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A Study of Process Parameters of Wear Characteristics of AISID2 Steel

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Abstract: *In sheet metal forming, the wear of deforming dies continues to be a great concern to the automotive industry as a result of increasing die maintenance cost and scrap rate. The demand to reduce the use of lubricants and increase tool life in sheet metal stamping has resulted in increased research on the sliding contact between the tool and the sheet material. Hence it has been recognized that the deforming conditions, such as - normal load, sliding speed, sliding time etc. affect the performance of the operation to a greater extent. These deforming parameters are required to be carefully selected to optimize the economics and quality of operations. This can be achieved by detailed investigation and mathematical modeling of performance as a function of sliding conditions using design of experiments (DOE).The objective of the present work is to assess the effect of the sliding parameters on the wear of AISI D2 steel. It is used as the stamping die material in many cold roll forming and other press working industries. It is also known as high carbon & high chromium steel. The wear experiments were performed on pins of D2 steel and disks of Aluminium alloy 6061. Design of experiment based on 2 level full factorial design with three independent factors (normal load, sliding speed, sliding time) has been used to develop relationships for predicting weight loss of pins caused by rubbing action. The weight loss of pins has been measured within* 10^{-4} *g precision.The 'design expert 8.0.4.1' software has been used for the analysis. A prediction model has been developed which indicates that interaction is present between sliding parameters. Model adequacy tests were conducted using ANOVA and the effects of various parameters were investigated and presented in the form of contour plots and 3D surface graphs. Numerical optimization has been carried out considering all the input parameters within range so as to minimize the weight loss (wear volume). The findings of this study would be beneficial to manufacturing industry making use of AISI D2 steel for deforming dies.*

INTRODUCTION

Among the property requirements of hot working dies, the following 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 fulfil these requirements and hence are the first choice for the dies in the pressure die casting industries. The sliding parameters such as normal load, sliding speed, sliding distance etc., play a vital role in controlling the wear of the die material.

The wear is the progressive loss or removal of material from a surface. It has important technological and economical significance because it changes the shape of the tool and die interfaces and hence that of the work-piece. Thus it affects the process, size & quality of the parts produced.

1. SIGNIFICANCE OF TOPIC

General Engineering materials have limitations 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. The aluminium 6061 alloy has the highest strength and ductility of the aluminium alloys with excellent machinability and good bearing and wear properties.

In pressure die casting industry, the wear of dies continues to be a great concern to the automotive industry as a result of increasing die maintenance cost and scrap rate. The demand to reduce the use of lubricants and increase life of dies in pressure die casting has resulted in increased research on the sliding contact between the die and aluminum alloys. The AISI D2 die steel are used as the die material in many pressure die casting industries due to its properties to withstand higher wear. However under the actual working conditions, wear of these hot die steels is a common problem in the pressure die casting industry.

The wear is a process where interaction between two surfaces or bounding faces of solids within the working environment results in dimensional loss of one solid, with or without any actual decoupling and loss of material. Aspects of the working environment which affect 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 which the last multiphase may combine liquid with solid particles and gas bubbles.

Hence this chapter presents the importance of sliding conditions between the hot die steel and the material to be cast. Different sliding conditions such as load, sliding speed, sliding time and sliding distance play a vital role during the casting process. These parameters have a major effect on wear of the die material. This in turn affects the quality of production, cost of production and production rate. Therefore a judicious selection assumes significance.

2. PREPARATIONS OF SPECIMENS

The wear experiments were performed on pins, made of AISI D2 steel and disk, made of 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. The preparation of the specimens was done at Gaurav engineering works, Chandigarh.

3. DESIGN OF EXPERIMENTS

The parameters and their levels are shown in Table 3.3. Complete design layout for experiments and experimental results are summarized in Table 3.4. This demonstrates a total of 14 runs required for complete experimentation. Fourteen experiments constitute 2^3 factorial point and six centre point.

Table 3.1 Parameters and their levels according to 2 level full factorial design

Factors	Symbol	Type	Levels		
Load (N)	A	Numeric	40	50	60
Speed (m/sec.)	B	Numeric	1	1.75	2.5
Time (min.)	C	Numeric	4	8	12

Table 3.2 Complete design layout and experimental results

Std.	Run	Independent parameters			Dependent parameters
		A:Load (N)	B:Speed (m/sec)	C:Time (min)	Weight loss (gm)
5	1	40	1	12	0.1213
7	2	40	2.5	12	0.0515
13	3	50	1.75	8	0.0653
10	4	50	1.75	8	0.0682
8	5	60	2.5	12	0.0686
14	6	50	1.75	8	0.0692
9	7	50	1.75	8	0.0652
4	8	60	2.5	4	0.0661
3	9	40	2.5	4	0.0256
11	10	50	1.75	8	0.0723
6	11	60	1	12	0.1241

2	12	60	1	4	0.0852
1	13	40	1	4	0.058
12	14	50	1.75	8	0.0672

4. WEIGHT LOSS MEASUREMENT

Wear is the progressive loss of material due to relative motion between a pin tested and disk. The pins tested were weighted before and after the test to within 10^{-4} g to calculate the weight loss. The volumetric loss of pin material can be determined via change of the pin masses during the test.

$$\text{WEAR VOLUME LOSS IN mm}^3 = \frac{W\square ighloss}{10 * density}$$

5. ANOVA analysis and development of prediction model

The ANOVA test for response surface model for weight loss (wear volume) is summarized in Table 5.1. This analysis was carried out for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%.

