MULTI OBJECTIVE PARAMETRIC OPTIMIZATION ON WEAR OF COCONUT FIBERS WITH POLYAMIDE MATRIX

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Abstract

Determination of optimum variables, during the wear test on polymer matrix composites (PMC), is an important issue for nowadays specifically, the wear rate (WR) and coefficient of friction (COF) needs to be minimized. Despite extensive research on wear process, influential the indented operating conditions in industrial arena needs skilled operators. The purpose of this study is to optimize the process variables such as normal force, sliding velocity and reinforcement to minimize wear rate and friction coefficient. Central Composite Rotatable Design (CCD) was selected to conduct the experiments. The empirical models were developed using nonlinear regression analysis. The worn out morphology of the surfaces were observed through scanning electron microscope (SEM). The input variables were optimized using RSM.

Key words- *Friction coefficient, Wear Rate, Polyamide, Coconut fiber, ANOVA, SEM, CCD*

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1. INTRODUCTION

The main features of using polymer matrix composites, when it is compare with other matrix metals are ease of production, simple in processing sequence with low cost of production. Addition of the fibers with matrix depends on size, shape and even distribution of the fibers on the matrix, and the bonding strength between the matrix and fibers which improves the properties of the composites, like higher strength to weight ratio, better mechanical and tribological properties. On the basis of its best performances it is use for industrial products and academic areas [1]. A uniform of fiber surface treatments have been made to improve the bonding of the different fibers with resins. Examples like, carbon fibers and glass fibers are processed such that electrolytically oxidized and silane coupling agents were included with PA66 matrix, these have in a wide variety of applications because of its enhancing the tribological and mechanical properties [2]. Wear of PTFE and CuO composites were suffered by various parameters like partisan load sustain by fibers, enlargement of transfer films over the disc area, contradictory structure on the specimen and the debris returned from disc to pin, fiber tearing and fracture on the tip of the fibers [3]. However, for the tribological process of polyamide composites, the optimum tribological variables must be ensuring to attain minimum wear and friction. Multiple performance optimizations is a technique, which have several objective functions, each one have determines the different optimal solution. Sometimes these results have divergence one with other. In the present work concentrated on the tribological characteristics of polyamide composites. Design of experiments (DOE) and regression analysis are used to study the influence of input parameters like normal force, sliding velocity and reinforcement, over technological variables such as WR and COF. The main attention is to enable the creation of second order polynomial models, which helps to give explanation the discrepancy connected with technical variables studied.

2. EXPERIMENTAL PLANNING

2.1 Composite fabrication and Wear Testing

Parameters

Treated short coconut fibers and Polyamide 66 composites were fabricated by hand layup process. The tribological test was done by a pin on disc wear tester by varying the predominant inputs like sliding velocity, normal force and different volume fractions of coconut fibers with fixed time interval. The size of the pin (test specimen) and disc are 10 mm X 20 mm and 55mm X 10 mm, with surface roughness of 0.1μm and a hardness of 60HRC. It is adjustable apparatus fabricated to evaluate wear rate and coefficient of friction under various conditions. Sliding generally occurs between a stationary pin and rotating disc. The disc rotates with an average speed range of 0-600 rev/min. The smooth and hardened steel disc surface (SS 316 HSS, hardness 72 HRC) served as a matching part and was finished by an abrasion against 1200-SiC grade sheet with the roughness of Ra 0.6-0.7μm. The test specimen located at right angles to the disc and corresponding to the sliding direction. The pin was rubbed against 400-SiC grade sheet before the test, to conform proper contact between pin and disc. The contact area of disc and pin were cleaned with a soft paper soaked in acetone before the test. Mass loss was calculated by an electronic weighing scale of 0.01 mg precision before and after the tests. An inbuilt computer running friction-measuring software is used to evaluate COF.

