MODELING DRY SLIDING WEAR BEHAVIOR OF COMPOSITES

The present chapter depicts the results of dry sliding wear of synthesized composites obtained by modeling through face centered, central composite design using response surface methodology (RSM). The design has been developed and analyzed using MINITAB 16 statistical package. The results have also been discussed in the light of observed experimental behavior.

6.1 RESULTS

6.1.1 Design of experiment

In the present work, the set of generated experimental data used the face centered, central composite design (CCD). A face centered, central composite design is the most commonly used response surface designed experiment. It is well suited for fitting a quadratic surface, which usually works well for process optimization. The face centered, central composite design is shown in Fig.6.1.

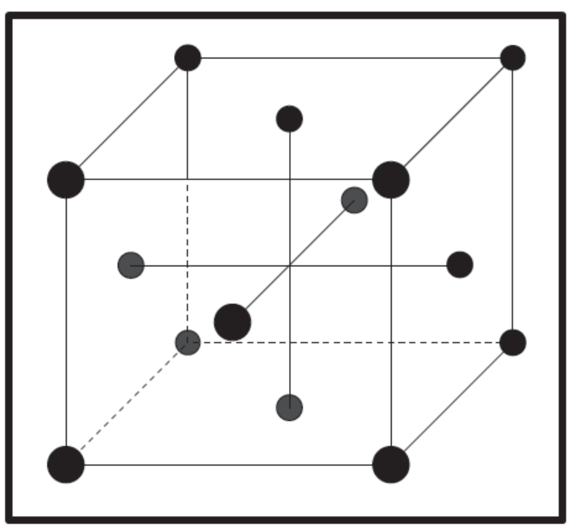

Fig. 6.1: Face centered central composite design.

Table 6.1 presents the levels of three process parameters i.e. load, wt.% of TiC particles and sliding distance and their ranges. The experimental plans were conducted using above mentioned conditions based on the face centered, central composite design and total of 20 experimental data were produced in the coded form as shown in Table 6.2. The face centered, central composite design contains an embedded factorial design with centre points. It is used to find the best set of values, for a set of factors, giving an optimal response as suggested by Pabari et al. (2012). The design was developed and analyzed using MINITAB 16 statistical package. MINITAB 16 is used for statistical data analysis and helps in analyzing and interpreting the results with confidence.

6.1.2 Response surface methodology and optimization

Response surface methodology is a compilation of mathematical and statistical techniques that are used for modeling and establishing the relationships between the process parameters and responses with a minimum number of experiments (Montgomery, 1997). The various process parameters selected were load, weight percentage of TiC particles and sliding distance whereas the responses were volume loss and coefficient of friction (COF). In order to find out the relationship between the process parameters and the responses, second order polynomial response surface mathematical model given below has been used.

$$Y_u = b + \sum b_i x_{iu} + \sum b_{ii} x^2{}_{iu} + \sum b_{ij} x_{iu} \quad (6.1)$$

where Y_u is the response variable (volume loss and coefficient of friction), b is the constant whereas, b_i, b_{ii} and b_{ij} are the linear, quadratic and interaction coefficients. In the above polynomial equation the second term under summation sign denotes the linear effect, the third term corresponds to the higher order effect and the fourth term is attributed to the interaction effect. The analysis of variance (ANOVA) was carried out on each model to validate the models with a confidence level of 95%. By using the MINITAB software, the response surface plots and contour plots were plotted to understand the effect of processing parameters on the responses. Optimization plots were also generated so to minimize the wear and coefficient of friction of the composites.

Table 6.1 Wear test parameters and their coded values.

Parameters	Units	Notations	Levels		
			Low (-1)	Medium (0)	High (+1)
Load	N	A	10	15	20
wt.% of TiC	%	B	0	2	4
Sliding distance	M	C	750	1500	2250

Table 6.2 Design layout and experimental results of wear tests of composites.

Run order	Process variable			Response	
	Load (N)	wt.% of TiC (%)	Sliding distance (m)	Volume loss (mm^3)	COF
1	0	0	0	2.865	0.620
2	0	1	0	0.887	0.740
3	-1	-1	-1	1.569	0.820
4	-1	1	1	0.929	0.830
5	1	1	1	2.402	0.880
6	1	0	0	3.552	0.720
7	-1	0	0	1.788	0.690
8	0	0	1	4.221	0.809
9	0	-1	0	4.510	0.650
10	0	0	-1	1.623	0.760
11	1	1	-1	0.703	0.900
12	0	0	0	2.865	0.620
13	1	-1	1	7.784	0.810
14	0	0	0	2.865	0.620
15	0	0	0	2.865	0.620
16	0	0	0	2.865	0.620
17	1	-1	-1	2.365	0.810
18	-1	-1	1	4.847	0.800
19	-1	1	-1	0.309	0.880
20	0	0	0	2.865	0.620

6.1.3 Design of experiment (DOE) for volume loss

Table 6.2 presents the experimental data generated from the face centered CCD on volume loss and coefficient of friction at different combination of the independent variables on the composites. It can be observed from the Table 6.2 that lowest wear volume loss of the composite was 0.309 mm^3 at 10 N load, 4 wt. % TiC and 750 m sliding distance, whereas the lowest coefficient of friction was 0.620 at 15 N load, 2 wt. % TiC reinforcement and 1500 m sliding distance. The analysis of variance (ANOVA) and estimated regression coefficient for wear volume loss of composites are presented in Tables 6.3.

