TRIBOLOGICAL INVESTIGATION OF Al7075/TIC/MOS2 HYBRID COMPOSITE MATERIAL

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Abstract - *In this paper, wear behavior of hybrid composites of Al7075 alloy reinforced with TiC & MoS_2 was investigated at ambient & elevated temperature. Al7075/TiC/MoS_2 specimens were prepared by the method of stir casting. The pin on disc apparatus was used to evaluate the wear behavior of specimens. Taguchi technique was used for optimization. Minitab 18 software was used for the statistical analysis purpose. An orthogonal L9 arrays were formed. The influence of various parameters such as applied load, temperature, sliding distance & % of reinforcement were investigated by ANOVA. For analysis, MINITAB 18 software was used. Further regression equations were used to determine the correlation between the parameters. The most influencing parameters found by S/N ratio. Results revealed that reinforcement shows negative influence on weight loss. weight loss decreases with increasing reinforcement. Applied load, sliding distance & temperature was influencing factors in wear resistance.*

Key Words: ANOVA, MINITAB 18, regression analysis, S/N ratio, orthogonal array, wear behavior, Taguchi technique.

1. INTRODUCTION

Today's technology offers materials which were light in weight and cost effective. This leads to development of advanced materials which possesses excellent properties like high stiffness, high specific strength along with superior wear resistance. Durability of any machine part is vital design consideration. There are many factors that directly influence the life of machine component. So, the biggest challenge in front of design engineer is careful material selection for particular application. Many engineering components in aviation, marine and automobile industries like rock climbing equipment, bicycle components, inline skating-frames and hang glider airframes has to possesses properties like high strength to weight ratio, improves wear resistance, corrosion resistance, high toughness both at ambient and elevated temperature condition.

Therefore, hybrid metal matrix composites are now a day considered to be smart alternative because of their superior tribological properties at both ambient and elevated temperature condition. Reinforcing aluminium alloy with other materials increases its temperature range in wear limited application like crankshaft, piston, cylinder heads, manifolds and heat exchangers. So, the present work focuses on development and tribological characterization of hybrid aluminium metal matrix composites for automobile and aerospace application.

2. LITERATURE REVIEW

Belete Sirahbizu Yigezu et al. had studied the abrasive wear characteristics of the in situ synthesized Al–12% Si/TiC composites were investigated based on the plan of full factorial design. During the experiment applied load, sliding distance, and weight percentage of reinforcement considered as input parameters and weight loss and coefficient of friction are considered as response parameters. The experimental result revealed that for the coefficient of friction sliding distance and weight percentage of reinforcement are most dominating factors. On the hand, for weight loss applied load was most dominating factor [1]. R. Anand Kumar et al. had studied Al–12% Si aluminium matrix reinforced with TiC powder and composite was prepared by the process of metal cladding. SiC, TiC, TaC, B_4C, WC were most widely used reinforcement materials in MMC. TiC was mostly attractive due to its high hardness, low heat conductive coefficient, high elastic modulus, high melting point, especially it's thermodynamic stability and good wettability with molten aluminium [2]. S. Jerome et al. had studied in situ Al-TiC (5 wt.%, 10 wt.%, 15 wt.%) composites were produced. The wear tests were conducted at room temperature 120^0c & 200^0c. Reinforcement shows the negative influence on the weight loss. Weight loss decreases with increasing reinforcement percentage of TiC at all temperature. On the other hand, wear rate increases with the increase in applied load. Results revealed that at room temperature transfer layer formation mechanism dominates the wear rate while at the elevated temperature wear rate reduces with oxidative layer formation [3]. Anand Kumar et al. were investigated abrasive wear modeling of in-situ Al-4.5% Cu /TiC metal matrix composite based on full factorial design. In the experiment applied load, sliding distance & weight % of reinforcement in the metal matrix were treated as control factors. It has also been observed that sliding distance was most dominating factor for the coefficient of friction. As sliding distance increases coefficient of friction also increases. On the other hand, weight loss increases with increase in applied load and sliding distance. Whereas reinforcement shows the negative influence on the weight loss, weight loss decreases with increasing reinforcement.

