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AN EXPERIMENTAL STUDY ON WEAR BEHAVIOUR OF NEW ENGINEERING MATERIAL USING STATISTICAL APPROACH

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ABSTRACT

The present study was conducted to understand effect of ceramic reinforcement, normal load and heat treatment on abrasive wear rate of aluminum metal matrix composite. A statistical approach: design of experiment was used for the present investigation. A mathematical model was developed relating reinforcement and applied load on the abrasive wear rate of the composites. Experiments were conducted on the both as-cast and heat treated condition. The developed model was checked for adequacy by regression analysis and analysis of variance. The result shows that Ceramic reinforcement will improve the wear resistance of the matrix material. The Predicted model yields an error of 0.028 and 0.0241 for the as-cast and heat treated condition respectively, which is indicated as standard error of estimate.

Keywords: Metal matrix composite; Titanium dioxide; ANOVA; regression analysis

1. INTRODUCTION

Metal matrix composites find wide application in engineering industries because of their excellent mechanical properties and wear resistance [1]. Particulate reinforced Al-based composites have attracted a lot of interest due to their enhanced wear resistance as compared with the monolithic alloys [2]. The modern trend for potential applications is to optimize the mechanical and tribological properties of composites. A lot of research on the dry sliding wear behavior of Aluminum composites reinforced with ceramic particles like SiC, Al_2O_3 TiC, TiB_2, Garnet, Graphite etc., are reported and few work are discussed. T. Miyajima et al. [3] carried out dry sliding wear tests using pin-on-disc wear tester where the pins were of

0.45% carbon steel and disc were made of Aluminum alloy composites (AMCs) reinforced with SiC-whisker, Al2O3-fibers and SiC particles and reported that particle reinforcement are the most effective in improving the wear resistance of metal matrix composites. Shipway et al. [4] produced TiC reinforced AMCs using novel casting technique and investigated the sliding wear behavior of the extruded composites. The result reveals that, particle addition of TiC has reduced the wear rates of the composites.

Ranganath et al. [5] studied the dry sliding wear of garnet reinforced Zinc-AMCs and reported that wear resistance of the MMCs increases as the content of the Garnet increases. Some of the researchers used soft reinforcement phases like Graphite, Molybdenum disulphide and calcium fluoride which will results in lowering of hardness of the composites [6] Addition of soft reinforcement in to metal matrix composites improves not only the anti-friction properties but also its wear resistance [7]. Das et al. [8] conducted wear test and reported that, Al-Si alloys with 3 % dispersed graphite particles shows a reduction in wear rate and improved in seizure properties. The improvement in the tribological properties in the presence of graphite is generally attributed to the formation of a lubricant film on the contact surface. Few research [9-11] studied abrasive wear behavior of aluminum metal matrix composite. Addition of ceramic particulates in the matrix material will favors for reducing the wear rate.

Meager information is available regarding the study and mathematical modeling of the abrasive wear behavior of the aluminum composites. In this light, current investigation was carried out to determine the abrasive wear of the Titanium dioxide particulate reinforced aluminum metal matrix composite. Design of experimental technique has been used for the conduction and analysis of test results. Further, a mathematical model was developed relating wear rate and the test parameters using multiple regressions and the model was checked for adequacy.

2. Experimental procedure

2.1 Materials

Aluminum2618 alloy contains Copper and Magnesium as major constituent is used as matrix material and its composition, is shown in Table 1. Titanium dioxide of laboratory grade was used as a reinforcing material. 0 to 8 Wt % of Titanium dioxide reinforced Al alloy composite was produced using stir-casting technique, which was used by researcher Mahindra et.al [12].

Table 1: Composition of Al 2618 alloy

Cu	Mg	Ni	Fe	Si	Ti	Mn	Al
2.18	1.43	1.1	0.93	0.16	0.04	0.028	Bal

2.2 Heat treatment of test specimens

Matrix alloy Al 2618 and the developed composite specimens are tested for both the as-cast and heat treated condition. T6 heat treatment was carried out. The heat treatment was carried out in two phase: 1. Solutionzing at a temperature of 529 ^{0}C $\pm 1^0$C for 2 hours duration, followed by (Ice + Water) quenching, 2: Artificial aged at 199^{0}C for 8 hours and then allowed to air cool. Muffle furnace was used for the heat treatment process which as a resolution of $\pm$ 1^{0}C.

