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Effect of Dilution on Wear Characteristics of High-Carbon-Ferro-Chrome Hardfacing Layer Made By Paste Technique Using E-6013 SMAW Electrode

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Abstract - **Hardfacing is a process of coating a wear resistant material on the surface of machine elements or tools by means of welding deposit. Its main purpose is to reduce the wear and tear of machine elements or tools by enhancing the wear resistance of the base metal. It is one of the most useful and economical way to improve the wear performance of a component. Surface properties and quality achieved by hardfacing depends upon the selected hardfacing metal and the welding process used for hardfacing. The variables of the tests were the welding current and coating thickness. High-carbon-ferro-chrome in powder form was mixed with sodium silicate and thick consistent paste was applied on the surface of the base metal. Three different coating thickness and welding current ranges were chosen for hardfacing. The investigation was carried out on all nine samples as per the design matrix. The tests such as wear test and dilution test were carried out to record the observations. The optimization of parameters was achieved by the use of factorial design. It was observed that optimum value for hardfacing is 2 mm coating thickness and 100 A current at which the dilution is minimum (22.02 %) and minimum wear rate (0.0468 gm/hr) is obtained. Also it was observed that with the increase in coating thickness up to certain level at a particular current, there was decrease in wear rate.**

*Keywords***-** Hardfacing, Paste coating, Wear, SMAW.

1. INTRODUCTION

Durability and reliability of any material is priceless for any nation especially developing countries like India. All types of industrial setup irrespective of whether being in manufacturing/assembly or service sector had drawn their reputation from the durability and reliability of their products. Studies shows that any industrialized nation losses between 4-6% of GNP only due to wear and only abrasion wear counts 63% of total loss due to wear. Degradation of material by wear and corrosion cost a very high loss whether it is of reputation or economic loss to all the countries. Although considerable attention has already been paid by the researchers to develop modern techniques and methods to arrest and control the problems resulting from wear and corrosion, still there is a need for further research to reduce the losses incurred because of them. It is estimated that more than 30% of wear and corrosion related cost can be reduced by developing and using better techniques of controlling wear and corrosion. A metal is deposited over another surface to increase the hardness of the surface and to make it resistant to abrasion, impact, erosion, galling and cavitation. This process is called hardfacing because the deposited surfaces are harder than the base metal.

Design of experiment is very important for setting up the experiments for efficient analysis [6, 10, 13]. In this paper, design of experiment is used for the optimization of input parameter such as welding current and coating thickness with three different ranges. For the optimization factorial design is used with the help of Design expert (DX06)

2. LITERATURE REVIEW

Buchanan V.E.,McCartney D.G., Shipway P.H.(2006) a proposed the comparison of the abrasive wear behavior of iron-chromium based hardfaced coatings deposited by SMAW and electric arc spraying. The study showed that variations in the morphology of the carbides and structure of the weld deposits produced marked differences in resisting dry abrasive wear. The arc-sprayed coating exhibited comparable wear resistance to that of the SMAW overlays. Erloglu M., Zedmir N.O.(2001) a proposed the Tungsten inert gas surface alloying of a low carbon steel. The alloyed surfaces with high-carbon-ferro-chromium layer with 2.4 mm layer showed an increase in hardness and wear resistance. This was attributed harder phase with higher volume fraction of carbides in the microstructure. Jha A.K. , Mondal D.P , Kumar Sanjay(2000) a proposed effect of microstructure and chemical composition of hardfacing alloy on abrasive wear behavior. 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. Leiko A., Navara E. proposed the microstructural characterization of high-carbon ferrochromium. The microstructure of a slowly cooled alloy contains primary gamma carbides and chromium ferrite, as a result of divorcing during the eutectic reaction. The volume fraction of the alpha phase is small, insufficient to bind the gamma crystals; as a consequence, slowly cooled ferrochromium is brittle and friable.

3. ADOPTED METHODOLOGY

Composition of base metal used:

C%	Si%	Mn%	P%	S%	Fe%
0.28	0.147	0.407	0.032	0.029	Rest

Composition of electrode used:

C%	Si%	Mn%	P%	S%	Fe%
0.10	0.25	0.35	0.03	0.03	Rest

Composition of metal powder used:

C%	Si%	Mn%	P%	S%	Cr%	Fe%
7.4	0.78	0.03	0.05	0.05	64	Rest

The paste was applied on the base metal thickness of 10 mm along 100 mm length. The paste was applied on 9 different plates with three different coating thickness of high-carbon-ferro-chrome with the help of custom made die according to the combination selected from the design matrix.

