

# **Abrasive Wear Mathematical Model of 140MXC Nano Structured Hardfacing**

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**ABSTRACT:** Hardfacing is a technique in which deposition of material on the surface of dissimilar material is done to improve its wear resistant properties. In the present work, 140MXC nano structured wire was deposited on IS2062 steel substrate by using GMAW, with two different conditions of low and high heat input. A set of mathematical models has been developed for the prediction of wear behaviour of 140MXC nano composite using 3-factor, 2 – levels factorial design. The factors considered were Load (L), Sliding velocity(SV) and Sliding distance(SD). The developed models were checked for their adequacy. The main and the interaction effects of the wear parameters on wear behaviour are presented in graphical form. The abrasive wear of low heat input (max.135mm<sup>3</sup>) was found to be less than that of high heat input (max.296mm<sup>3</sup>).

**KEYWORDS:** Wear; Gas Metal Arc Welding; Factorial Design Approach.

## **I. INTRODUCTION**

Wear has been recognized as the phenomenon of material removal from a surface due to interaction with a mating surface Olivera et al (2010). Almost all machines lose their durability and reliability due to wear and the possibilities of new advanced machines are reduced because of wear problems KenchiReddy and Jayadeva, 2012. Different category of wear exists but the most typical modes are – Abrasion, Impact, Metallic (metal to metal), Heat, Corrosion etc. Badisch et al. (2006). In engineering industries, abrasive wear is probably the most significant cause of mechanical damage of equipments components coming in contact with abrasive/erosive bodies. Hard abrasive particles penetrate the components and cause damage in the form of material loss Kumar et al. (1999). Therefore, wear control has become a strong need for the advanced and reliable technology of the future.

Surface features can be improved from the point of view of the material being deposited or from the point of view of the depositing process Oliveira et al. (2002). Welding assisted hardfacing technology has utilized Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), Gas Tungsten Arc Welding (GTAW), Submerged Arc Welding (SAW), and Plasma Transferred Arc Welding (PTAW) for fulfilling the requirement of dense and thick coating Balsubramanian et al., (2009). GMAW is extensively used due to its high reliability, all position capability, ease of use, low cost, high productivity, high deposition rate, cleanliness and ease of mechanization as mentioned by Kannan and Yoganandh, (2010).

Researches on the welding assisted hardfacing technology were mainly focused on the investigation of the influence of hardfacing materials on the wear characteristics and hardness to choose a proper hardfacing material Ahn (2013). Numerous studies has been carried out for analysing the effect of wear parameters on wear rate. Arc spraying and gas metal arc welding (GMAW) techniques were employed to hardface boride-rich coatings on the surface of St52 steel, low carbon steel. Comparison was done stating that boride coatings obtained by welding technique had better adhesion to steel substrate and were far more resistant to spalling Amushahi et al. (2010).The effects of some wear test conditions on air and vacuum plasma-sprayed (APS and VPS) TiC–NiCrBSi coatings using a pin-on-disk tribometer was investigated. The wear parameters considered were load and sliding speed. It was concluded that, higher loads, during sliding, led to higher wear rates for both air and vacuum plasma sprayed coatings. The rate of change of total

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wear versus load was decreasing. Higher sliding speed led to decreased wear rates in both the cases Smith (1992). A Fe–Cr–C hardfacing alloy was overlaid on low carbon steel using GMAW process. Pin on disc machine was used for wear testing. A significant effect of primary carbides on the abrasive wear resistance of weld deposits was found. The results showed that the two layer complex carbide deposits gave the best abrasive wear resistance. Chotoborsky et al. (2008). The influence of Cr was studied by conducting tests using E410, E430 and modified E430 electrode. It was concluded that C & Cr supports the improvement of wear resistance, hardness & refined microstructure on the weld overlays. The wear rate increases with increase in sliding velocity and applied load. As a result of increase in Cr, the hardness increases due to the formation of Cr carbide at the grain boundaries and there was also a progressive refinement in the grains of the welded layer. Selvi et al., (2008) It has been observed that the wear rate of hardfacing alloys is lower than that of mild steel. The hardfacing alloy having the highest chromium content exhibits the lowest wear rate and concluded that load has more severe effect on abrasive wear as compared to other parameters like sliding distance Navas et al. (2006). The addition of WC upto 20% in WC–Co–Cr coatings increases the hardness and abrasive wear resistance and further addition of WC increases hardness marginally Maiti et al. (2007). The abrasive wear behaviour of commercially available Fe–Cr–C hardfacing alloys, a hypereutectic type (A1) and a hypoeutectic type (A2), that are commonly used in the sugar industry was studied. It was reported that the mass loss of the hardfacing increased linearly with sliding distance in both dry and slurry conditions. However, the wear rate was not always directly proportional to load Buchanan (2007). The effect of load and wear rate is also governed by other sliding parameter such as reciprocating velocity. Increase in load at low reciprocating velocity increases the wear gradually and relationship between two is almost linear, while at high velocity with increase in load (from 60 N to 120 N) transition from mild to severe wear with abrupt increase in wear rate. The effect of reciprocating velocity on wear rate is dependent on the load. Increase in reciprocating velocity at low load yields to decrease wear rate. While at high loads, wear rate first decreased with increase in reciprocating velocity and above certain critical velocity (0.8 m/s), abrupt increase in wear rate took place. The wear rates increase abruptly above a critical load of 60 N. This transition to severe wear regime is induced by frictional temperature rise and characterized by massive plastic deformation and gross material removal Rajeev et al. (2010). Load has a more severe effect on abrasive wear of the coating as compared to the sliding distance and abrasive size on the abrasive wear of composite coating. Interactions effects of applied factors on abrasive wear are of the same order as that of their main factor effects. The interaction effect of abrasive size and sliding distance is considerably higher than load and abrasive size for composite coating. Abrasive wear rate of composite coating is approximately 5 times lower than the substrate. Sharma et al. (2012)

