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SEM and XRD STUDY OF Fe-Cr-C HARDFACING AND METALLURGICAL PROPERTIES OF MILD STEEL USING ARC WELDING PROCESS

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ABSTRACT

In this investigation, the microstructure of Fe-Cr-C hardfacing alloy was studied using XRD and SEM analysis. SEM test result shows that the microstructure consist of primary austenite dendrites with eutectic of (Fe,Cr)7C3 +austenite. X-ray diffraction is used to recognize the phases and determining lattice parameter of microstructure components. The investigation of XRD test for the low wear resistance and high wear resistance before and after wear test were analyzed that the percentage of chromium showing maximum peak values both in specimen 1 and specimen 5. The average content of chromium in the primary austenite is 19.5%. XRD test result determined that lattice parameter of primary austenite is 0.361 nmThe microstructure of this alloy consists of hard iron- chromium carbide in a supportive matrix and are particularly suited for abrasion resistant applications which are, demanded by the mining and cement industries. These alloys in composition range of 12-30% chromium are extensively used for hard-facing of components that manipulate and mechanically process aggregates and raw materials. Such components include ore crushers, rollers, ball mill liners and pulverizing equipment.

Keywords: Chromium Carbide, Hardfacing alloys, Microstructure, SEM, XRD.

I. INTRODUCTION

Wear is one of the most frequently observed failure modes of mechanical components. Hardfacing is commonly employed method to exert wear resistance properties on these equipments. In this respect wide varieties of hardfacing alloys are commercially available for application and wear control. Two types of Hardfacing alloys were used for over laying. These are basically iron-based alloys having varying amount of chromium, carbon , silicon and other alloying elements as they are suitable for shielded metal arc welding process.

Fe-Cr-C is the most popular type of hardfacing alloy because of its relatively low cost compared to than the others.The microstructure of this alloy consists of hard iron- chromium carbide in a supportive matrix and are particularly suited for abrasion resistant applications which are, demanded by the earthmoving equipments and agricultural implements[1],[2],[8]. These alloys in composition range of 12-30% chromium are extensively used for hardfacing of components that manipulate and mechanically process aggregates and raw materials. Such components include earthmoving equipment's , agricultural implements ,ore crushers,mines, rollers and ball mill[9].

Fe-Cr-C alloys are used in several conditions where extreme erosion occurs and therefore the abrasion resistance is necessary[3],[4]. Their exceptional abrasive and erosive wear resistance results from their high volume fraction of hard carbides and contributes to the wear resistance.

Fe-Cr-C alloys are used in severe conditions where there is extreme erosion and therefore abrasion resistance is necessary[6]. Their exceptional abrasive and erosive wear resistance results primarily from their high volume fraction of hard carbides, though the toughness of the matrix also contributes to the wear resistance. The investigations of Fe-Cr-C alloy microstructures have shown that these types of materials have hypoeutectic, eutectic, and hypereutectic structures[5],[10].

II. EXPERIMENTAL PROCEDURE

A. 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. The chemical composition is given in Table 1.

Table 1. 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

B. Hardfacing 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. Chemical compositions of two electrodes are presented in table 2.

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

C. Welding Conditions

The standard size test specimens of 16 nos. with the dimensions of 250×100×12 mm were selected for the experiment. The following precautions are taken before hardfacing.

- The electrodes are perfectly dried in the furnace and baked at 250^{o} C one hour before the use.
- Area of the weld is properly cleaned.
- Preheated the hardfacing area to a minimum of 200^{o} C.

D. Machine Specifications

Name: TORNADO MIG 630 Arc welding machine
Current: 100-630 Amps
Input Voltage: 415 volts± 10% / 50-60 HZ / 3 Phase
Machine Capacity: 50 KVA.

III. METHODOLOGY

The experiment was carried out in three stages to investigate the effect of current, travel speed and voltage on hardfacing electrodes, and the corresponding hardness was determined.

(i) In first stage, voltage (V) and travel speed (S) were kept constant and current (A) was increased.
(ii) In second stage, voltage (V) and current (A) were kept constant and travel speed (S) was increased.
(iii) In third stage, current (A) and travel speed (S) were kept constant and voltage (V) was increased.

A. Microstructure Analysis

Optical microscope (OM) was used to analyze the microstructure of the specimens. Different types of carbides present in the microstructures were first identified on the basis of their morphologies and confirmed by micro-hardness measurements.

