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Study of Wear Characteristics of AISI D2 Steel

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Abstract :- Here AISI D2 steel is taken into consideration. Its use can be categorized into stamping die material which is being used in many cold roll forming and other press working industries. Its other names are high carbon & high chromium steel. On the pins of D2 steel and disks of Aluminum alloy 6061 the wear experiments were performed. To develop relationships for predicting weight loss of pins because of rubbing action design of experiment based on 2 levels full factorial design along with three independent factors (normal load, sliding speed, sliding time) has been used. With the utmost precision of 10^{-4} g the weight loss of pins has been measured. Among the topics of high concern to automotive industry the wear of deforming dies continues to be a great concern because increasing die maintenance results increase in cost and scrap rate. As per the current trend the demand to reduce the use of lubricants and increase tool life in sheet metal stamping has lead to increase in research on the sliding contact between the tool and the sheet material. So it has been found out that the deforming conditions, such as - normal load, sliding speed, sliding time etc. leads to much more effect on the performance of operation to a much greater extent. The selection of all these deforming parameters must be carefully done so that optimization of such economics and quality of operations can be carried out easily. This goal can be attained only when the detailed investigation and mathematical modeling of performance as a function of sliding conditions using design of experiments (DOE) is done and implemented in such manner.

The main aim of the present work is to grant the permission access to the effect of sliding parameters. The 'design expert 8.0.4.1' software has been used for the analysis. With the development of a prediction model the necessary interaction prevailing between sliding parameters can be known. With the help of ANOVA model adequacy tests were conducted, several other effects and various parameters were investigated and presented in the form of contour plots and 3D surface graphs. Along with this, few numerical optimizations have been carried out in which all the input parameters within range were included so as to minimize the weight loss (wear volume). The result obtained by this research work is helpful to manufacturing industry that make use of AISI D2 steel for deforming dies.

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I. INTRODUCTION

Considering the requirements of hot working dies, the one stated below can be considered to be the most important: hot strength, thermal stability, ability to resist abrasion by the work piece scales formed at the high temperatures of working. Chromium containing steels hardened and tempered largely accomplish these requirements and because of this they are the first choice for the dies in the pressure die casting industries. In controlling the wear of the die material the sliding parameters such as normal load, sliding speed, sliding distance etc., play a vital role.

From a surface progressive loss or removal of material is known as wear. It has great technological and economical significance as it changes the shape of the tool and die interfaces and thus that of the work-piece. Thus it affects the process, size & quality of the parts produced.

General Engineering materials have many limitations such as it has problem in achieving optimum levels of strength, stiffness, density, toughness and wear resistance. To overcome these shortcomings, discontinuously reinforced aluminium metal matrix composites are gaining importance due to their high specific strength, high stiffness, low density and good wear resistance and they have the potential to replace their monolithic counterparts primarily in automotive, aerospace and energy applications. Of all the aluminum alloys the aluminum 6061 alloy has the highest strength and ductility with excellent machinability and good bearing and wear properties.

The wear of dies continues to be a great concern in pressure die casting industry and to the automotive industry because of heavy increase in die maintenance cost and scrap rate. Due to heavy demand of reducing the use of lubricants and increasing life of dies in pressure die casting has considerably increased research on the sliding contact between the die and aluminium alloys. In many pressure die casting industries AISI D2 die steel are used as the die material because of its properties to withstand higher wear. But because of actual working conditions, wear of these hot die steels is a kind of normal problem in the pressure die casting industry.

Wear is related to interactions between surfaces and specifically the removal and deformation of material on a surface as a result of mechanical action of the opposite side. Among all the aspect of the working environment that causes effect upon wear include loads and features such as unidirectional sliding, reciprocating, rolling, and impact loads, speed, temperature, but also different types of counter-bodies such as solid, liquid or gas and type of contact ranging between single phase or multiphase, in this the last multiphase can combine liquid with solid particles and gas bubbles.

Thus this chapter gives detailed information of the usefulness of sliding conditions between the hot die steel and the material which is to be casted. During casting process different sliding conditions such as load, sliding speed, sliding time and sliding distance play a vital role. Wear of die material is greatly affected by these parameters. Resultantly the quality of production cost of production and production rate also have a great impact on them. Therefore a judicious selection assumes significance.

