Optimization of Wear Behavior of Al 5456 Alloy/TiB$_2$ Composite using ANOVA and TAGUCHI Method

S.Balaji, P.Maniiarasan, S.Senthilkumar

Abstract— In this present study, wear behavior of Al 5456 Alloy reinforced with 0,3 and 6 wt %TiB$_2$ were investigated by ANOVA and Taguchi's (L$_9$) method. The composite samples were prepared by stir casting technique. Wear experiment was carried out by pin on disc apparatus under the different parameters of loads (10N, 20N and 30N), sliding velocity (2,4 and 6m/s) and time (10,15 and 20 min).This paper revealed that addition of Titanium diboride (TiB$_2$) improves the wear resistance of Al5456 composite. The result showed that wear rate was decreased with increasing the weight percentage of TiB$_2$. ANOVA and Taguchi method results were tabulated in MINITAB-18 Software package to analyze the influence of individual parameters on the wear rate. Additionally, regression equation was also found the relation between input parameters and wear rate.

Keywords: Wear behavior, Oil fired furnace, Taguchi's technique, MINITAB-18 Software.

I. INTRODUCTION

Aluminum Matrix Composites (AMCs) are produced mostly for commercial applications like automotive, aerospace, transportation industries etc., because of its high elastic modulus, good wear resistance, high thermal stability. For improving mechanical, physical, electrical wear resistance properties of AMCs, Many scientists and researchers use the various types of reinforcement materials (SiC, TiC, TiB$_2$ and B$_4$C) with material matrix. Aluminum 6061 alloy which possessed low wear resistance, high thermal conductivity and low density. To overcome this problem, Titanium diboride (TiB$_2$) mixed with aluminum alloy in order to improve the wear resistance [1,2]. Researchers examined wear resistance of SiC, Fly ash reinforced aluminum composites. They observed wear resistance was increased with rise in fly ash particle because of breakage of bonds between aluminum matrix and fly ash content and also evaluated the analysis of variance of each parameters in MINITAB-17 software. Also few authors prepared Al5083 alloy/SiC (3 to 7wt%) composite by stir casting method and conducted wear test on pin on disk equipment [3]. The result showed that hardness rises from 62 to 73 HV corresponding to the rise in SiC weight percentage. They used spark plasma sintering

technique to produce composite material of Diamond-SiN$_4$, the highest value of wear resistance was noticed [4]. Researchers tested wear behavior of A356 alloy/Melon shell under the different loads (2N,5N). Anaton paar TRN tribometer and stainless steel abrasive ball as apparatus and tool to perform the experiment.

The aim of this paper is to determine the wear rate of Al 5456/(TiB$_2$) composite produced by stir casting technique. Wear experiment is experimented on pin on disc apparatus, and measured the weight before and after the test. Using Taguchi (L9 orthogonal array) technique, experimental design of individual parameters of load, sliding velocity, time and reinforcement wt% are calculated for wear rate. ANOVA is prepared to study the influence of individual parameters on response variable. Finally ANOVA and Taguchi's readings are tabulated by MINITAB-18 software.

II. EXPERIMENTAL PROCEDURE

2.1 Sample Preparation

The composite (Al5456/TiB$_2$) is prepared by stir casting technique. Composition of Al5456 alloy is specified in Table 1. Al5456 alloy gets placed in to the oil fired furnace (shown in Figure1) and is heated about 750°C. Titanium diboride (TiB$_2$) particles is preheated at 300°C for 25 min which helps to make an oxide layer on the particles. Afterwards, preheated TiB$_2$ is mixed with molten alloy(Al5456) for 10 to 15 minutes at constant temperature (750°C).stainless steel stirrer is utilized for mixing of TiB$_2$ particle and molten alloy. The mixture is poured in mould structure for obtaining desired samples. This process is repeated for 6wt% of TiB$_2$ particles. After cooling the casting, properly cut and shaping the samples to make suitable dimension for wear test.

