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Effect of Chromium Content on Microstructure and Wear Resistance of Fe-Cr-C Hard facing Layers

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Abstract: *Layers of Fe-Cr-C Hard facing material containing various amounts of chromium were deposited on mild steel base metal. Optical Microscope (OM), Scanning Electron Microscope (SCM) and X-ray diffraction (XRD) were used to investigate the effect of chromium content of micro structural characteristics of Fe-Cr-C hard facing layers. The M_7C_3 carbide refinement mechanism exists on base metal. The experimental results show the micro structure of Fe-Cr-C hard facing layers consists of primary (Cr, Fe)$_7C_3$ carbide and the eutectic phases. In the solidification process and growth of the primary (Cr, Fe)$_7C_3$ carbides occur along there long axis which parallels the direction of heat flow. With the increase of chromium content, the primary (Cr, Fe)$_7C_3$ carbides were refined how here it is not proper to increase chromium content without limits. Chromium based alloys are extensively used in the valve industries for wear application, since the possess high resistance to wear plastic deformation at elevated temperature above 750°C. Shielded Metal Arc Welding (SMAW) as been in use for many years however some major issues still exists regarding the ability of the SMAW process to deposit sound welds on high interigity application.*

Keywords: *Abrasive wear**,** Carbides, Hard facing, Micro Structure, Welding.*

I. Introduction

Hard facing is a metal welding process where harder or tougher material is applied to base metal. It is welded to the base material, and generally takes the form of specialized electrodes for arc welding or filler rod for saw, oxyacetylene and TIG welding [1,4]. Hard facing by arc welding is a surfacing operation to extend the service life of industrial components, preemptively on new components, or as part of a maintenance time and production costs has meant that this process has been adopted across many industries such as steel, cement , mining, petrochemical, power sugarcane and food [2]. For each industrial application and wear phenomena, there is a welding wire to provide high hardness and wear resistance. Hard facing can be deposited by various welding methods: open arc welding, Gas shielded welding MIG/MAG, Submerged arc welding, Thermal spraying. The quality of the machine components prone to water and tear depends on their surface characteristics, which include surface roughness, microstructure and hardness. Hence surface deterioration is an important phenomenon for service life of components in many engineering applications. The wear properties of hard facing welding depend upon several factors such as hardness, thickness of surfacing layers, the micro hardness and toughness of matrix structure, volume fraction and distribution of the hardness phases, operating conditions, welding process, etc. Complex carbides electrodes are also used, especially when abrasive wear is accomplished by other wear mechanisms. The main aim of present study was to improve the hardness of hard facing layer with addition of high chromium and manganese and compare by varying the percentage of chromium and manganese in flux.

As we know heat treatment is a process of controlled heating and cooling of metal for the purpose of changing properties without a concurrent change in the product shape. This process improves surface indentation fatigue ad wear. Case hardening is one of the important surfaces hardening process, which improves the toughness, impact strength, wear properties [3, 10]. Hard facing is the deposition of different metal over the parent material to achieve the required properties [11, 15]. Alloys can be added by various ways to hardfacing surface by various means, such as incorporating the powdered form in flux and making electrodes of alloying elements [8].

The alloying elements can be selected according to the purpose i.e. Austenite alloy for impact resistance, Chromium Carbide alloys for impact and abrasion resistance, Cardibe alloys- abrasion and heat resistance, Cobalt alloys – toughness and abrasion [6,7]. In this work it has been proposed to carry out a research to observe the hardness of bead using Submerged Arc Welding Process by varying the travel speed, voltage and current by different welding process such as SMAW, FCAW, and SAW [9,12]. Each process has its inherent advantages. In this present research using Chromium Carbide as hard facing alloy is carry out a comparative study.

II. Experimental Details

2.1 Base Metal

The selection of base metal is very essential in deciding what alloy to use for hardfacing deposit. Since welding procedure differs according to the base metal. Mild steel was selected as the base metal for the study which composes the main elements of carbon, silicon, manganese, sulphur, and phosphorous [13]. The chemical composition is given in Table 1.

2.2 Hard facing Alloys

In the study, two different commercial hardfacing alloys were used for overlaying. These are basically iron – based alloys having varying amount of chromium, carbon, silicon and other alloying elements as they are more suitable for shielded metal arc welding process [14]. Chemical compositions of two electrodes are presented in table 2.