Here in this study work, the wear behaviour of AISI D2 die steel sliding opposite to that of aluminium alloy has been evaluated at different sliding speed, loads and sliding distances at elevated temperature with the help of pin-on-disk tribometer.

The most important aim of present work is to check and investigate the wear behaviour of the AISI D2 die steel against aluminum 6061 alloy at elevated temperature. The sliding parameters are tested in various condition such as load, speed in dry environments. Efforts are made to create a wear prediction model in the terms of sliding parameters with the help of response surface methodology (RSM) which is depended on 2 level full factorial designs.

II. EUIPMENTS

A PIN-ON-DISK APPARATUS

Under a loaded wear pin a high torque drive motor is rotated at a flat sample and this is how pin-on-disk wear tester works. Circle of required diameter is created through wear pin by offsetting the pin relative to the sample's centre of rotation. On one sample, number of tests can be performed by the help of different wear track diameters. For other tests same linear speed can be used speed can be used just by adjusting the rotational speed for each diameter. By adjusting the amount of dead weight hung load can be changed just by changing the amount at the end of the loading beam.

On the sample table all the samples are positioned. Then via computer control Values for the following parameters are selected.

RPM:This controls the speed of the rotation of the sample (disk).

MAXIMUM TIME: This sets the duration of the test.

The following parameters are set manually:

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LOAD APPLIED & TRACK DIAMETER

Table I Technical specification of Wear and Friction monitor TR-201

Parameters	**Min**	**Max**
Pin Size (mm)	6	8
Disk Size (mm)	-	165
Wear Track dia. (mm)	50	90
Disk speed (rpm)	100	1000
Normal load (N)	10	100
Temperature (fixed)	-	300ºC

B PREPARATIONS OF SPECIMENS

Pins were the tool at which wear experiments were performed. Pins were made of AISI D2 steel and disk including aluminium 6061 alloy. All the pins used in experimentation were 8 mm in diameter and 30 mm in length. All the disks used in experimentation were 165 mm in diameter and 6 mm in thickness. Chemical composition of AISI D2 steel and mild steel was obtained by spectral analysis.

C Manufacturing of Pins

In this study, based on two level full factorial design, total 14 pins of AISI D2 steel have been selected for experimentation. The size of each pin was 8 mm × 30 mm. Chemical composition of AISI D2 steel, % weight is shown in table

Table II Chemical composition of AISI D2 steel, % weight

Element	C	Mn	Si	Ni	Cr	V	Moly	Fe
Percentage	1.398	0.7095	0.573	0.085	12.34	0.029	0.141	rest is Fe

III. RESULT AND DISCUSSION

ANOVA analysis and development of prediction model

The ANOVA test for response surface model for weight loss (wear volume) is summarized in Table. This analysis was carried out for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%.

Table III Resulting ANOVA table (partial sum of squares) for quadratic model (response: Weight loss)

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Source	Sum of squares	degree of freedom	Mean Square	F Value	p-value Prob > F
Model	0.00806	6	0.001343	225.1131	0.0001
A-LOAD	0.000959	1	0.000959	160.7407	0.0001
B-SPEED	0.003907	1	0.003907	654.7599	0.0001
C-TIME	0.002132	1	0.002132	357.2761	0.0001
AB	9.52E-05	1	9.52E-05	15.95643	0.0072
AC	0.000286	1	0.000286	47.86008	0.0005
BC	0.000681	1	0.000681	114.0855	0.0001
Curvature	0.000175	1	0.000175	29.37196	0.0016
Residual	3.58E-05	6	5.97E-06		
Lack of Fit	1.25E-07	1	1.25E-07	0.017517	0.8999
Pure Error	3.57E-05	5	7.14E-06		
Cor Total	0.008271	13			
Std. Dev.	0.002443			R-Squared	0.995577
Mean	0.071986			Adj R-Squared	0.991155
C.V. %	3.393516			Pred R-Squared	0.992821
PRESS	5.94E-05			Adeq Precision	53.47612

Table shows that the value of "Prob. > *F*" for model is 0.0001 which is less than 0.05, that indicates the model is significant, which is desirable as it indicates that the terms in the model have a significant effect on the response. In the same manner, the value of "Prob. > *F*" for main effect of load, speed, time and two-level interaction of load and speed, load and time, speed and time are less than 0.05 so these terms are significant model terms.