Process parameters and their working ranges:

Parameter	Units	Level 1	Level 2	Level 3
Welding current	A	100	120	140
Coating thickness	mm	1	1.5	2

For stability of the arc during the welding, baking was done to remove the moisture from the paste. For this, the plates were placed in muffle furnace for baking at 80^0C upto 2 days, after that at 100^0C for next 2 days and at 150^0C for next 2 days to remove the moisture from the paste. Beads on mild steel plates have been deposited as per design matrix using E 6013 electrode of 3.15 mm dia. and 350 mm length. DCEN polarity was used to minimize the dilution which otherwise will decrease the hardness of the material. Experiments were conducted according to the design matrix with different combinations of welding current and coating thickness. To start the arc, a little space was left without paste on the plate to maintain arc stability. After that dilution test and wear test were performed.

4. RESULTS AND DISCUSSION OF THE TEST PERFORMED

4.1 Effect of process parameter on dilution

ANOVA table is constructed based on the recorded observation tabulated in table-1 and a mathematical model is developed for the dilution. Table 1 shows that when current is increased then the dilution is also increased, but at same level of welding current when the coating thickness increases the dilution decreases.

Table 1: Dilution readings of all samples

Experiment	Welding current (A)	Coating thickness (mm)	Dilution (%)
1	100	1	24.03
2	100	1.5	23.36
3	100	2	22.02
4	120	1	27.24
5	120	1.5	25.23
6	120	2	23.47
7	140	1	29.88
8	140	1.5	28.45
9	140	2	26.14

Analysis of dilution

Table 2 shows the ANOVA for the dilution with different welding current and coating thickness. It is observed that welding current has the most significant effect on the dilution. Further, coating thickness and interaction between welding current and coating thickness are also significant factor which affects the dilution.

Table 2: Analysis of variance for dilution

Source	Sum of Squares	Degree of Freedom	Mean Square	F value	Prob >F	Whether significant (S) or not (N.S)
Model	53.65	3	17.88	167.31	< 0.0001	S
A-Welding current	37.80	1	37.80	353.62	< 0.0001	S
B-Coating thickness	15.11	1	15.11	141.30	< 0.0001	S
AB	0.75	1	0.75	7.00	0.0267	S
Residual	0.96	9	0.11		--	--
Lack of Fit	0.96	5	0.19		--	--
Cor. Total	54.62	12	--	--	--	--

Values of "Prob > F" less than 0.05 indicates that the model terms are significant. In this case A, B and AB are significant model terms.

Final Equation in Terms of Coded Factors for dilution:

Dilution = 25.44 + 2.51 * A - 1.59 * B - 0.43 * A * B

Final Equation in Terms of Actual Factors:

Dilution = 35654 + 0.19037 * Welding current + 2.01667 * Coating thickness - 0.043250 * welding current * Coating thickness

Figure 1 shows that increase in welding current, increases the depth of penetration due to intense heat of arc force. It could be attributed to the fact that enhanced arc force and heat input per unit length of the weld bead resulted in higher current density that caused melting a larger volume of the base metal and hence deeper penetration.