6.1.4 Design of experiment (DOE) for coefficient of friction

The analysis of variance (ANOVA) and estimated regression coefficients for coefficient of friction of composites are presented in Table 6.4. The predictability of the model for COF is at 95% confidence level.

6.1.5 Regression analysis

To establish the relationship among the wear parameters (load, wt. % of TiC and sliding distance) and the response variables (volume loss and coefficients of friction), linear regression models were developed using MINITAB16 software (Minitab Inc. 2000). The developed regression analysis can be effectively used to predict the volume loss and coefficient of friction of composites at 95% confidence level. The regression equation of volume loss and coefficient of friction for composites are given in equations (6.2 and 6.3):

Volume loss (mm^3) = -1.79194+ (0.243931)*Load (N) + (0.501772)*wt.% of TiC(%) + (0.000859721)*Sliding distance (m) + (-0.00703600) Load (N)*Load (N) +(-.0367833) Wt.% of TiC (%)*wt. % of TiC (%) + (0.0000001360) Sliding distance (m)* Sliding distance (m) + (-0.0233136)*Load (N)*wt. % of TiC (%) +0.000107354)*Load (N)*Sliding distance (m) + (-0.000531461)*wt.% ofTiC(%)*Sliding distance (m) (6.2)

Coefficient of friction = 1.60076+ (-0.0589773)*Load + (-0.0271477)*wt. % of TiC (%) + (-0.00069825)* sliding distance (m)+(0.0018909)*Load (N)*Load(N) + (0.00931818)*Wt.% of TiC (%)*Wt.% of TiC(%) + (0.000000225374) Sliding distance (m)* Sliding distance (m) +(0.000875000)*Load (N)*wt. % of TiC (%) + (0.00000166667)*Load (N)*Sliding distance (m) + (0.00000416667)*wt.% of TiC (%)*Sliding distance(m) (6.3)

The obtained mathematical models indicate the degree of significance of the linear terms, square terms and interaction terms on the wear behavior of the composites. The plot between the measured and predicted values of the volume loss and coefficient of friction used for the 20 experiments are presented in Figs.6.2 (a) and (b). These plots show that experimental and predicted values lies on a straight line and there is linearity between the experimental and predicted values.

6.1.6 Confirmation test

For the confirmation of second order response surface quadratic model, three confirmation experiments were performed for the volume loss and coefficient of friction in order to verify the adequacy of obtained quadratic model. The predicted values for volume loss and COF are compared with the measured value and the difference between the two values is presented in Table 6.5.The percentage error was calculated by using the equation (6.4)

$$\text{Percentage error} = \frac{\text{Estimated values} - \text{Predicted values}}{\text{Predicted values}} \times 100 \qquad (6.4)$$

The maximum and minimum percentage errors in case of experimental volume loss and predicted volume loss are 12.63 and 1.10, where as the maximum and minimum percentage errors in case of coefficient of friction are 13.04 and -11.65, respectively.

Table 6.3 Analysis of variance and estimated regression coefficients for volume loss of composites.

Source	DF	Seq.SS	Adj.SS	Adj.MS	F	P
Regression	9	56.1766	56.1766	6.2418	187.25	0.000
Linear	3	49.0619	49.0619	16.3540	490.60	0.000
Load (N)	1	5.4210	5.4210	5.4210	162.63	0.000
wt.% of TiC (%)	1	25.1068	25.1068	25.1068	753.18	0.000
Sliding distance (m)	1	18.5341	18.5341	18.5341	556.00	0.000
Square	3	0.2992	0.2992	0.0997	2.99	0.082
Load (N)* Load (N)	1	0.2382	0.0851	0.0851	2.55	0.141
wt.% of TiC (%)*wt.% of TiC (%)	1	0.0449	0.0595	0.0595	1.79	0.211
Sliding distance (m)* Sliding distance (m)	1	0.0161	0.0161	0.0161	0.48	0.503
Interaction	3	6.8155	6.8155	2.2718	68.15	0.000
Load (N)* wt.% of TiC (%)	1	0.4348	0.4348	0.4348	13.04	0.005
Load (N)* Sliding distance (m)	1	1.2966	1.2966	1.2966	38.90	0.000
wt.% of TiC (%)* Sliding distance (m)	1	5.0841	5.0841	5.0841	152.52	0.000
Residual error	10	0.3333	0.3333	0.3333		
Lack of fit	5	0.3333	0.3333	0.0667		
Pure error	5	0.0000	0.0000	0.0000		
Total	19	56.5099				

Table 6.3 (Continued)