2.3. Selection of Orthogonal array

Abrasive wear experiments were carried out as per the standard orthogonal array (OA). The parameters chosen for the experiment were: Titanium dioxide reinforcement and applied load. The non-linear behavior of the process parameters, if exists, can only be revealed if more than two levels of the parameters are investigated. Therefore, each parameter was analyzed at five levels. The process parameters along with their values at five levels are given in Table 2. It was also decided to study the two factor interaction effects on wear behavior of the sample. The selected interaction is R*L. The experiment consists of 25 tests according to L_{25} orthogonal array is as shown in Table3. The first column was assigned to TiO_2 reinforcement, second column was assigned to normal load. The remaining columns were assigned to their interactions [13-18]. The response to be studied is the abrasive wear rate in grams with the objective of ‘Smaller is the Better’ type of quality characteristic.

Table 2: Process parameters with their different levels

Factors	**Units**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Factor A	**Wt % of TiO_2**	0	2	4	6	8
	Code (R)	**R1**	**R2**	**R3**	**R4**	**R5**
Factor B	**Load in N**	2	4	6	8	10
	Code (L)	**L1**	**L2**	**L3**	**L4**	**L5**

Table 3: Orthogonal array for abrasive wear test

Test	Factor A	Factor B	R	L	Experimental wear in grams		Predicted wear in grams	
					As-Cast Specimen	Heat treated	As-Cast Specimen	Heat treated
1	0	0	**R1**	**L1**	1.019	0.992	1.013	1.002
2	0	1	**R1**	**L2**	1.062	1.024	1.060	1.031
3	0	2	**R1**	**L3**	1.151	1.126	1.141	1.096
4	0	3	**R1**	**L4**	1.234	1.164	1.256	1.198
5	0	4	**R1**	**L5**	1.448	1.36	1.405	1.335
6	1	0	**R2**	**L1**	0.96	0.906	0.956	0.918
7	1	1	**R2**	**L2**	1.033	0.987	0.998	0.947
8	1	2	**R2**	**L3**	1.062	1.03	1.074	1.012
9	1	3	**R2**	**L4**	1.155	1.1	1.184	1.112
10	1	4	**R2**	**L5**	1.332	1.272	1.328	1.249
11	2	0	**R3**	**L1**	0.89	0.836	0.895	0.835
12	2	1	**R3**	**L2**	0.94	0.89	0.932	0.863
13	2	2	**R3**	**L3**	0.983	0.943	1.003	0.926
14	2	3	**R3**	**L4**	1.098	1.046	1.108	1.026
15	2	4	**R3**	**L5**	1.3	1.196	1.247	1.162
16	3	0	**R4**	**L1**	0.811	0.744	0.830	0.751
17	3	1	**R4**	**L2**	0.897	0.8	0.862	0.778
18	3	2	**R4**	**L3**	0.93	0.825	0.928	0.841
19	3	3	**R4**	**L4**	1.035	0.911	1.028	0.940
20	3	4	**R4**	**L5**	1.2	1.062	1.162	1.075
21	4	0	**R5**	**L1**	0.746	0.685	0.761	0.666
22	4	1	**R5**	**L2**	0.782	0.701	0.788	0.693
23	4	2	**R5**	**L3**	0.904	0.76	0.849	0.755
24	4	3	**R5**	**L4**	0.969	0.89	0.944	0.853
25	4	4	**R5**	**L5**	1.035	1.034	1.073	0.988

2.4 Experimental set –up

2.4.1. Abrasive Wear

The three-body abrasion test was performed at room temperature on composite and matrix material according to OA shown in table 3. The tests were carried out using standard rubber wheel abrasion test apparatus as per ASTM G 65 -81 standards. Figure 1 shows the photograph of the test rig. Specimens of size 75 x 24 x 8 mm prepared from the casting are used to evaluate abrasive wear characteristic. Load applied on the specimen is varied, while maintaining a constant wheel speed of 200 rpm. Silica sand of size 50 – 80µm was used as abrasive media. Test duration of 30 minutes was adopted for all the specimens. The wear loss was measured in terms of mass loss using a digital weighing balance of accuracy 0.1 mg. The details of the sand abrasion tester used in this study are tabulated in table 4. The abrasive test is carried out according to L25 orthogonal array and the test results are tabulated in table 3 for both the heat treated and as-cast condition.