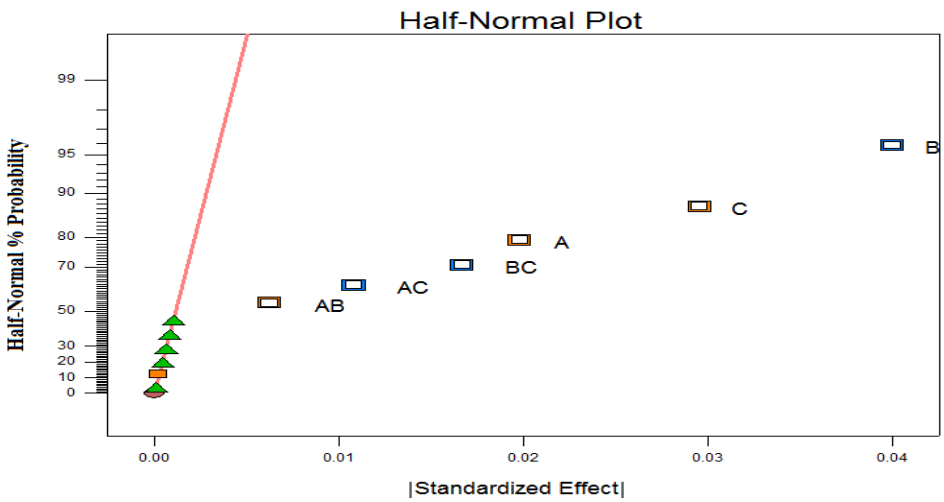
The value of "Prob. > *F*" for lack-of-fit is 0.8999 which is greater than 0.05 and it indicates the insignificant lack of fit. If the model does not fit the data well, this will be significant. The insignificant lack of fit is desirable.

The R^2 value (the measure of proportion of total variability explained in the model) is equal to 0.995 or close to 1, which is desirable. The adjusted R^2 value is equal to 0.99; it is particularly useful when comparing models with different number of terms. The result shows that the adjusted R^2 value is very close to the ordinary R^2 value. Adequate precision value is equal to 53.47; a ratio greater than 4 is desirable which indicates adequate model discrimination. Adequate precision value compares the range of the predicted values at the design points to the average prediction error.

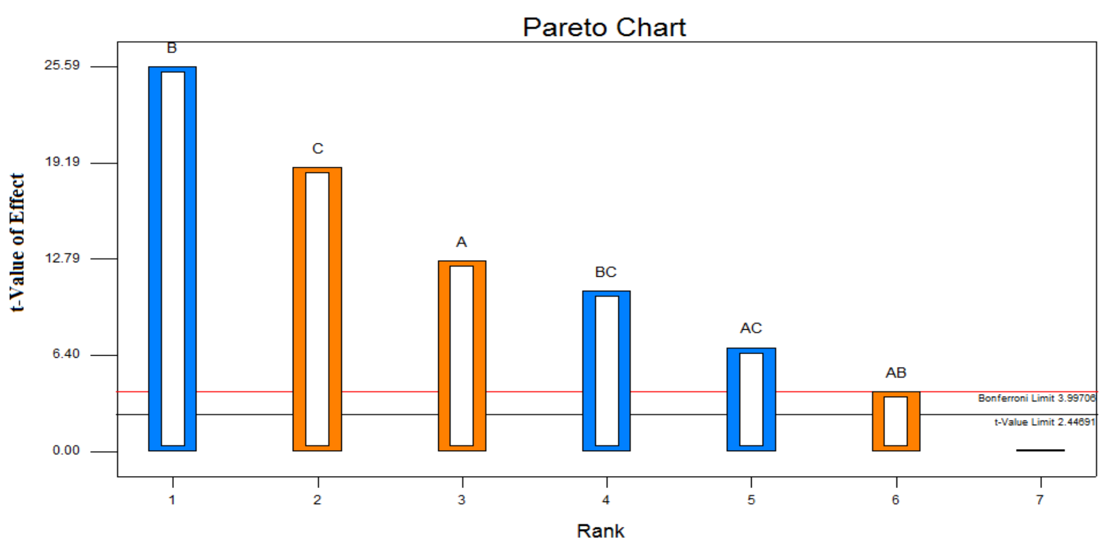
The regression model for weight loss in terms of coded factors is shown as follows:

CONTRIBUTION OF WEAR PARAMETERS ON WEIGHT LOSS

The fig. shows the half normal plot, the extreme right side factor has the highest effect on the response, however as the dots corresponding to the particular factor comes nearer and nearer to the line, it shows these value affects the least.



