COMPARATIVE STUDY ON TRIBOLOGICAL BEHAVIOR OF COMMERCIAL AUTOMOBILE CLUTCH MATERIAL WITH A360/TIB2 COMPOSITE

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Abstract: The comparative tribological behavior of A360/TiB_2 alloy with conventional semi-metallic clutch pad material was investigated using pin on disc apparatus. A360/TiB_2 specimens were prepared by the method of stir casting. Minitab 17 software was used for statistical analysis. L_9 orthogonal arrays were formed using Taguchi design of experiment. The analysis of variance, regression analysis and signal to noise ratio were used to study the optimal study parameters. The analysis showed that sliding distance was the most significant factor while sliding speed and load were less significant factors. Similarly for coefficient of friction, applied load was most significant whereas sliding speed and sliding distance were less significant. The analysis also showed that with the increase in weight percentage of TiB_2 wear rate was decreased.
Index Terms: Analysis of variance, Minitab17, pin on disc, regression analysis, semi-metallic, signal to noise ratio, stir casting, Taguchi, tribological behavior.

I. INTRODUCTION

Al alloys and Al-matrix composites (AMC) have been widely used in many sectors like automobile, aerospace and structural applications. AMC have many advantages like higher wear resistance, good coefficient of friction, and thermal stability at higher temperature, light in weight and high specific strength. An improvement in wear properties is observed when Al alloys are reinforced with TiB2, SiC, TiC particles. AMC provides better mechanical strength, self-lubricating properties and high wear resistance. These composites are preferably used in automobile and aircraft components like clutch, brake, piston, cylinder liner, gear and engine block housing. Clutch is an integral part of transmission system for the automobile. According to the operation, there is frequent engagement and disengagement between friction plate and flywheel. It is desirable that the coefficient of friction for the flywheel and friction plate should be in range from 0.35 to 0.45. The wear of friction plate should be less for increasing the life of friction pad.

II. LITERATURE REVIEW

Mechanical and wear properties of TiB2 reinforced Al composites have been extensively studied and significant improvement has been observed with the increase in weight percentage of TiB2 compared with base alloy. Koksal et al. [1] had studied experimental optimization of dry sliding wear behavior of AlB2/Al composite by Taguchi method. They performed no of experiments on pin on disc apparatus. The responses were studied by Minitab software. It has been seen that by the use of Taguchi method no of experiments to be performed had been decreased. P Ravindran et al. [2] had studied tribological behavior of Al hybrid composites. They had shown the significance of ANOVA. It is used to find the % of contribution of particular factor in response. Kiran et al. [3] had studied dry sliding wear behavior of hybrid composite by Taguchi method. They had shown the significance of signal to noise ratio. It is used to determine the optimum testing condition for given response. Yigezu et al. [4] had investigated abrasive wear characteristics of Al hybrid composite. They had given the importance of regression model. Regression equations are used to find the responses for any operating conditions. It also helps to check experimental and statistical analysis results. Kumar et al. [5] had studied abrasive wear behavior of Al-4Cu alloy with 5 and 10 wt.% and it was observed that there was significant improvement of wear property with increase in TiB2. Mandal et al. [6] also investigated the abrasive wear behavior of Al-4Cu composite reinforced with TiB2. They observed reduction in wear rate of with increase wt.% of TiB2. Mandal et al. [7] had studied dry sliding wear behavior of A356 reinforced with TiB2. It was observed that wear rate was 150% lower of 10TiB2 than base alloy. Mandal et al. [8] had investigated sliding wear behavior of Al-12Si alloy 10 wt.% TiB2 and showed a 60% decrease in wear rate as compared with base alloy. B. S. Murtey et al. [9] had studied the wear property of Al-7Si alloy reinforced with 5 and 10% TiB2 composite and found 36 and 66% improvement in wear properties compared with base alloy. The wear rate reduced with the increase in wt. % TiB2. Kumar et al. [10] had studied the erosion behavior of A356-10 wt.% TiB2 by design of experiment and found out the importance of main and interaction factors on erosion rate by ANOVA. It was observed that the effect of abrasion and impact wear is less for composite. Kumar et al. [11] also studied high temperature wear behavior of Al-7Si-TiB2 composites. They had conducted experiments with load 80, 60 and 40N at temperatures 100, 150 and 200 °C with 5 and 10 wt.% TiB2. It was reported that wear resistance increases with the addition of TiB2 even at elevated temperatures. Shivprasad et al. [12] had studied the abrasive and erosive wear behavior of Al 6063 with 5 and 10 wt.% TiB2 composites. They had also shown an improvement in wear property with increase in TiB2. Natarajan et al. [13] had studied sliding wear behavior of Al6063 reinforced with TiB2 at elevated temperature. It was observed 50% improvement in wear resistance with 10 wt.% TiB2 at 30 N; 40% increase in wear resistance at 100 degrees and 50% increase in wear resistance at 200 and 300 degrees when compared with base alloys. S. Kumar et al. [14] had studied the influence of room temperature and cryogenic temperature wear behavior of Al-4Cu-5TiB2. The results had shown an improvement in wear resistance of composites compared with base alloy. Ramesh et al. [15] had investigated the mechanical and wear behavior of Al 6063-13.12 wt. % TiB2 composites. Al composite had shown an improvement in wear rate of 70 and 100% at 50 and 10 N loads at sliding speed of 0.2 m/s for 30 min. For a load of 50 N, 32% reduction in wear rate was observed. K. Niranjan et al. [16] had studied dry sliding wear behavior of A356-6 wt. % of TiB2 composite. They explained the improvement in wear resistance due to strong bonding of particle and matrix and therefore shear deformation resistance was also increased. H.B.M Rajan et al. [17] had studied the wear behavior of AA7075 Al alloy reinforced with TiB2 composite and observed a reduction in plastic deformation due to TiB2 reinforcement. J. Xue et al. [18] had studied the dry sliding wear behavior of Al 2014 alloy with 5 vol. % of TiB2 composites. The reduction in wear rate was observed with increase in vol. % of TiB2. The principle objective of this paper is to fabricate aluminium matrix composite reinforced with TiB2 by stir casting route and determine their basic tribological properties. The effect of load, sliding speed and sliding distance on coefficient of friction and wear behavior of friction plate material of clutch and AMC is studied. Taguchi method and Minitab software are used for further analysis.