Coefficient of friction decreases with increase in applied load and weight percentage of TiC reinforcement in composite and conversely sliding distance increases coefficient of friction increases [4]. V. C. Uvaraja and N. Natarajan et al was predicted tribological behavior of Al alloy reinforced with SiC particle by pin on disc apparatus and optimize different operating parameters such as applied load, sliding distance & sliding speed by Taguchi technique. Percentage of reinforcement shows negative influence on wear loss followed by applied load, sliding distance & sliding speed. Also, percentage of reinforcement was most dominating factor for the coefficient of friction [5]. T. S. Kiran et al. had studied the dry sliding wear behavior of hybrid metal matrix composite by using Taguchi method. Zinc based alloy reinforced with SiC & Gr particles and form hybrid metal matrix composite. MINITAB software was used for statistical analysis. Applied load was found as most influencing factor followed by sliding distance and sliding speed in causing weight loss. Graphite particles along with metal matrix pressed between the pin on disc and forming ceramic mixed mechanical layer [6]. S. Basavrajappa et al. were investigated Taguchi robust design technique to study the dry sliding wear behavior of metal matrix composite. In this work they compare the tribological behavior of aluminium metal matrix reinforced with SiCp & Gr particles. Sliding distance had highest influence on weight loss of both the composite [7]. N. Radhika et al. were predicted the dry sliding wear behavior of aluminium hybrid metal matrix composite. L9 orthogonal array was used to obtained the desired combination of variables. Result revealed that wear loss increases with increase in temperature and load. Sliding velocity shows the negative influence on the wear loss. ANOVA shows that load had highest significant effect on weight loss followed by temperature & sliding velocity [8]. N. Radhika et al. were studied tribological properties of aluminium alloy (Al-Si10Mg) reinforced with graphite (3%) and alumina (9%) fabricated by stir casting method was investigated. Wear and coefficient of friction are most affected by sliding speed followed by applied load and sliding velocity [9]. Ranjit Kumar et al. had studied optimization of tribological behavior of molybdenum disulphide reinforced with aluminium metal matrix composite. The result shows that with increase in load wear rate also increases. The MoS_2 revealed less wear loss compared to conventional material [10]. P. Shanmughasundaram et al. was predicted the wear behavior Al7075-SiC composites. The result shows that wear resistance of composite decreases with increase in temperature, applied load and sliding velocity within the observed range. It was found that applied load was significant factor influencing wear rate followed by the temperature and sliding velocity [11]. Pruthvi Serrao et al. had studied the abrasive wear properties of Cp titanium using Taguchi technique. The result shows that wear properties enhanced compared to the conventional material [12]. Mahadiar Valefi et al. have studied the wear properties of alumina ball with 5% wt. of copper oxide at a temperature of 700^0c. The result shows that coefficient of friction and wear rate were strongly depend on temperature. The principle motive of this paper is to fabricate the aluminium matrix composite reinforced with TiC by the stir casting process and determine basic tribological behavior. The influence of applied load, sliding distance, temperature and weight percentage of reinforcement on wear behavior and coefficient of friction is studied. Multi response optimization also done to optimize the wear characteristics of the composite. Taguchi technique and MINITAB software is used for further analysis [13].

3. SPECIMEN PREPARATION

3.1 *Material Selection*

In this paper, dry sliding wear tests were conducted on Al7075 alloy by varying (0%, 5% and 10%) TiC and adding constant weight percentages of MoS_2 (3%). The pins are basically made up of Al7075 alloy and reinforced with titanium carbide particles of size 25 micrometer. The pins are of 30mm length and circular in cross section 10mm in diameter. The disc used for the experimentation is made up of steel EN31 grade with surface roughness of 1.57 micrometer.

TABLE 1: Chemical composition of Al7075 alloy (weight %)

Material	Mg	Si	Fe	Cu	Ti	Cr	Zn	Mn	Be	V	Al
Wt.%	0.92	0.76	0.28	0.22	0.10	0.07	0.06	0.04	0.003	0.01	Balance

3.2 Manufacturing Hybrid Metal Matrix Composite

The Al7075 alloy reinforced with (0%, 5%, 10% wt.) of TiC and (3% wt.) of MoS_2 were fabricated by stir casting process. The stir casting set up consist of muffle furnace and two thermocouples which precisely controls the temperature of electric furnace. Al7075 alloy was melted at a temperature of (477- 635^0c) in muffle furnace. Titanium carbide particles of size 25 micrometer are melted into electric furnace upto 900^0c and introduced into the slurry. The composite slurry temperature was increase to its liquidous state and automatic stirring was continued to about 10 minutes under the protected organ gas. The Al7075-TiCp-MoS_2 composite was fabricated with a blended mixture of TiCp & MoS_2 particles respectively. The mixture is introduced into the molten slurry and stirring is continued. The titanium carbide particles help in distributing the molybdenum disulphide particles uniformly throughout the matrix alloy. The molten metal was then poured into a permanent mould. The die was release near about 5 hours and the cast specimens were taken out. The pin on disc test apparatus is used to study the dry sliding abrasive wear characteristics of the composite. During the test, the composite pin is pressed against the counter face EN31 steel disc. After testing the specimens is removed, cleaned with acetone, dried and weighted to determine the mass loss due to wear.

