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Effect of Input Process Parameter on the Adhesion Wear Characteristics of Ti-3Al-2.5V Alloy: A Statistical Approach

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Abstract: Current study focused on the effect of process variables namely normal load, sliding velocity, and sliding distance on wear characteristics of Ti-3Al-2.5V alloy. Wear study has been accomplished through pin on disc method in order to determine the specific wear rate of the titanium alloy. A central composite design (CCD) and ANOVA technique was performed to ascertain an outcome of process parameters on specific wear rate. The worn out samples were analyzed using scanning electron microscope (SEM). Study results indicated that amongst process variables, normal load is the most significant factor that influences the dry sliding wear behaviour of the alloy. however, wear rate of the alloy found to be increases with increasing the normal load and sliding velocity. Microstructure study explained the possible mechanism resulting in the behavior of the alloys.

Keywords: Titanium Alloy, Specific wear rate, RSM, SEM

I. INTRODUCTION

Light weight materials play a vital role in aerospace and automobile sectors due to their excellent combination of properties. Among the alloy materials available, titanium alloys in different grades are mostly used in various engineering applications due to high strength cum low density property. Very important application of the Titanium alloys lies in the field of Bio-medical application owing to its outstanding corrosion resistant to human body which made them as special class of attractive material. Most of the researchers reported that Galling, abrasive wear, plastic deformations are some of the wear mechanisms observed during the dry sliding wear of titanium alloys under different condition [3, 4, 5]. Though most of the authors studied the effect of sliding distance and load on wear behavior of titanium alloys but its effect at different working environments viz., atmospheric, vacuum, High temperature condition, simulated body fluid and cryogenic conditions has been merely explored [6, 9]. Chauhan, et al [17] studied the dry sliding wear behaviour of titanium alloy using response surface methodology. Sahoo, et al [18] discussed the effect of microstructure on dry sliding wear behaviour of titanium alloy.

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Sharma, et al [19] reported the tribological behaviour of Ti-3Al-2.5V alloy sliding against EN32 steel disc of hardness 62HRC, under dry sliding condition. In 2016, Sharma, et al [20] investigated the optimization of friction and wear characteristics of Ti-3Al-2.5V alloy sliding against EN32 steel disc of hardness 62HRC, under dry sliding condition.

It is clearly evident from the literature survey that very few studies have been explored on the wear behavior of Ti-3Al-2.5V alloy. Thus main work of this current study pertains to development of a mathematical model to predict the specific wear rate of Ti-3Al-2.5V alloy and analyse the effect of load, sliding distance and sliding speed on it.

II. MATERIALS AND EXPERIMENTAL METHOD:

Materials

In this study commercially available Ti-3Al-2.5V alloy with chemical composition as listed in the Table 1 was used as the work piece. The EN32 steel material was selected as counterface because it possesses higher hardness than the selected work piece (titanium alloy). A pin on disc tribometer setup was used to carry out the experiments as shown in Fig. 1

Table. 1 Ti-3Al-2.5V alloy and its chemical composition

Elements	Al	V	Fe	O	N	Ti
%	2.90	2.47	0.03	0.010	0.015	94.5

Wear Test using Pin on Disc apparatus

Wear test was performed under dry sliding conditions in accordance to ASTM G99 standard using pin-on-disc tribometer. Figure 1 shows the setup of pin-on-disc apparatus used for carrying out the experiments. Specific wear rate was measured for the different levels of input parameters. Hardened steel E32 used as a counterface

material against titanium specimen under different load and velocity conditions. Wear on the specimen eventually takes place at the interface of specimen and steel disc. Initially the specimens were cleaned with acetone and dried thoroughly before the test. Also, the counterface was polished using different grades of emery sheets for the removal of debris spread over the disc. The electronic weighing machine with an accuracy of 0.0001g was used to measure the mass loss of the specimens. The specific wear rates are calculated using the Eq.(1)

