Wear characteristics of chromium carbide hard faced layer made by paste technique using e-7014 SMAW electrode

[1]Preetinder Singh, [2]Taljeet Singh, [3]Dilpreet Singh, [4]Avtar Singh
[2]Assistant Professor, [3]Assistant Professor, [4]Assistant Professor
[2,3,4]Mechanical Engineering Department
Chandigarh Engineering College, Mohali(Punjab),India

Abstract
Hardfacing is a process of depositing the filler metal on to a compatible surface for the enhancement of wear properties. The process is called hardfacing because the deposited surfaces are harder than that of base metal. Hardfacing is one of the most useful and economical way to improve the wear performance of a component. Surface properties and quality achieved of the hardfaced component depends upon the selected hardfacing alloys and the welding process used for hardfacing. Shielded metal arc welding is most commonly used process for hardfacing due to its easy availability and versatility of operation. Low carbon steel is selected for the present work as substrate material due to its low cost, easy availability and variety of applications. In the present work a detailed study was done to study the effect of different compositions of chromium powder on mild steel, deposited by paste coating process. On coating weld metal of AWS E7014 SMAW electrode was deposited with SMAW Process.

Three different compositions of metal powder chosen for hardfacing material. The investigation was done on three categories of samples prepared by these compositions. Various rigorous tests were carried out on the batch of three samples per category i.e. total nine samples. Wear test, micro-hardness test, dilution test were done to record the observations. Wear test was performed on dry wear and friction testing machine. It was observed that Cr 90% is the best composition in terms of deposit quality, hardness achieved, and wear rate among the three compositions in study. It was observed that with an increase in Cr content there is an increase in micro hardness values as well as the wear resistance is also improved. Best micro hardness was obtained at lower current. It was also found that dilution mainly depend upon heat input and chemical composition of base metal and electrode material. It was further observed that sample have higher Cr content possess fine grain.

Keywords: *Hard facing, Paste coating, Wear, SMAW.*

I. Introduction

Durability and longevity of any material is priceless for any nation especially developing countries like India. All types of industrial set ups irrespective of whether being in manufacturing/assembly or service sector had off late drawn their reputation from the durability and reliability of their products. 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 that 30% of wear and corrosion related cost can be reduced by developing and using better techniques of controlling wear and corrosion [26]. These wear and corrosion related problems can be minimized mainly by following two methods:

1. By using high cost wear and corrosion resistant alloys/metals better than the existing low cost ones.
2. By improving the wear and corrosion resistance of the existing metals and alloys by applying certain modifications to the surface.

As the wear is a surface phenomenon and occurs mostly at outer mating surfaces, therefore it is more appropriate and economical to use the latter method of making surface modification than using the former one which will not only involve very high cost of the operation but also involve longer time as compared to the second technique.

In this presented thesis on wear study, the Shielded Metal Arc Welding (SMAW) method of making surface modification to improve the wear properties of mild steel materials has been used. The mild steel is hardfaced with different compositions of chromium powder. The mild steel is frequently used material for hardfacing due to its low cost, which at same time soft material with poor wear properties.

To reduce this wear problem, the hardfacing was done by paste coating(paste of Cr and sodium silicate) using SMAW on the mild steel plate and were investigated with regard to their wear, microhardness; dilution and bead geometry characteristics

II. Design of experiment

Design of Experiments (DOE) is a commonly used technique in analyzing experimental data resulting in the optimization of processes parameters. The design of experiment is a procedure of selecting number of trials and conditions running them, essential and sufficient for solving a problem that has been set with the required precision. The advantages of designs of experiments are summarized as follows:

1. Numbers of trials are significantly reduced.
2. Identification of important decision variables, which control and improve the performance of the product or process.
3. Optimal setting of the parameters can be found out.

III. Experiental design technique applied

A three level factorial design of (3^2 =9) nine trials has been selected for determining the effect of two independent parameters. The selection of three level factorial design helps in reducing experimental runs to the minimum possible [14].

1. Current, Cr percentage has been identified as critical variables for carrying out the experimental work and to find their effect on the wear. All the remaining variables were kept constant.
2. Upper, medium and lower levels of the process parameters have been carefully selected by carrying out the trial runs. The direct and indirect parameters except under consideration have been kept constant. The upper level has been coded as (H), medium level as (I) and lower level as (L).
3.The design matrix developed to conduct the nine trials runs of 3^2 factorial design.
4. Beads on the mild steel plates have been deposited as per the design matrix with the SMAW E-7014 electrode.
5. The response parameter (wear) is recorded by conducting experiments as per the design matrix.
6. Assuming a linear relationship in the first instance and taking into account all the possible two factors interaction and confounded interaction.
7. The model can be developed by the method of regression. Analysis of variance method has been used to check the significance of the model. The software *Design -for-experts(DX8)* version is used to implement factorial design consisting of nine experiments and to develop a model showing the relationships between the response wear and process parameters (welding current and % of Cr) for coded values of (H), (I), (L) for each of the process parameters. To test the goodness of fit and validation of the develop models, adequacy has been determined by the analysis of variance technique (ANOVA).