4. TAGUCHI TECHNIQUE

The design of experiments approach using Taguchi method has been successfully used by many researchers in their investigation of wear behavior of aluminium metal matrix composites. The DOE consist of three main phases: the planning phase, the conducting phase, and the analysis phase. The most important step in the DOE process is the determination of the combination of factors and levels which will provide the desired information. Analysis of the experimental results which uses a S/N to aid in the determination of the best process designs. The Taguchi method is a powerful method used for acquiring the data in a controlled way and to analyse the significance of the process parameter over some specific parameters which is unknown function of these process parameters and for the design of high quality systems. This method has been successfully used by many researchers in the investigation of wear behavior of aluminium metal matrix composites. This method develops a standard orthogonal array to accommodate the effect of several factors on the target value as well as defines the plan of experiment. The experimental results are analysed with the help of analysis of means and variance to study the significance of parameters. A multiple linear regression model is formulated to predict the wear rate of hybrid composites. The main aim of the present investigation is to analyse the significance of the parameters such as applied load, temperature, percentage of reinforcement and sliding distance on dry sliding wear of Al7075/TiC/MoS_2 hybrid metal matrix composites with the help of Taguchi technique.

4.1 Plan of Experiment

In this abrasive wear experiment, the plan order for performing abrasive wear was generated by the design of experiment (DOE) method and analysis of variance (ANOVA) technique is used for the analysis of the parameters. To consider the effect of all the factors such as applied load, temperature, weight percentage of reinforcement of TiC and sliding distance an orthogonal array is generated. Sliding distance and revolution per minute of rotating disc kept constant. Sliding velocity is taken as 1.57 m/s and corresponding RPM of disc is taken as 300 RPM. Each control factor having three levels like low, medium and high denoted by 1, 2 and 3. Selected number of variables with these three levels are shown in table 2. Taguchi method is used to find out the total number of experiments based on the number of variables and their level. Thus, minimum number of experiment to be carried out for these combinations is selected as 9, hence we select L9 orthogonal array for our experimental testing.

TABLE- 2: Control Factors and Levels

Level of factor for experimental test				
Parameter	Unit	Level		
		1	2	3
Applied load	N	10	20	30
Temperature	^{0}C	100	150	200
Weight % of TiC	Wt%	0	5	10
Sliding distance	M	400	600	800

TABLE- 3: L9 Orthogonal Array

Experimental No	Applied load (N)	Temperature (^{0}c)	Wt. % of reinforcement	Sliding distance (m)
1	10	100	0	400
2	10	150	5	600
3	10	200	10	800
4	20	100	5	800
5	20	150	10	400
6	20	200	0	600
7	30	100	10	600
8	30	150	0	800
9	30	200	5	400

4.2 Abrasive Wear Experiment

The experiment was conducted on pin on disc apparatus (TR20PHM400) at ambient and elevated temperature. The experiment was performed according to ASTM G99 standard. The specimens were cylindrical shape of size 10mm diameter and 30 mm length made up of Al7075 alloy reinforced with (0%, 5%, 10% wt.) TiC and (3% wt.) MoS_2. Before starting test, the flat surface of cylindrical specimens was polished with fine grained of emery papers having the surface roughness value 0.36micron meter. While testing, the flat surface of cylindrical specimen was pressed against horizontal rotating steel disc EN31 grade having hardness 65HRC. The wear tests were performed under three different loads (10N, 20N and 30N), three temperatures (100^{0}c, 150^{0}c and 200^{0}c), three distinct sliding distances (400m, 600m and 800m), three percentage of TiC reinforcements (0%wt, 5%wt and 10%wt.) and sliding velocity of 1.57m/s was kept constant. Reduction in height of cylindrical specimen is measured by using LVDT sensors mounted on test setup and by using this height sensors volume loss of test specimen was calculated. Thus, abrasive wear rate is calculated in the form of mm^3/min. Separate specimen is used for each sliding distance. The COF is calculated by the ratio between tangential force(F_t) and normal force(F_n) given by Eq. (1). The value of tangential force is directly recorded form the apparatus display. Readings of tangential forces were uniformly recorded within the time interval of 30sec and average value was used for the calculation. Mean value of COF is directly measured by WINDCOM software.