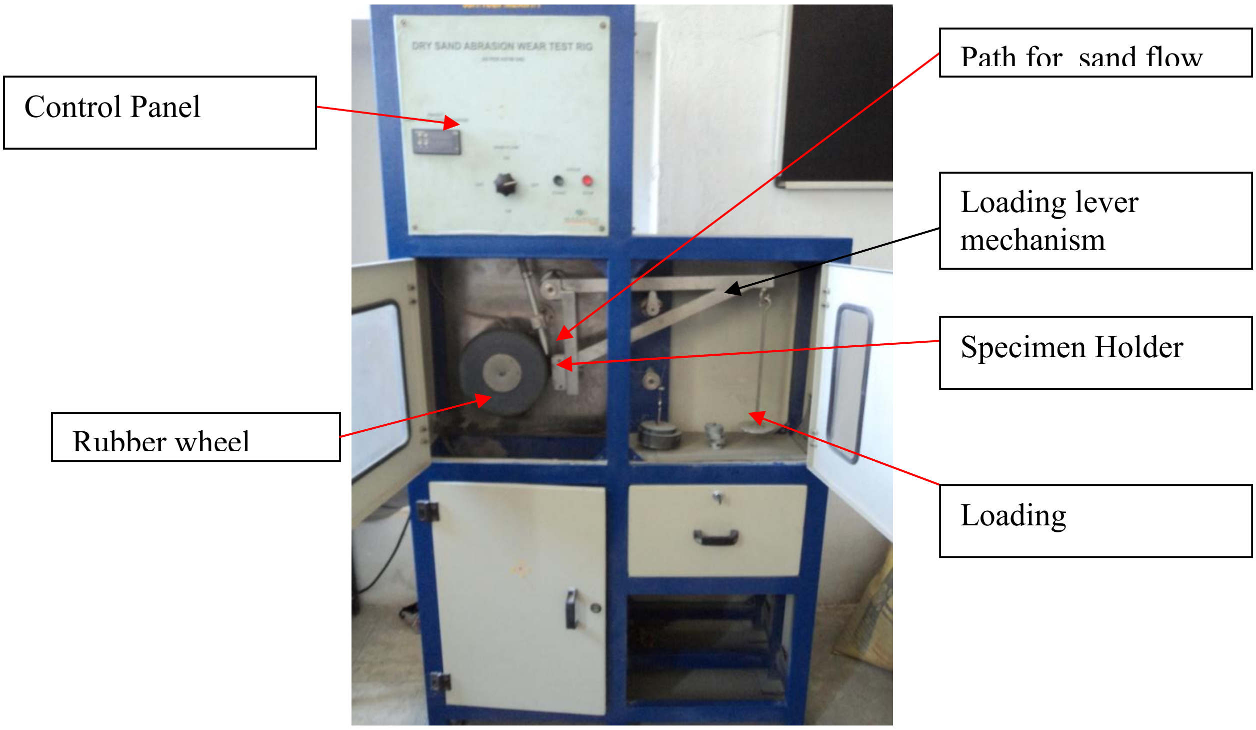


Figure 1: Photograph of abrasive wear test rig.

Table 4: Details of Sand abrasion tester

Sl.No.	Description	Capacity
1	Abrasive	AFS 50-70 TEST SAND
2	Wheel speed	200 rpm, helical geared motor

3	Test load	1-45 N
4	Wheel Diameter	228 mm
5	Power input	430 V AC
6	Erodent	AFS 3080
7	Mass flow rate	0.25 kg/min or 2.45 N /min
8	Rubber hardness	60-62 Shore A
9	Duration	30 min(6000rev)
10	Pressure	5.88 N/mm^2
11	Load	12.75 N

3. Prediction of abrasive wear model.

The response function representing the abrasive wear of the composite material is expressed as, **$Y = f(R, L)$** -----------------(1)

Where Y is the response for the abrasive wear rate

The second order polynomial regression equation used to represent the abrasive wear for K factors is given

$$Y=b_0 + b_1R + b_2L + b_{11}R^2 + b_{22}L^2 + b_{12}RL \text{ ------------ } (2)$$

Where Y is the response to the abrasive wear

The second order polynomial regression equation used to represent the abrasive wear for K factors is given in equation 2. Where b_o is the constant coefficient of the regression equation, the coefficients b_1, b_2……..b_k are linear constant, b_{11},b_{22}….b_{kk} are the quadratic constants and b_{12},$b_{13…}$…b $_{k-1}$, k are the interaction constant terms. The values of coefficients of the polynomial of equation (2) are calculated by the regression method. Systat -software package has been used to calculate the values of the coefficients for both the as-cast and heat treated composites. The regression summary for the as-cast model is shown in the table 5. The mathematical model as determined by regression analysis is shown below.