The value at the right extreme has the strongest effect on the weight loss and keeps on decreasing as it comes nearer and nearer to the line. It can also be understood in the fig , which shows the of effectiveness rank wise. The graph is between t-value and rank of factors.



The t-value here denotes the effectiveness of the factor. As it can be seen from the fig above, that the most effective factor is B alone, followed by C then A, the effectiveness is of the combination of B & C which is followed by the AC than AB.

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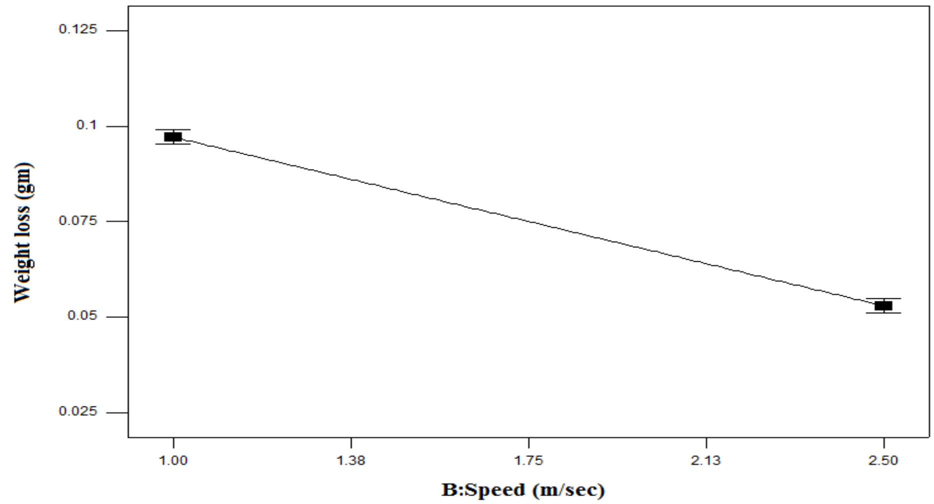
EFFECT OF SLIDING PARAMETERS ON WEIGHT LOSS

Effect of sliding speed on weight loss

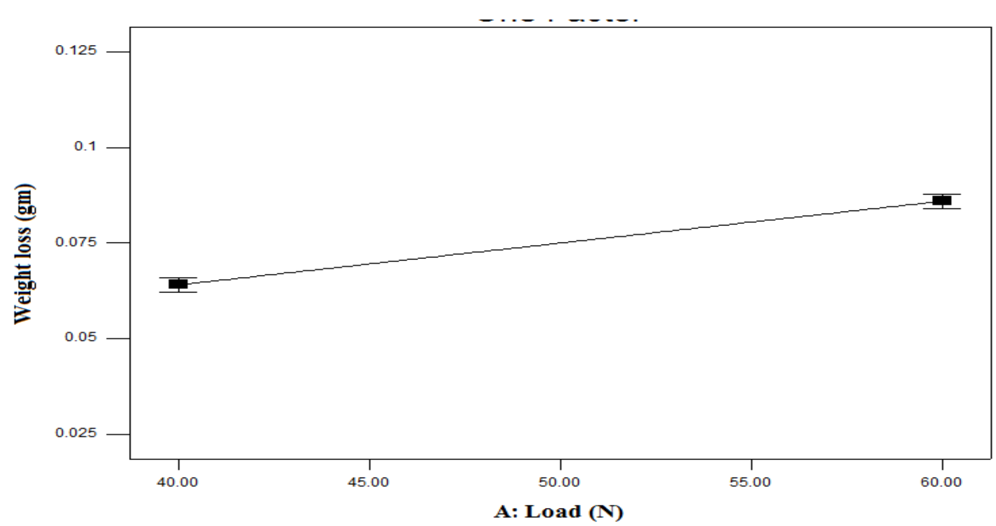
Influence of sliding speed on weight loss at constant load of 50 N and time 8 min is shown in fig. .