The study was carried out explaining the importance of welding heat input on the structures and properties of weld metal. Most of the researchers had not taken the effect of temperature while selecting the parameters, to characterize the feasible parametric zone Olivera et al. (2010). A methodology was presented for comparison of heat input for partially and fully penetrated welds using cryogenic calorimetry and thermography. He concluded that rate of increase in wear of hardfaced material with the increase in load is very significant and observable Quintino et al. (2013). Sliding wear rate and average friction coefficient of coatings modified with CeO<sub>2</sub> was lower than unmodified powder coatings and the alloy with 0.9% wt CeO<sub>2</sub> exhibited best wear resistance at larger loads and speeds. The improvement in tribological property of CeO<sub>2</sub> modified coating is more at high load of the friction couple but not at low load. Purakayastha and Dwivedi (2014). The volume loss by the material due to the wear process on pin on disc machine can be calculated by the help of its developed mathematical model. And can be verified by ANOVA technique Wang et al. (2008). A mathematical model was formulated in order to study the effect of wear on the microstructure of the Fe–Cr–C Hardfacing alloy. Ultimately he concluded that Wear resistance increases with increase in percentage of chromium & carbon content in weld deposits and the hardness mainly depends on process parameters such as welding current, speed of arc travel and voltage Reddy and Jayadeva (2012). Response surface methodology (RSM) approach is an excellent tool, which can be successfully used to develop an empirical equation for the prediction of wear and understanding of wear behaviour of composite coatings in terms of individual factors (L, A, S and T) as well as in terms of the combined effects (LA, LS and AS) of applied factors. The sliding distance has a more severe effect on abrasive wear of the coating as compared to load and abrasive size on the abrasive wear of composite coating Purakayastha and Dwivedi (2014). Heat input influences solidification mode and secondary metallurgical transformation. Both facts have affect on the microstructure at different welding zones. If the actual heat input is higher, there is an increase in the solidification time and a reduction in the cooling time. Both characteristics increase the grains size and accordingly, the metal quench

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ability. Thus, in turn, influences the mechanical properties of weld metal and HAZ, such as hardness and tensile strength. Accurate estimation of heat input in welding technology is thus of major relevance Quintino et al. (2013). Literature review suggested that study of wear behaviour of TAFA 140MXC Nano structured hardfacing wire is scarcely available. Hence, the investigation was aimed to study the abrasive wear behaviour of TAFA 140MXC, deposited on low carbon steel substrate through GMAW with two different conditions of low and high heat input. A set of mathematical models were planned for predicting the wear behaviour using 3-factor, 2 – levels Factorial design, considering load (L), sliding velocity(SV) and sliding distance(SD) as process parameters.

## II. MATERIAL AND METHODS

The experiment was carried out by the deposition of 140MXC Nano structured wire of 1.6 mm diameter using Miller Migmatic 273 welding machine. IS2062 used as base plate, was cut in 250 x 150 x 10mm size with some allowances for grinding etc. The chemical composition of substrate and filler wire is given in Table 1. After cutting the samples of required size from a single plate, the following preparatory treatment was given prior to welding:

1. Smut removal: Specimens were dipped in 15% HNO<sub>3</sub> for about 5 –10 minutes. Then were rinsed once again in tap water and were dried up by hot air using a hot blower.
2. Final cleaning: Chemically cleaned samples brushed using stainless steel wire brush followed by swabbing with acetone.