Estimated regression coefficient for volume loss

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	-1.79194	0.06277	45.529	0.000
Load (N)	0.243931	0.05774	12.752	0.000
wt.% of TiC (%)	0.501772	0.05774	-27.444	0.000
Sliding distance (m)	0.000859721	0.05774	23.580	0.000
Load (N)* Load (N)	-0.00703600	0.11010	-1.598	0.141
wt.% of TiC (%)*wt.% of TiC (%)	-0.0367833	0.11010	-1.336	0.211
Sliding distance (m)* Sliding distance (m)	0.0000001360	0.11010	0.695	0.503
Load (N)* wt.% of TiC (%)	-0.0233136	0.06455	-3.612	0.005
Load (N)* Sliding distance (m)	0.000107354	0.06455	6.237	0.000
wt.% of TiC (%)* Sliding distance (m)	-0.000531461	0.06455	-12.350	0.000

S = 0.182577; R-Sq. = 99.41%; R-Sq. (pred) = 91.54%; R-Sq. (adj) = 98.88%.
DF: degrees of freedom, Seq SS: sequential sum of squares, Adj SS: adjusted sum of squares, Adj MS: adjusted mean squares.

Table 6.4 Analysis of variance and estimated regression coefficient for coefficient of friction (COF).

Source	**DF**	**Seq.SS**	**Adj.SS**	**Adj.MS**	**F**	**P**
Regression	9	0.187322	0.187322	0.020814	29.87	0.000
Linear	3	0.012728	0.012728	0.004243	6.09	0.013
Load (N)	1	0.001000	0.001000	0.001000	1.44	0.259

wt.% of TiC (%)	1	0.011560	0.011560	0.011560	16.59	0.002
Sliding distance (m)	1	0.000168	0.000168	0.000168	0.24	0.634
Square	3	0.173357	0.173357	0.057786	82.93	0.000
Load (N)* Load (N)	1	0.106142	0.006145	0.006145	8.82	0.014
wt.% of TiC (%)* wt.% of TiC (%)	1	0.023018	0.003820	0.003820	5.48	0.041
Sliding distance (m)* Sliding distance (m)	1	0.044196	0.044196	0.044196	63.43	0.000
Interaction	3	0.001238	0.001238	0.000413	0.59	0.634
Load (N)* wt.% of TiC (%)	1	0.000613	0.000613	0.000613	0.88	0.371
Load (N)* Sliding distance (m)	1	0.000312	0.000312	0.000312	0.45	0.518
wt.% of TiC (%)* Sliding distance (m)	1	0.000313	0.000313	0.000313	0.45	0.518
Residual error	10	0.006968	0.006968	0.000697		
Lack of fit	5	0.006955	0.006955	0.001391		
Pure error	5	0.000013	0.000013	0.000003		
Total	19	0.194291				

Table 6.4 (Continued)

Estimated regression coefficient for COF

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	0.635491	0.009075	70.028	0.000
Load (N)	0.010000	0.008348	1.198	0.259
wt.% of TiC (%)	0.034000	0.008348	4.073	0.002

Sliding distance (m)	-0.004100	0.008348	-0.491	0.634
Load (N)* Load (N)	0.047273	0.015918	2.970	0.014
wt.% of TiC (%)* wt.% of TiC (%)	0.037273	0.015918	2.342	0.041
Sliding distance (m)* Sliding distance (m)	0.126773	0.015918	7.964	0.000
Load (N)* wt.% of TiC (%)	0.008750	0.009333	0.938	0.371
Load (N)* Sliding distance (m)	0.006250	0.009333	0.670	0.518
wt.% of TiC (%)* Sliding distance (m)	-0.006250	0.009333	-0.670	0.518

S = 0.0263974; R-Sq. = 96.41%; R-Sq. (pred) = 90.21%; R-Sq. (adj) = 93.19%
DF: degrees of freedom, Seq SS: sequential sum of squares, Adj SS: adjusted sum of squares, Adj MS: adjusted mean squares