$$COF, \mu = F_t / F_n \quad ...(1)$$

The principle objective of this experiment is to developed the mathematical model by ANOVA to predict the significance of wear parameters on wear rate and coefficient of friction of the experimental composites. The model was developed based on statistical approach by using MINITAB 18 software. Experimental values of abrasive wear rate and coefficient of friction was tabulated in table 4

5. RESULTS AND DISCUSSION

Experimental values of abrasive wear loss and COF for the given responses are listed below

TABLE -4: Experimental Result of Wear Test

Exp. No	Applied load (N)	Temperature (^0c)	Wt. % Reinforcement	Sliding Distance (m)	Wear rate (mm^3)	COF
1	10	100	0	400	0.014167	0.462
2	10	150	5	600	0.014147	0.469
3	10	200	10	800	0.014259	0.449
4	20	100	5	800	0.014476	0.471
5	20	150	10	400	0.014227	0.412
6	20	200	0	600	0.015385	0.493
7	30	100	10	600	0.014483	0.457
8	30	150	0	800	0.015125	0.506
9	30	200	5	400	0.015682	0.476

5.1 ANOVA For Wear Loss

Table 5 shows the result of analysis of variance of wear loss TiC and MoS_2 particles reinforced with Al7075 alloy hybrid matrix composite. ANOVA was performed to study the combined effect of all variables. The analysis was carried out at 95% confidence level and 5% significance level that means value of significance factor alpha is 0.05. Pr value indicating percentage of contribution and shows degree of influence of each variable on abrasive wear loss. From analysis of variance most significant factor were denoted on the basis of P value. It should be noted that P value for load is approximately zero. It should be observed that load has greater influence on wear loss (45.51%). Following to load temperature (29.79%), percentage of reinforcement (17.94%) and sliding distance (0.29%) were less dominating factors respectively.

TABLE -5: ANOVA for Wear Loss

Source	DOF	Adj SS	Adj MS	F Value	P Value	% Contribution
Regression	4	0.000003	0.000001	14.45	0.012	96.53
Load	1	0.000001	0.000001	28.13	0.006	45.51
Temperature	1	0.000001	0.000001	18.41	0.013	29.79
% Reinforcement	1	0.000000	0.000000	11.09	0.029	17.94
Sliding Distance	1	0.000000	0.000000	0.18	0.695	0.29
Error	4	0.000000	0.000000			6.47
Total	8					100

5.2 ANOVA For Coefficient of Friction

From the table it was observed that effect of load and temperature on coefficient of friction is negligible. Percentage of reinforcement contributes more i.e. 59.12% in analysis of coefficient of friction followed by sliding distance (16.70%), load (10.06%) and temperature (2.27%).

TABLE- 6: ANOVA for Coefficient of Friction

Source	DOF	Adj SS	Adj MS	F Value	P Value	% Contribution
Regression	4	0.005082	0.001270	7.44	0.039	88.15
Load	1	0.000580	0.000580	3.40	0.139	10.06
Temperature	1	0.000131	0.000131	0.77	0.431	2.27
% Reinforcement	1	0.003408	0.003408	19.95	0.011	59.12
Sliding Distance	1	0.000963	0.000963	5.64	0.076	16.70
Error	4	0.00683	0.000171			11.85
Total	8					100