Table 5.1 Resulting ANOVA table (partial sum of squares) for quadratic model (response:Weight loss)

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

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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.

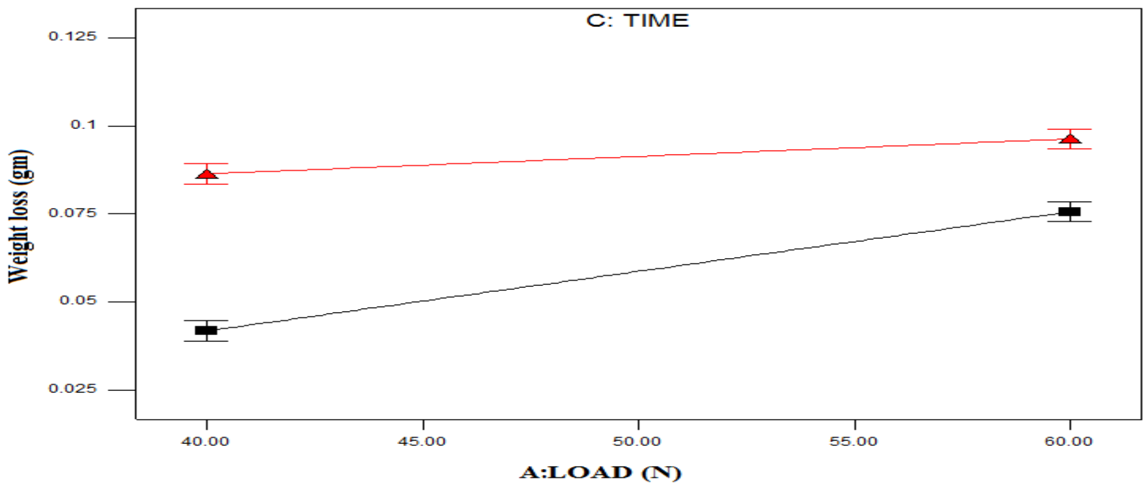
The regression model for weight loss in terms of coded factors is shown as follows:

$$w\square igh\square\square\square\square = 0.075 + 0.011 * \square = 0.022 * \square + 0.016 * \square + 0.0034 * \square * \square - 0.006 * \square * \square - 0.01 * \square * \square \quad (5.1)$$

While, the following equation is the empirical model in terms of actual factors

$$W\square a\square\square\square\square\square = -0.0234 + 0.0015 L\square a\square - 0.027 * S\square\square\square\square + 0.016 * \square i\square\square + 0.00046 * \square\square a\square * \square\square i\square i\square g\square\square\square\square\square - 0.00015 * L\square a\square * \square i\square\square + 0.0037 * S\square\square\square\square * \square i\square\square$$

(5.2)