Heat input can be referred to as "the electrical energy supplied by the welding arc to the work piece" Nassar and Nassar (2011).

Mathematically, it is represented as–

$$HI = (I*V*60) / S \tag{1}$$

Two set of conditions at low and high heat input, considering various welding parameters were used for deposition, as shown in Table 2. The weld runs were then performed on each of these strips throughout the length of the strip using the miller magmatic 273 welding machine in DCEP polarity. Shielding gas used was pure Argon with flow rate kept constant at 25 l/min.

**Table 1 Chemical composition of base plate and filler wire**

IS 2062								
Element	C	Si	Mn	S	P	Fe		
%	0.227	0.161	0.50	0.05	0.023	Balance		
140MXC Nano–structured wire								
Element	Cr	C	Mo	B	W	Si	Nb	Fe
%	20.8	2.84	12.1	0.64	9.79	0.54	0.8	Balance

**Table 2 Welding parameters**

Experiment No.	Wire feed rate m/min(Current,A)	Speed cm/min	Voltage V	Heat, KJ/cm
1	9.04(300)	27	32	21.33
2	7.62(250)	36	26	10.83

Microhardness of the overlaid specimen for high and low input was determined using Vickers microhardness tester along the horizontal axis and close to the surface of the plate, starting from the central line of the weld. Microhardness was measured at an interval of 0.5 mm in the weld zone, 0.1 mm in HAZ and at an interval of 0.5 mm in the base plate. Microhardness corresponding to the conditions of high and low input along the horizontal direction is shown in Fig.1.

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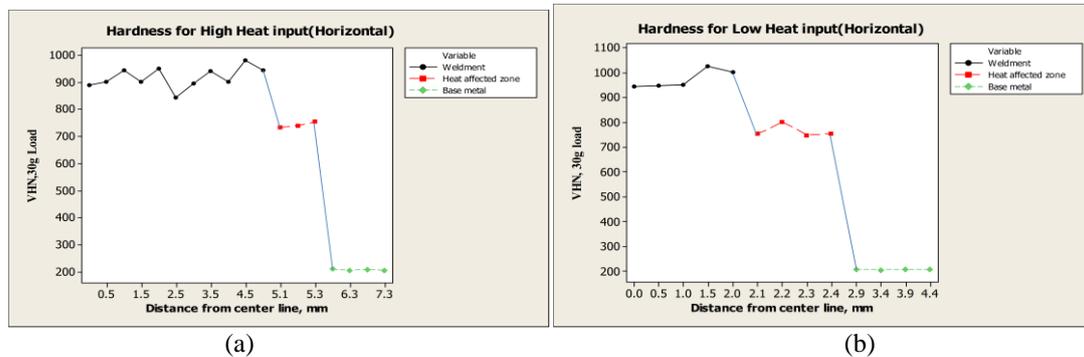


Fig. 1 Microhardness (a) high heat input (b) low heat input

It was observed that average microhardness of low heat input was higher than high heat input. This may be due to the fact that higher the rate of heat input higher is the cooling rate which in turn results in coarse grain boundary reducing the hardness.

### III. PLAN OF INVESTIGATION

The research work was planned to be carried out in the following steps:

(i) identifying the important process control variables; (ii) determining the upper and the lower limits of the control variables, having significant influence on abrasive wear behaviour; (iii) developing the design matrix; (iv) conducting the experiments as per the design matrix and recording the response; (v) developing the mathematical models; (vi) calculating the coefficients of the polynomials; (vii) checking the adequacy of the models; (ix) testing the significance of the regression coefficients and arriving at the final mathematical models; (x) presenting the main effects and the significant interactions between the different parameters in graphical form Srimath and Murugan (2011).

#### 1. Identifying the important process control variables

From the literature survey it was found that wear rate in general is influenced by Load, Sliding Velocity, Sliding distance and Temperature. Therefore, for developing the matrix, out of these wear parameters, only three independently controllable parameters namely Load (L), Sliding velocity (SV) and Sliding distance (SD) were considered as variable. The Temperature parameter was not considered for the study due to the unavailability of heating coil or any other heating element on the Pin on Disc Machine.

#### 2. Determining the Upper and Lower levels for the input variables

The upper and lower limits of these process control variables are shown in Table 3.