Table I: Chemical Composition Of Base Metal (In Weight Percentage)

C	Si	Mn	S	P	Fe
0.18	0.32	1.47	0.013	0.029	Bal

2.3. Welding Conditions

The standard size of test specimens of 16 nos. with the dimensions of 250×100×12 mm was selected for the experiment.

The following precautions are taken before hard facing:

1. The electrodes are perfectly dried in the furnace and baked at 250°C one hour before the use
2. Area of the weld is properly cleaned
3. Preheated the hard facing area to a minimum of 200°C

Machine specifications

Name: TORNADO MIG 630 Arc welding machine

Current: 100-630 A

Input Voltage: 415 V ± 10% / 50-60 Hz / 3 Phase   Machine Capacity: 50 KVA

2.4 Stages of Experiment

The experiment was carried out in three stages to investigate the effect of welding parameters such as current, travel speed and voltage on hardfacing electrodes and the corresponding hardness was determined by using Vickers hardness

Table 2: chemical composition of hardfacing alloy (in weight percentages)

Electrode	C	Si	Mn	S	P	Cr	Mo	Ni	V	Fe
Hardfacing 1	0.33	0.28	1.15	0.014	0.025	2.22	-	-	-	Bal
Hardfacing 2	0.1	0.38	1.51	0.024	0.03	2.15	0.745	1.09	0.103	Bal

testing machine.

1. In first stage, voltage (V) and travel speed (S) were kept constant and current (A) was increased.
2. In second stage, voltage (V) and current (A) were kept constant and travel speed (S) was increased.
3. In third stage, current (A) and travel speed (S) were kept.
4. Constant and voltage (V) was increased.

Stages of Experiment

Table 3 Varying Current

Electrode	**Current (A)**	**Voltage (V)**	**Travel Speed (cm/min)**	**Hardness (HV 0.5)**	
	200	25	23.1	380	
Hardfacing 1					
	250	25	23.1	318	
	300	25	23.1	317	
	180	25	23.1	370	
Hardfacing 2					
	200	25	23.1	416	
	250	25	23.1	330	

Table 4 Varying Travel Speed

Electrode	**Travel speed (cm/min)**	**Voltage (V)**	**Current (A)**	**Hardness (HV 0.5)**	
	15.0	25	200	417	
Hardfacing 1					
	21.4	25	200	418	
	50.0	25	200	356	
	16.67	25	200	377	
Hardfacing 2					
	25.0	25	200	388	
	50.0	25	200	406	

Table 5 Varying Voltage

Electrode	**Voltage**	**Current**	**Travel Speed**	**Hardness**	
	(V)	**(A)**	**(cm/min)**	**(HV 0.5)**	
	15	215	37.5	537	
Hardfacing 1					
	25	215	37.5	390	
	15	215	37.5	401	
Hardfacing 2					
	25	215	37.5	357	

Figure 1. Standard Test Specimen Of Size 75mmx 26mmx6mm

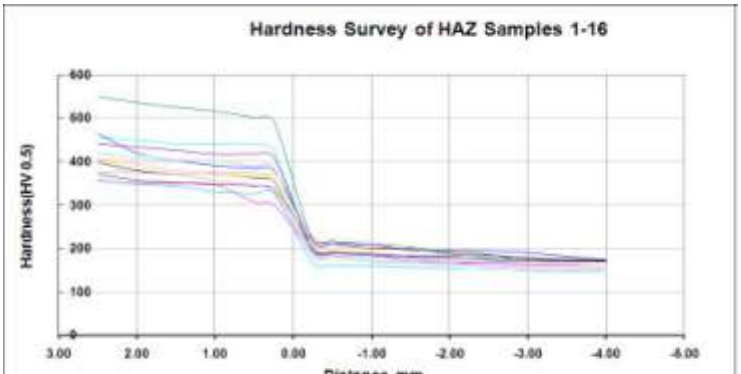


Figure 2. Hardness Survey of Haz.

III. Results And Discussion

3.1 Hardness Test

The specimens were cut to a size of 100x30x12mm for hardness testing and were polished using standard metallographic procedure. Micro hardness surveys were made on these specimens using Vickers hardness tester along the direction of thickness from the top surface towards the base metal after every 0.5mm. These surface values are plotted in the form of a graph shown in figure 2. The hardness survey of heat affected zone (HAZ) samples for every 0.5mm depth was made. The results indicate that the hardness values are more on the welded surface and decrease towards the base metal and remain constant on the base metal.