Microstructures of different hardfacing deposits

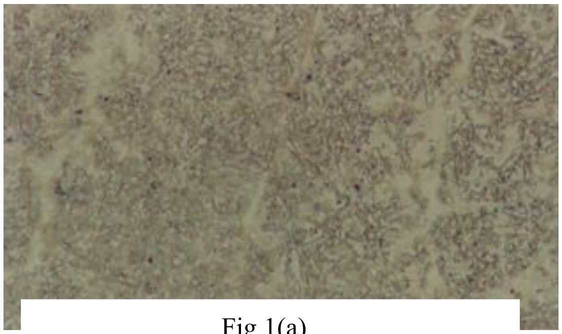


Fig 1(a)

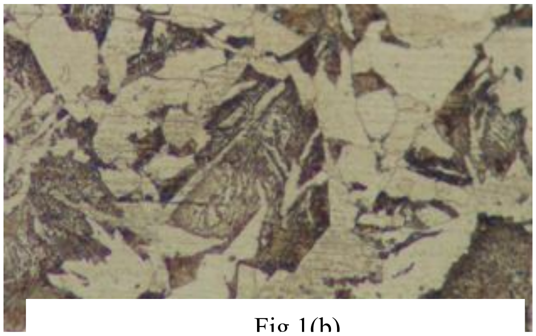


Fig 1(b)

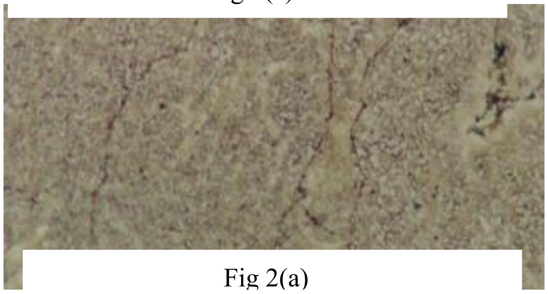


Fig 2(a)

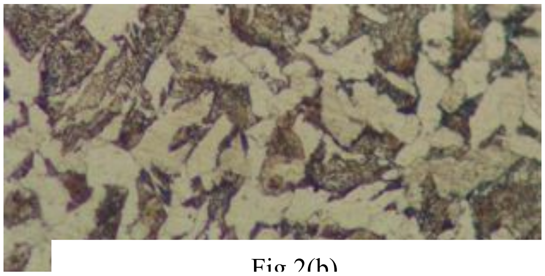


Fig 2(b)

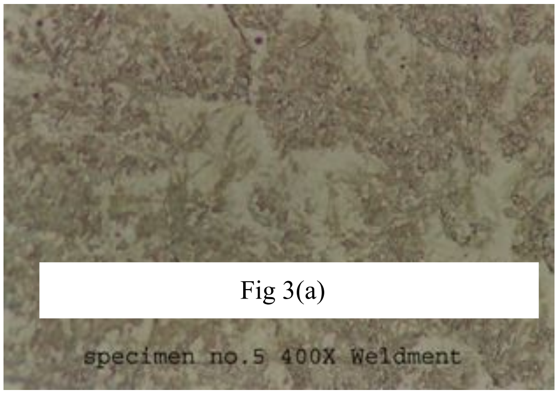


Fig 3(a)

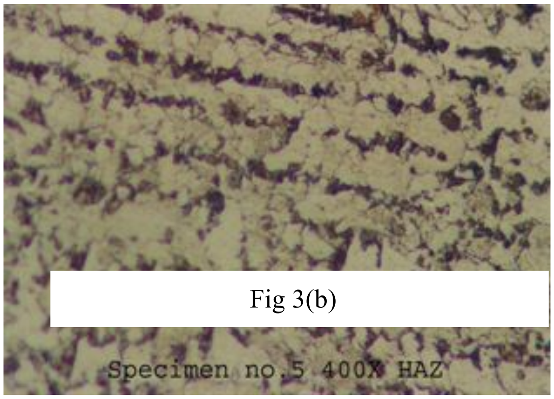


Fig 3(b)

In fig 1(a) & (b), the amount of ferrite and Pearlite is more hence resulting in lower hardness and wear resistance. In fig 2(a) & 2(b) the amount of ferrite and pearlite is medium hence moderate hardness and wear resistance. In fig 3(a) & (b), the structure consists martensite with retained austenite and patches of pearlite distributed uniformly.

B. Scanning electron micrographs

The photographs for the specimens 1, 3and 5 after dry sand abrasion test through SEM are shown in figures 4, 5 and 6. The worn out specimens consists of low, medium and high abrasion resistance at the entry and exit. Examination of the wear scars indicate that morphologies for all the samples were similar consisting of three zones, a short entrance and exit area and the main wear zone in middle. At the entrance and exit zones where the pressure applied to the abrasive is lowest the damage morphologies were consistent with particle rolling. In the centre of wear scar, parallel grooves were formed, typical of particle sliding, a result of the higher pressures forcing abrasives in to rubber wheel. The worn surfaces are characterized by shallow continuous grooves and micro cuttings in sample in fig 6 (a) & (b) indicating that material removal is associated primarily with ploughing mechanism. The fine grained silica sand corresponds to low wear level where as the high energy level of coarse corundum particles is resulting in a severe wear region abrasion test were carried out on a dry sand rubber wheel with three body abrasion condition under low stress according to ASTM G65 procedure A. rotational speed, normal load work kept constant at 200 rpm and 130.5 N respectively, characterization of microstructure has been done with optical microscopy and scanning electron microscopy quantitative analysis of the microstructure was carried out by the use of intronic image C software. Hardness measurements were carried out with a standard Vickers hardness technique HV0.5 for microscopic hardness. Quantitative wear characterization has been done by gravimetric mass loss of the testing specimen during wear testing. Qualitative characterization of worn surfaces and worn edges has been carried out by evaluating of macroscopic and cross section images and by SEM investigations. The sample numbers & its relation between hardness and abrasion resistance is shown in table 3 and 4.