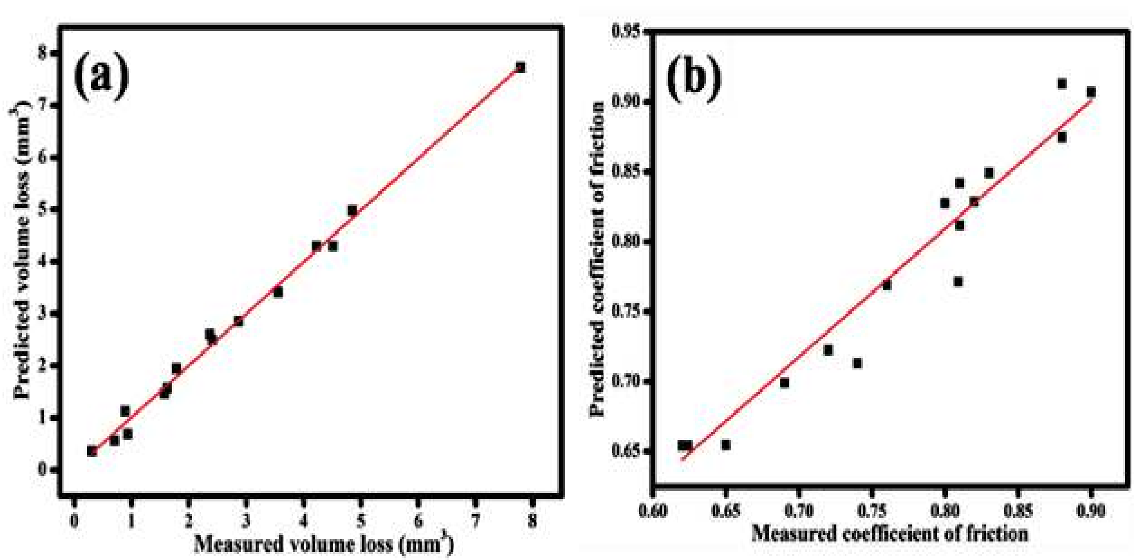

Fig.6.2: (a) Measured and predicted values of the volume loss; and (b) measured and predicted values of the coefficient of friction.

Table 6.5 Results of confirmation experiment and their comparison with regression analysis.

Run order	Load (N)	wt. % of TiC (%)	Sliding Distance (m)	Volume loss (mm^3)	Predicted volume loss (mm^3)	% Error of volume loss	COF	Predicted COF	% Error of COF
1	7.5	0	375	0.321	0.285	12.63	0.91	1.03	-11.65
2	12.5	2	1125	1.992	1.884	5.73	0.78	0.69	13.04
3	22.5	4	1875	2.193	2.169	1.10	0.84	0.93	-9.67

6.1.7 Effect of process parameters on volume loss and coefficient of friction

The response surface plots have been generated by using MINITAB software for the models discussed above. In generating response surface plots, two process parameters are in the middle level and these are plotted in 'X' and 'Y' axis and responses are taken on the 'Z' axis. The surface plots clearly indicate the optimal response point and thus it helps in understanding the effect of parameters on the responses. A contour plot not only helps in visual demonstration of the area of optimal factor settings but also gives an idea whether an optimum point is situated with sensible accuracy by observing the shape of the surface.

Figures 6.3 to 6.8 illustrate the response surface plots and contour plots for volume loss and coefficient of friction generated for all pairs of process parameters. In all the figures presented capital letters "L" and "H" indicate the lowest and the highest cumulative volume loss and coefficient of friction, respectively. The results of all the interactions of test variables on the volume loss and coefficient of friction can be obtained from these response surface plots and contour plots. Figure 6.3 shows the surface and contour plots of the interaction of TiC wt. % and sliding distance and its effect on the wear volume loss. It is evident from the Fig. 6.3 that as the wt.% of TiC increases the volume loss decreases whereas the volume loss increases with sliding distance. The surface and contour plots of the interaction of TiC wt.% and load and its effect on the wear volume loss is illustrated in Fig. 6.4. It is clear from the Fig. 6.4 that as the wt.% of TiC increases its volume loss decreases while volume loss increases with increase in the load. Similarly Fig.6.5 shows the surface and contour plots of the interaction of load and sliding distance and its affect on the volume loss. As the load and sliding distance increases the volume loss increases.

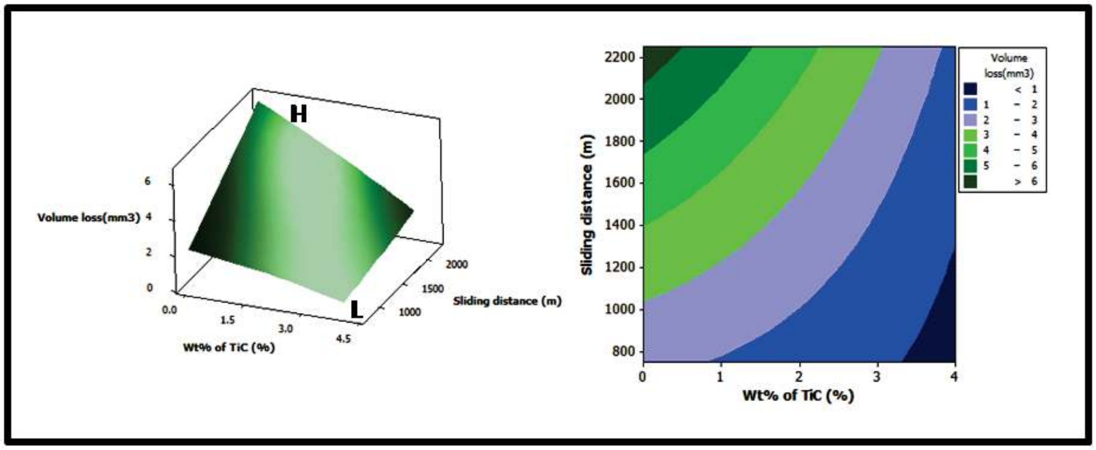

Fig.6.3: Surface plots and contour plots of the combined effects of wt.% of TiC and sliding distance on volume loss of composites.