2.2 Response Surface Methodology

Response surface methodology (RSM) is the procedure for calculating the association between various process inputs with the different tribological criteria and to estimate the effect of these process parameters on the coupled responses [4]. i.e. WR and COF. In order to study the effect of the tribological parameters on the above-mentioned criteria, a second order polynomial response can be fitted into the following equation

$$Y_u = b_o + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x^2{}_i + \sum_{j>1}^{k} b_{ij} x_i x_j \qquad (1)$$

Where Y_U is response and the $x_{i\,(1,2,\ldots,k)}$ are coded level of k quantitative variables. The friction coefficient b_0 is the constant term, the coefficients b_i are the linear terms, b_{ii} are the quadratic terms and b_{ij} are the interaction terms. The significant process parameter selected for the current investigations are normal force, sliding velocity and reinforcement on the WR and COF during the tribological process. The three input process variables, the design needs 20 tests with 8 factorial points, 6 axial points to form face centered composite design with α = 1 and 6 centre points for replication to estimate the experimental error. The design was created and analyzed using MINITAB.16 software.

Table-1: Process Inputs and Their Levels

Parameter	-1.682	-1	0	+1	+1.682
Normal force (N)	2	3	4	5	6
Sliding Velocity (m/sec)	0.2	0.4	0.6	0.8	1.0
Reinforcements %V_f (Coconut fiber)	1.5	2.0	2.5	3.0	3.5

Table-2: Experimental Matrix and Responses

Sl.No	Normal Force (N)	Sliding Velocity (m/sec)	Reinforcement	WR (mm^3/Nm)	COF (µ)
1	3	0.4	2.0	0.859	0.110
2	5	0.4	2.0	0.951	0.125
3	3	0.8	2.0	0.953	0.127
4	5	0.8	2.0	0.843	0.139
5	3	0.4	3.0	1.059	0.171
6	5	0.4	3.0	1.009	0.165
7	3	0.8	3.0	1.031	0.169
8	5	0.8	3.0	1.012	0.173
9	2	0.6	2.5	0.995	0.166
10	6	0.6	2.5	0.982	0.153
11	4	0.2	2.5	0.913	0.141
12	4	1.0	2.5	0.999	0.147
13	4	0.6	1.5	0.798	0.129
14	4	0.6	3.5	1.123	0.198
15	4	0.6	2.5	0.875	0.149
16	4	0.6	2.5	0.879	0.145
17	4	0.6	2.5	0.880	0.151
18	4	0.6	2.5	0.879	0.169
19	4	0.6	2.5	0.879	0.142
20	4	0.6	2.5	0.878	0.151

2.3 Expansion of Empirical Models Based on RSM

The empirical relationship, obtained for analyzing the influences of the different input tribological parameters on the WR is given by,

$$WR= 1.54120 + 0.16950A + 0.03270B - 0.44740C - 0.00170A^2 - 0.03636B^2 + 0.05768C^2 + 0.00188AB + 0.03550AC + 0.00125BC \qquad (2)$$

The empirical relationship, obtained for analyzing the influences of the different input tribological parameters on the COF is given by,

$$COF= 0.140205 - 0.005676A - 0.019176B + 0.003352C + 0.000795A^2 + 0.001136B^2 - 0.000318C^2 - 0.000625AB - 0.001250AC + 0.00625BC \qquad (3)$$

2.4 Examination of the Empirical Models

The analysis of variance (ANOVA) and the F-ratio test have been done to confirm the goodness of fit of the empirical models. The considered values of F- ratio for lack of fit have been compared to standard values of F-ratio matching to their degrees of freedom to find the adequacy of the different developed empirical models. The F-ratio has been calculated as a ratio of Mean sum of square of source to mean sum of experimental error.

The fit summary suggested that the empirical model is statistically noteworthy for analysis of WR. The value of R^2 is over 99.86 %, which means that the empirical model gives an excellent enlightenment of the relationship between the independent variables (factors) and the response (WR).The associated P-value for the model is lower than 0.05(i.e., p **= 0.05,or 95% confidence) indicates that the model is considered to be statistically noteworthy. T**he ANOVA table for the empirical model for WR is shown in table.3.

In the same way the value of R^2 for COF is 93.42 %,which means that the empirical model provides an excellent enlightenment of the relationship between the independent variables (factors) and the response (COF).The associated P-value for the model is lower than 0.05(i.e., p **= 0.05,or 95% confidence), which shows that the model is considered statistically significant. T**he ANOVA table for the empirical model for COF is shown in table.4. The standard percentage point of F distribution for 95%confidence limit is 5.05. The F- values (1.56 and 2.48) for lack of fit are smaller than the standard value. Thus both the models are sufficient.

