

## Tribological Properties of Al 7075 Composite Reinforced with ZrB<sub>2</sub> Using Grey Relational Analysis

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### ABSTRACT

In this work, the authors investigate the optimal tribological parameters of Al 7075 composite reinforced with ZrB<sub>2</sub> using Grey Relational Analysis (GRA). Initially, the composite specimens were prepared by the variation of reinforcement 5%, 10% and 15% using stir casting routing method. Further, the developed metal matrix composites are used to measure the wear and frictional properties on pin-on – disc testing apparatus. The input parameters such as, wt% of reinforcement (5%, 10% and 15%), load (4.92N, 9.81N and 14.72N) and the time required for conducting the wear test is (15 min, 30 min and 45 min). A Taguchi L<sub>9</sub> orthogonal array was designed for conducting the number of experiments. Based on the combination of number of experiments wear study has been conducted on the wear testing apparatus. Moreover, GRA was used for obtaining the best optimal input control parameters that gives minimum magnitude of wear and coefficient of friction (COF). Finally, the confirmatory experiments are conducted and verified with the Taguchi grey relational analysis. The results shows that the predicated optimal mean value is almost similar to the experimental value.

**Keywords:** Al 7075, dry sliding wear, stir casting routing technique, wear, COF.

### INTRODUCTION

In general composites are developed by reinforcing the several ceramic particulates into various grades of Al alloys. Therefore, the strength of the Al alloy is increases after adding various ceramic particulates. Because, day by day the usage of Al alloys are increases in all automobile, aerospace, nuclear and naval industries [1–3] due to light in weight. Based on the literature [4–7] it has been found that the strength of Al 7075 has high and more potential in tribological applications. Around the world, many researchers [8–10] studied the tribological properties of the Al 7075 alloy reinforced with numerous ceramic particles such as, titanium carbide (TiC), graphite (Gr), silicon carbide (SiC), alumina (Al<sub>2</sub>O<sub>3</sub>), titanium boride (TiB<sub>2</sub>) etc. In [11], the authors observed the effect of in situ formation of ZrB<sub>2</sub> particulates on microstructure and tensile behavior of Al

7075 composite. The morphologies show that the ZrB<sub>2</sub> particulates are exhibited in numerous shapes such as, cylindrical, hexagonal, and spherical and the size also nano, sub-micron and micron level. It has been observed that a good interfacial bonding obtained between Al 7075 and ZrB<sub>2</sub> particulates and also the mechanical properties are enhanced after adding the ZrB<sub>2</sub> particulates. Moreover, Rengasamy et al. [12] developed Al 4032/ZrB<sub>2</sub>/TiB<sub>2</sub> hybrid metal matrix composites for mining applications. The developed composite specimens are used for dry sliding wear test on pinon disc testing apparatus. The result confirms that the mechanical properties of the obtained composite is increases when increasing the reinforcement particles. In addition to the above research work, Kaku et al. [13] examined the deformation properties of Al alloy with the reinforcement of ZrB<sub>2</sub> ceramic particles. The developed composites are used for testing the hardness and corrosion

rate and obtained the hardness increases when deformation increases and the rate of corrosion is decreased with the extent of deformation. Girish et al. [14] obtained the tribological properties of recursively friction stir processed AA 7075 alloy on wear testing apparatus. The experiments are conducted using Taguchi experimental design and the analysis of variance (ANOVA) was used to determine the impact of the several input parameters on wear rate. Further, Narendra et al. [15] discussed the effect of AA 5052/ZrB<sub>2</sub> composite on tribological properties. The result shows that the COF and wear rate increases continuously when increasing the sliding velocity and load. In [16], the authors discussed tribological properties of Al 7075-TiC MMC's specimens. A Taguchi GRA is used to minimize the wear rate, COF and specific wear rate and maximize the wear resistance. Siriyala et al. [17], studied the grey taguchi method for optimizing the wear properties and designed an L<sub>25</sub> orthogonal array for conducting the number of experiments. Further, Alfryyan [18], discussed the improvement of mechanical, microstructural and wear resistance properties of dual phase medium carbon steel. From the results, it has been observed that there is an enhancement in mechanical and microstructural properties when samples are cooled at 10% ice water. Khalid and Nawal [19], examined on dry sliding wear behavior of Tin-Bronze alloys and the reinforcement is ZrO<sub>2</sub> and the composite was developed by the concept of powder metallurgy technique. In addition to, Mulugundam et al. [20], studied the optimization of Al 7075 turning process parameters namely, material removal rate and surface finish using ANOVA and GRA. Kannan et.al [21], developed a mathematical model for Al 7075 based hybrid nanocomposites and also an ANOVA is used for determining the optimal input parameters for obtaining the tribological properties.