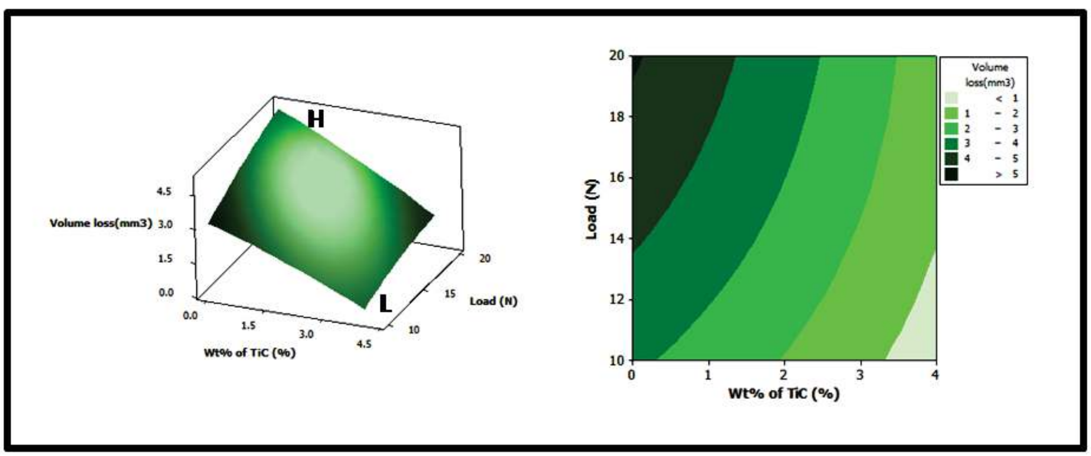

Fig.6.4: Surface plots and contour plots of the combined effects of the wt.% TiC and load on volume loss of composites.

The surface and contour plots of the interaction of the weight percentage of TiC reinforcement and sliding distance and its effect on the coefficient of friction are presented in Fig.6.6.

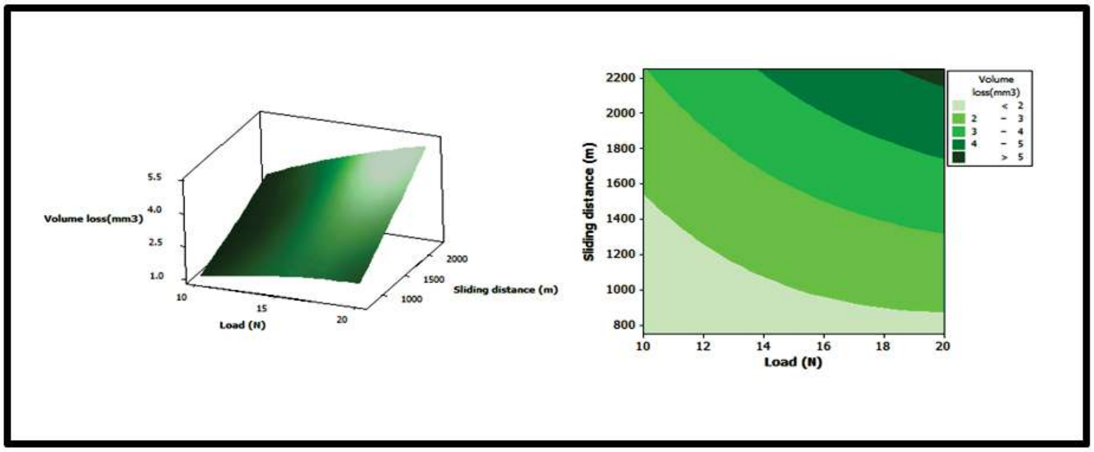

Fig.6.5: Surface plots and contour plots of the combined effects of the load and sliding distance on volume loss of composites.

One can observe that friction coefficient increases with increasing weight percentage of TiC. The surface and contour plots of the interaction of the wt.% of TiC and load and its effect on the coefficient of friction are shown in Fig.6.7. It can be observed that COF increases with increase in wt.% of TiC and load. Figure 6.8 depicts the surface and contour plots of the interaction of the load and sliding distance and its effect on the coefficient of friction.