3.2 Dry Sand Abrasive Wear Test

In the present study, sample of 75x26x6 mm size were used for testing as shown in figure 1 as per ASTMG65 standards. Specimens were ground using surface grinder to make the surface flat. Before the abrasive wear test all the specimens were cleaned with acetone and then weighed on an electronic balance with an accuracy of ± 0.1 mg. The three-body abrasive wear tests were conducted using a dry sand/rubber wheel abrasion tester as per ASTM G65-04 (2010) shown in figure 6a. The sand particles of AFS 60 grade (figure 6b) were used as abrasives and they were angular in shape with sharp edges. The sand particles were sieved (size200–250 µm), cleaned and dried in an oven for 6 hr at 40°C. In this test, samples were held against a rotating rubber wheel under the constant flow of abrasives in between the sample and the rubber wheel under predetermined load. The actual photograph of the testing machine is shown in figure.

3.3 Test Conditions

Speed: 200 ± 5 rpm

Sample test duration: 15 and 30 min.

Abrasive: loose silica sand having particle size 200 - 250µm.

Load is kept constant at 130.5 N for all the samples. After each test, the samples were cleaned with acetone and then weighed on the electronic balance. The wear loss was calculated as weight losses in gms. Sample of 26x75x6 mm size were used for analysis. Specimens were ground using surface grinder to make the surface flat. Dry sand abrasive wear test was carried out as per ASTM G65 standards. In this test, samples were held against a rotating rubber wheel under the constant flow of abrasives in between the sample and the rubber wheel under predetermined load. The wear testing machine is shown in figure 4 and the test conditions are given here under:

Speed: 200±5rpm

Sample run duration: 30 minutes

Abrasive: loose silica sand having particle size 200 to 250 µm

Silica sand of size between 200 to 250µm was used as abrasive. Load is kept constant at 130.5N for all the specimens. The wear rate was calculated as weight loss in gms. Results indicate that as hardness increases, the loss of wear decreases. Electrode-I has less wear as compared to electrode-II as the percentage of chromium, carbon and silicon is more in electrode-I. However the composition of chromium, carbon & silicon in the weld deposit made with type-I electrode is higher than that of weld deposit made with type-II electrode. Higher amount of chromium, carbon, silicon and finer structure resulted in higher hardness where as lower hardness values were recorded in weld deposit with less amount of Cr, C & Si & coarser structure. From wear testing data under various conditions of the parameters, it can be stated that weld deposits made with type I electrode are more wear resistant than the weld deposits made with type II electrode.

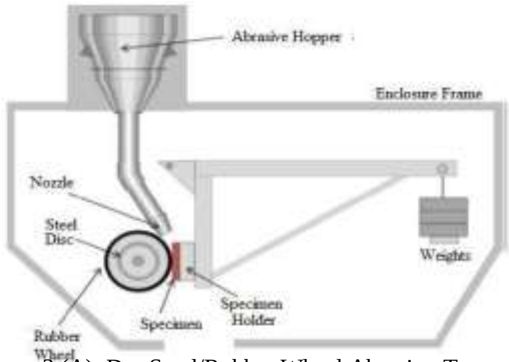


Figure 3 (A): Dry Sand/Rubber Wheel Abrasion Tester

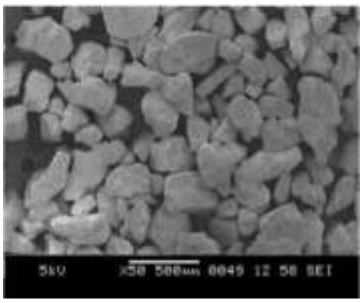


FIGURE 3 (B): SEM PICTURE OF SILICA SAND (200-250 µm)

In three-body abrasion, the sand particles behaved in one of the following ways. From free fall, the sand particles gained energy from the rubber wheel (FIGURE 3 A) and then struck the sample surface, which would result in the formation of pits. Secondly, the abrasive particles were embedded in the rubber wheel, transforming the three-body abrasion into multi-pass two-body abrasion (FIGURE 3 B).