Table-3: Anova Table for the Empirical Model for WR

Analysis of Variance for WR						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.015379	0.015379	0.001709	1498.52	0.000
Linear	3	0.009169	0.006523	0.002174	1906.81	0.000
Nor.For	1	0.000000	0.000029	0.000029	25.55	0.000
Sli.Vel.	1	0.000001	0.000004	0.000004	3.90	0.077
RF	1	0.009168	0.004556	0.004556	3995.52	0.000
Square	3	0.006206	0.006206	0.002069	1814.18	0.000
Nor.For*Nor.For	1	0.000434	0.000073	0.000073	64.06	0.000
Sli.Vel.*Sli.Vel.	1	0.000544	0.000053	0.000053	46.65	0.000
RF*RF	1	0.005228	0.005228	0.005228	4584.98	0.000
Interaction	3	0.000004	0.000004	0.000001	1.28	0.334
Nor.For*Sli.Vel.	1	0.000001	0.000001	0.000001	0.99	0.344
Nor.For*RF	1	0.000003	0.000003	0.000003	2.74	0.129
Sli.Vel.*RF	1	0.000000	0.000000	0.000000	0.11	0.747
Residual Error	10	0.000011	0.000011	0.000001		
Lack-of-Fit	5	0.000004	0.000004	0.000001	1.56	0.733
Pure Error	5	0.000007	0.000007	0.000001		
Total	19	0.015391				

Table-4: Anova Table for the Empirical Model for COF

Analysis of Variance for COF						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.000290	0.000290	0.000032	30.95	0.000
Linear	3	0.000266	0.000007	0.000002	2.26	0.144
Nor.For	1	0.000264	0.000003	0.000003	3.14	0.107
Sli.Vel.	1	0.000002	0.000002	0.000002	1.47	0.253
RF	1	0.000000	0.000000	0.000000	0.25	0.631
Square	3	0.000018	0.000018	0.000006	5.68	0.016
Nor.For*Nor.For	1	0.000017	0.000016	0.000016	15.29	0.003
Sli.Vel.*Sli.Vel.	1	0.000000	0.000000	0.000000	0.05	0.828
RF*RF	1	0.000000	0.000000	0.000000	0.15	0.704
Interaction	3	0.000006	0.000006	0.000002	2.04	0.172
Nor.For*Sli.Vel.	1	0.000000	0.000000	0.000000	0.12	0.736
Nor.For*RF	1	0.000003	0.000003	0.000003	3.00	0.114
Sli.Vel.*RF	1	0.000003	0.000003	0.000003	3.00	0.114
Residual Error	10	0.000010	0.000010	0.000001		
Lack-of-Fit	5	0.000010	0.000010	0.000002	2.48	0.009
Pure Error	5	0.000001	0.000001	0.000000		
Total	19	0.000300				