Table 5: Regression summary for as cast specimens

Effect	**Coefficient**	**Standard error**	**Standard coefficient**	**Tolerance**	**T**	**P – Value**
Constant	1.048	0.046	0		22.988	0
R	-0.046	0.022	-0.387	0.032	-2.079	0.051
L	0.001	0.022	0.01	0.032	0.053	0.958
R * R	-0.002	0.003	-0.1	0.037	-0.58	0.569

L * L	0.017	0.003	0.888	0.037	5.154	0
R * L	-0.005	0.003	-0.179	0.1	-1.701	0.105

$$\textbf{Abrasive Wear}_{\text{as cast}} = 1.048 - 0.046R + 0.001L - 0.002R^2 + 0.017L^2 - 0.005RL \quad \text{----(3)}$$

$$\textbf{Abrasive Wear}_{\text{H.T}} = 1.0905 - 0.0819R - 0.024L + 0.00021R^2 + 0.018L^2 - 0.0007RL \text{----(4)}$$

4. Result discussion

The equation 3 and 4 are the developed abrasive wear model for the both as-cast and heat treated specimen. The theoretical wear rate was calculated using this model and the predicted wear values are summarized in the table 3. Table 5 shows the regression coefficients for the second order model for the as cast specimens. The as-cast coefficient of the main factors: reinforcement has negative value and normal load have positive value, which shows that, reinforcement has significance effect on the wear rate of the matrix material. Where as, the interactions R * L have negative effects on the abrasive wear which is favoring to reduce the wear rate. The reinforcement regression coefficient for heat treated specimen is less than as-cast condition, which in turn shows that heat treatment will favour for reducing the abrasive wear rate. This factor is also evident from the graph 2, which shows minimum wear was recorded for the heat treated condition for the different applied load condition. Similar results of reduced wear were also observed by researcher C.S. Ramesh et al., [19].

Figure 2 of (a) depicts analysis of means graph for the test results. The graph explains the effects of two factors at five levels on the abrasive wear rate. The wear rate of the composite decreases as the reinforcement content of the TiO_2 is increased from 0 to 8 weight % is shown in the graph. This reduction in wear rate is expected since TiO_2 particles being a very hard dispersoid, contribute positively to the hardness of the composite [20]. The analysis of means graph also reveals that minimum wear rate is obtained for the fifth reinforcing factor which is 8 wt % of TiO_2 reinforced composite. Also, wear rate increases linearly as the applied load increase. From the figure2, it is clear that factors combination of R5 and L1 yields minimum wear rate for both as-cast and heat treated conditions..