The result shows that the weight loss decreases as the sliding speed increases from 1 m/s to 2.5 m/s. As the sliding speed increases, rate of generation of frictional heats also increases which raises the surface temperature of rubbing materials. The rise of surface temperature softens the rubbing materials. Due to this wear rate decreases.

Effect of load on weight loss

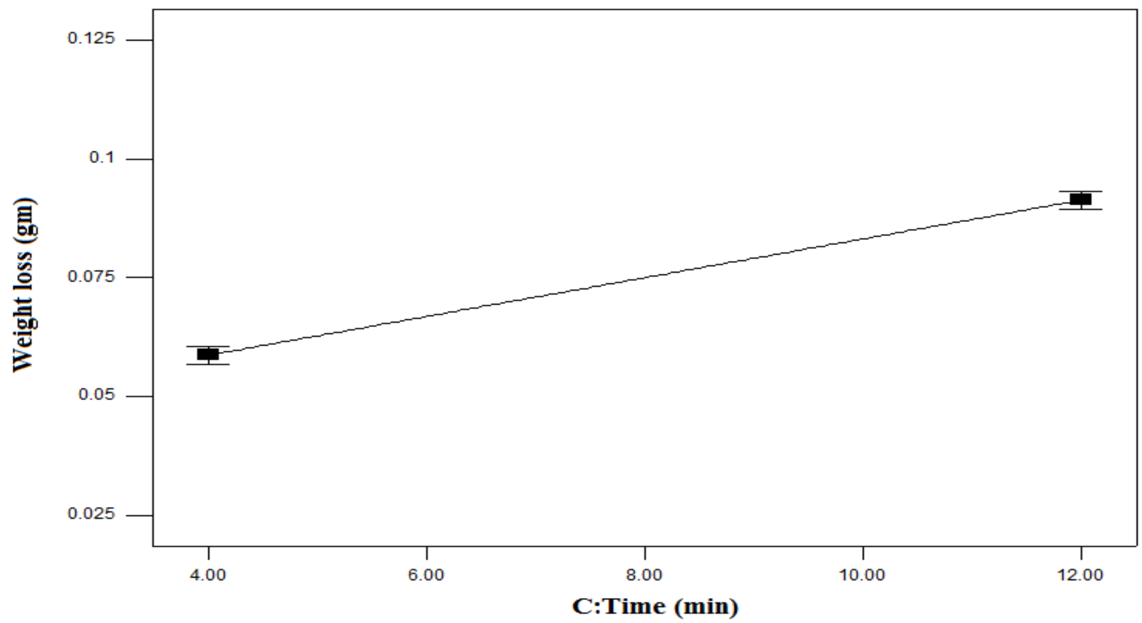
Influence of normal load on weight loss at constant speed of 1.75 m/s and time 8 min is shown in fig. .



The result shows that the effect of normal load on weight loss. The weight loss increases as the normal load increases. The increase in wear rate is caused by the massive volume in the pin undergoing plastic deformation due to increase in load.