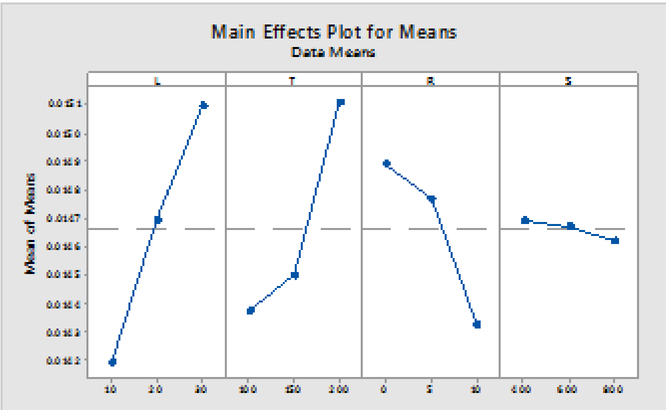

Fig 1 Main effects plot for means for wear loss of Al7075/TiC/MoS_2

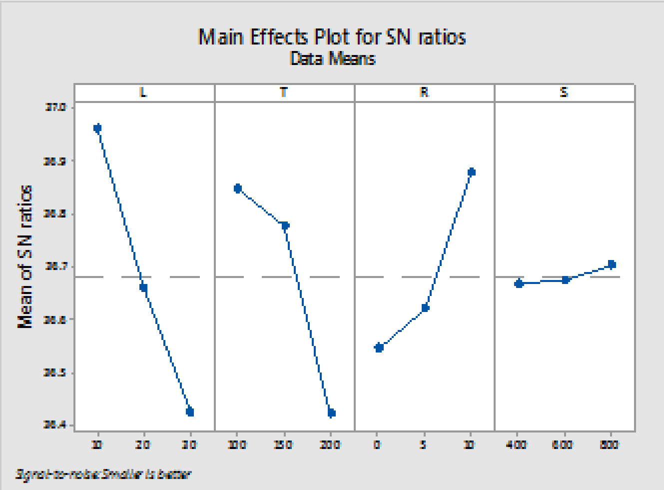

Fig 2 Main effects plot for SN ratios for wear loss of Al7075/TiC/MoS_2

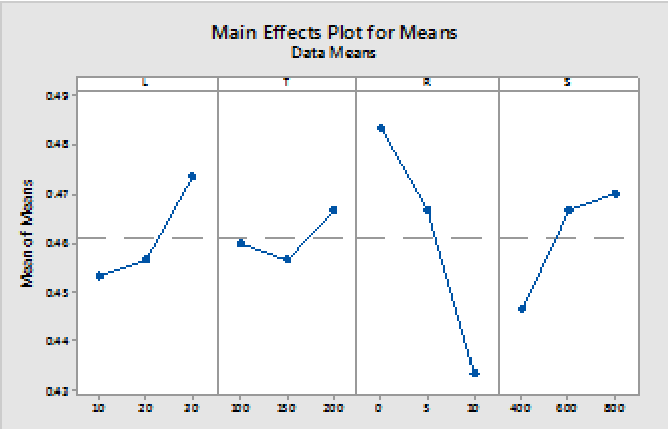

Fig 3 Main effects plot for means for COF of Al7075/TiC/MoS_2

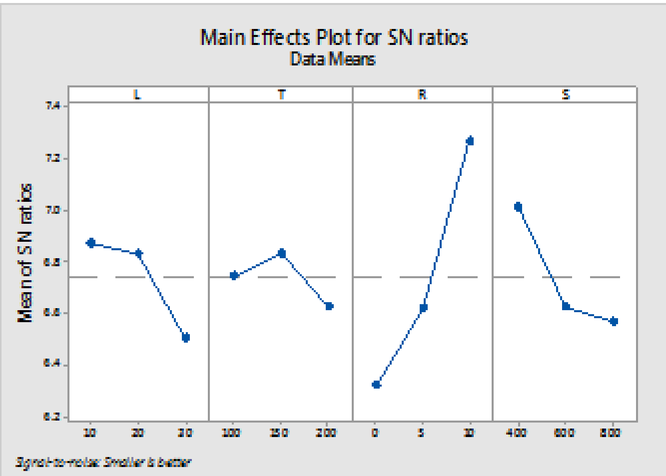

Fig 4 Main effects plot for SN ratios for Al7075/TiC/MoS_2

5.3 Analysis of Signal to Noise Ratio

For design parameter optimization signal to noise ratios were investigated by using Taguchi technique. The most significance control factors were measured by signal to noise ratio. There are three main types of approaches: smaller is the better, nominal is the best and larger is the better. In this case smaller is the better approach was selected. Smaller is the better minimizes the undesirable defects or effects. In this case we want to minimize the abrasive wear loss and COF. The signal to noise ratios were formulated for both the abrasive wear loss and coefficient of friction. The S/N ratio graph and main effect graphs were plotted with the help of MINITAB 18 software. In S/N ratio graph the factors which lies far away from horizontal line has most significant effect on the response variables and the factor which lies closer to horizontal line has less significant effect. From main effect plot it shows that applied load and temperature lies far away from horizontal line and hence most influencing factor in wear loss. The response table for S/N ratio was calculated in MINITAB 18 software. Ranking of each factor was formulated on the basis of delta value which is the difference between maximum and minimum value of signal to noise ratio. The parameter having highest value of delta is the most significant factor for abrasive wear loss. It can be noted from the result that percentage of reinforcement was most significance factor in coefficient of friction. Similarly, load was most dominating factor in wear loss.