IV. Experimental setup & material selection

1. Base metal

Mild steel was selected as base material for hardfacing purpose as we know that it is mainly used in wide application in the fabrication.

2. Selection of electrode

The commonly used electrode for welding mild steel AWS E-7014 is selected. It is a high-speed iron powder type electrode that can be used on AC or DC welding current. This electrode has smooth arc characteristics, good arc stability, low spatter and produces medium to low penetration. E7014 offers outstanding slag removal and bead appearance. This rod is ideal for jobs that require high deposition and speed of travel.

AWS Specification : AWS A5

AWS Classification: E7014

Welding Current: AC-DC

Welding Positions: All positions

2. Selection of metal powder

One hardfacing powder was selected. This hardfacing powder is mixed in sodium silicate and coating is applied in the form of paste. This hardfacing powder was mixed in different proportions in sodium silicate to prepare pastes, which was applied on to the surface to be hardfaced in the form of coating. The powder name given below:

- Chromium powder
- Sodium silicate (Binder)

4. Welding process

There are various different welding methods which can be used for hardfacing. Shielded Metal Arc Welding (SMAW) is mostly used for hardfacing due to its easy operation and low cost. So SMAW was selected as hardfacing process.

5. Process parameters and their levels

The process parameters affecting wear have been identified to enable the carrying out the experimental work and the development of mathematical models. They are welding current (C), chromium percentage (Cr %) .The upper limit of a factor is coded as (H) and lower limit as (L) or intermediate limit as (I). The decided values of process parameters with their units and notations are given in table 1.

Table No. 1. Process parameters and their levels for experimentation

Sr.no.	**Parameters**	**Units**	**Higer level**	**Intermediate Level**	**Lower Level**
1.	Cr %	--------	90 %	80 %	70 %
2.	Current	Ampere	150	130	110

6. Development of design matrix

The design matrix developed to conduct the nine trials of (3^2 =9) three level factorial design. Where H denotes higher level I denotes intermediate level, L denotes lower level [14].

V. Experimentation

1. Preparation of base material

Three mild steel plates (200×30×10) mm has been selected. The mild steel specimens were taken as the base metal or substrate material upon which the hardfacing material was deposited by SMAW welding after the application of paste.

Before depositing the hardfacing material the specimens were thoroughly prepared cleaned mechanically and chemically in order to avoid experimental errors. (Emery paper, acetone, grinding etc).

2. Conducting trial runs

To select current range for corresponding hardfacing electrode the trial runs were conducted over a high, medium and low percentage of chromium with respect to single electrode. Number of specimens were prepared and examined visually and then selective specimens were selected for further investigations based upon the visual examination, hardness testing and wear test examinations were conducted over selected specimens.

3. Conducting actual runs

- As per the data generated by the trial runs the actual experiments were conducted by laying down the beads of different powders paste.
- To develop chromium carbide based harfacing alloy a paste was made with the mixture of chromium and a binder (sodium silicate), coated on a mild steel plate with the help of custom made die.

***Figure 1** Paste coated mild steel plate*

- Depositions were made with different formulations.
- On coating weld metal weld metal was deposited with **AWS** E7014 SMAW electrode.
- Cut specimens were taken for microhardness, microstructure wear and ductility evaluation.
- Experimental conditions for conducting actual runs have been mentioned in table for each type of electrode and the category of experiment.
- Based upon the above mentioned criteria and the sample categorization 3 batches (HH,HI,HL,II,IH,IL,LL,LI,LH) & three samples each batch were selected for further investigations. Total 9 samples with 3 categories were investigated.

4. Testing of samples obtained from actual runs

Following tests were done on hard faced samples.

1. Microhardness test

2. Dilution test

3. Wear test

5. Microhardness test

Microhardness measurement was carried out at Institute For Auto Parts & Hand Tools Technology, Ludhiana using microhardness tester on VHN (Vickers Hardness Number) Scale.

6. Dilution

Dilution is an important factor in hardfacing, Proper amount of dilution is very necessary, if dilution is less that means filler metal has not penetrated inside the base & it will be lacking in bond strength. On the other hand, if dilution is higher than more metal of electrode will penetrate which will result in wastage of material. Dilution basically depends upon the heat input and chemical composition of electrode and base metal. Dilution was measured by profile projector machine. The results of dilution are discussed in next chapter.