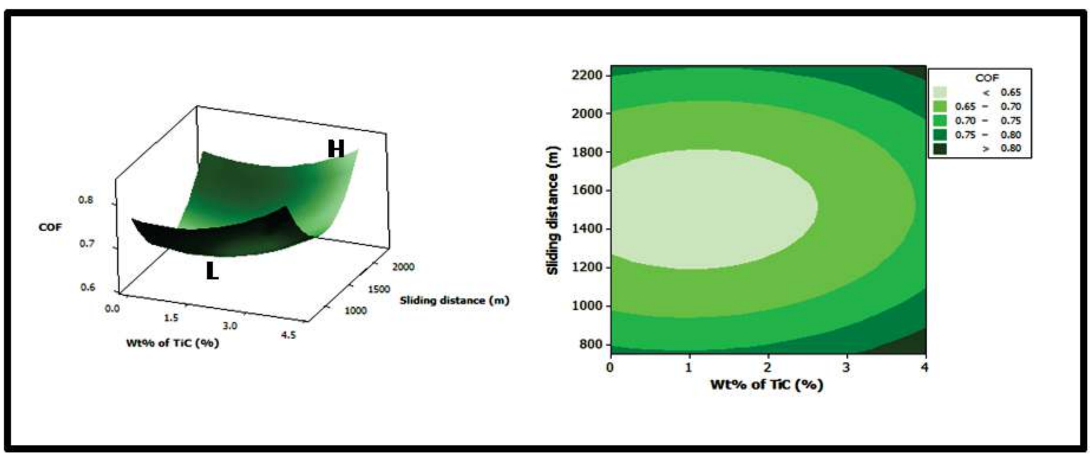

Fig.6.6: Surface plots and contour plots of the combined effects of the wt.% of TiC and sliding distance on coefficient of friction of composite.

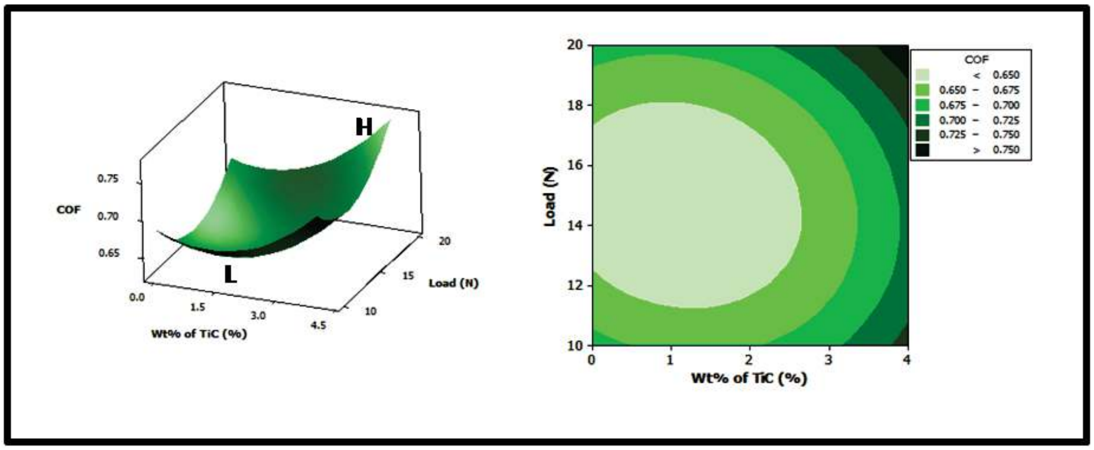

Fig.6.7: Surface plots and contour plots of the combined effects of the the wt.% TiC and load on coefficient of friction of composites.

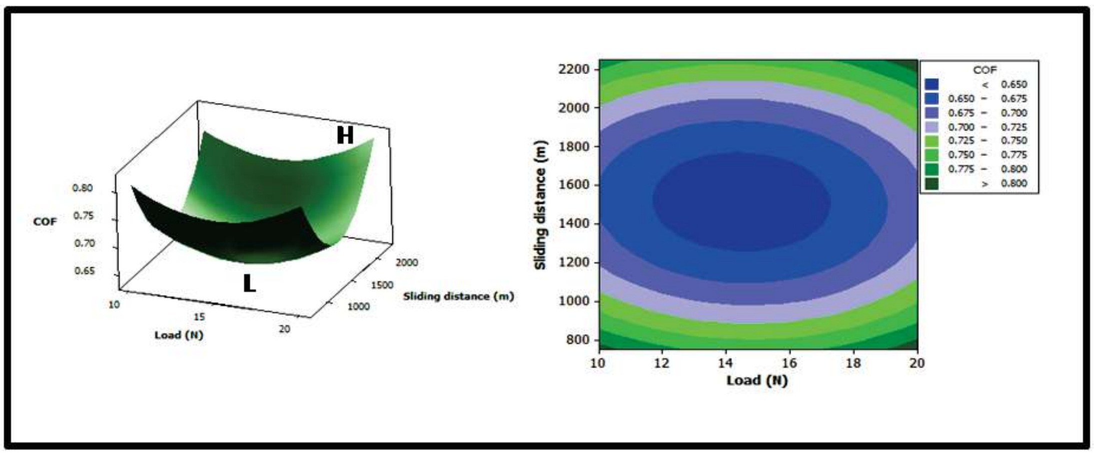

Fig.6.8: Surface plots and contour plots of the combined effects of the load and sliding distance on coefficient of friction of composites.

6.1.8 Optimization of responses

One of the major benefits in using response surface methodology is that it helps in optimizing responses by manipulating the process parameters. The use of desirability function based optimization techniques for multi-response optimization problems have been advocated by investigators (Chang et al. 2014; Montgomery et al.1997; Chauhan et al. 2012). It is a known fact that the frictional and wear behavior not only on the material properties but the sliding conditions also play a major role in process of wear. If one wants to enhance the service life span of materials by reducing its wear and friction then it is necessary to choose optimum process parameters i.e. load, weight percentage of reinforcement and sliding distance. The desirability function was then maximized to predict the optimum control factors. In the present work, volume loss and coefficient of friction were both optimized by the response optimizer option of MINITAB software. Table 6.6 depicts the target value along with upper value for both volume loss and coefficient of friction of composites.