3. RESULTS AND DISCUSSION

3.1 Influence of input parameters on WR and COF

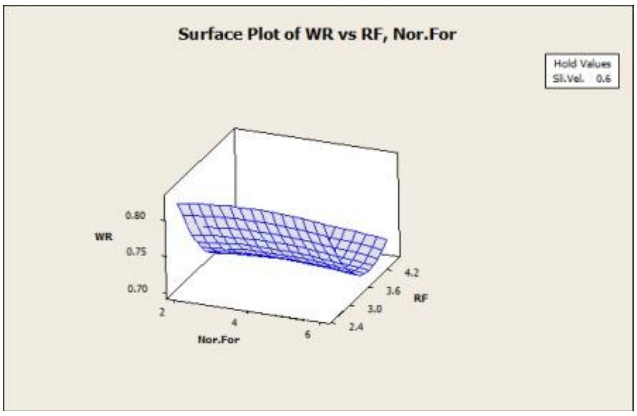


Fig-1 Influence of normal force and RF On WR

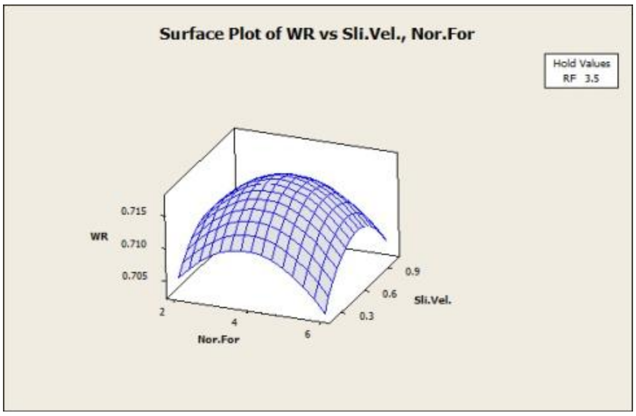


Fig-2 Influence of normal force and Sliding velocity on WR

The estimated response surface plot for WR is presented in figure1. As normal force increases WR also increases. It is attributed due to the excessive frictional heat originated as increasing of normal force. The frictional heat can result in excessive deterioration of the composites transfer from materials to the disc counterpart. Furthermore, increase of normal force will lead to excessive damage of the fibers and thus result in a disproportionate increase in wear loss [5]. On the other hand by the addition of reinforcement, WR decreases. This is because of addition of reinforcements are impracticable to rub strikingly against the surface of composites on the disc, and the debris form a slim transfer film on the counter surface, hence it reduces the abrasion process significantly.

Surface plot of WR with respect to normal force and sliding velocity is shown in figure 2. It is clear from the graph that increases in sliding velocity and normal force, WR increases. This could be due to during sliding two surfaces are in contact and it results in friction exists between two surfaces converts kinetic energy to heat energy leads to thermal softening of polyamide resin, which causes decrease in shear strength and thermal softening of the composites results in an increase in the WR. Further increase in normal force and sliding velocity WR decreases. It is owing to the mechanism of heat energy barrier by third body particles at the disc surface is not enough. As a result, the particles cannot penetrate deeper into the polymer matrix, which acts as a solid lubricant and form wear scar, plucked and ploughed marks and micro fracture on the composites [6].

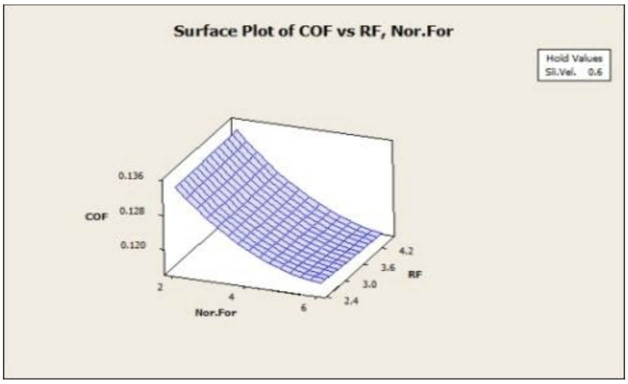


Fig-3 Influence on normal force and RF of COF

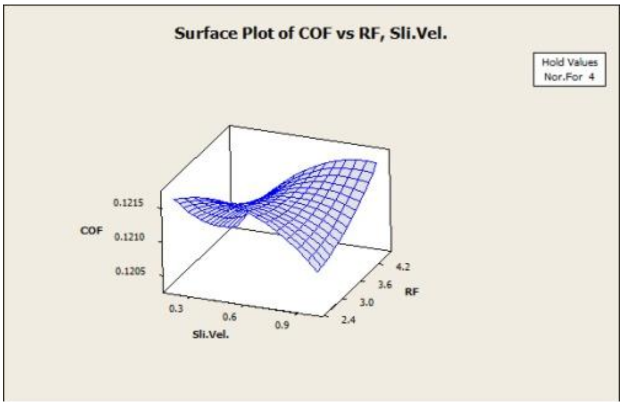
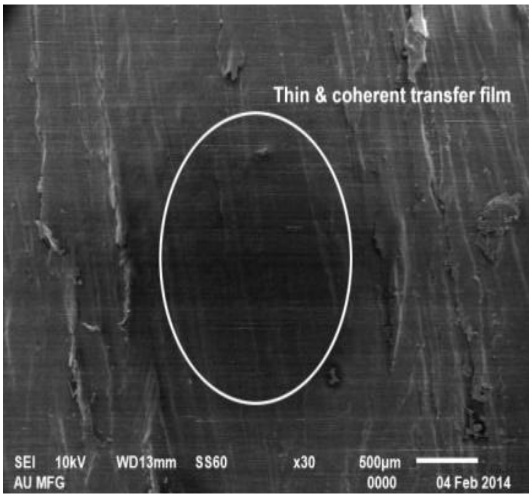