Wear parameters were coded as (+1) and (-1), corresponding to the high and low levels for the ease of recording and processing of the data using equation (2).

$$X_j = (X_{jn} - X_{jo}) / J_j \tag{2}$$

Where,  $X_j$  is the coded value of the parameter,  $X_{jn}$  is the natural value of the parameter,  $X_{jo}$  is the natural value of the basic level,  $J_j$  is the variation interval and  $j$  is the number of parameter.

Table 3 Levels of the welding parameters.

Variables	Unit	Symbols	Levels	
			Lower	Upper
Load	N	L	10 (-)	50 (+)
Sliding velocity	m/s	SV	1 (-)	3 (+)
Sliding distance	m	SD	1500 (-)	1800 (+)

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### 3. Developing the design matrix

Factorial design can be written in the form of a design matrix where the rows correspond to different trials and the columns correspond to the levels of the process parameters. The design matrix developed to conduct eight trials of 2<sup>n</sup> fractional factorial design is given in Table 4.

Table 4 Design Matrix

S.No.	Load (L)	Sliding velocity(SV)	Sliding distance(SD)
1	1	1	1
2	-1	-1	-1
3	1	1	-1
4	1	-1	1
5	-1	1	1
6	-1	1	-1
7	1	-1	-1
8	-1	-1	1

### 4. Conducting the experiments as per the design matrix and recording the response

After hardfacing of the substrate, eight test pieces of each level were cut out by wire EDM cutting process, of the cross section 10mm\*10mm. Some of the specimens are shown in Fig. 3. These test pieces were then welded to 8mm diameter cylindrical pin on the face opposite to that of hardfaced face. This was done so that these test specimens could be clamped on pin on disc machine. Fig. 4 shows some of the final test specimens. The material selected for disc was ASTM M2 Steel. The diameter of the disc was 165mm.



Fig. 3 Wear test specimens



Fig. 4 Final Test specimens

Initially the test specimens were cleaned with acetone to make the surface free from grease, dust and other impurities on test surface. Then the test pieces were weighed on an electronic balance machine having sensitivity of up to five decimal places. Test pieces were then mounted on the pin on disc machine for wear testing for the selected parameters. After performing the testing on machine, the test specimens were again washed-off the debris with acetone and dried properly. The test pieces were then again weighed on electric weighing machine. The difference in weight of test specimen was used to determine the wear volume. Wear volume can be calculate as

$$W_v = (W_i - W_f) / \text{Density} \tag{3}$$

Experiments were then conducted as per the design matrix given in Table 4. Table 5 shows the observed wear volume of each specimen, according to heat input level.

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**Table 5 Observed wear volume**

Experiment No.	Load (L)	Sliding Velocity (SV)	Sliding Distance (SD)	Wear Volume (High heat input)	Wear Volume (Low heat input)
1	50	3	15	296.6	128.112
2	10	3	40	188.5	103.62
3	10	1	40	113.1	69.3312
4	50	1	40	265.2	105.504
5	10	3	15	213.6	92.9392
6	50	1	15	226.2	94.2
7	50	3	40	314.2	135.648
8	10	1	15	103	61.7952

### 5. Selection of a mathematical model

The response function Y, representing the wear volume, could be represented as:

$$Y = f(L, SV, SD) \tag{4}$$

Where, the response variable, ‘Y’ could be any of the wear volume loss corresponding to high and low heat input. The direct process parameters; Load (L), Sliding velocity (SV) and Sliding distance (SD) were considered as variable. Assuming a linear relationship in the first instant and taking into account all the possible two-parameter interactions, the above expression can be expressed as:

$$Y = b_0 + b_1L + b_2SV + b_3SD + b_4L*SV + b_5L*SD + b_6 SV*SD \tag{5}$$

Where,  $b_0, b_1, b_2, \dots, b_6$  are the coefficients of the polynomial equation

### 6. Evaluation of Coefficients and developing the mathematical models

Regression analysis was used for determining the coefficients of the model. The regression coefficients of the selected model were calculated using Equation (6)

$$b_{ij} = \frac{\sum_{i=1}^M X_{ji} Y_i}{M}, j = 0,1,2,3,\dots,k \tag{6}$$

Where,  $X_{ji}$  is the value of a parameter or interaction in coded form,  $Y_i$  is the average value of the response parameters,

$M$  is the number of observations and  $k$  is the number of coefficients of the model.