Table 6.6 The target value and upper value of responses of composites.

Responses	Target value	Upper value
Volume loss (mm^3)	0.309	7.784
COF	0.620	0.90

The optimization plot of the responses of composites is presented in Fig.6.9. The optimum values for the input parameters can be seen in the plot which is 12.7273 N for load, 2.8283 wt% for the TiC content and 1431.81 m for the sliding distance.

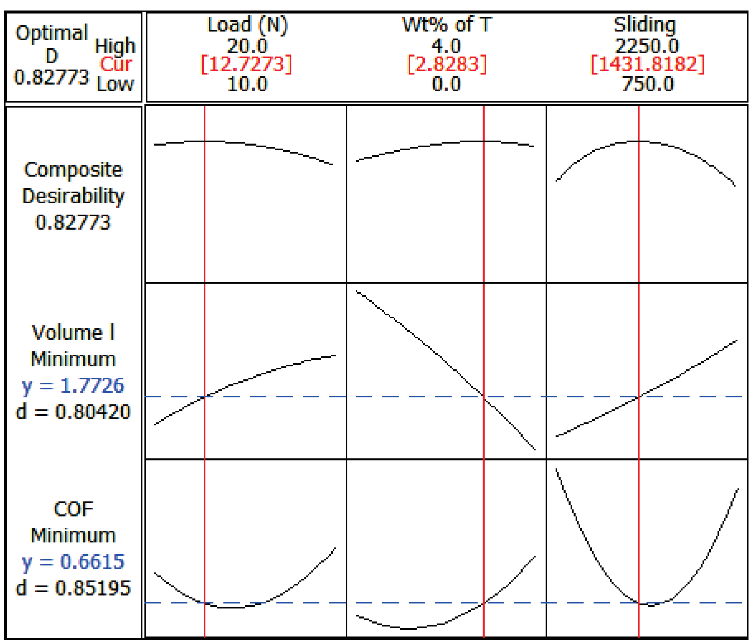

Fig.6.9: Optimal conditions of process variables on the responses of composites.

6.2 DISCUSSION

Central composite design helps in estimating the first and the second-order terms. Face centered, central composite design is shown in Fig. 6.1. The factorial portion of central composite design is a type of full factorial design having factors at two levels (high, +1 and low, -1) and composed of the eight star points, and six central points (coded level 0) which is the midpoint between the high and low levels. The star points are positioned at the face of the cubic portion on the design which correspond to an α value of 1 and this type of design is usually known as the face centered, central composite design (CCD). Levels of three process parameters i.e. load, wt.% of TiC particles and sliding distance and their ranges are shown in Table 6.1. These are necessary input parameters for the modeling. Table 6.2 presents the design layout and experimental results obtained from face centered, central composite design (CCD). It was found that the face centered, central composite design (CCD) is very well fitted to the second order response surface. Face centered central composite design finds importance over the entire design space because it affords comparatively high quality prediction (Chauhan et al. 2012).The design was developed and analyzed using MINITAB 16 statistical package. RSM provides quantitative measurements of possible interactions between factors, which are difficult to obtain using other optimization techniques and it is the right procedure to deal with the responses influenced by multi-variables as envisaged by Huiping et al. (2007), also. Also, this method significantly reduces the number of trials that are required to respond to a model as suggested by Velamanirajan et al. (2012).

Analysis of variance and estimated regression coefficients for volume loss of composites are depicted in Table 6.3. The P-value of each factor shows its significance level; that is, suitable or unsuitable. The P-value is a measure of how likely the sample results are, assuming that the null hypothesis is true. P-values range from 0 to 1. A small P-value (<0.05 or 0.1, a commonly used level of significance) indicates that the control factor has a statistically significant effect on the result. It is clear from the last column of the ANOVA Table 6.3, that P value of the load, wt. % of TiC and sliding distance is zero. Similarly the interaction of various process parameters is also zero or less than 0.05.The terms having P value < 0.05 have a major influence on the response variables whereas those with a P value > 0.05 do not significantly affect the response variables. The R^2 and adjusted R^2 values are found to be 99.41% and 98.88%, respectively, which are very close to each other confirming thus, that the developed regression analysis predicts well the relation between the volume loss and the process parameters such as load, wt. % of TiC and sliding distance.