TABLE- 7: S/N ratio of wear loss: smaller is better

Lev el	Applie d load	Temperatu re	% Reinforcem ent	Sliding Distan ce
I	36.96	36.85	36.55	36.67
II	36.66	36.78	36.62	36.68
III	36.43	36.42	36.88	36.70
Delt a	0.53	0.43	0.43	0.04
Ran k	1	2	3	4

TABLE 8: S/N ratio of COF: smaller is better

Level	Applied load	Temperature	% Reinforcement	Sliding Distance
I	6.874	6.746	6.321	7.016
II	6.833	6.837	6.620	6.626
III	6.505	6.628	7.270	6.570
Delta	0.369	0.208	0.950	0.446
Rank	3	4	1	2

5.4 Analysis of Regression Equation

To develop the relationship between control factor and response factor multiple regression equation is used. Negative value of correlation coefficient corresponding to percentage of reinforcement indicates that wear loss and COF are inversely proportional to coefficient of friction. Correlation coefficient having positive value shows there is direct relationship between control factor and response factor. As the control factors such as applied load, temperature and sliding distance increases wear loss and coefficient of friction also increases. Sliding distance has a negligible effect on wear loss whereas applied load and temperature has negligible effect on coefficient of friction.

Regression equation for wear loss is given as below:

Wear loss = 0.013048 + 0.0000450 (Load) +0.0000007 (Temperature) – 0.000057 (% Reinforcement) + 0.000000176 (Sliding Distance)

COF = 0.4183 + 0.000983 (Load) + 0.000093 (Temperature) -0.00477 (% Reinforcement) + 0.000063 (Sliding Distance)

5.5 Confirmation Experiment:

The final step in experiment is confirmation test conducted for hybrid composite material by selecting set of variables as shown in table 9. In confirmation experiment values of wear loss obtained from regression equation are compared with experimental value and corresponding error is determine.

TABLE 9: Factors for Confirmation Experiment

Experiment No.	Applied load	Temperature	% Reinforcement	Sliding Distance
1	15	100	0	300
2	25	150	5	600
3	35	200	10	900

TABLE 10: Confirmation Experiment for Wear Loss

Experiment No.	Experimental Value	Regression Value	% Error
1	0.014982	0.014475	3.38
2	0.015269	0.014920	2.28
3	0.016842	0.015540	7.73

TABLE 11: Confirmation Experiment for Coefficient of Friction

Experiment No.	Experimental Value	Regression Value	% Error
1	0.4782	0.4612	3.55
2	0.4920	0.4707	4.31
3	0.5147	0.4803	6.68

From the result we observed that, wear value for wear loss is varies from 2.28% to 7.73% whereas for coefficient of friction error value varies from 3.55% to 6.68%. Thus, the calculated values for wear loss and COF closely resemble with actual data with minimum error, design of experiment (DOE) by Taguchi technique was successful for calculating abrasive wear loss and coefficient of friction(COF) for hybrid metal matrix composite.

6. CONCLUSION

In the study of tribological behavior of aluminium metal matrix composite by using Taguchi method following conclusion can be drawn.

1. Taguchi technique was successfully used to minimize the number of experiment to be performed for given set of operating parameters.

2. Percentage contribution of various control factors such as applied load, temperature, percentage of reinforcement and sliding distance on wear loss and COF is determine by using ANOVA technique.

3. For wear loss applied load (45.51%) is most dominating factor followed by temperature (29.79%) and percentage of reinforcement (17.94%).

4. For COF percentage of reinforcement (59.12%) is most dominating factor followed by sliding distance (16.70%) and load (10.06%).

5. Signal to noise ratio is used for optimization of operating condition. Maximum value of signal to noise ratio in S/N ratio plot gives us optimum condition. The result shows that applied 10N load, 100^0c temperature, 10% reinforcement and 400m sliding distance gives optimum condition.

6. Confirmation of experiment is done which shows error for wear loss is varies from 2.28% to 7.73% and for coefficient of friction (COF) it varies from 3.55% to 6.68%, resulting in conclusion that design of experiment (DOE) by Taguchi method is successful for calculating wear loss and COF with least error.

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