the composite. The disc's wear was disregarded. A dead weight was placed on the pan to apply the desired load to the sample.

Figure 2: Wear Test apparatus

III. RESULTS AND DISCUSSIONS

The tests were carried out in accordance with the Taguchi technique's specified Design of tests. Each experiment's time frame was wear track radius was also maintained at 0.070 metres and kept constant at 15 minutes. The average linear wear was 0.51, 0.33, and 0.28 microns for B_4C concentrations of 0%, 3%, and 5%, respectively. While the average COF for B_4C concentrations of 0%, 3%, and 5% was 0.532, 0.47, and 0.389. When compared to AZ91D magnesium alloy, the average linear wear improved by 46.95%, and the coefficient of friction increased by 26.9%.

TABLE 4
OBSERVATION (L9 ORTHOGONAL ARRAY)

S.No	Specimen Material	Load on Pin	Speed	Coefficient of Friction	Wear rate
	Wt% of B_4C	N	RPM	COF	μm/min
1	0	4.905	200	0.79	0.0327
2	0	9.81	300	0.435	0.033
3	0	14.715	400	0.37	0.036
4	3	4.905	300	0.75	0.022
5	3	9.81	400	0.42085	0.024
6	3	14.715	200	0.24	0.0193
7	5	4.905	400	0.53	0.0187
8	5	9.81	200	0.345	0.0207
9	5	14.715	300	0.29	0.018

D. *Analysis of Variance*

ANOVA is used to statistically analyse the results of the experiment and create a useful regression model. In this experiment, ANOVA was performed using MINITAB 19. Table 5 presents the findings of the ANOVA analysis.

TABLE 5
ANALYSIS OF VARIANCE

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
B4C	2	0.187103	0.093551	8.71	0.103
Load	2	0.106497	0.053248	4.96	0.168
RPM	2	0.008425	0.004212	0.39	0.718
Error	2	0.021472	0.010736		
Total	8	0.323497			

According to the analysis of variance, reinforcement and load have a greater impact on wear and coefficient of friction, respectively. Error was very low.

TABLE 6
MODEL SUMMARY

S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
0.103615	93.36%	84.72%	68.90 %

It is to be noted that the predicted R2 of 0.6890 is in reasonable agreement with the adjusted R2 of 0.8472 i.e., the difference is less than 0.2.

The highest values produce the best results in the main effect plot for means. As a result, the ideal level is reinforcement at 5 weight percent, load at 14.715 N, and speed at 200 RPM.

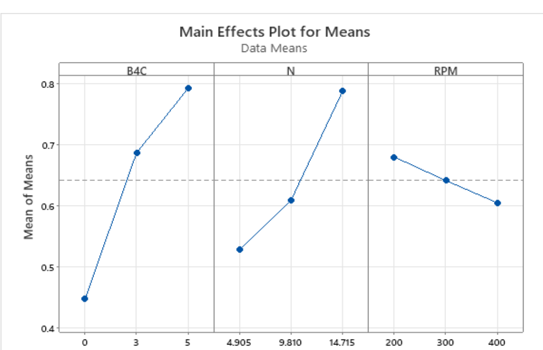

Figure 3: Main effect plot for Means

E. *Development of Mathematical Models Using Response Surface Method*

RSM examines the system objectively by using statistical and regression techniques. It then analyses and optimises the quantitative data acquired from a limited number of tests. Utilising statistics, this approach looks at how input and output elements relate to one another. This experimental method is frequently used to statistically analyse data across several academic disciplines. The response surface approach was developed largely to increase output accuracy around a target value and provide robust designs that are resistant to component fluctuation. When building a regression model, either a first order model or a second order model is taken into account. In cases when a small area is selected, the first order polynomial is employed. Two independent variables are included when an ac order model is produced.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i$$

F. *Mathematical models generated using Design Expert Software (RSM)*

wear rate = +0.030072-0.003039*B4C-3.39789E-06*Load+1.00000E-05*Speed

COF = +0.955220-0.028019*B4C-0.039755 *Load - 0.000090*Speed

TABLE 7
VALIDATING THE MATHEMATICAL MODELS

	Predicted	experimental	Error (%)
Coefficient of Friction	0.2125	0.2228	4.62
Wear Rate	0.017245	0.01805	4.45

According to the optimal level of parameters, confirmation experiment was conducted at 5% of B_4C, 14.715 N Load, and 200 RPM Speed. The Coefficient of friction was found to be 0.2228, and Wear rate was found to be 0.01805 microns/min. The predicted value for coefficient of friction was 0.2125 while the Wear rate was 0.017245 microns/min respectively, which were calculated from the corresponding mathematical models developed using Response Surface Methodology in Design Expert Software.

An error of 4.28% was observed for COF while 3.08% error was observed for wear rate for experimental responses compared to the predicted parameters. This error might have been attributed due to the wobbling of disk, vibrations in the equipment, aging of the linear and frictional force sensors.

IV. CONCLUSIONS

The hybrid metal matrix composite of AZ91D/B_4C/ZrO_2 was produced via stir casting. For three test specimens, the proportion of ZrO_2 was changed while the percentage of B_4C remained constant. The results of the experiment were used to derive the following conclusions. The ideal set of wear test settings is reinforcement at 5 weight percent, load at 14.715 N, and speed at 200 RPM. When compared to AZ91D magnesium alloy, The wear rate decreased by 74.85% for sample with 2% ZrO_2 + 5% B_4C [0.0187 microns/min] reinforced composite compared to that of base alloy [0.0327 microns/min] and The Coefficient of friction has slightly reduced (i.e. 6.14%) with increase in Speed.

The composite with 5% B_4C and 2% ZrO_2 reinforcements showed superior wear resistance. The constructed mathematical models were optimally tested, and they little deviated from the experimental findings.

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