III. SPECIMEN PREPARATION

A. Material for pin

The pin samples were prepared from semi-metallic clutch pad material of car and A360 alloy reinforced with 5 and 10 wt. % of TiB2. In case of semi-metallic material as it was not possible to produce the pins in circular cross-section, they were produced in square cross of size 8 mm and 10 mm in length. Pins of A360 composite alloy were prepared by stir casting method. A360 was used as the matrix material. A360 was charged into the crucible and the temperature of electric furnace was raised up to 600°C. Preheated TiB2 particles were added gradually and stirred continuously for 3 to 5 min. The stirring operation was done in order to distribute TiB2 particles homogeneously in A360 matrix and to avoid blow-hole defect. Finally the molt composite was poured into mould to get pins of size dia. 10 mm × 30 mm length. The chemical composition of matrix alloy is given in Table 1.

Table 1 Chemical composition of the matrix alloy

Element	Si	Fe	Cu	Mg	Ni	Zn	Mn	Al
Content %	10	1.3	0.6	0.5	0.5	0.5	0.35	Balance

B. Material for disc

The disc used for experimentation was from made of same material as that of flywheel. The disc was made from grey cast iron (FG-260). The disc was manufactured at Bhagwati Casters Pvt. Ltd. Nasik. The chemical composition of grey cast iron is given in table 2.

Table 2 Chemical composition of grey cast iron

Element	C	Mn	Si	S	P	Fe
Content %	3.44	0.53	1.97	0.078	0.097	Balance

IV. DESIGN OF EXPERIMENT

Taguchi is an efficient and systematic approach to decide optimum design parameters. It reduces the no of experiments to be performed as compared with conventional factorial method. In conventional method, one factor is changed while other factors are kept constant. The major drawback of conventional method is that it fails to consider all possible combinations of control parameters. It is not possible to study all factors and determine the effect in single experiment. These all drawbacks are overcome by the Taguchi method. The Taguchi method is used for process optimization and identification of optimal combination of control factors for given responses.