$$K_s = \frac{\Delta M}{\rho L F V} \quad (1)$$

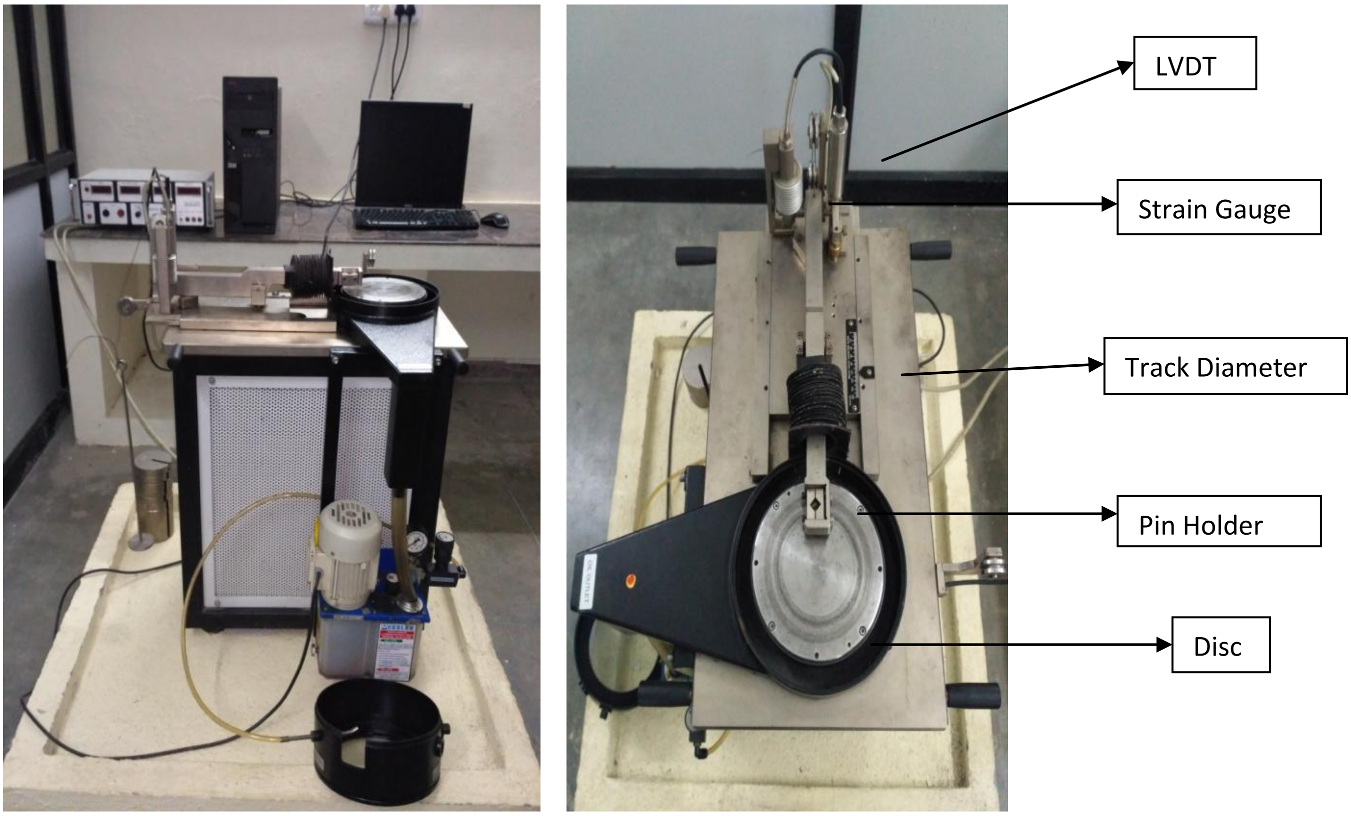


Fig. 1 Pin-on-disc tribometer setup

Fig. 2 Prepared Wear specimens

Design of experiments using Response Surface Methodology

Response surface methodology is a technique used to predict the relationship between input parameters and desired output performance based on the experimental runs performed. A statistical software Design expert 10 was used to design the experiments. Central composite design under RSM was selected and it generated 20 experimental runs for three factors and its three levels and it is detailed in the Table 2.

The experimental design and a result has been listed in Table 3. The objective function of the optimization is to reduce the wear rate of the titanium alloy thus second order polynomial regression equation as shown in Eq. (1)
and (2) has been developed to predict the specific wear rate of titanium alloy by correlating the input parameters.

Table. 2 Wear parameters and their levels

Factors	Units	Low level (-1)	Medium level (0)	High level (1)
Normal Load (A)	N	50	70	90
Sliding Velocity (B)	m/s	2	4	6
Sliding Distance (C)	m	1000	1500	2000

Table 3. Specific Wear Rate of Ti-3Al-2.5V alloy.