Table 1. Composition of Al5456 alloy in % wt

Elements	Cr	Cu	Fe	Mg	Si	Mn	Ti	Zn	Al
Percentage	0.2	0.1	0.4	5.5	0.25	1.0	0.2	0.25	Remaining

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Fig. 1. Oil fired furnace

2.2 Wear test

Wear test is executed on the pin in the disc tribometer apparatus. The pin specimen sample (Ø10 x 30 mm) is polished with help of different grades of abrasive paper and clean the surface by acetone before performs the test. Totally 9 pin samples are prepared to conduct the experiment. Tribometer has the disk where the pin specimen revolves around it during test. the material is removed from the pin specimen surface due to friction between the specimen and disk. The quantity of rate of wear is evaluated by weighing the specimen before and after test. The loss of weight is measured by digital weigh balance. The change of weight loss depends on various factors like load (10N,20N and 30N),sliding velocity(2m/s,4m/s and 6m/s),time(10,15 and 20 min) and reinforcement wt%. the wear rate and density of the composite are calculated by below formula 1 and 2.

$$W_s = \frac{\text{Weight loss (or) Mass loss}}{\text{Density of the composite} * \text{Time} * \text{Sliding velocity} * \text{Load}}$$

$$\frac{\text{Weight loss (or) Mass loss}}{\text{Density of the composite} * \text{Time} * \text{Sliding velocity} * \text{Load}}$$

(1)

$$\rho_{composite} = \rho_{Al5456} \cdot V_{Al5456} + \rho_{TiB2} \cdot V_{TiB2} \qquad (2)$$

Where, ρ_{Al5456} = Density of aluminum 5456 alloy (2.66g/cm^3), ρ_{TiB2}= Density of Titanium diboride (4.52g/cm^3), V_{Al5456}= volume % of aluminum 5456 alloy, V_{TiB2}= volume % of Titanium diboride

2.3 Design of experiments

Experiment plans are done by taguchi's method (L9 orthogonal array) which is employed to achieve the optimum outcomes with reduced experimentations. Wear rate of the pin sample is evaluated using S/N ratio (Smaller is better).experiments are carried out by considering three levels of four input constraints like load, sliding velocity, time and reinforcement wt %. Input variables and their level values are given in table 2. Additionally, the tst results are examined by means of ANOVA for analyzing the effect of input parameters on wear rate.

Table 2. Input parameters with three levels

Parameters	Unit	level 1	level 2	level 3
Load	kg	10	20	30
Sliding velocity	m/s	2	4	6
Time	min	10	15	20
Reinforcement	Wt(%)	0	3	6

III. RESULTS AND DISCUSSION

The contribution of each input parameters (Load, Sliding velocity, time and reinforcement wt %) are analyzed by MINITAB-18 Software. Tests are carried out as per L9 orthogonal array Taguchi's method. Wear rate values and their corresponding S/N ratio results are displayed in the table 3. The higher value of SN ratio will give minimum wear loss.

Table 3. Experiments result with SN ratio value

Exp.no	Load(N)	Sliding velocity (m/s)	Reinforcement wt%	Time (min)	Wear Rate (mm^3/Nm)	SN ratio
1	10	2	0	10	0.00475	46.4661
2	10	4	3	15	0.00366	48.7304
3	10	6	6	20	0.00204	53.8074
4	20	2	3	20	0.00289	50.7820
5	20	4	6	10	0.00314	50.0614
6	20	6	0	15	0.00462	46.7072
7	30	2	6	15	0.00246	52.1813
8	30	4	0	20	0.0037	48.6360
9	30	6	3	10	0.00389	48.2010