Fig-4 Influence on RF and sliding velocity on COF

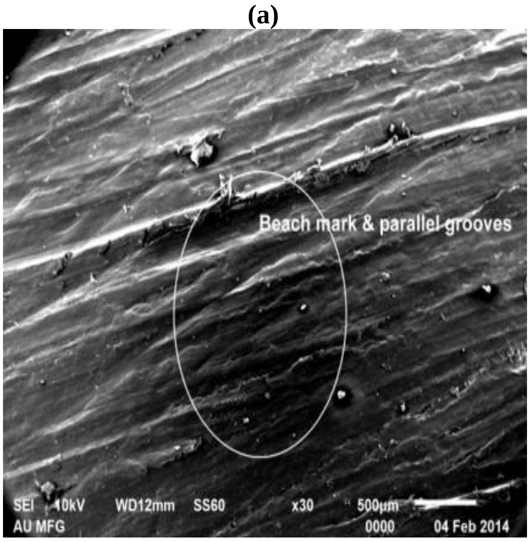
Figure 3 highlights the COF on normal force, reinforcement and sliding velocity. It can be found that COF decreased almost linearly with increasing the normal force and reinforcement. While sliding, the frictional heat increased rapidly with the increasing load, which resulted in two dissimilar effects on the COF. The worn surfaces become smoother with increasing normal force and reinforcement. It can be explained that when the normal force increases the composites went to viscous state, the COF at this time was leveled mainly by the viscous fluid flow on the surface of the disc. The composite surface viscosity decreased due to the friction heat generation and the formation of lubricant film that confined the materials, and then the COF decreased [7].

The effect of reinforcement and sliding velocity on COF is shown in fig.4. Initially, when the increasing of sliding velocity, the pin and the disc counterparts were rough and thus strong binding took place, thus resulting in a high COF. Further increasing, COF decreases linearly. It depicts that the formation of transfer film was entirely covered over the counter surface and it leads to tangential force in the contact zone. COF increases with increasing of reinforcement. It is due to during sliding surface grip, deformation of asperities and ploughing by wear fragments or hard asperities [8].

3.2 Scanning Electron Microscope (SEM) Observation

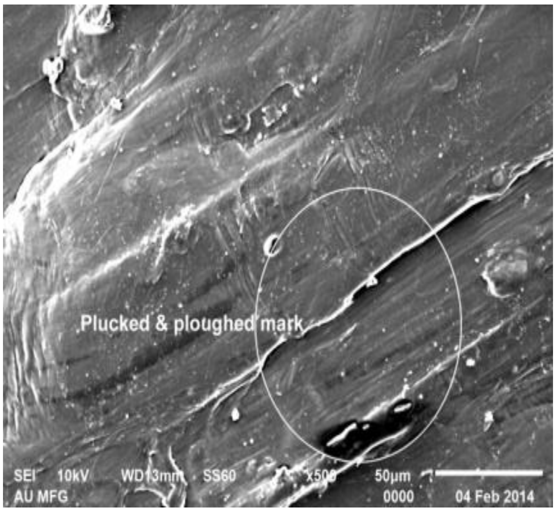


(a)

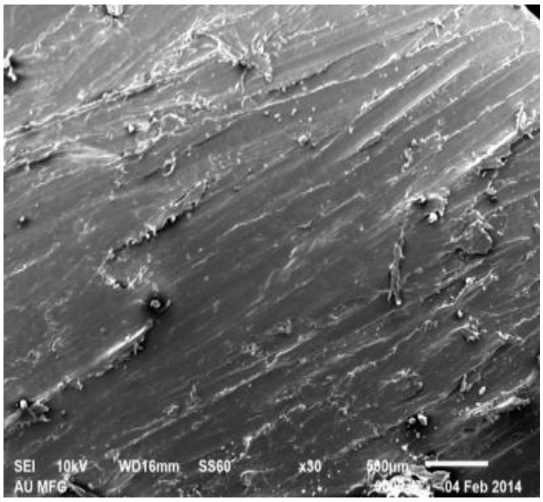


(b)