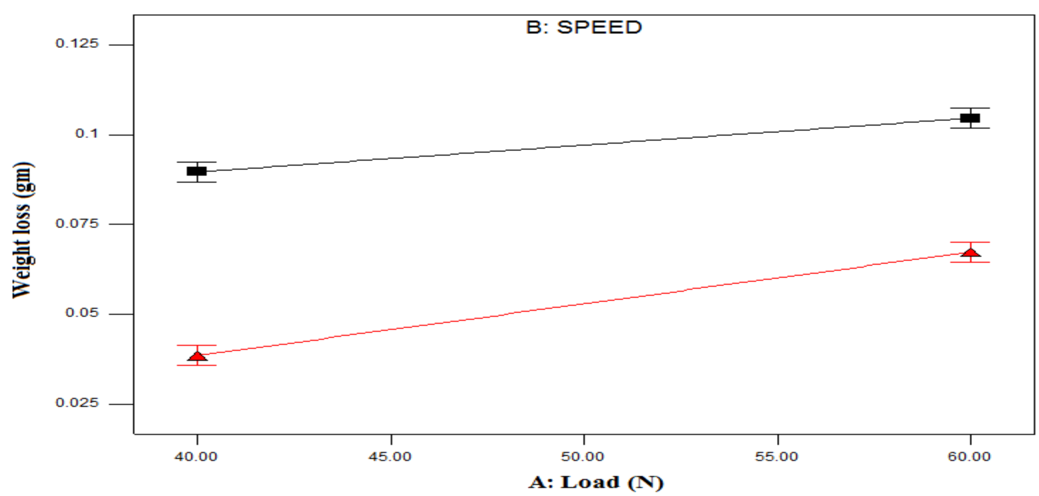
Effect of sliding time on weight loss

Influence of sliding time on weight loss at constant load of 50 N and speed of 1.75 m/s is shown in fig.. It is clear from the plot that as the sliding time increases from 4 min to 12 min, the value of weight loss increases.



Interaction effect of normal load and sliding speed

Influence of interaction between load and speed on the average weight loss at constant sliding time of 8 min is shown in fig 4.9.The black line shows the graph between load and weight loss at 1m/s speed while red line shows the graph between load and weight loss at 2.5 m/s speed. From the interaction plot it is clear that as the load increases the weight loss also increases at both cutting speed. It is also visible that for every value of load, the weight loss is higher at low speed as compare to high speed.



Interaction effect of normal load and time

The interaction between load and time on the average weight loss at constant sliding speed of 1.75 m/s is shown in fig .The black line shows the graph between load and weight loss for 4min sliding time while red line shows the graph between load and weight loss for 12 min sliding time. From the interaction plot it is clear that as the load increases the weight loss also increases for both sliding time. It is also visible that for every value of load, the weight loss is higher at high sliding time as compare to low sliding time.

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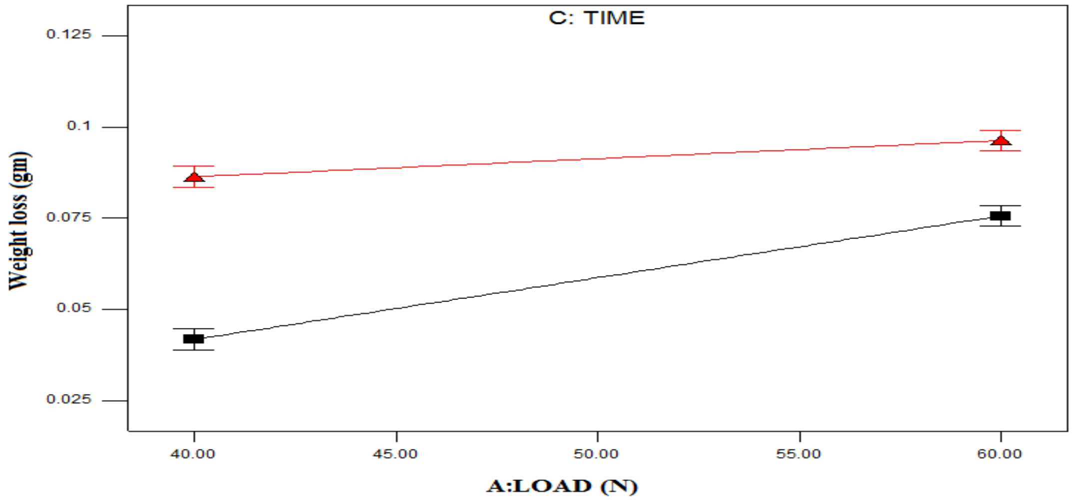

Fig. Interaction plot between load and time at sliding speed 1.75 m/s

Interaction effect of speed and time

The interaction between speed and time on the average weight loss at constant load of 50 N is shown in fig .The black line shows the graph between speed and weight loss for 4 min sliding time while red line shows the graph between speed and weight loss for 12 min sliding time. From the interaction plot it is clear that as the speed increases the weight loss decreases at both the values of time. It is also visible that for every value of speed, the weight loss is higher at high value of time as compare to low value of time.