In the figures 2(a),(b), The wear resistance rises with the rise in reinforcement wt%. But wear resistance reduces with reduction in load, sliding velocity and time. Table 4, 5 shows the response table for Signal to Noise ratio and means corresponding to wear rate where the ranking indicates directly the effect of input parameter levels based on delta value. Delta is the change flanked by the peak values of SN ratio (higher value –lower value). Among these ranks, reinforcement wt % is the first rank parameter which has its influence followed by time, sliding velocity and load in minimize the wear rate of composites.
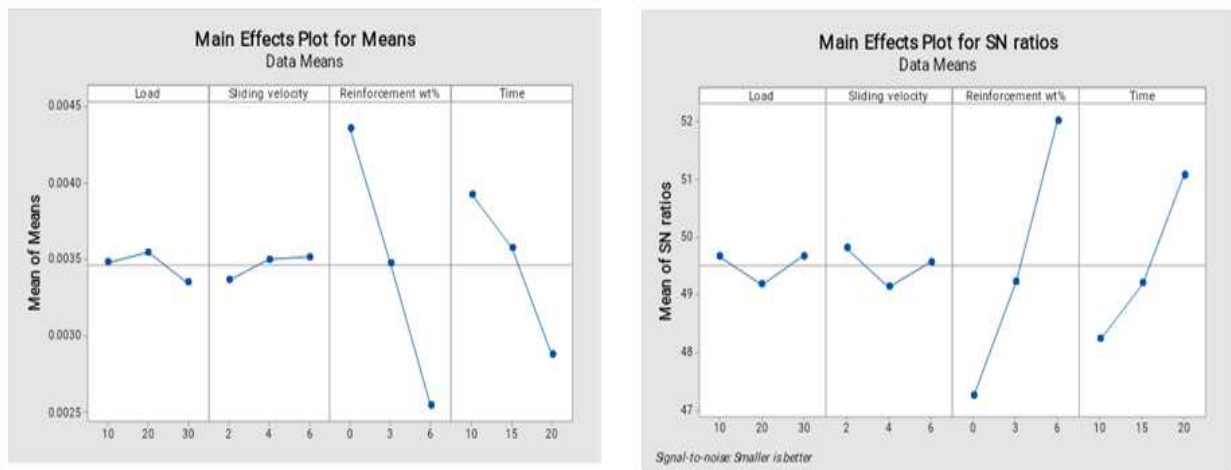
Fig 2. (a) Main effects plot of SN ratios for wear rate   (b) Main effects plot of means for wear rate

Table 4. Response Table for Signal to Noise Ratios (Smaller is better)

Level	Load	Sliding velocity	Reinforcement wt%	Time
1	49.67	49.81	47.27	48.24
2	49.18	49.14	49.24	49.21
3	49.67	49.57	52.02	51.08
Delta	0.49	0.67	4.75	2.83
Rank	4	3	1	2

Table 5. Response Table for Means (Smaller is better)

Level	Load	Sliding velocity	Reinforcement wt%	Time
1	0.005483	0.003367	0.004357	0.003927
2	0.003550	0.003500	0.003480	0.003580
3	0.003350	0.003517	0.002547	0.002877
Delta	0.000200	0.000150	0.001810	0.001050
Rank	3	4	1	2

Regression analysis is also carried out between four input parameters (independent variables) and one response variable (dependent variable) in MINITAB-18 Software. The obtained regression equation is given below

Wear Rate = 0.005924 - 0.000007 Load + 0.000037 Sliding velocity - 0.000302 Reinforcement wt% - 0.000105 Time