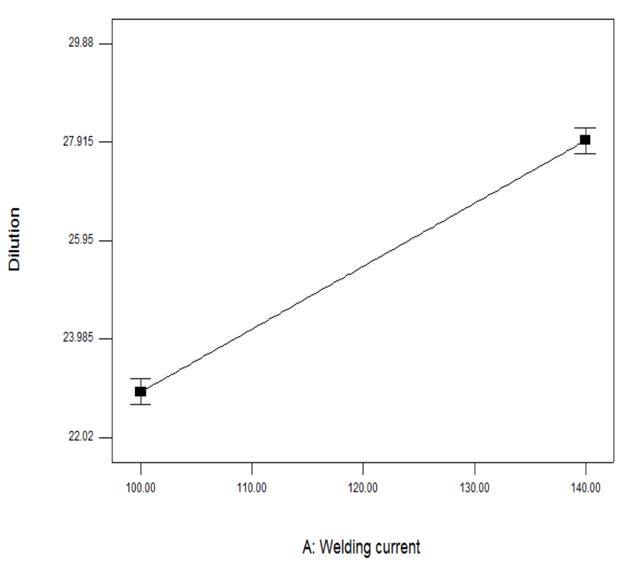

Figure 1: Dilution vs. Welding current

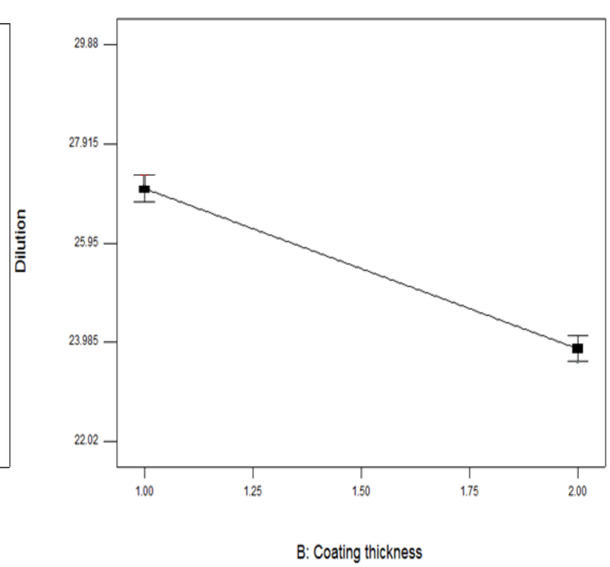

Figure 2: Dilution vs. Coating thickness

Figure 2 shows that graph between coating thickness and dilution, the dilution value decreases linearly from low to intermediate level of coating thickness and also decrease linearly with increase in value of coating thickness from intermediate to high level. So, a proper reduction in penetration in deposited metal, lead to lower dilution levels.

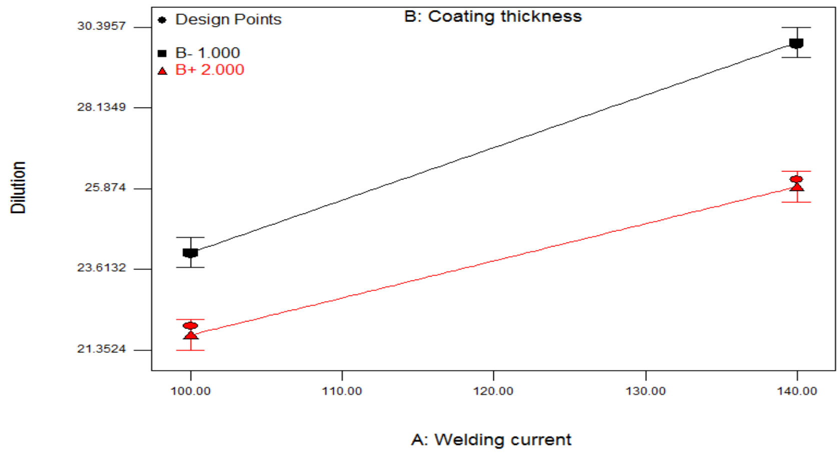

Figure 3: Interaction plot for dilution vs. welding current and coating thickness

Figure 3 shows that the interaction plots are the graphical representation of interaction information in a matrix experiment. Estimating interaction means determining the non-parallelism of the factor's effects in the present investigation, we are interested in studying the interaction between welding current and coating thickness. For this purpose interaction plots have been plotted which are useful in interpreting the interaction between them.

4.2 Effect of process parameters on wear rate

ANOVA table is constructed based on the recorded observation tabulated in table 3 and a mathematical model is developed for the wear rate. It is clear from the table 3, as the value of welding current is increased, the value of wear rate increases due to increases in dilution.

Table 3: Wear rate readings of all samples

Sample	Current (A)	Coating Thickness(mm)	Initial Weight(gm)	Final Weight (gm)	Loss Weight (gm)	Wear rate (gm/hr)
1	100	1	7.2543	7.2480	0.0063	0.0756
2	100	1.5	7.1125	7.1068	0.0057	0.0684
3	100	2	7.3705	7.3666	0.0039	0.0468
4	120	1	7.1983	7.1903	0.0080	0.0970
5	120	1.5	7.0370	7.0301	0.0069	0.0830
6	120	2	7.3186	7.3136	0.0050	0.0610
7	140	1	7.0045	6.9899	0.0146	0.1760
8	140	1.5	7.3519	7.3425	0.0094	0.1130
9	140	2	7.4197	7.4140	0.0057	0.0690

Analysis of wear rate

Table 4 shows the ANOVA for the dilution with different welding current and coating thickness. It is observed that coating thickness has the most significant effect on the wear rate. Further, welding current and interaction between welding current and coating thickness are also the significant factor which affects the dilution.

Table 4: Analysis of variance for wear rate

Source	Sum of Squares	Degree of Freedom	Mean Square	F value	Prob >F	Whether significant (S) or not (N.S)
Model	0.0111	3	0.0036	43.69	< 0.0001	S
A-Welding current	0.0046	1	0.0046	54.79	< 0.0001	S
B-Coating thickness	0.0049	1	0.0049	58.40	< 0.0001	S
AB	0.0015	1	0.0015	17.88	0.0022	S
Residual	0.0076	9	0.0084	--	--	--
Lack of Fit	0.0076	5	0.0015	--	--	--

Cor. Total	0.012	12	--	--	--	--

Values of "Prob > F" less than 0.05 indicates that the model terms are significant. In this case A, B and AB are significant model terms.