Method to calculate dilution as: Dilution = $\{A1/ (A1+A2)\}\times 100$

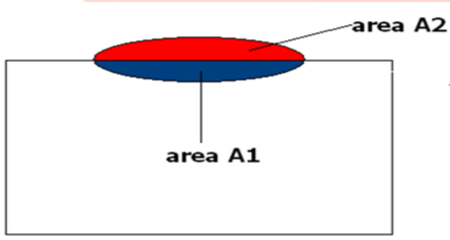

Figure 2 *Dilution*

Where A1 = Area weldment penetration

A2 = Area of weld bead on top surface

7. Wear test

Wear test was carried out on wear test machine at Welding Metallurgy Laboratory of Mechanical Engineering department, SLIET, Longowal. The wheel rotation was 1000 rpm. Three reading were taken to find out the average value. The sample weight was checked after 5 minute. Final loss in weight was measured of the samples; loss in weight can be correlated to indicate the wear rate of each sample. Table 2 gives the parameter used for wear testing machine.

Table No. 2 Wear resistance test data

Applied load	2 Kgs.
Disc dia	50 mm.
Time	5 minutes
Specimen size	25 mm length*6 mm dia.

VI. RESULTS

Table No.3. Microhardness result (all samples)

Sample no.	Sample name	Harness in VHN
1.	HH	637
2.	HI	587
3.	HL	557
4.	IH	615
5.	II	589
6.	IL	562
7.	LH	365
8.	LI	321
9.	LL	282
10.	BASE METAL	208

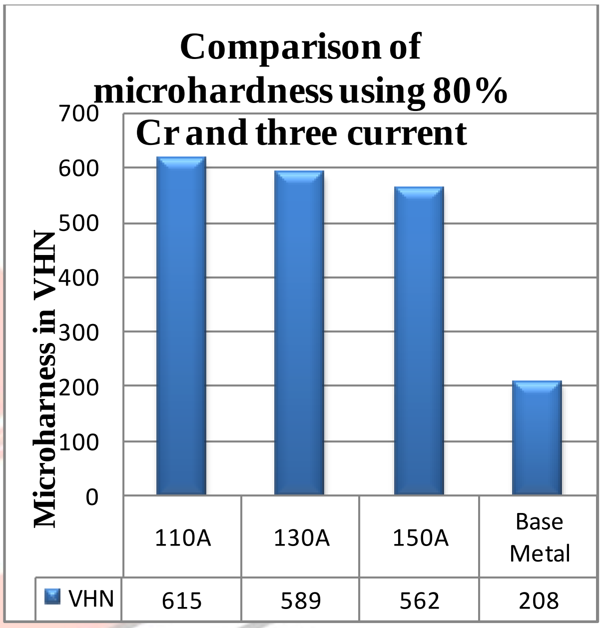

Figure 4 *Comparison of microhardness of 80% Cr using three current*

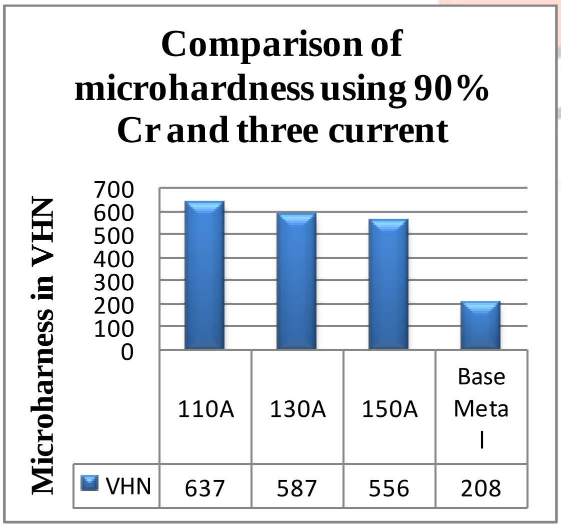

Figure 3 *Comparison of microhardness of 90% Cr using three current*

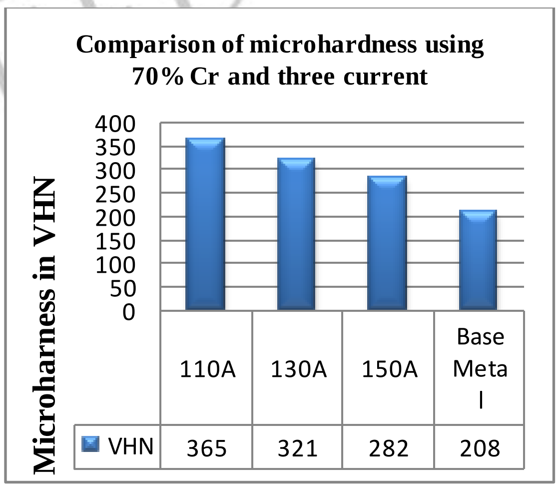

Figure 5 *Comparison of microhardness of 70% Cr using three current*

From the above observation it can be easily concluded that at 110A current the micohardness is coming higher as compared to micohardness values at 130A an150A. The main reason is that with the increase of current hardness decrease for all the three compositions of the paste due to reason that high current results in slower cooling rates resulting in softer matrix having lower hardness. Higher the cooling rate will produce higher micohardness. It has been also observed that the hardness values can be enhanced by approximately 3.10 times using 90% Cr, 3.04

times by using 80% Cr and 1.88 times by using 70% Cr Powder, due to the reason that higher amount of chromium results in increased carbide formation.