The models for predicting wear volume for high and low heat input mentioned above are given below:

$$WV1 = 98.769 + 16.061S.V - 4.757L + 17.097S.D + 0.047S.V*L - 0.475S.V*S.D - 0.047L*S.D. \tag{7}$$

$$WV2 = 215.05 + 38.18S.V + 60.50L + 5.20S.D - 8.32S.V*L - 7.08S.V*S.D + 8.95L*S.D \tag{8}$$

For the sake of simplicity, symbol for wear volume for high and low heat input was assigned as WV1 and WV2 respectively.

### 7. Checking the adequacy of the models

The adequacy of the model and significance of the coefficients was tested by applying ‘F’ and student’s ‘t’ test respectively Singla et al. (2010). Details of analysis of variance for high and low heat input are given in Table 6 and 7. To ensure the accuracy of the developed model and survey the spread of values, results were plotted using the scatter diagram. The scatter diagram of high and low heat input, for observed vs. estimated values of wear volume for different rows of the design matrix is represented in Fig. 6.

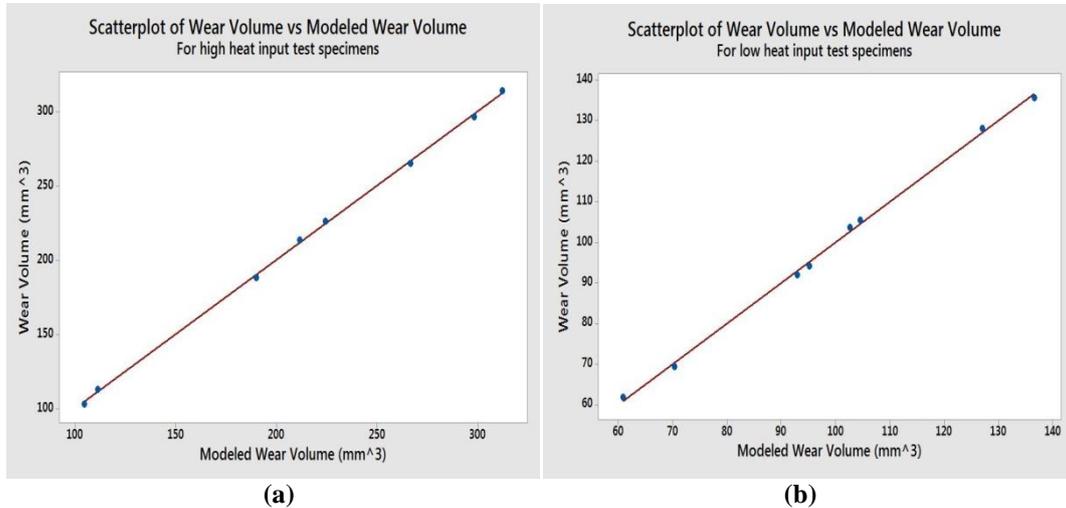
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**Table 6 Analysis of variance (ANOVA) for (a) high heat input (b) high heat input**

(a)						(b)					
Source	DF	Adj SS	Adj MS	F value	P value	Source	DF	Adj SS	Adj MS	F value	P value
Model	6	42752.7	7125.4	299.33	0.044	Model	6	4583.31	763.88	97.60	0.077
Linear	3	41157.0	13719.0	576.31	0.031	Linear	3	4583.25	1527.75	195.20	0.053
S.V.	1	11658.6	11658.6	489.76	0.029	S.V.	1	2063.67	2063.67	263.68	0.039
Load	1	29282.0	29282.0	1230.08	0.018	Load	1	2338.54	2338.54	298.80	0.037
S.D.	1	216.3	216.3	9.09	0.204	S.D.	1	181.04	181.04	23.13	0.131
2-Way Interaction	3	1595.7	531.9	22.34	0.154	2-Way Interaction	3	0.05	0.02	0.00	1.000
S.V.* Load	1	554.4	554.4	23.29	0.130	S.V.* Load	1	0.02	0.02	0.00	0.970
S.V.* S.D.	1	400.4	400.4	16.82	0.152	S.V.* S.D.	1	0.02	0.02	0.00	0.970
Load * S.D.	1	640.8	640.8	26.92	0.121	Load * S.D.	1	0.02	0.02	0.00	0.970
Error	1	23.8	23.8			Error	1	7.83	7.83		
Total	7	42776.5				Total	7	4591.13			



**Fig. 6: Scatter diagram (a) high heat input (b) low heat input**

### 8. Testing the significance of the regression coefficients and final proposed mathematical models

The proposed models developed for wear volume after dropping insignificant coefficients Kumari et. al (2011). are given in Table 8. Based on these models, graphs have been drawn for interpretation of the direct and interaction effects of the process parameters on bead geometry.