Figure 5 (a) represents by the addition of coconut fibers, WR decreases. This is because of addition of hard, sharp edged fibers, which are impossible to rub against the counterpart and the debris formed during rubbing action, a lean and articulate transfer film was formed on the steel disc and hence it reduce the scuffing process considerably. It was found that erosion, ploughing marks appear on the worn surfaces due to more plastic deformation and weakening of molecular chain interaction, which is related to the lesser WR of the coconut fibers with higher volume fraction, is shown in figure 5 (b). It was found from the figure 5 (c), that while rubbing, the disc and pin surfaces acclimatized to each other and more frictional heat was observed at the counterpart, thus resulted in the formation of uniform transfer layer, which may cause the escalation of COF. The composite surface viscosity decreased due to generation of more heat and the formation of uniform thin lubricating film that protected the material, which is observed from figure 5 (d).



(c)



(d)

Fig- 5: SEM pictures of polyamide composites at 50N load and 4.0 m/s sliding speed under dry sliding (a) 1% RF and 0.2 m/sec SV (b) 2% RF and 0.6 m/sec SV (c) 3% RF and 0.8 m/sec SV (d) GV1 (e) 5% RF and 1.0 m/sec SV.

3.3 Multi-Objective Optimization using Response Surface Methodology

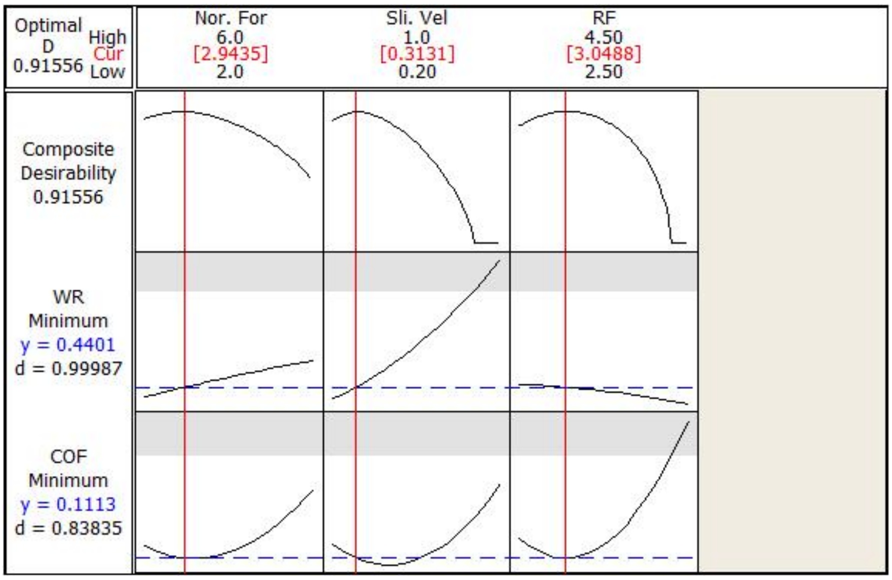


Fig-5: Optimal chart obtained through RSM

The optimization of the process variables has been determined by using RSM. The attractiveness of the optimization has also been considered to show the possibility of the optimization parameter. After that both the responses have been optimized with respect to the target value, thus getting the parameter setting for the entire process optimization. Desirability for the entire process optimization has been done to show the feasibility of optimization, i.e., to explore whether all the parameters are within their working range or not. The plan was to reduce WR and COF while both are measured at a time. The composite desirability is close to one. Figure 5 exhibits optimization plot for the both responses. The optimum values obtained from the plot are WR is 0.4401 (mm^3/Nm), COF is 0.1113 (µ) and the relevant parameters such as normal force, sliding velocity and reinforcement are 2.9435 N, 0.3131 (m/sec) and 3.0488 (%V_f) respectively.

4. CONCLUSIONS

A detailed study was carried out for wear behavior of Polyamide composites. The following conclusions are drawn from this study. The empirical models have been developed on the basis of RSM. The empirical models thus developed have been found to be fairly unique, powerful and flexible were used for optimization. These models reflect the intricate, interactive and higher order effects of the various prime process parameters on the respective wear rate and co-efficient of friction, as has been justified through the variety of experimental analyses and test results. The optimum values obtained through RSM were WR is 0.4401 mm3/Nm and COF is 0.1113 µ, and the relevant parameters normal force, sliding velocity and reinforcements are 2.9435 N, 0.3131 m/sec and 3.0488 V_f respectively.

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