Table 3 Control factors and their level

Parameter	Unit	Notation	Level		
			Level 1	Level 2	Level 3
Load	N	L	10	20	30
Sliding speed	m/s	V	1	2	3
Sliding distance	m	D	250	500	750

The experiments were conducted to find the effect of testing parameters on coefficient of friction and wear loss for semi-metallic material and Al composite. By considering 3 control factors and 3 level of design, L_9 orthogonal arrays were formed for 3 different compositions. The control factors are load, sliding speed and sliding distance. The control factors and their level and L_9 array are shown in table 3 and 4.

Table 4 L_9 Orthogonal array

Experiment No	L	V	D
1	10	1	250
2	10	2	500
3	10	3	750
4	20	1	500
5	20	2	750
6	20	3	250
7	30	1	750
8	30	2	250
9	30	3	500

V. EXPERIMENTAL PROCEDURE FOR WEAR TEST

Dry sliding wear tests were conducted on pin on disc apparatus (TR-20LE). The counter disc was made of cast iron (FG-260). Before performing tests disc and testing specimen were polished by 320 emery papers. Pin was inserted in jaw holder. Jaw was tight by the ensuring proper sitting of pin. The wear track diameter was set as 100mm. the controller was switched on and controller display was allowed to normalize. The experiment time was set. The rotational speed of disc was also set.

Then controller was switched off. The appropriate weight was taken in the pan and applied on the pin. By adjusting the screw the wear was set as zero. Then again the experiment was started. The readings of frictional force and wear loss were taken from controller display. The coefficient of friction was determined from applied load and frictional force. The variations of responses with respect to testing parameters were found out by Winducom 2010 software.

Table 5 Specification of Pin on disc apparatus

Sr. No.	Test parameter	Details
1	Speed	Min 100 rpm, max 2000 rpm
2	Normal load	200N max
3	Frictional force	200N max
4	Wear	±2 mm
5	Wear track diameter	Min 50mm, max 100mm
6	Timer format	Hr/min/s
7	Sliding speed	Min 0.5 m/s, max 10 m/s
8	Counter disc	Diameter 165mm × 8mm thick
9	Pin size	Pin Diameter 1,3,6,8 and10mm
10	Software	Windcom 2010

VI. RESULTS AND DISCUSSION

A. Experimental Results

The responses for coefficient of friction and wear loss are given in table 6 and table 7 respectively.

Table 6- Design parameter responses for coefficient of friction

Experiment No.	L	V	D	Semi-metallic	A360 +5% TiB_2	A360 +10% TiB_2
1	10	1	250	0.23	0.23	0.25
2	10	2	500	0.26	0.29	0.32
3	10	3	750	0.28	0.32	0.34
4	20	1	500	0.29	0.28	0.31
5	20	2	750	0.34	0.36	0.37
6	20	3	250	0.36	0.37	0.41
7	30	1	750	0.31	0.37	0.39
8	30	2	250	0.33	0.36	0.42
9	30	3	500	0.39	0.42	0.46

Table 7- Design parameter responses for wear loss (mm^3)

Experiment No.	L	V	D	Semi-metallic	A360 +5% TiB_2	A360 +10% TiB_2
1	10	1	250	0.0036	0.0025	0.0019
2	10	2	500	0.0045	0.0032	0.0028
3	10	3	750	0.0058	0.0038	0.0031
4	20	1	500	0.0058	0.0045	0.0037
5	20	2	750	0.0078	0.0052	0.0048
6	20	3	250	0.0042	0.0032	0.0028
7	30	1	750	0.0092	0.0068	0.0058
8	30	2	250	0.0054	0.0036	0.0031
9	30	3	500	0.0066	0.0044	0.0039

B. ANOVA and the impact of testing factors

To get a concrete effect of testing parameters L (load), V (sliding speed) and D (sliding distance); it advisable to perform an analysis of variance (ANOVA) table to calculate the rank of contribution of testing parameters. This analysis was performed under a level of confidence of significance of 5%. ANOVA of coefficient of friction and wear loss were performed for semi-metallic, A360/5%TiB_2 and A360/10%TiB_2. Table 8 and 9 show results of ANOVA for coefficient of friction and wear loss of A360/10%TiB_2.