Figure 4: Dry Sand Abrasive Wear Testing Machine

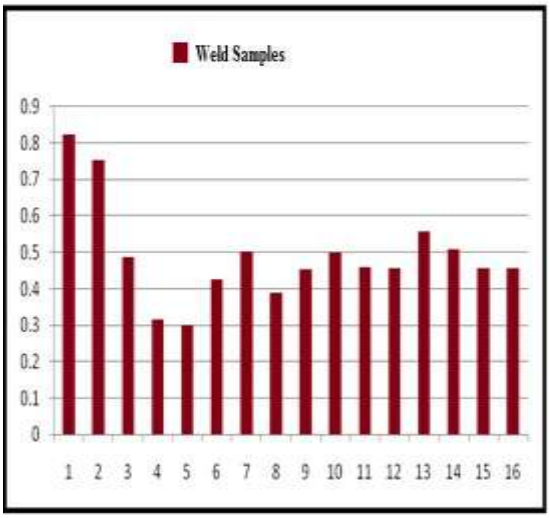


Figure 5: Wear Loss Of Weld Sample 15 Min

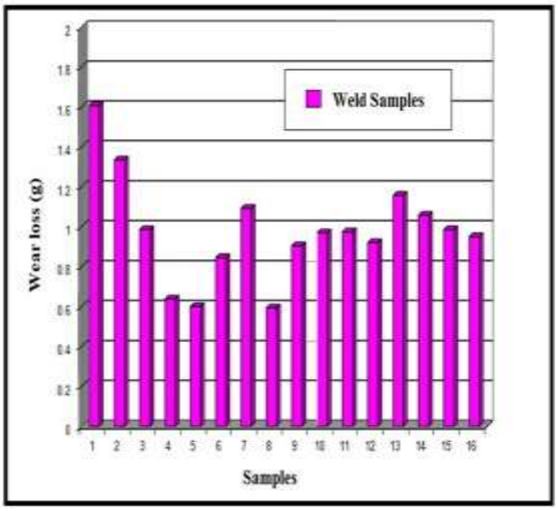


Figure 6: Wear Loss Of Weld Samples 30 Min

The results indicate that as hardness increases, the loss of wear decreases (figures5 and 6). Electrode-I has less wear as compared to electrode- II as the percentage of chromium, carbon and silicon are more in electrode-I. However the composition of chromium, carbon and silicon in the weld deposit made with type-1 electrode is higher than that of weld deposit made with type-2 electrode. Higher amount of chromium, carbon, silicon and finer structure resulted in higher hardness whereas lower hardness values were recorded in weld deposit with less amount of Cr, C and Si and coarser structure.

The wear resistance increases with increase in chromium, carbon and silicon present in the hardfaced alloy 1. The experimental results are in agreement with those reported [9-11] on hardfacing alloys tested under low stress against a rubber wheel. Meanwhile, decrease in the wear resistance with decreasing chromium, carbon and silicon were observed in type 2 electrode and is in consistent with other published works. The reduction of the wear resistance with type 2 electrode could be due to the fact that the surface hardness was greatly reduced as compared to type 1 electrode. Higher hardness of samples increasing the apparent contact area allows a large number of sand particles to encounter the interface and share the stress. This, in turn, leads to a steady state or reduction in the wear rate.

The wear test results of the type 1 electrode deposited hardfaced alloy indicate that a better wear performance. In type 2 electrode deposited hardfaced alloy, the wear resistance is poor compared to those obtained for type 1 hardfacing alloys. In type 2 electrode deposited hardfaced alloys, the abrasion was simultaneously initiated on the hard and soft phases of the weld material. In this situation, soft surface was continuously exposed to the interface throughout the entire test. It can be clearly seen from figures 9 and 10 that the presence of lower chromium and silicon in the interface increases the wear rate. On the other hand, in the case of the rich chromium, and silicon, the abrasion started through contact with the hard phase.

Mechanical properties influence the abrasive wear performance of a material. When considering the properties individually, it has been found that the hardness played a main role in controlling the abrasive wear [13]. The compression strength could have a stronger influence on the abrasive wear property than the tensile strength thereby the load is applied in the form of compression thereby pressing the specimen towards the sand particles at the interface [14]. This attracted the attention to explore the possibility of a correlation between the selected mechanical properties and the wear loss of the hard faced alloys.

Table 6 and 7 shows the wear loss as well as the hardness of all the samples [Electrode I and Electrode II]. From the table it can be seen that when considering the hardness alone, the wear resistance of all the hardfaced alloys tested, a better correlation was obtained in the present work. The higher the hardness, the lower was the wear loss [15]. From wear testing data under various conditions of the parameters, it can be stated that type 1 electrode deposited hardfaced alloys are more wear resistant than the type 2 electrode deposited hard faced alloys.