Bead geometry diagrams used to calculate dilution according to sample names:

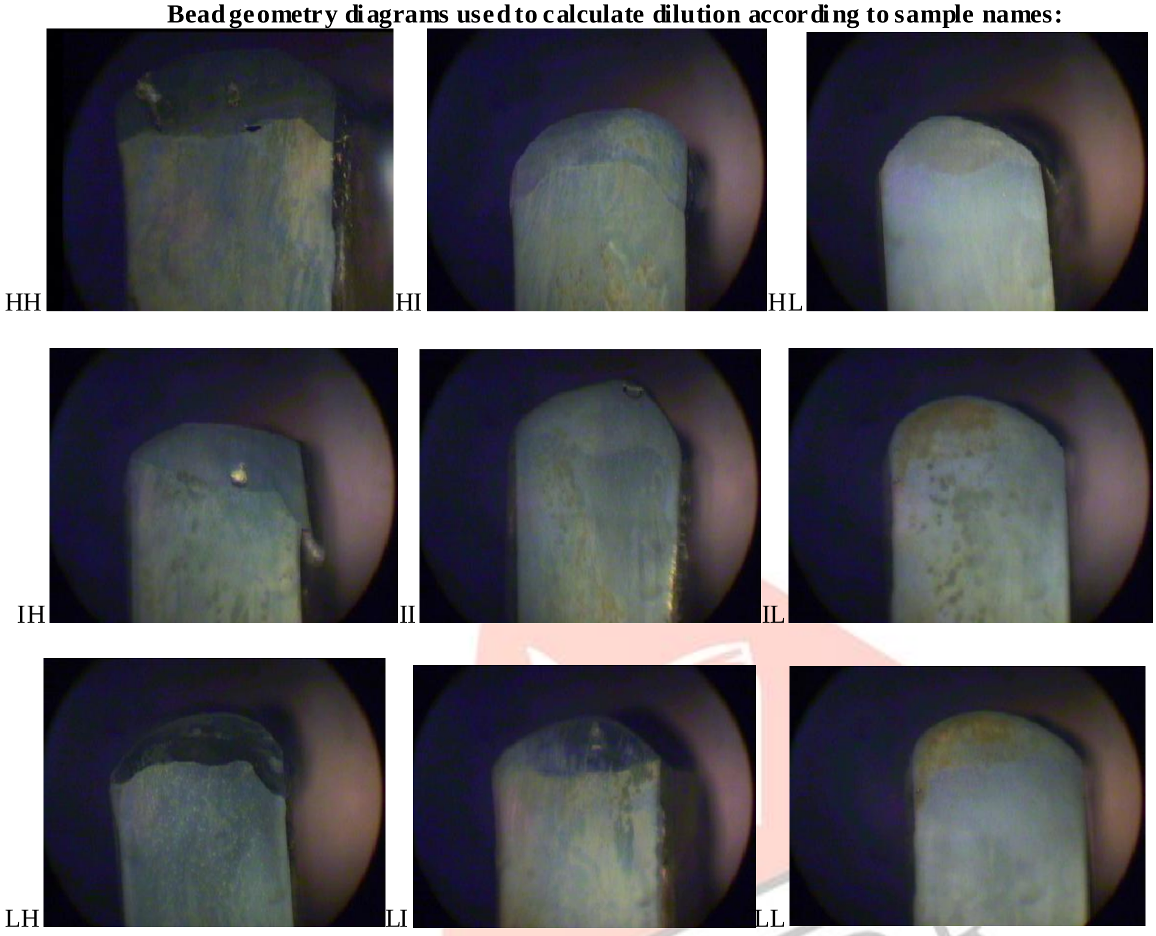

Figure 6 *Samples showing dilution*

Table No.4 Dilution results for all samples

Sample no.	Sample name	Dilution in mm square
1.	HH	24.17
2.	HI	29.1
3.	HL	39.35
4.	IH	27.11
5.	II	32.01
6.	IL	36.11
7.	LH	18.78
8.	LI	25.53
9.	LL	31.11