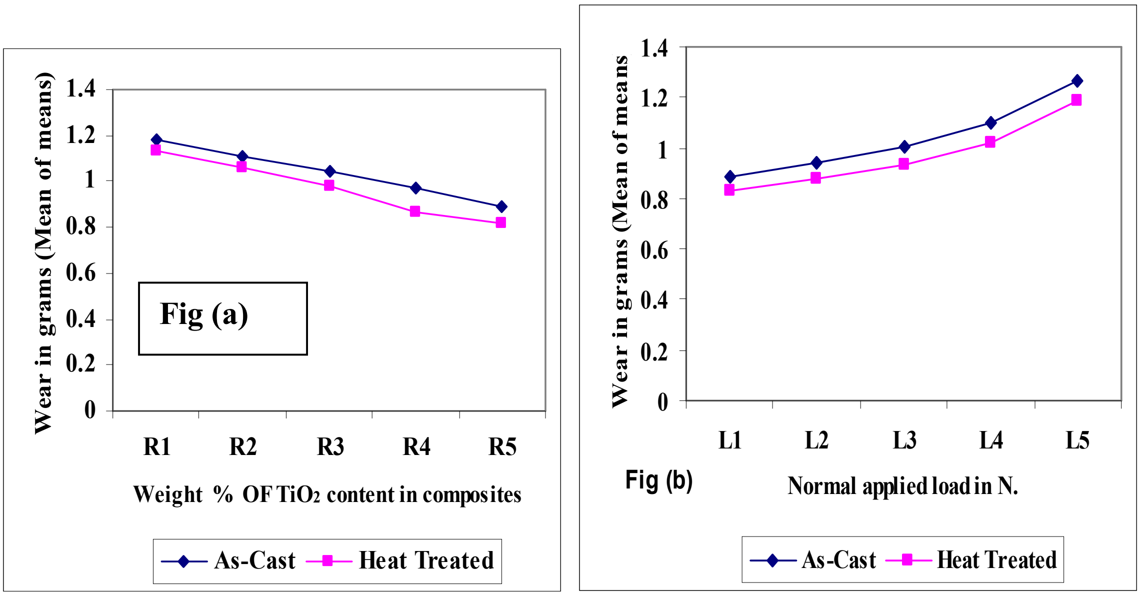
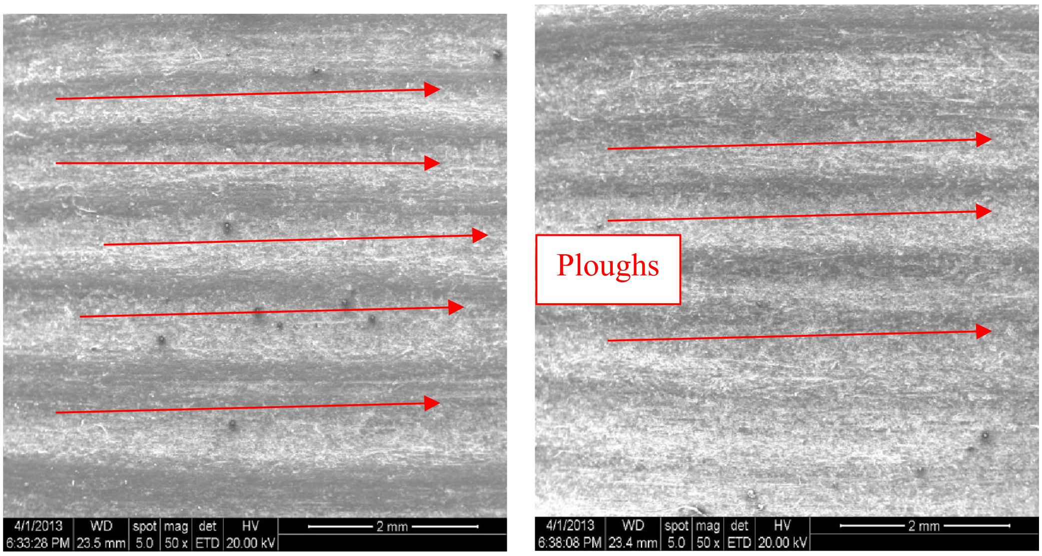


Figure 2: Main effect plot of mean value of abrasive wear in grams. (a) Reinforcement effect (b) Load effect

Figure 3 show the SEM images of 2 and 8 weight fractions of titanium dioxide reinforced composites. The SEM, image of (a) and (b) shows that the plastic grooving and ploughing is more for lower weight fraction of reinforcement. The minimum grooving is observed for higher reinforcement and this improvement can be mainly attributed to the increased hardness of the composites for higher weight fraction of reinforcement [21]. Due to lower hardness of the matrix material the abrasive particles are capable to dig in and plough out the material which increases the wear rate in matrix material. In harder composite material, the abrasive particles do scratch the surfaces with minimum ploughing out leading to lower material removal [22].



(a) Al2618-2wt%TiO$_2$ composite (b) Al 2618-8wt % TiO$_2$ composite

Figure 3: Abrasive wear of TiO2 reinforced composite Load: 6N, Heat treated

4.1. Verifying the adequacy of the abrasive wear model

Table 6 shows the summary for verifying the adequacy of the model. The value of squared multiple of R is 0.979 and 0.9850 for as-cast and heat treated condition, which shows that 97.9% & 98.5 % of experimental data fits the developed model. The number of factors selected for the developed model is 97.3 % and 98.11 % which, is illustrated from adjusted R^2 value. Since the value of squared multiple of R is close to the adjusted R^2 value, the model does not appear to be over fit and has the adequate predictive capability. The Predicted model yields an error of 0.028 and 0.0241 which is indicated as standard error of estimate in table 6. Further, the results are analyzed using analysis of variance**.** The p-value for the factor R in the regression summary table 6 is 0.051, which, shows that the model estimated by the regression procedure is significant at a α-risk of 0.05 (95 % confidence level).. The analysis of variance table 7 shows that, the calculated value of the F-ratio of the model is more than the standard tabulated value of F-ratio for the desired 95 % confidence level. This shows that model is adequate within the confidence limit of 95 %. Figure 4 shows the percentage of error for both the As-cast and heat treated specimen.