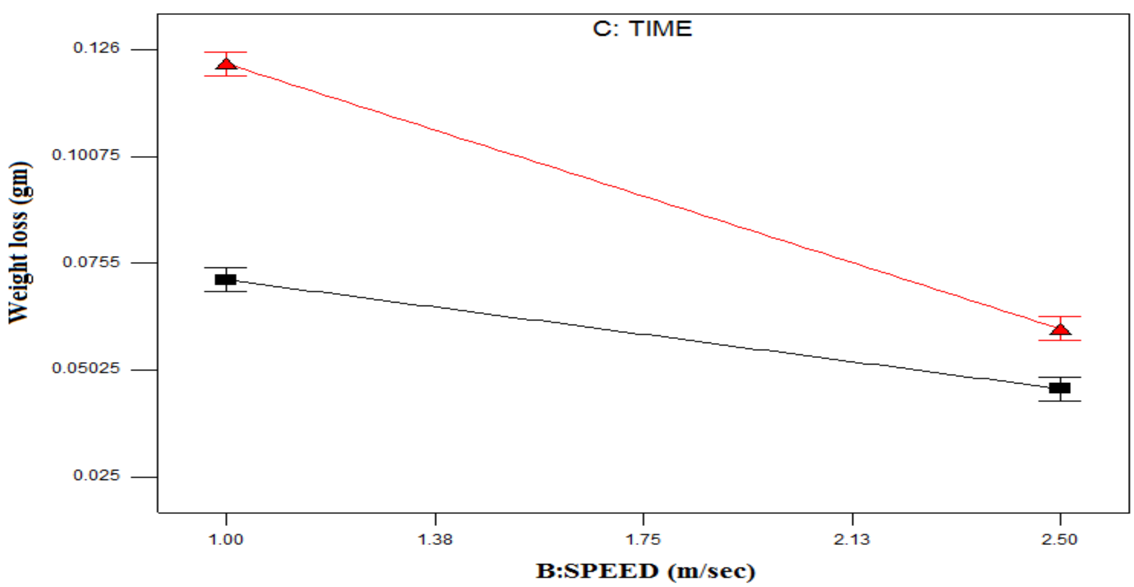

Fig. Interaction plot between load and speed at time 8 min

CONFIRMATION EXPERIMENTS

Statistically developed mathematical model for weight loss, given by equations 4.1 and 4.2 , has been already validated through F-tests and lack-of-fit test. The fitted model seems to be significant and the lack of fit insignificant. The coefficient of variation (R^2) for model is 0.99, which indicates the model ability for making predictions. This conclusion must be further supported through the confirmation runs. A set of three confirmation runs have been performed to verify the prediction ability of the developed weight loss model. The values of weight loss obtained by confirmation run and those predicted through the model are compared in Table. The percentage error between the experimental and the predicted values of weight loss is found to be less than 5% per cent. In other words, all the experimental values are within the 95 percent prediction interval, which clearly demonstrates the accuracy of the models developed in this study.

Table Plan of confirmation experiments and results

Test No.	Sliding Conditions			Wt. Loss (gm)		Error (%)
	Speed (m/s)	Load(N)	Time (min)	Predicted	Experimental	
1	2.5	40	4.00	0.0255	0.0247	3.2
2	2.5	45	4.00	0.0354	0.0371	4.58
3	2.34	40	4.00	0.0290	0.0300	0.33

IV. CONCLUSION

The list of conclusion drawn from above work can be understood as under:

1.) The development of relationship between weight loss (wear volume) and applied load, sliding speed, sliding time has been undertaken. Compared to the predicted results the measured ones are in good agreement. Within the certain ranges of tested parameters only, these relationships are applicable.

2.) All the three independent parameters (load, speed, time) turn out to be the influential sliding parameters.

3.) The developed mathematical models show that the speed is the most significant factor.

4.) Increasing sliding time and load results in the heavy weight loss (wear volume). The weight loss (wear volume) increases with it but it also decreases with increasing sliding speed.

4.) the developed mathematical model is verified by ANOVA and the confirmation runs they declare that the model for weight loss (wear volume) present an excellent fit and give the predicted values of weight loss which are close to the experimental values, along with 95 percent confidence level.

6.) 0.0255gm is the optimum result of weight loss, corresponding to normal load = 40N, sliding speed = 2.5 m/s, sliding time = 4 min.

V FUTURE SCOPE

Here mathematical modeling and optimization have been utilized only for one response variable i.e. weight loss. To consider more response variable the work can be extended to variables like force of friction, surface roughness etc.

Even few more parameters such as temperature can be added to have a better view into the process.

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