Runs	Load	Sliding Velocity	Sliding Distance	SWR
	(N)	(m/s)	(m)	(mm^3/Nm)
1	36	4	1500	0.0209
2	104	4	1500	0.032
3	70	4	660	0.0265
4	70	4	1500	0.028
5	50	2	1000	0.0234
6	70	4	1500	0.0276
7	50	6	2000	0.0251
8	70	4	1500	0.026
9	90	2	2000	0.032
10	70	4	1500	0.0275
11	50	6	1000	0.0271
12	90	6	1000	0.028
13	70	4	1500	0.0276
14	90	6	2000	0.0321
15	50	2	2000	0.0234
16	90	2	1000	0.0286
17	70	4	2341	0.0278
18	70	1	1500	0.0254
19	70	7	1500	0.03
20	70	4	1500	0.0275

III. RESULTS AND DISCUSSION

Analysis of Variance (ANOVA)

ANOVA is sought after statistical technique which is primarily used to determine the individual effects among input parameters on the output response. Analysis of average and ANOVA used for the interpretation of the experimental results to find out the most significant factors amongst the variables.

Table. 4 ANOVA for specific wear rate

Source	Sum of squares	df	Mean Square	F Value	Prob> F	
Model	1.528E-004	9	1.697E-005	23.85	< 0.0001	significant
A-Load	*1.193E-004*	*1*	*1.193E-004*	*167.68*	*< 0.0001*	significant
B-Sliding Velocity	*1.169E-005*	*1*	*1.169E-005*	*16.43*	*0.0023*	significant
C-Sliding Distance	*4.326E-006*	*1*	*4.326E-006*	*6.08*	*0.0334*	significant
AB	*4.351E-006*	*1*	*4.351E-006*	*6.11*	*0.0329*	significant
AC	*1.128E-005*	*1*	*1.128E-005*	*15.85*	*0.0026*	significant
BC	*2.112E-007*	*1*	*2.112E-007*	*0.30*	*0.5978*	
A^2	*8.593E-007*	*1*	*8.593E-007*	*1.21*	*0.2976*	
B^2	*5.636E-007*	*1*	*5.636E-007*	*0.79*	*0.3944*	
C^2	*1.576E-010*	*1*	*1.576E-010*	*2.214E-004*	*0.9884*	
Residual	7.116E-006	10	7.116E-007			
Lack of fit	*4.703E-006*	*5*	*9.405E-007*	*1.95*	*0.2408*	*not significant*
Pure error	*2.413E-006*	*5*	*4.827E-007*			
Cor total	1.599E-004	19				
S.D	8.436E-004		R-Squared		0.9555	
Mean	0.027		Adjusted R-squared		0.9154	
C.V %	3.09		Predicted R-squared		0.7460	
PRESS	4.061E-005		Adeq precision		17.352	

It is observed from the ANOVA table that, R^2 and adjusted R^2 value obtained from the significance test were 95.5 and 91.5% respectively. The parameters are tested for the significance level of 5% and 95% confidence level (Table 4). Significant parameters are included in the model and the insignificant parameters are removed without affecting the accuracy of the developed model. Analysis of variance (ANOVA) for specific wear rate is reported in the Table 4.The lack of fit has an F value of 1.95, which is less than the standard F value of 5.05 for the 95% confidence level, hence the developed model is adequate to predict the specific wear rate of titanium alloy within these input parameters and their levels. Also it is observed that load contributes more on specific wear rate followed by the sliding distance and sliding speed. From the Fig. 3 it is clearly evident that there lies a good relationship between the specific wear rate and predicated specific wear rate since the values were scattered on the both side of the line and more clearly the slope is close to unity as indicted in the graph.

Therefore, the obtained quadratic model for specific wear rate in terms of coded and actual factors are shown as follows:

Specific wear rate in terms of coded factors

$$SWR=0.027+0.00295\times F+0.000925\times N+0.000562\times L-0.000737\times F\times N+0.00118\times F\times L-0.000162\times L\times N-0.000244F^2+0.000197N^2+0.0000330L^2 \quad (2)$$

Specific wear rate in terms of actual factors

$$SWR=0.0176+0.000288\times F+0.0000160\times N+0.000000657\times L-0.00000184\times F\times N+0.000000118\times F\times L-0.0000000162\times L\times N-0.000000610F^2+0.0000000494N^2+0.00000000132L^2 \quad (3)$$

Where F is the normal load, L is the sliding distance and V is the sliding velocity.