**Table-8 Proposed models for wear volume**

$$WV1 = 98.769 + 16.061S.V - 4.757L + 17.097S.D - 0.047L * S.D. \quad (9)$$

$$WV2 = 215.05 + 38.18S.V + 60.50L + 5.20S.D \quad (10)$$

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## 9. Significant Main Effects and Interactions

The variation of wear volume with respect to load (L), sliding velocity (SV) and sliding distance (SD) are shown in, Fig. 7 and 9. The interaction effects of load and sliding distance is shown in Fig. 8.

### IV. ANALYSIS OF RESULTS

The mathematical models that were fitted to the experimental data provided satisfactory correlations. This is also evident from the scatter diagrams as shown in Fig. 5 and 6. The direct effect and interaction effect of various wear parameters on wear volume were depicted by feeding the coded values in the final model of wear volume and by varying one input parameter at a time and keeping others at fixed value. The main and interaction effect for both the conditions have been discussed as under:

#### 1. Effect of load, sliding velocity and sliding distance on wear volume for high heat input

Main effect and interaction effect of all the wear parameters i.e. load (L), sliding velocity (SV) and sliding distance (SD) for high heat input are shown in Fig. 6 and 7 respectively. Fig. 8(b) shows the response surface due to the interaction effect of load (L) and sliding distance (SD).

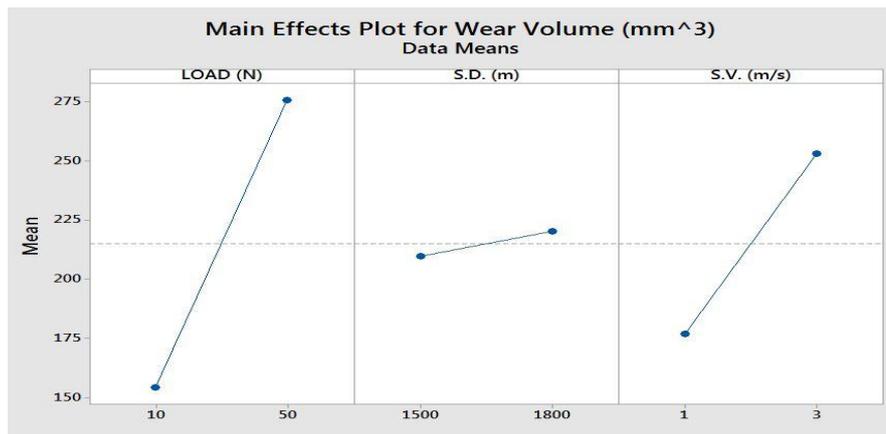


Fig. 7 Main effect of load, sliding velocity and sliding distance on wear volume for high heat input

It is evident from Fig. 7, that load has the most harmful effect in comparison to sliding velocity and sliding distance.

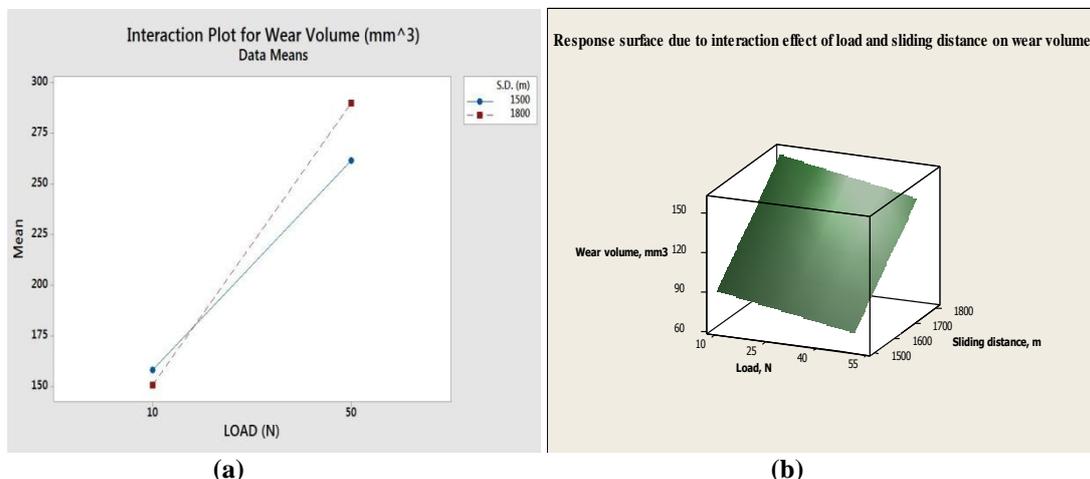


Fig. 8 (a) Interaction effect of load and sliding distance on wear volume (b) response surface