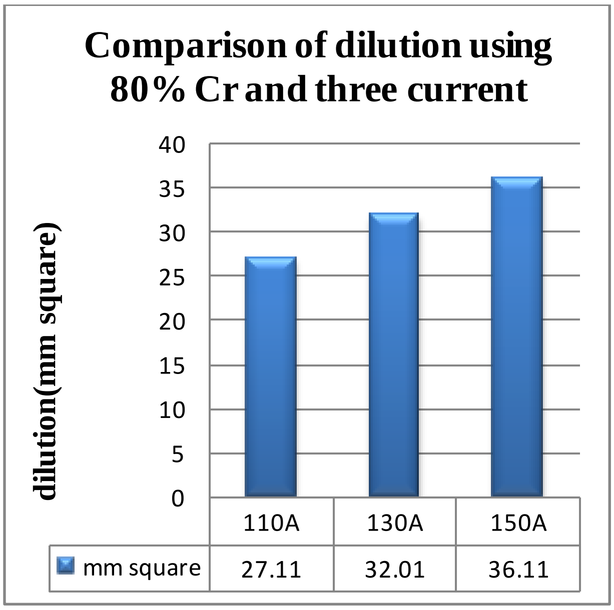

Figure 8 *Comparison of dilution of 80% Cr using three current*

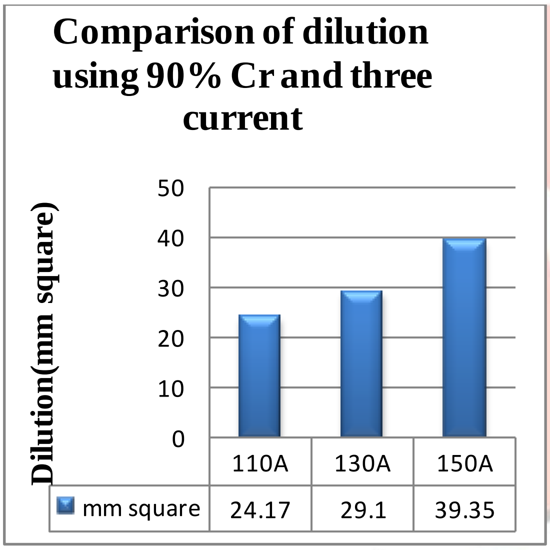

Figure 7 *Comparison of microhardness of 90% Cr using three current*

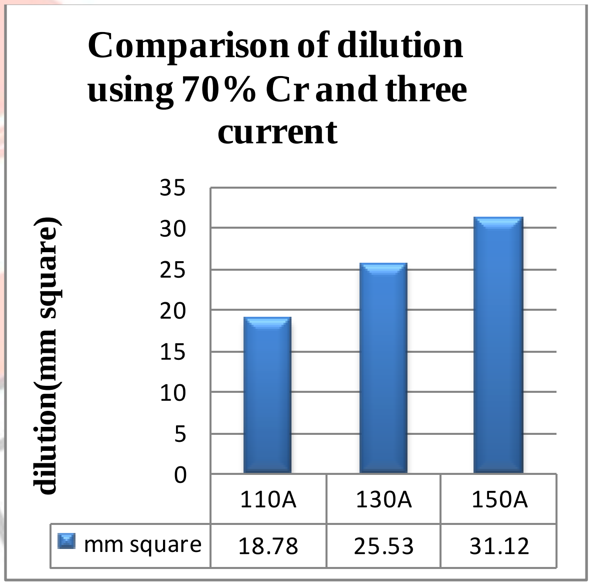

Figure 9 *Comparison of dilution of 70% Cr using three current*

From above observation we can conclude that dilution is higher at higher current as compapare to intermediate and lower levels of current. The dilution basically depends upon heat input given. It is due to the fact that current density increases with increase in welding current as a result higher melting of the electrode takes place. The melting of electrode is due to arc heat and resistance heat. With an increase in welding current, there is a linear increase in arc heat, while the resistance heat increases exponentially which are responsible for electrode melting, resulting increased area of penetration hence dilution.

Table No. 5 showing wear rate results for all samples

Sample no.	Name	Initial Weight(g)	Loss Weight(g)	Final Weight(g)	Wear rate (g/hr)
1	HH	5.6896	0.0051	5.6845	0.0612
2	HI	5.6825	0.0039	5.6786	0.0468
3	HL	5.6876	0.0021	5.6855	0.0252
4	IH	5.5934	0.0051	5.6845	0.0924
5	II	5.6382	0.0049	5.6333	0.0588
6	IL	5.801	0.0046	5.7964	0.0552
7	LH	5.589	0.0108	5.5782	0.1296
8	LI	5.6341	0.0089	5.6252	0.1068
9	LL	5.6559	0.0081	5.6528	0.0972
10	BASE METAL	5.5611	0.134	5.4271	1.608