Table 8 indicates that load (64.29%) was the most significant factor for coefficient of friction. Sliding speed (34.13%) and sliding distance (0.20%) were less significant factors. Table 9 indicates that sliding distance (52.88%) was the most significant factor for wear loss. Load (39.82%) and sliding velocity (3.89%) were less significant.

C. Effect of testing parameter on coefficient of friction

Fig 1 shows a graph of main effect of different factors on coefficient of friction. Load was the most influencing factor for coefficient of friction as L (load) factor line had highest slope, while other factors had less significant effect.

Table 8 ANOVA for coefficient of friction of A360/10%TiB_2

Source	Degrees of freedom	Sum of squares	Percentage of contribution	Adjusted Sum of squares	Adjusted Mean of squares	F-value	P-value
L	2	0.021600	64.29%	0.021600	0.010800	46.29	0.021
V	2	0.011467	34.13%	0.011467	0.005733	24.37	0.039
D	2	0.000067	0.20%	0.000067	0.000033	0.14	0.875
Error	2	0.000467	1.39%	0.000467	0.000233		
Total	8	0.033600	100%				

Table 9 ANOVA for wear of A360/10%TiB_2

Source	Degrees of freedom	Sum of squares	Percentage of contribution	Adjusted Sum of squares	Adjusted Mean of squares	F-value	P-value
L	2	0.000004	39.82%	0.000004	0.000002	11.69	0.079
V	2	0.000000	3.89%	0.000000	0.000000	1.14	0.467
D	2	0.000006	52.88%	0.000006	0.000003	15.52	0.061
Error	2	0.000000	3.41%	0.000000	0.000000		
Total	8	0.000011	100%				

Fig 1 Main effects plot for means for coefficient of friction of A360/10%TiB_2

Fig 2 Main effect plot for means for wear of A360/10%TiB_2

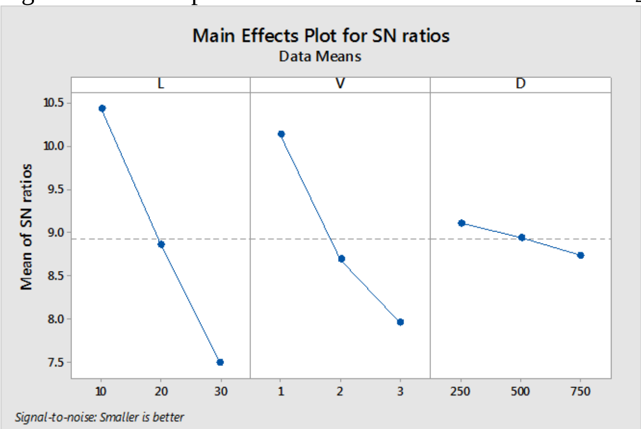

Fig 3 Main effects plot for SN ratios for coefficient of friction of A360/10%TiB_2

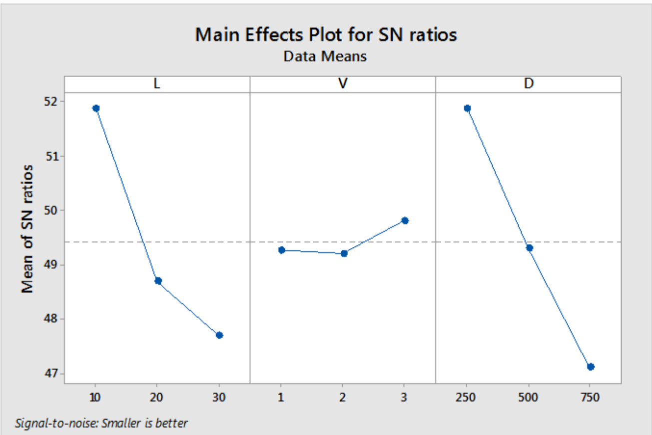

Fig 4 Main effect plot for SN ratios for wear of A360/10%TiB_2

D. Effect of testing factors on wear loss

Fig 2 shows a graph of various parameters on wear loss. In the main effect graph, if the line for a particular factor is near horizontal line, then the factor has not any significant contribution. On the other side, if a factor for which the line has the highest slope, then that factor has most significant effect. It was clear from the main effect plot that sliding distance (D) was the most contributing factor, while sliding speed and load were less significant. Increase in sliding distance caused more asperity to asperity time of contact. This turned into increase in real area of contact and formation of wear debris. Finally it resulted into wear of material. It was seen that wear loss for composite material was less than semi-metallic material. It was also observed that with the increase in wt. % of TiB2, wear loss decreased.