ANOVA is carried for estimating the percent contribution of each inputs on response. The last column in table 6 shows that contribution percentage which mentions the influence of input parameters on wear loss. It is perceived that, reinforcement wt% of TiB_2 (72.8%) is the leading contributing parameter that influences wear loss, subsequently time (25.5%), load (0.92%) and sliding velocity (0.60%). Maximum wear resistance gets attained at the load 10N, sliding velocity 6 m/s, reinforcement wt 6% and time 20 min. The wear resistance has a tendency to decrease, if the composite gets exposed towards large loads and sliding velocities.
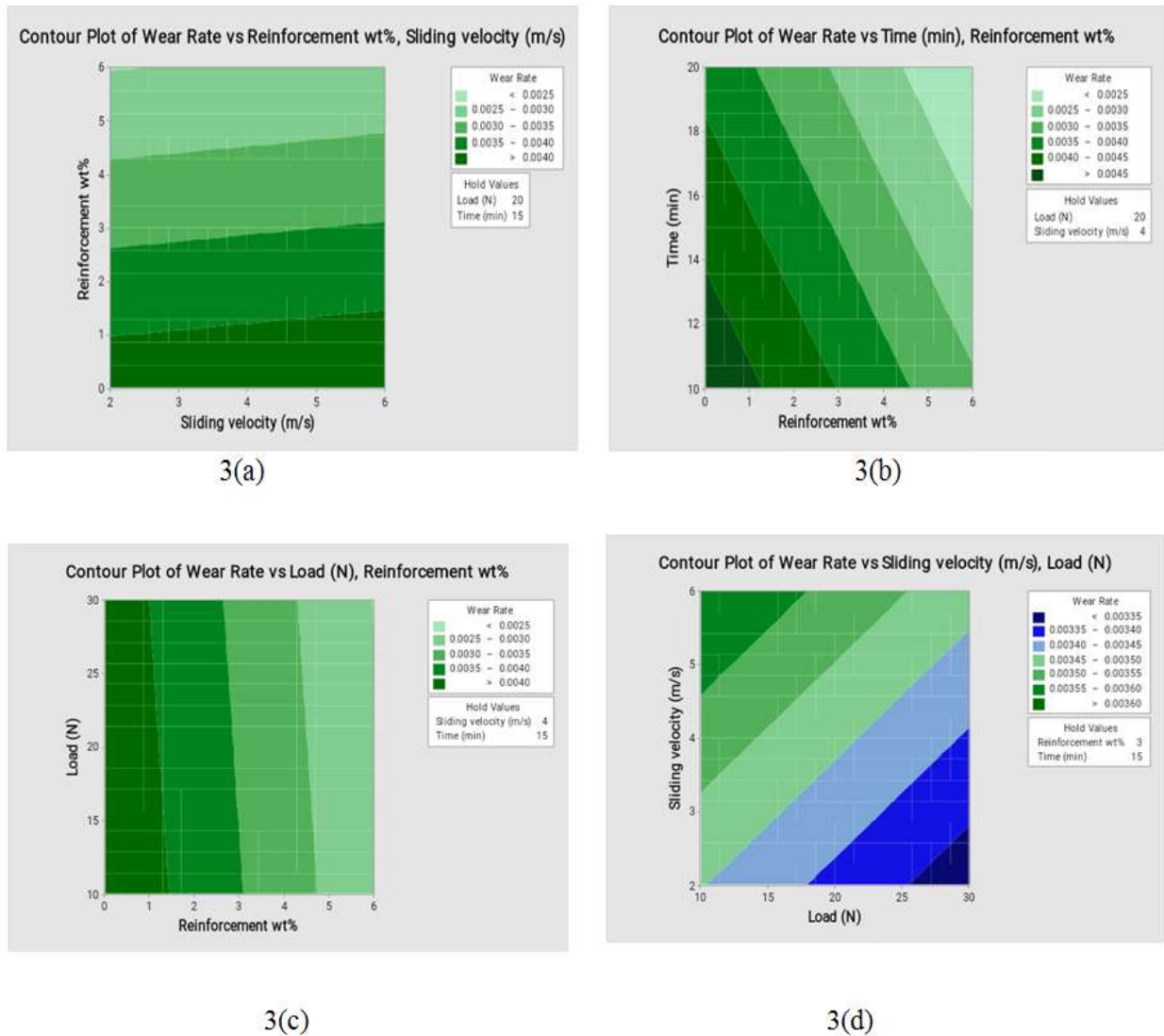
Table 6. ANOVA result for wear rate of composites

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution (%)
Load (kg)	2	0.000000	0.000000	0.03	0.973	0.92%
Sliding velocity (m/s)	2	0.000000	0.000000	0.02	0.982	0.60%
Reinforcement (wt%)	2	0.000005	0.000002	8.10	0.020	72.98%
Time (min)	2	0.000002	0.000001	1.03	0.414	25.50%

The following figures 3(a), 3(b), 3(c), 3(d), demonstrates the contour plot of variation for the various input parameters (Reinforcement, load, time an sliding velocity) on wear rate.

3(a)

3(b)

3(c)

3(d)

Fig 3(a) sliding velocity vs reinforcement, 3(b) Reinforcement vs time, 3(c) Reinforcement vs load, 3(d) Load vs sliding velocity

From the Fig 3.1(a), it is shown that plot has been drawn between load and reinforcement variable. The wear rate 0.0025 happens when the load value is 10 N and Reinforcement is 6 wt %. Similarly, the plots are drawn among the input variables in figures 3(b), 3(c), 3(d) on wear rate.

IV. CONCLUSION

Aluminum matrix composite with different weight percentage gets formed by means of stir casting method. Wear property for the composite has been evaluated with the aid of wear test via pin on disc apparatus. The experimentation has been conducted by Taguchi's method with L9 orthogonal array. Wear resistance in AMC gets increased over increase in TiB_2 percentage due to good bondage between Al5456 and reinforcement particle TiB_2, but decreased with increase in load. The influence of input parameters is estimated over wear rate, the reinforcement wt% of TiB_2 is the leading contribution parameter is about 72.98%, followed by time is about 25.5%,load is about 0.92% and sliding velocity is about 0.60% as per ANOVA results.

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