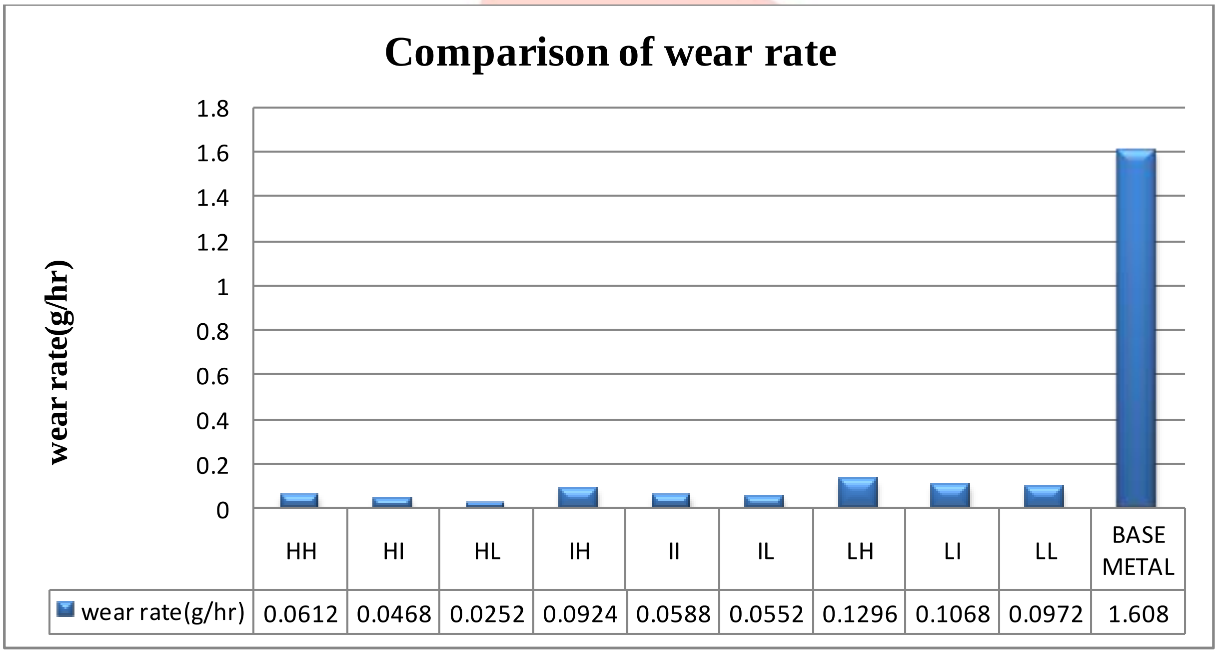

Figure 10 *Comparison of wear rate for all samples*

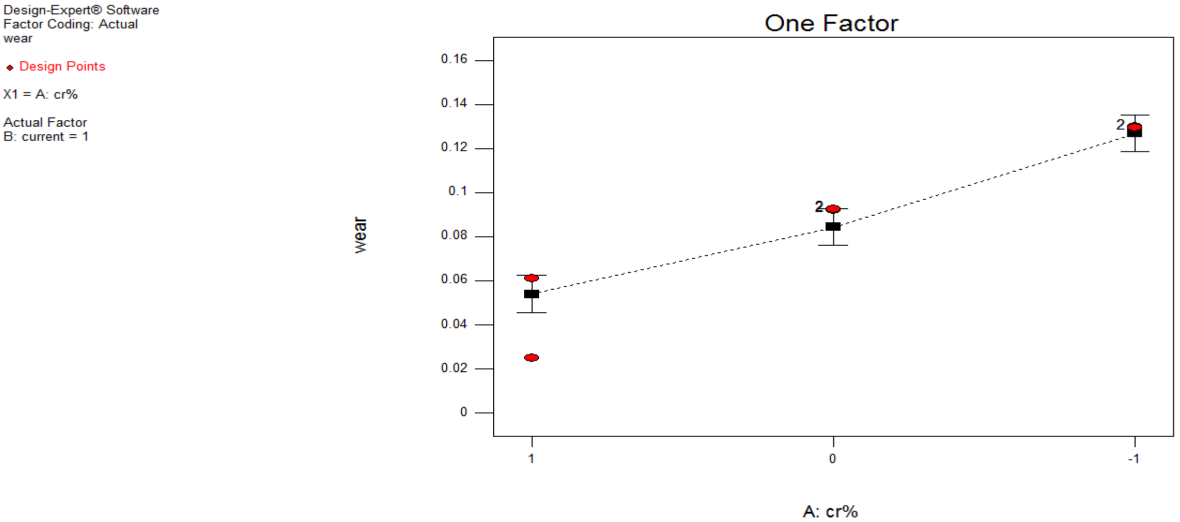

Figure 11 *Interaction between wear and Cr%*

Where point 1 denotes higher Cr 90%,0 denotes intermediate Cr 80% , -1 denotes lower Cr 70%

Variation of wear(g/hr) w.r.t Current(Amp.)