## EXPERIMENTAL PROCEDURE

In this section, the chemical composition of a base alloy and reinforcements, fabrication procedure, experimental design procedure and the instruments are used for conducting the tribological tests are discussed. Further, a Taguchi GRA was used for obtaining the optimal tribological properties.

### Materials

Initially, the matrix Al 7075 and the reinforcement ZrB<sub>2</sub> were procured from the vendor and verified the chemical composition. Once the matrix and reinforcements are verified the percentage of reinforcement was varying from 5%, 10% and 15%. The chemical composition of the Al 7075 was shown in Table 1. Later, the MMC's prepared by using stir casting process shown in Fig. 1.

Authors are going considered as future work of the microstructure and micro hardness of the sample. At present the authors working on microstructures. The material used for counter sample is EN31 steel disc. The chemical composition of the EN31 steel is given in Table 2. The authors



Fig. 1. Stir casting process

Table 1. Chemical composition of Al 7075 alloy

Element	Al	Zn	Mg	Cu	Fe	Si	Mn	Ti	Cr	Pb	Sn
Chemical composition (wt. %)	89	5.6	2.4	1.3	0.5	0.4	0.3	0.2	0.18	0.03	0.012

Table 2. Chemical composition of EN 31 steel

Element	SiO	Cr	C	S	P	Ni	Mo	Mn	Fe
% of Weight	25	1.46	1.08	0.015	0.022	0.33	0.06	0.53	Rest

**Table 3.** Control factors and their levels

Parameters	Level 1	Level 2	Level 3
Reinforcement %	5	10	15
Load (N)	4.92	9.81	14.72
Time (min)	15	30	45

were conducted wear test on counter sample before conducting the experiment. The authors considered wear in terms of friction.

### Design of experiments

Based on the available literature It has been found that many factors were affecting on the tribological properties of the composite specimens [22]. In this study, the authors considered three control process parameters namely, reinforcement (wt.%), applied load (N) and time (min) which are directly influencing on the wear and COF. The key objective of the current research work, is to minimize the wear rate and COF [23]. The control factors and their levels which are used for current study is shown in Table 3. To optimize the number of experiments for determining the wear rate and COF, in this work an  $L_9$  orthogonal array is considered.

### Dry sliding wear test

In the current investigation, the wear rate and COF were determined from dry sliding wear test. Fig. 1 and 2 shows the samples prepared for wear test and pin-on disc testing apparatus. The composite specimens are prepared with the diameter is 8 mm and length is 30 mm. A 90 mm diameter hardened steel disc was used a counter surface material with the hardness is 60HRC. The authors used wire cut EDM for cutting the samples. The



**Fig. 2.** Wear testing specimens



**Fig. 3.** Pin-on-disc testing apparatus

authors have conducted the surface roughness and achieved with in the range only. Each test was conducted in three times using same input parameters. A lever arrangement is used for applying the load also it acts as a counter weight for balancing the pin (Fig. 3). Initially, the developed composite specimens and the steel disc are polished by using emery paper and cleaned by using acetone solution for obtaining the clean surface. Each test was conducted in three times using same

**Table 4.**  $L_9$  orthogonal design: Input and output responses

S.No	% of reinforcement	Load (N)	Time (min)	Wear rate (mg/min)	Coefficient of friction
1	5	4.82	15	4.267	0.042
2	5	9.81	30	5.667	0.016
3	5	14.72	45	6.42	0.079
4	10	4.82	30	1.67	0.127
5	10	9.81	45	1.533	0.096
6	10	14.72	15	1.067	0.04
7	15	4.82	45	1.711	0.228
8	15	9.81	15	2.711	0.051
9	15	14.72	30	3.711	0.173

input parameters. Finally, the authors considered the average of three tests. In the present research work the authors considered as mean wear rate and coefficient of friction. An  $L_9$  orthogonal array is used for conducting the number of experiments and the responses of input and outputs are given in Table 4.

## RESULTS AND DISCUSSIONS

After designing the  $L_9$  orthogonal array the number of tests are conducted as per the design. To determine the multi response optimization in the current research work a GRA has been used for attaining the optimal input variables after calculating the GRG. In the current section the results related to the GRA has been discussed.