Dry Sliding Wear Characteristics

Set of limited experimental run generated by the design expert software in accordance to the central composite design were carried out using pin on disc apparatus. Experimental study showed that wear characteristics are not only dependent on input process parameters and above them, other factors like, surface roughness, composition of the disc material, geometry of contact will also affect the wear performance and this is strongly holds good with discussion made by the previous researchers.

Influencing parameters on specific wear rate were investigated using the response surfaces plot generated by RSM and shown in (Figs 3-6) respectively. (Fig 3) shows the relationship between the actual the predicted response increase in load at all levels of sliding velocities (Fig 4). Further any increase in the load upsurges temperature at the specimen and counterface which eventually result in the tremendous improvement in the wear rate. In support of this hypothesis Ming et al [9] and Chen et al [16] have also reported similar observation. They stated that wear rate increases due to the continous contact of specimen with the counterface. From the plot it is clearly evident that, high wear rate observed when the disc is traversing at the velocity 6 m/s with an applied load of 90 N, due to which contact surface of between the specimen and counterface (disc) increases resulting in the wear loss from the specimen. Furthermore, result also showed that specific wear rate decreases by increasing the sliding distance at all levels of loads (Fig. 5). This may be attributed due to the presence of solid lubricants which is basically formed by the oxide layers. Figure (6) depicts wear rate increases with increase in sliding velocity and sliding distance. The reason behind this phenomenon is the temperature at the interface raises upto some level and gets oxidized because of its low thermal conductivity.

This oxidized surface becomes stable to some extent thereby reducing the wear rate. evident from the plot that specific wear rate increases with as a function of normal load and sliding velocity.

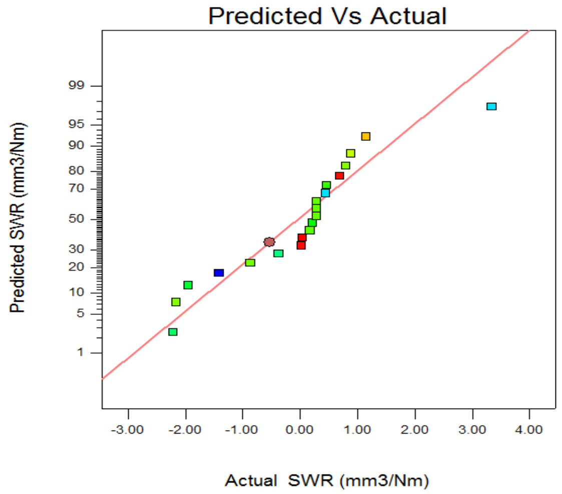


Fig. 4 Specific wear rate

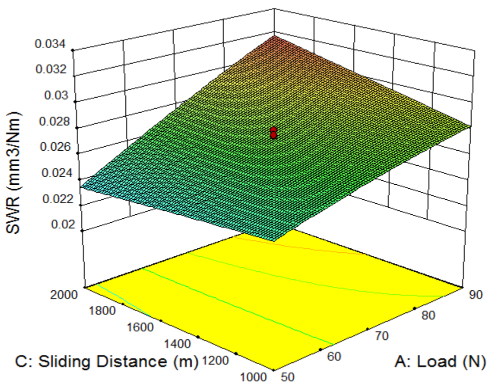


Fig. 5 Specific wear rate as a function of sliding distance and normal load.

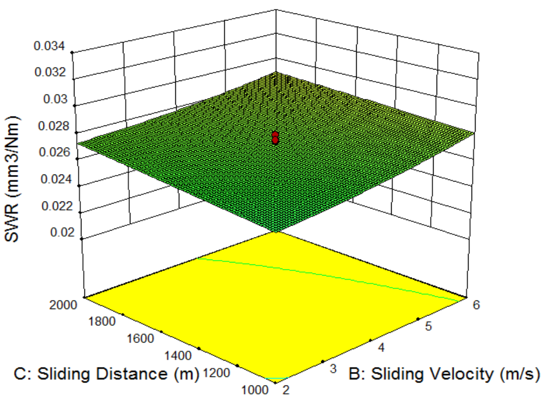
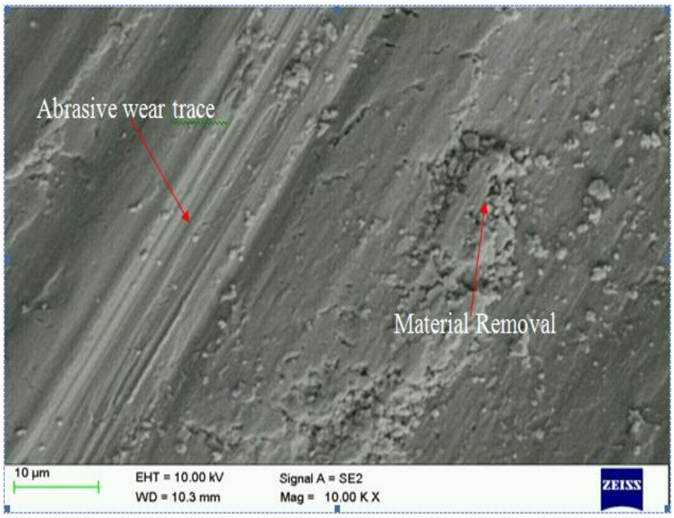