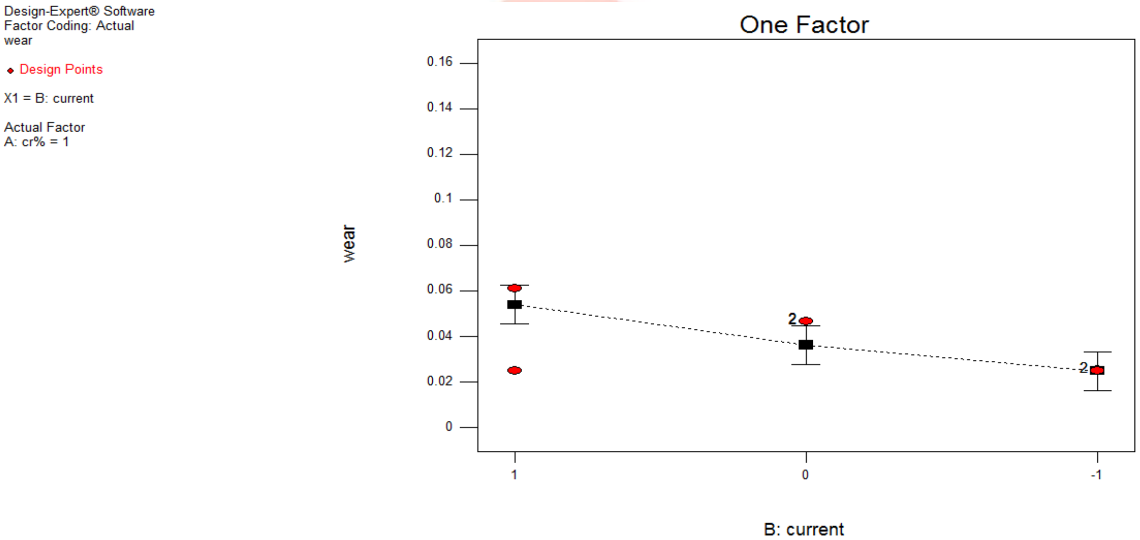

Fig 12 *Interaction between current and wear*

Where point 1 denotes higher current 150A,0 denotes intermediate current 130A , -1 denotes lower current 110A.

Combined interactions of wear(g/hr), Current(Amp.) &% wt of Cr

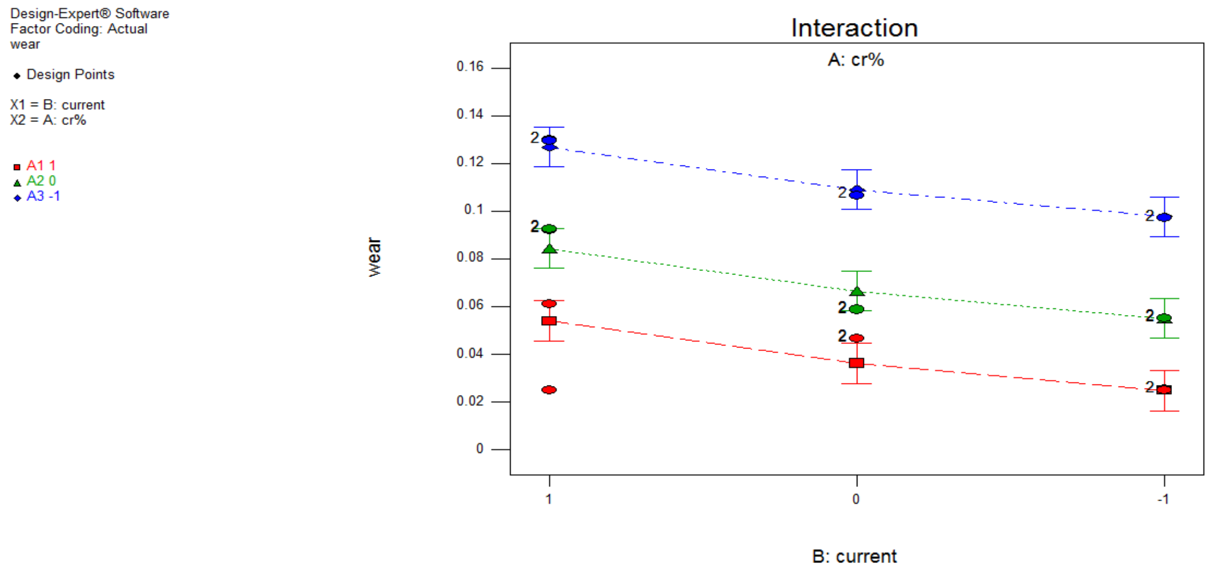

Figure 13 *Combined Interaction of process parameters*

Where A1.1 denotes 90% Cr, A2.0 denotes 80% Cr and A3.1 denotes 70% Cr.