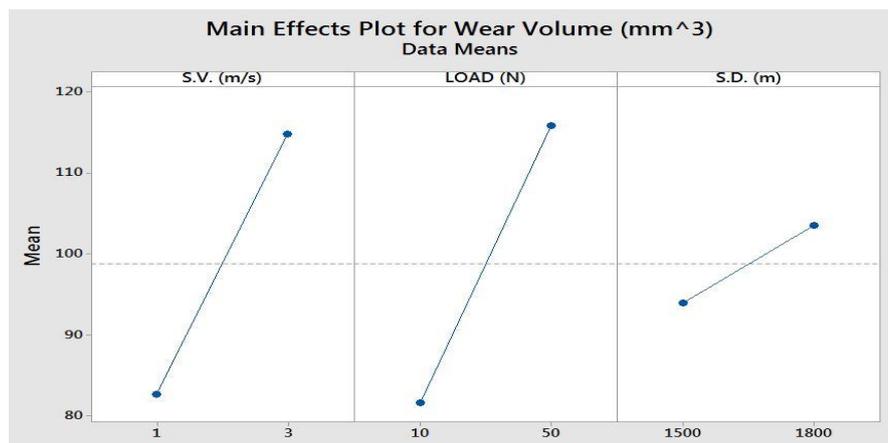
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### 2. Effect of load, sliding velocity and sliding distance on wear volume for low heat input

Main effects of all the wear parameters i.e. load (L), sliding velocity (SV) and sliding distance (SD) for low heat input are shown in Fig. 9.



**Fig. 9 Main effects of load, sliding velocity and sliding distance on wear volume for low heat input.**

It is evident from Fig. 9, that load has the most harmful effect in comparison to sliding velocity and sliding distance.

## V. CONCLUSION

The conclusions are drawn from the study of mathematical models as well as the experiments conducted in actual condition. Important results are as follows:

1. Response Surface Methodology (RSM) approach is an excellent and effective tool, for the development of mathematical model for the prediction of response.
2. Scatter diagram ensures the accuracy of the model.
3. Wear is in direct relation with Load, Sliding velocity and Sliding Distance.
4. As the hardness of low heat input specimen (LHI) is higher than that of high heat input (HHI) specimen hence the wear of low heat input (max.135mm<sup>3</sup>) is less than that of high heat input (max.296mm<sup>3</sup>).
5. The effect of load and sliding velocity on the rate of wear is predominant over sliding distance. {W<sub>v</sub> for load=118(LHI), 275(HHI)mm<sup>3</sup>; W<sub>v</sub> for SV=115(LHI), 250(HHI)mm<sup>3</sup>; W<sub>v</sub> for SD=102(LHI), 215(HHI)}
6. Wear rate of any material is in inverse relation with the hardness of that material.