Final Equation in Terms of Coded Factors for wear rate:

Wear rate =0.086 + 0.028 * A - 0.029 * B - 0.019 * A * B

Final Equation in Terms of Actual Factors for wear rate:

Wear rate = -0.34448 + 0.0043 – 003 * Welding current + 0.17600 * Coating thickness – 0.0019 - 003 * Welding current * Coating thickness

Figure 4 shows that the effect of variation of welding current on the wear rate. It is observed that, with the increase in welding current wear rate increases due to higher percentage of dilution. Figure 5 shows that the wear rate value decreases linearly from low to intermediate level of coating thickness and again decreases linearly with increase in value of coating thickness from intermediate to high level. From this we can easily conclude that the coating thickness has the most significant effect on the wear loss in the samples.

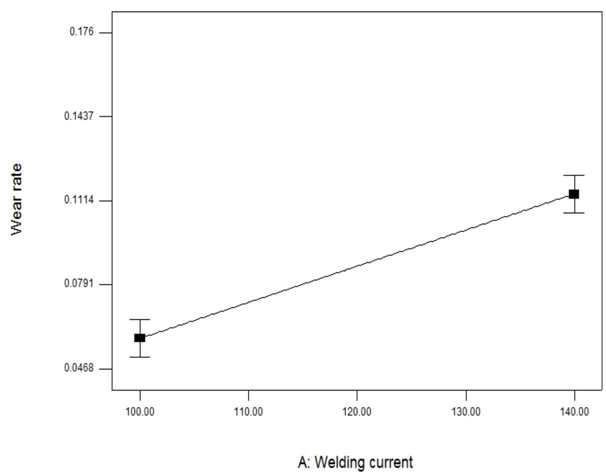

Figure 4: Wear rate vs. Welding current

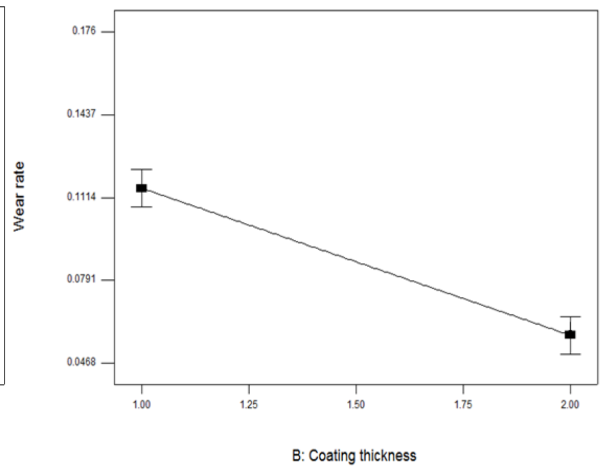

Figure 5: Wear rate vs. Coating thickness

The interaction plots indicate the effect of welding current and coating thickness on wear rate. If there is absolutely no interaction, these lines would be parallel. From figure 6 it is noticed that as the current increases from 100 A to 140 A for the same coating thickness, the wear rate increases due to higher percentage of dilution.

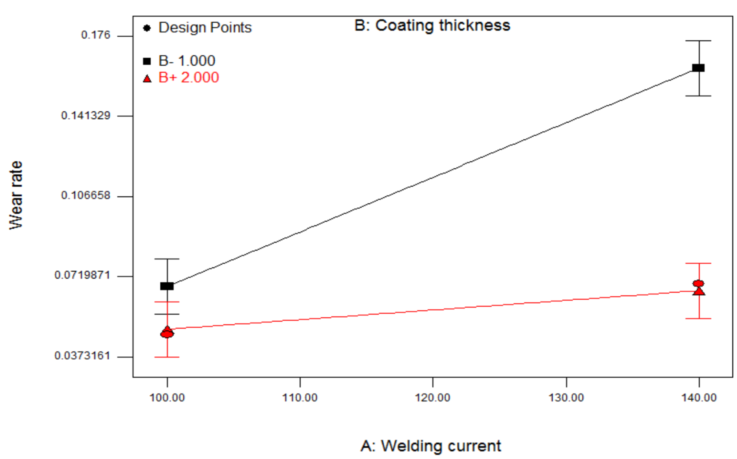

Figure 6: Interaction plot for wear rate vs. welding current and coating thickness

5. CONCLUSIONS

1. Minimum dilution of 22.02 % is noticed with 100 A current and 2 mm coating thickness while maximum dilution of 29.88 % with 140 A current at 1 mm coating thickness is observed. The dilution studies shows that as the current increases from 100 A to 140 A for the same coating thickness, the % age dilution increases due to intense heat of arc force.
2. Minimum wear rate of 0.0468 gm/hr is observed at 100 A current and 2 mm coating thickness while the maximum wear rate is 0.176 gm/hr at 140 A current and 1 mm coating thickness. Also it is noticed that as the current increases from 100 A to 140 A for the same coating thickness, the wear rate increases due to increase in dilution.

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