### Grey relational analysis

The GRA tool was developed by Prof. Deng and it is efficiently useful to resolve the difficult problems with interrelationships between the multi objective characteristics. During this analysis, the process of optimization is very difficult to change the multi performance characteristics to single grey relational grade. In the present research work, the GRA was used for obtaining the minimum combination of the control variables namely percentage of reinforcement, applied load, and time. The main focus of this study is to minimize the wear rate and COF and also to calculate the effect of individual control parameter on the output characteristics. The following steps was used for obtaining the grey relational grade.

- Step 1 (S/N ratio) – a Taguchi method is used for calculating the S/N ratios for all output parameters. In this investigation, the wear rate and COF are considered as lower and the equation is used for obtaining the S/N ratio is given below.

$$\frac{S}{N} \text{ ratio} = -10 \log_{10} \left( \frac{1}{n} \sum_{k=1}^n Y_{ij}^2 \right) \quad (1)$$

- Step 2 (Normalization): A grey relation theory is used for normalizing the values between 0 to 1. Equation 2 is used for normalizing the original order if the performance, value is smaller –the better- characteristics.

$$Y_i^*(k) = \frac{\max Y_i(k) - Y_i(k)}{\max Y_i(k) - \min Y_i(k)} \quad (2)$$

Moreover, equation 3 is used for normalizing the original order if the performance, value is larger –the- better characteristics.

$$Y_i^*(k) = \frac{Y_i(k) - \min Y_i(k)}{\max Y_i(k) - \min Y_i(k)} \quad (3)$$

where:  $Y_i^*(k)$  denotes the order of sequence after data preprocessing,  $Y_i(k)$  indicates the original sequence of performance values,  $\max Y_i(k)$  represents the maximum value of  $Y_i(k)$  and  $\min Y_i(k)$  denotes the minimum value of  $Y_i(k)$ .

- Step 3 (Grey relational coefficient): Once the data is preprocessed, the GRC  $\xi_i(k)$  is obtained from equation (4), for all the output responses were calculated from the normalized S/N ratio values.

$$\xi_i(k) = \frac{\Delta \min + \zeta \cdot \Delta \max}{\Delta_{0i}(k) + \zeta \cdot \Delta \max} \quad (4)$$

Therefore,  $k = 1, 2, 3, \dots, m$ ;  $I = 1, 2, 3, \dots, n$ . where:  $m$  and  $n$  indicates the number of responses and experimental data values. For the current investigation the values of  $m$  and  $n$  are considered as 2 and 16. Further,  $\Delta_{0i}(k)$  is calculated the absolute value of the difference between  $Y_0^*(k)$  and  $Y_i^*(k)$ . The value  $\zeta$  is denoted as the distinguish coefficient which is varying in between 0 and 1. Therefore, in the current study the value of  $\zeta$  is considered as 0.5 where,  $\Delta \min$  indicates minimum value of  $Y_i^*(k)$  and  $\Delta \max$  represents the maximum value of  $Y_i^*(k)$ .

- Step 4 (Grey relational grade): After obtaining the GRC of each experiment, The GRG was measured by averaging the GRC for each experiment. Equation 5 is used for calculating the grey relational grade.

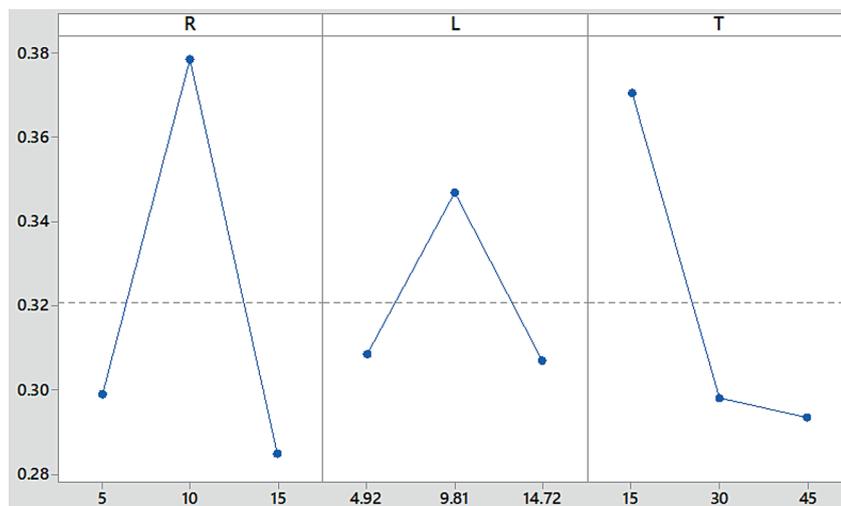
$$\gamma_i = 1 \sum_{k=1}^m \xi_i(k) \quad (5)$$

where:  $\xi_i$  and  $\gamma_i$  represents the GRC and GRG for  $i^{\text{th}}$  experiment,  $m$  denotes the number of output responses. The calculated normalization data, deviation sequence, GRC and GRG and order of the rank are given in Table 5.