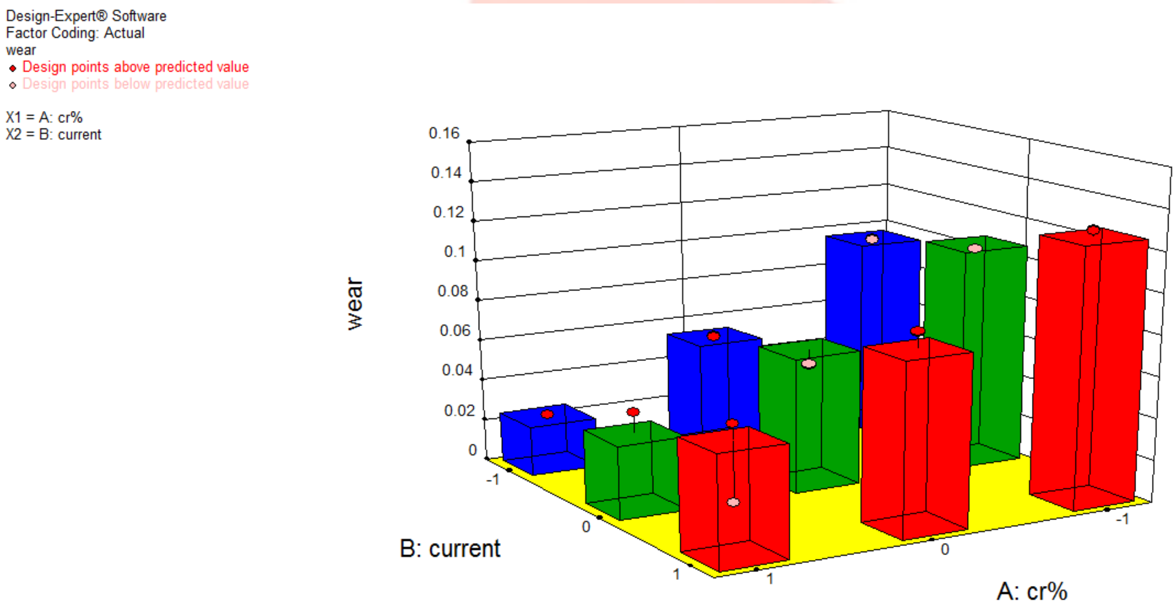

Figure 14 *Combined Interaction of process parameters (3 dimensional view)*

Wear is strongly influenced by the amount of chromium in the paste composition. As the amount of wear resistant elements (like Cr) increases, carbide formation gets increased, which results in enhanced wear resistance.

In **Fig 11** point 1 represents the higher chromium level 90% hence low wear at that point as compare to point 0 (80%Cr)and -1 (70% Cr). This is due to the fact that formation of carbides is higher at point 1 as compare to the point 0 and point -1. It has been observed that with the increase in current, wear also increases for all the three compositions of the paste due to reason that high current results in slower cooling rates resulting in softer matrix having lower hardness.

Fig 12 shows that point 1 denotes the higher level of current hence lower hardness due to the slower cooling rate which results in high wear rate as compare to the point 0 and point -1.

Fig 13 and 14 shows the combined effect of process parameters on wear. It has been observed that as the current is increasing the wear rate also increasing due to decreasing hardness and when Cr% is increasing the wear rate decreasing due to higher formation of carbides. The same observations have been noticed in all the three compositions of paste.

VII. CONCLUSIONS

Following conclusions have been made from the dissertation work:

- The hardness value of mild steel can be enhanced by approximately 3.10 times using 90% Cr, 3.04 times by using 80% Cr and 1.88 times by using 70% Cr powder, as higher amount of chromium results in increased carbide formation.
- Wear resistance of mild steel can be increased up to 26 times using 90% Cr, 17 times using 80% Cr and 12 times by using 70% Cr.
- Considering all the aspects it may be concluded that paste with 90% Cr gives better wear resistance properties and micro-hardness as compared to paste with 80% and 70% Cr content.
- It has been also observed that dilution increases with the increase in welding current. It is due to the fact that, current density increases with increase in welding current, resulting higher melting of electrode. Also the resistance heat which increases exponentially results for the higher melting and thereby increasing the area of penetration hence dilution.
- It has been observed that with the increase of current hardness decreases for all the three compositions of the paste. The reason is that higher current results in slower cooling rates resulting in softer matrix having lower hardness.
- The wear studies show that as the current increases the wear rate also increases due to decreasing hardness. The same observations have been noticed in all the three compositions of paste.

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