E. Signal to Noise ratio

The experimental readings are converted into an S/N ratio. S/N ratio is the essential criterion for analyzing the experimental readings in Taguchi method. Depending upon type of characteristic, different types of S/N ratios are used. There are three types of S/N ratio- smaller the better, larger the better and nominal the best. S/N ratio for minimum wear loss and coefficient of friction goes under smaller the better type. To get optimum testing combination S/N ratio should be maximum. Fig 3 and 4 show main effect plot of S/N ratios for coefficient of friction and wear loss. The analogy of interpretation for means and S/N ratio is same. The S/N response table 10 and 11 are prepared for coefficient of friction and wear loss. Delta statistics gives ranking in the response table. Ranks are given according to delta values. The optimum testing conditions for coefficient of friction were 10N load, 1 m/s sliding speed and 250m sliding distance. The optimum testing conditions for wear loss were 10N load, 3m/s sliding speed and 250m sliding distance. Response tables for signal to noise ratio for coefficient of friction and wear loss of A360/10%TiB2 are given below.

Table 10 Response table for signal to noise ratios for coefficient of friction of A360/10%TiB2

Level	L	V	D
1	10.436	10.131	9.107
2	8.851	8.689	8.938
3	7.486	7.953	8.728
Delta	2.950	2.178	0.378
Rank	1	2	3

Table 11 Response table for signal to noise ratios for wear loss of A360/10%TiB_2

Level	L	V	D
1	51.88	49.26	51.88
2	48.69	49.20	49.89
3	47.69	49.80	47.09
Delta	4.19	0.6	4.79
Rank	2	3	1

F. Regression analysis

The regression analysis was used to establish the correlation between design factors and responses. Linear regression model was used. The regression equations are given below.

For coefficient of friction of semi-metallic material
COF= 0.1533 + 0.004333L + 0.03333V + 0.000007D

For coefficient of friction of A360/5%TiB2
COF= 0.1233 + 0.005167L + 0.03833V + 0.00006D

For coefficient of friction of A360/10%TiB2

COF= 0.15 + 0.006L + 0.04333V + 0.000013D

For wear loss of semi-metallic material
WEAR= 0.000911 + 0.000122L – 0.000333V + 0.000006D

For wear loss of A360/5%TiB2
WEAR= 0.001 + 0.000088L – 0.0004V + 0.000004D

For wear loss of A360/10%TiB2
WEAR= 0.000444 + 0.000083L – 0.000267V + 0.000004D

G. Conformation test

To validate the results obtained in experiments, conformation test was conducted. In conformation test, the experimental and analytical calculated values from regression equation were compared and error was calculated. Testing conditions used for conformation test is given in table 12.

Table 12 Parameters for conformation test

Test Material	L	V	D
Semi-metallic	10	2	250
A360/5%TiB_2	20	3	750
A360/10%TiB_2	30	1	500

Conformation test results for wear loss and coefficient of friction are given in table 13 and 14 respectively.

Table 13 Conformation test for wear loss

Experiment No.	Experimental value	Regression model value	% Error
1	0.0030	0.002965	1.16
2	0.0050	0.00456	8.80
3	0.0045	0.004667	3.71

Table 14 Conformation test for coefficient of friction

Experiment No.	Experimental value	Regression model value	% Error
1	0.25	0.26504	6.01
2	0.4	0.38663	3.34
3	0.36	0.3798	5.50

Based on the conformation test, it was observed that the error related with experimental values and regression values was minimal. Thus the regression models obtained can be used effectively to predict wear loss and coefficient of friction of composite with better accuracy.

VII. CONCLUSIONS

Design of experiment was done by Taguchi's method. For wear loss, sliding distance was most significant factor. For coefficient of friction, applied load was most significant factor. With the increase in wt. % of TiB2, wear loss was decreased. Hence composite material is better than semi-metallic material.

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