Interaction plot between load and time at sliding speed 1.75

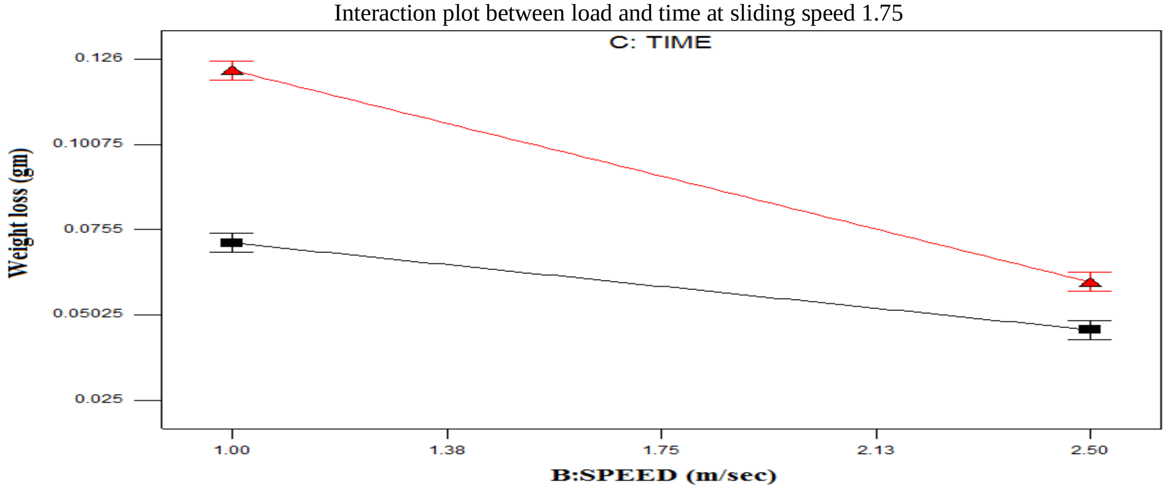


Fig.4.11 Interaction plot between load and speed at time 8 min

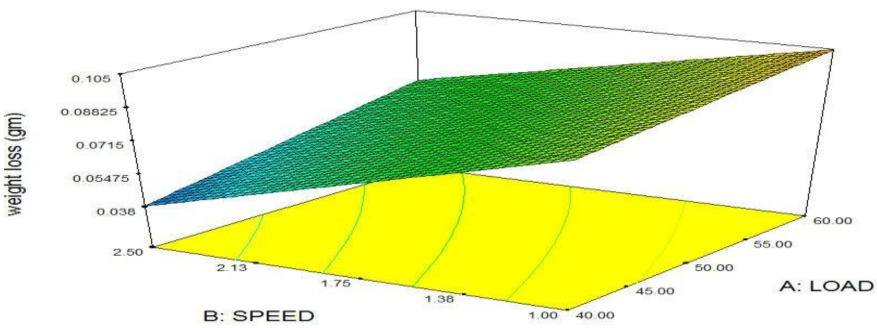


Fig.4.12 3D plot between load and speed at time 8 min

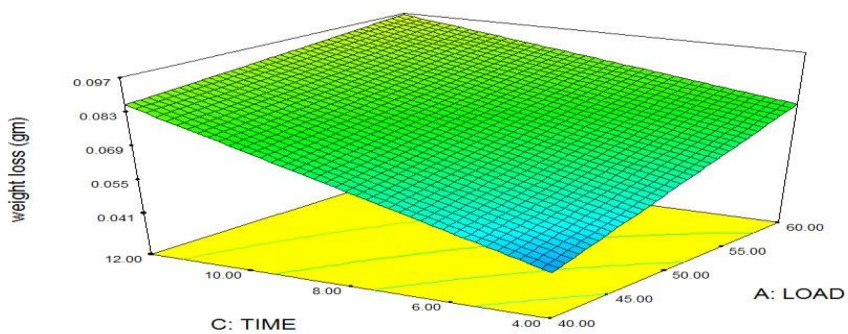


Fig.4.13 3D plot between load and sliding time at sliding speed1.75 m/s

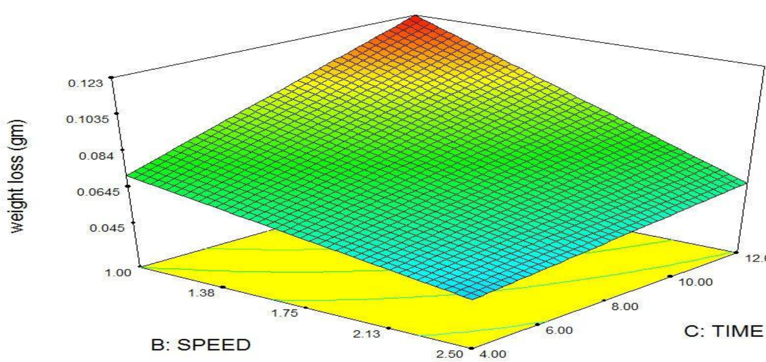


Fig.4.14 3D plot between time and speed at load 50 N

6. OPTIMIZATION OF SLIDING CONDITIONS

In the present study, the aim is to obtain the optimal values of sliding parameters in order to minimize the value of weight loss of AISI D2 steel pins. The constraints used during the optimization process are summarized in Table 6.1.The optimal solutions are reported in Table 6.2

Table 6.1 Constraints for optimization of sliding conditions

Condition	Units	Goal	Lower limit	Upper limit
Ssliding speed	m/s	Is in range	1	2.5
Load	N	Is in range	40	60
Time	min	Is in range	4	12
Weight loss	gm	Minimize	0.0256	0.1241

Table 6.2 Optimization results

Solution No.	Sliding speed (m/s)	Load (N)	Time (min)	Wt. Loss (gm)	Desirability	Remarks
1	2.5	40	4.00	0.0255	1	Selected

7. 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 4.4. 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 4.4 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

CONCLUSION

The important conclusions drawn from the present work are summarized as follows:

1.) The relationship between weight loss (wear volume) and applied load, sliding speed, sliding time has been developed. The predicted results are in good agreement with the measured ones. These relationships are applicable within the ranges of tested parameters.

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

3.) The mathematical models developed clearly show that the speed seems to be the most significant factor. 4.) The weight loss (wear volume) increases with increasing sliding time and load but decreases with increasing sliding speed.

4.) The results of ANOVA and the confirmation runs verify that the developed mathematical model for weight loss (wear volume) show excellent fit and provide predicted values of weight loss that are close to the experimental values, with a 95 percent confidence level.

6.) The optimum result of weight loss has been observed to be 0.0255gm, corresponding to normal load = 40N, sliding speed = 2.5 m/s, sliding time = 4 min.

7. FUTURE SCOPE

- In this study mathematical modeling and optimization has been attempted only for one response variable i.e. weight loss.

- The work can be extended to consider more response variables like force of friction, surface roughness etc.
- Also more parameters such as temperature can be introduced to have a better insight into the process.

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