Analysis of variance and estimated regression coefficient for coefficient of friction (COF) are shown in Table 6.4. It is clear from the last column of the ANOVA table that P value for the linear terms such as wt. % of TiC is 0.002 which is less than 0.05 suggesting that wt.% of TiC has a significant influence on the coefficient of friction. While other terms such as load and sliding distance have P value of 0.259 and 0.634, indicating that these do not affect the coefficient of friction of composites in a significant manner. Similarly, the square terms (load*load), (wt. % of TiC*wt. % of TiC) and (sliding distance*sliding distance) have also a more pronounced effect on the coefficient of friction as evident from their P values given in Table 6.4. The P values of interaction terms load (N)* wt.% of TiC (%) is 0.371, load (N)* sliding distance (m) is 0.518 and wt.% of TiC*sliding distance is 0.518, suggesting that interaction terms negligibly affect the coefficient of friction. The R^2 and adjusted R^2 values obtained from the significance test are 96.41% and 93.19%, respectively, which are fairly close to each other and it reveals that the developed regression analysis predicts well the relation between the coefficient of friction and process parameters.

It can be observed from Eq. (6.2) that linear terms (load and wt.% of TiC) and interaction terms have more prominent effect on the volume loss whereas square terms has less influence. Similarly, it can be inferred from equation (6.3) that linear and square term affects the coefficient of friction more rather than interaction terms. It is clear from Fig. 6.2 that there is substantial linearity in the relation among the measured and predicted values of volume loss and coefficient of friction of the composites. Further it can be concluded from the Table 6.5 that the predicted values are closer to the measured values with a confidence level of 95%. It is also indicative of the adequacy of the regression model.

It can be observed from Fig.6.3 that as the weight percentage of TiC increases in the matrix alloy its wear volume loss decreases. The decreases in the volume loss can be attributed to the other factors encountered during sliding. It may be due to the abrasive action caused by the TiC particle. This can be credited to the fact that TiC reinforcement in the composite may possibly act as a load sustaining element and these hard particles defend against wear and protect the surface (Kumar et al., 2013). As sliding distance increases, it increases the samples' sliding wear duration and as a result causes the wear volume loss. It can be inferred from Fig. 6.4 that as load increase volume loss of the composites increases while volume loss decreases with increase in weight percentage of TiC reinforcement. When the load increases, it helps to increase the real area of contact between specimen and counter-face. This phenomenon gives rise to severe plastic deformation and consequently leads to larger removal of material from the specimen's surface. The relation between the volume loss of the composites with load and sliding distance can be described according to Archard's equation (Archard, 1953) as stated below:

$$w = k\frac{LS}{H} \tag{6.5}$$

where W is wear volume loss, K is the wear coefficient, L is the applied load, S is the sliding distance and H is the hardness of the softer material. According to this equation (6.5), the wear volume loss is directly proportional to load and sliding distance while inversely proportional to hardness. Fig.6.5 shows the surface plots and contour plots of the combined effects of the load and sliding distance on volume loss of composites. It is earlier explained the effect of load and sliding distance on the volume loss.

Figure 6.6 depicts the surface plots and contour plots of the combined effects of the wt. % of TiC and sliding distance on coefficient of friction of composites. As the weight percentage of TiC increases coefficient of friction increases. This can be attributed to the fact that at any particular instant a little TiC particles may be entrapped between the sliding surfaces which promotes the three body abrasion and hence coefficient of friction increases. It can be observed that sliding distance has non uniform effect on the coefficient of friction. The reason for this fluctuating effect can be due to the presence of particles coming out during dry sliding wear. The other cause for the fluctuating effect can be the disparity in contact that occurs when the sample and the counterface are evolving to develop a better surface conformity. From the Fig. 6.7 it can be observed that COF increases with increases in wt.% of TiC and load. Coefficient of friction increases with increase in load and this can be due to the more real area of contact at higher load and this type of contact give rise to more surface asperity contact and hence coefficient of friction of the composites increases. Figure 6.8 shows the surface plots and contour plots of the combined effects of the load and sliding distance on coefficient of friction of composites. It is explained earlier.

For the optimization process MINITAB 16 software has been used and three factors lower, upper and target values are taken from the experimental results which fulfill the aim and create desirability indices (Singh et al.2106).Table 6.6 depicts the target value along with upper value for both the volume loss and the coefficient of friction of composites. Prior to the setting of value of desirability function, the response surface regression modeling was carried out by using 'Analyze response surface design' option in MINITAB software and ‘Full quadratic’ term was used for generating response surfaces and the response surface regression equations. The main aim of the experiments was to reduce the wear and friction of the composites. For that reason, the target value of the responses is the lowest values taken from the experimental data. The optimization plot of the responses of composites is presented in Fig.6.9. It is clear from the optimization plot that the optimum predicted condition of the independent variables to yield lowest responses of volume loss and the lowest coefficient of friction are 12.72 N, 2.82 wt.% TiC and 1431.82 m sliding distance with a composite desirability of 0.82773.

In this chapter modeling of the dry sliding wear of synthesized composites is performed through face centered, central composite design using response surface methodology (RSM). Load, weight percentage of TiC particles reinforcement and sliding distance were considered as input parameters and volume loss and coefficient of friction were taken as response variables. ANOVA results have been used to check the adequacy of the developed model and it has been concluded that linear and interaction terms have significant influence on the volume loss while the linear and square terms affect the coefficient of friction of the composites. Developed mathematical models have the potential to evaluate the volume loss and coefficient of friction of composites with fairly good accuracy.