From the Table 5, it has been observed that the highest value of GRG influences the

**Table 5.** Calculates normalization, deviation sequence, GRC and GRG

Ex. No	Normalization		Deviation Sequence		GRC		GRG	Rank
	Wear	COF	Wear	COF	Wear	COF		
1	0.4022	0.8774	0.5978	0.1226	0.4555	0.8030	0.3146	6
2	0.1407	1.0000	0.8593	0.0000	0.3678	1.0000	0.3420	4
3	0.0000	0.7028	1.0000	0.2972	0.3333	0.6272	0.2401	8
4	0.8874	0.4764	0.1126	0.5236	0.8161	0.4885	0.3262	5
5	0.9129	0.6226	0.0871	0.3774	0.8517	0.5699	0.3554	2
6	1.0000	0.8868	0.0000	0.1132	1.0000	0.8154	0.4538	1
7	0.8797	0.0000	0.1203	1.0000	0.8061	0.3333	0.2848	7
8	0.6929	0.8349	0.3071	0.1651	0.6195	0.7518	0.3428	3
9	0.5061	0.2594	0.4939	0.7406	0.5031	0.4030	0.2265	9



**Fig. 4.** Main effect plot for GRG

consistent combination of parameter is closer to the optimum level (Fig. 4). The highest GRG that is, 0.4538 is achieved at experiment no 6 which consists of a better combination of optimal input parameters such as, reinforcement is 10 wt.%, applying load is 9.81 N and time is 15 min. The objective is to minimize the wear rate and COF for the tribological properties of Al 7075-ZrB<sub>2</sub> MMC's. Table 5 and 6 shows the response table for signal to noise ratio and mean. Once the mean value is determined from the Taguchi predicated and the confirmation tests are

**Table 6.** Response table for signal to noise ratio

Level	% Reinforcement	Applying load (N)	Time (Min)
1	-10.585	-10.228	-8.735
2	-8.526	-9.202	-10.650
3	-11.035	-10.717	-10.761
Delta	2.508	1.515	2.026
Rank	1	3	2

conducted by using the optimal input parameters. After conducting the confirmation tests it has been observed that there is no deviation between the Taguchi predicated and experimental value. It concludes that the Taguchi predicted value is almost accurate.

**Table 7.** Response table for mean

Level	% Reinforcement	Applying load (N)	Time (Min)
1	0.2989	0.3085	0.3704
2	0.3785	0.3467	0.2982
3	0.2847	0.3068	0.2935
Delta	0.0937	0.0399	0.0770
Rank	1	3	2

**Table 8.** Conformation experiment

Optimal settings	Taguchi predicted value	Experimental value
R <sub>2</sub> – L <sub>2</sub> – T <sub>1</sub>	0.454218	0.4785

## CONCLUSIONS

The dry sliding wear behaviour of Al 7075-ZrB<sub>2</sub> metal matrix composites were studied and the conclusions are made is as follows. Al 7075-ZrB<sub>2</sub> metal matrix composites were prepared through stir casting routing technique. A Taguchi L<sub>9</sub> orthogonal array was used for conducting the number of experiments. The dry sliding wear behaviour parameters were analysed and the objective is to minimize the wear rate and coefficient of friction. Grey relational grade has been calculated and assigned the rank by the using the concept of larger is better. After calculating the GRG in the current study the authors considered as larger is better and provide the ranking process. Based on the rank, the optimum combination of the input parameters such as, reinforcement is 10%, load is 9.81 N and time is 15 min. The conformations test was conducted and compared the Taguchi predicted value to experimental value. It has been observed that there is no huge deviation among the predicted and experimental value.

The novelty of this research work is to determine the optimal input parameters namely, % of reinforcement, load and time using GRA. The obtained input parameters will help to minimize the wear rate and coefficient friction. Further, in [11] and [13] developed a metal matrix composite Al 7075 with reinforcement of ZrB<sub>2</sub> and they conducted mechanical and microstructural properties. In the current research work, the authors obtained tribological properties using GRA.

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