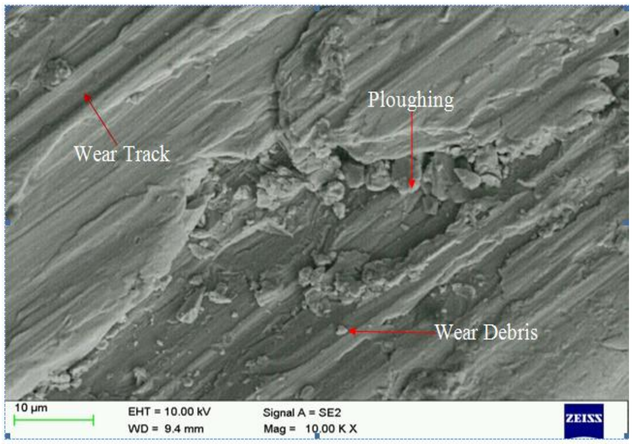
Fig. 6 Specific wear rate as a function of sliding distance and sliding velocity.

SEM Analysis

Microstructure of the worn-out surfaces were analyzed using scanning electron microscope (SEM). Figures 7(a) and 7 (b) presents SEM micrographs of titanium alloy at 6 m/s and load of (a) 50N and (b) 90N respectively. The wear mechanisms responsible for the loss of material during dry sliding of parent titanium alloy were studied using the morphology of worn out surfaces. The analysis of worn out surfaces generated during the wear test at 50N shows the wear tracks were formed due to Fray, abrasion and rupturing of matrix. The morphological analysis of worn out surfaces generated during 90N shows the formation of cracks, ploughing and severe delamination, this is due to the high temperature rise at the interfaces and presence of abrasive grooves aligned in the direction of sliding. Titanium alloy encountered adhesive and abrasive traces at low load conditions, whereas with an increase in load the worn surfaces became rougher. The main mechanism responsible for wear of titanium alloy is ploughing, oxidative wear and metallic delamination. The same wear patterns were observed by some investigators (Molinari et al (5) and Sahoo et al (18)).



(a)



(b)

Fig. 7 Worn surface at sliding speed of 6m/s and applied normal load of (a) 50N and (b) 90N respectively.

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Confirmation Test

The confirmation test was conducted to ensure the adequacy of a developed mathematical model with the experimental results. The values are shown in Table 5. The errors were calculated for specific wear rate based on the mathematical equations (2) & (3) with the experimental values. The error percentage of specific wear rate varied between 1.38% to 1.74%. Based on the results, the developed model can be suitable for prediction of wear rate.

Table 5. Confirmation tests and their results

S.No	Variables			Specific wear rate (mm^3/Nm)			
	A	B	C	Actual	Predicted	Residual	Error (%)
1	50	200	1000	0.0234	0.0230	0.0004	1.38
2	70	400	1500	0.0275	0.0270	0.0005	1.81
3	90	600	2000	0.0321	0.0315	0.0006	1.74

IV. CONCLUSION

From the wear investigation of the Titanium alloys the following inferences can be drawn:

- The applied load is considered to be the influencing factor which determine the dry sliding wear characteristic of titanium alloy followed by the sliding velocity and sliding distance.
- Peculiar wear morphology was noticed when the specimen travelled at low and high load conditions. Wear tracks were found at lower load condition whereas matrix rupture were dominant at higher load test. Besides, formation of cracks, deep grooves and severe delamination were also observed in SEM pictures.
- The developed model predicts well the relation between the predicted and the measured values, which indicates that this model can be effectively used for predicting the dry sliding wear characteristics of titanium alloy.
- The main mechanism responsible for wear of titanium alloy is ploughing, oxidative wear and metallic delamination.

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