Table 6 : Summary for verifying the adequacy of the model

Dependent	**As-cast abrasive wear**	**H.T. abrasive wear**
N	25	25
Squared multiple R	0.979	0.9850
Adjusted squared multiple R	0.973	0.9811
Standard error of estimate	0.028	0.0241

Table 7 : Analysis of Variance table for as- cast condition

Source	**Type 1SS**	**Df**	**Mean Squares**	**F – Ratio**	**P-Value**
Regression	0.702	5	0.14	176.171	0.000
Residual	0.015	19	0.001		

$F_{0.05, 5, 19} = 2.90$

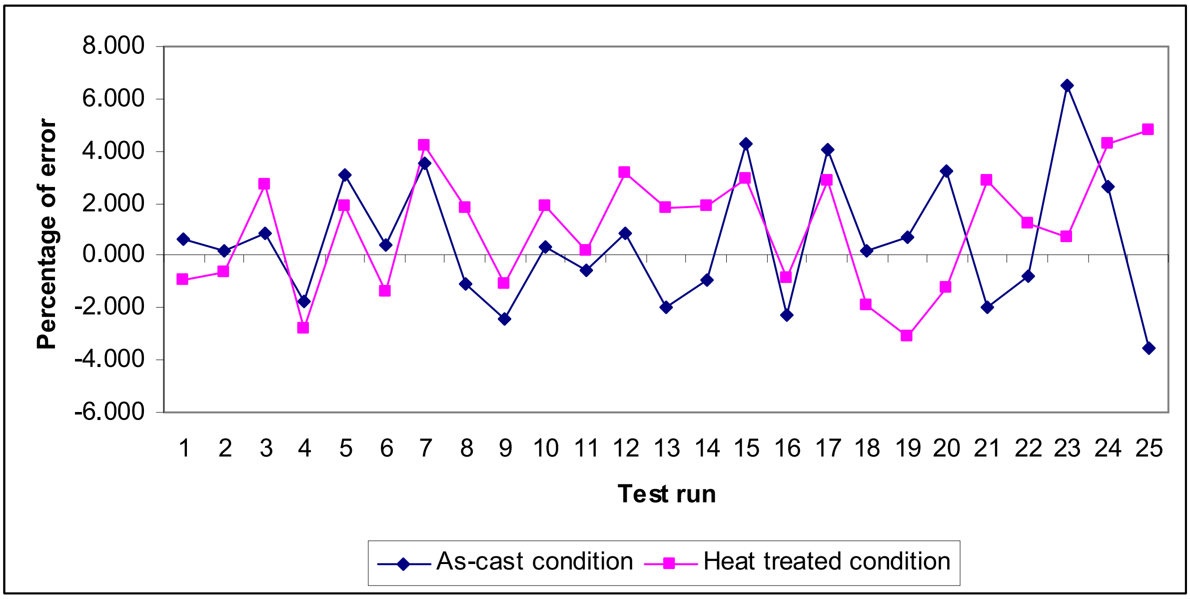


Figure 4: Graph of percentage of error obtained for as-cast and Heat treated condition

5. CONCLUSIONS

The statistical method is applied to study the abrasive wear behavior of aluminum metal matrix composite. The following are the conclusions drawn from the present study.

1. Ceramic reinforcement will favors for improving the wear resistance of the matrix material.
2. Heat treated specimens shows improvement in the abrasive wear as compared to As-cast specimen
3. The developed model estimates the abrasive wear which yields an error of 0.028 and 0.0241 for both as-cast and heat treated condition.
4. The analysis of variance table shows that, the calculated value of the F-ratio of the model developed is more than the standard tabulated value of F-ratio for the desired 95 % confidence level. This shows that model is adequate within the confidence limit of 95 %.

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