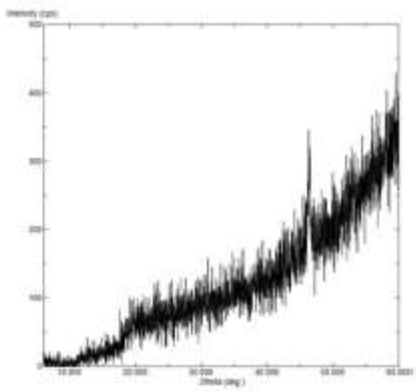
The work summarizes that type 1 electrode deposited by considering optimum weld parameters i.e., current 200 Amps, travel speed of 21.3 cm/min and potential difference of 15 volts of hardfaced alloys has beneficial effect on the three-body wear as well as on the hardness, thus re-emphasizing the fact that the introduction of rich Cr, C and Si in type 1 electrode has got the advantage of enhancing the properties.

Table 6: The Relation Between Hardness And Abrasion Resistance For Hardfacing 1(Electrode 1)

Sample number	Load (N)	Weight loss (g)	Hardness (HV 0.5)
1	130.5	1.6075	377
2	130.5	1.3345	318
3	130.5	0.9861	380
4	130.5	0.638	417
5	130.5	0.6007	418
6	130.5	0.8454	356
7	130.5	1.0923	537
8	130.5	0.5934	390

Table 7: The Relation between Hardness And Abrasion Resistance For Hardfacing 2(Electrode 2)

Sample number	Load (N)	Weight loss (g)	Hardness (HV 0.5)
9	130.5	0.9051	330
10	130.5	0.9698	416
11	130.5	0.9746	370
12	130.5	0.9205	406
13	130.5	1.1571	388
14	130.5	1.0576	377
15	130.5	0.9852	357
16	130.5	0.9506	401



DIFFRACTOMETER TRACE FOR THE SPECIMEN NO. 1 BEFORE WEAR TEST

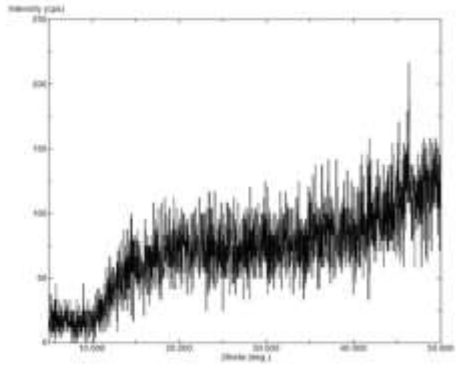


FIGURE 8 DIFFRACTOMETER TRACE FOR THE SPECIMEN NO. 1 AFTER WEAR TEST

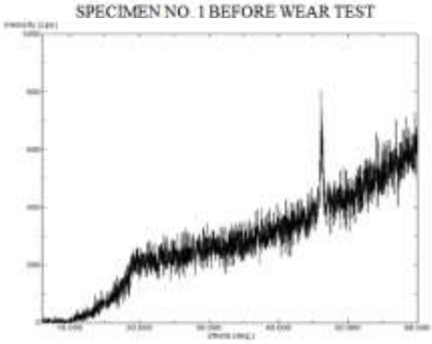


FIGURE 10: DIFFRACTOMETER TRACE FOR THE FOR THESPECIMEN NO. 5 BEFORE WEAR TEST

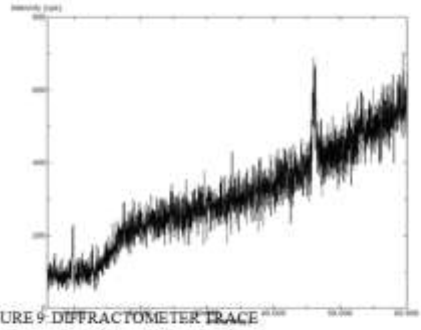


FIGURE 9: DIFFRACTOMETER TRACE SPECIMEN NO. 5 AFTER WEAR TEST

IV. Conclusions

Experimental investigation revealed that, weld metal chemistry & hardness have significant influence on wear property. 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, arc voltage & speed of arc travel. The analysis carried out on hardness survey of HAZ samples for every 0.5mm depth indicates that the hardness values are more on the weld surface & decrease towards the base metal & remains constant on the base metal.

Fractography analysis was conducted to worn-out specimens of low medium and high abrasion resistance. Results showed that small and narrow wear track clearly indicates there will be less in wear and the wear resistance increases with increasing hardness. The XRD results showed that primary austenite was found in samples 1 and 5 before and after wear test. Since the primary austenite contains more chromium (max peak) from the XRD graphs. It is clear that a significant effect of primary carbides in the weld deposits leading to improved abrasive wear resistance.

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