## REFERENCES

- [1] Amushahi, M., H., Asharfizadeh, F. and Shamanian, M., 2010. Characterization of boride-rich hardfacing on carbon steel by arc spray and GMAW processes. *Surface and Coatings Technology*, Volume 204, Issues 16–17, Pages 2723–2728.
- [2] Arulmani, R. and Pandey, S., 2003. Surfacing applications – A review, *National Workshop on Welding Technology, S.L.I.E.T., Longowal, April 25–26*, 233–238.
- [3] Badisch, E., Katisich, C., Winkelmann, H., Franek, F. and Roy, M., 2006. Wear behaviour of hardfaced Fe–Cr–C alloy and austenitic steel under 2–body and 3–body conditions at elevated temperature, *Journal of Tribology International*.
- [4] Balasubramanian, V. and Varahamoorthy, R., 2009. Selection of welding process for hardfacing on carbon steels based on quantitative and qualitative factors. *Journal of Advance Manufacturing Technology*, 40, 887–897.
- [5] Buchman, V. E. and Shipway, P. H., 2007. Microstructure and abrasive wear behaviour of shielded metal arc welding hard facings used in the sugarcane industry. *Wear*, 263, pp. 99–110.
- [6] Buchman, V. E. and McCartney, D. G., 2008. A comparison of the abrasive wear behavior of iron–chromium based hardfaced coatings deposited by SMAW and electric arc spraying. *Wear*, 264, 542–549.
- [7] Chatterjee, S. and Pal, T. K., 2006. Weld procedural effect on the performance of iron based hardfacing deposits on cast iron substrate. *Journal of Material Processing Technology*, 173, 61–69.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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- [8] Choteborsky, R. & Hrabec, P., 2008. Abrasive wear of high chromium Fe–Cr–C hardfacing alloys. *Res. Agr. Eng.* 54, 192–198.
- [9] Dong, G., A., 2013. Hardfacing Technologies for Improvement of Wear Characteristics of Hot Working Tools: A Review International Journal of Precision Engineering And Manufacturing. Vol. 14, No. 7, pp. 1271–1283.
- [10] Kannan, T. and Yoganandh, J., 2010. Effect of process parameters on clad bead geometry and its shape relationships of stainless steel claddings deposited by GMAW. *Int. J Adv Manuf. Technol.* 47: pp 1083–1095.
- [11] KenchiReddy, K. M. and Jayadeva, C. T., 2012. An Experimental Study on the Effect of Microstructure on Wear Behavior of Fe–Cr–C Hardfacing Alloys procedures, *Bonfring International Journal of Industrial Engineering and Management Science*, Vol. 2, No.1.
- [12] Kumar, S. & Mondal, D. P., 2000. Effect of microstructure and chemical composition of hardfacing alloys to abrasive wear behavior. *Journal of Material Processing Technology*, 9, 649–655.
- [13] Kumari, P., Archana, K., Parmar, R.S., 2011. Effect of Welding Parameters on Weld Bead Geometry in MIG Welding of Low Carbon Steel. *International Journal of Applied Engineering Research*. 6( 2): pp. 249–258.
- [14] Maiti, A.K., Mukhopadhyay, N. and Raman, R., 2007. Effect of adding WC powder to the feedstock of WC–Co–Cr based HVOF coating and its impact on erosion and abrasion resistance, *Surface & Coatings Technology* 201, pp 7781–7788.
- [15] Nassar, A. E. and Nassar, E. E., 2011. Design and Fabrication of a Wear Testing Machine” *Leonardo Electronic Journal of Practices and Technologies*. ISSN 1583–1078, pp. 39–48.
- [16] Navas, C., Colaço, R., De Damborenea, J., Vilar, R., 2006. Abrasive wear behaviour of laser clad and flame sprayed–melted NiCrBSi coatings. *Surface and Coatings Technology*, Volume 200, Issue 24, pp. 6854–6862.
- [17] Olivera, P., Meri, B., Zlatan, M. and Sepold, G., 2010. The effect of heat input on the weld metal toughness of surface welded joint, *Wear, Journal*, pp.147s – 153s.
- [18] Purakayastha, S. and Dwivedi, D.K., 2014 ‘Slurry erosion performance of CeO<sub>2</sub> modified Ni/WC coatings”, *Industrial Lubrication and Tribology*, Vol 66, 533–537.
- [19] Quintino, L. and Olga, L., Louriel, V. and Américo, S., 2013. Heat input in full penetration welds in gas metal arc welding (GMAW), *Int. J Adv Manuf. technology* 68: pp 2833–2840.
- [20] Rajeev, V. R., Dwivedi, D. K. and Jain, S.C., 2010. Effect of load and reciprocating velocity on the transition from mild to severe 4 wear behavior of Al–Si–SiCp composites in reciprocating conditions. Technical Report, Materials and Design.
- [21] Selvi, S. S. and Srivatsavan, R., 2008. Comparative study of hardfacing of valve seat ring using MMAW process. *Journal of Material Processing Technology*, 207, 356–362.
- [22] Sharma, S., Dwivedi, D. K. and Jain, P. K., 2012. Abrasive Wear Response Surface Model of HVOF Sprayed NiCr–WC–Co Composite Coatings. *Journal of Engineering Tribology*, 226: pp 57–70.
- [23] Singla, M., Singh, D. and Dharmal, D., 2010. Parametric Optimization of Gas Metal Arc Welding Processes by Using Factorial Design Approach. *Journal of Minerals & Materials Characterization & Engineering*, Vol. 9, No.4, pp.353–363.
- [24] Smith, R.W., 1992. Thermal Spray Technology. Homesmdy Course. Lesson 2, ASM International, Materials Engg. Lng Institute, Materials Park. OH.
- [25] Srimath, N. and Murugan, N., 2011. Prediction and Optimization of Weld Bead Geometry of Plasma Transferred Arc Hard faced Valve Seat Rings. *European Journal of Scientific Research* Vol.51 No.2, pp.285–298.
- [26] Wang, X., Fang, H., Xuemei, L., Shiyao, Q. and Zengda, Z., 2008. Microstructure And Wear Properties Of The Fe–Ti–V–Mo–C Hard Facing Alloy. *Wear*, volume 265, Issues 5–6, pp. 583–589.