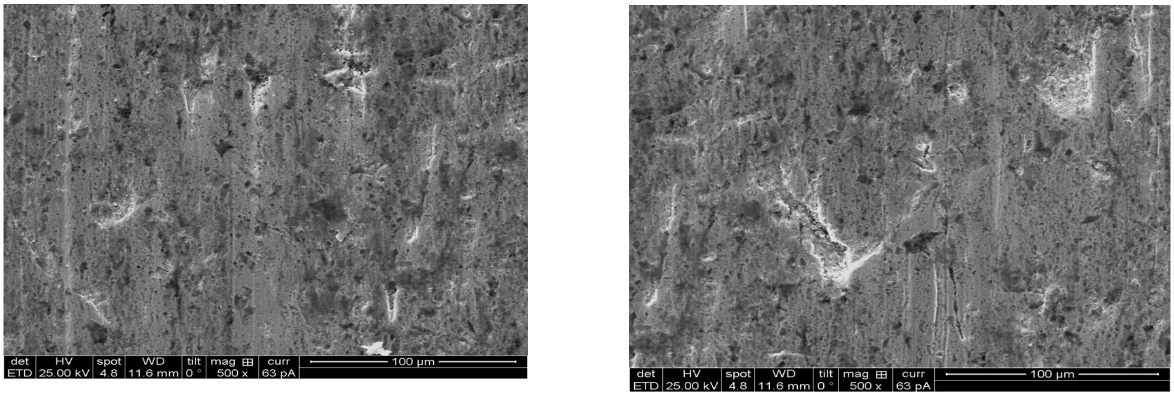
IV. RESULTS AND DISCUSSION

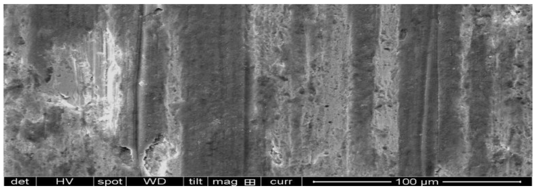
A. SEM Analysis

The typical microstructure of the studied hardfacing alloys are shown in figures 4, 5 and 6. The worn surfaces were observed under SEM and secondary electrons were used to analyze these surfaces, to establish the possible mechanisms of material removal. In Figure 4, the surface wear is presented for all the three hardfacing alloys. Figure 4 shows, wear loss increases with the abrading distance and demonstrate that sample 1 wear loss is higher than that of sample 5, suggesting that carbides indeed have a reinforcing effect.

Figures 4 (a) & (b) shows the worn surface features of sample 1, where micro-ploughing and micro-cutting are the main abrasive wear mechanisms. Figure 5 (a) & (b) indicate the surface of sample 3, where micro-cutting and wedge formation were the main abrasive mechanisms. The worn surface of samples 1 and 3 clearly shows obvious evidence of cutting and ploughing (Fig. 4 and 5). However, no obvious plastic deformation can be found on the worn surface of sample 5 (Fig. 6) although there are some slight traces of ploughing to be seen on the matrix area, these cease when elements such as carbides are encountered, indicating that the silica and chromium elements effectively stop the abrasive form cutting or ploughing into the surface layer during the wear process, thereby noticeably lowering the wear loss. However, the grooves were not deeper than samples 1 and 3; this hardfacing deposit presented higher abrasion resistance, because the large quantity of carbides rich in titanium, uniformly distributed in the matrix, blocked the abrasive particles. Further, the resistance of silica, manganese and chromium elements to the abrasive could be attributed to its higher hardness. Further observations of figure 6 also provide evidence of cutting and cracking of the carbides. It is reasonable to believe that the wear resistance of the materials will increase if the hardfacing alloy is improved.

Fig.4 Worn surface features of sample 1(a) 15 min (b) 30 min





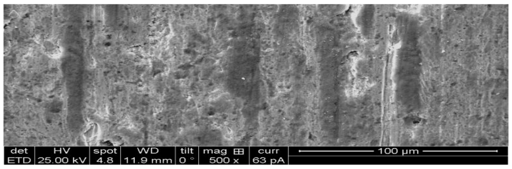


Fig. 5 Worn surface features of sample 3(a) 15 min (b) 30 min.

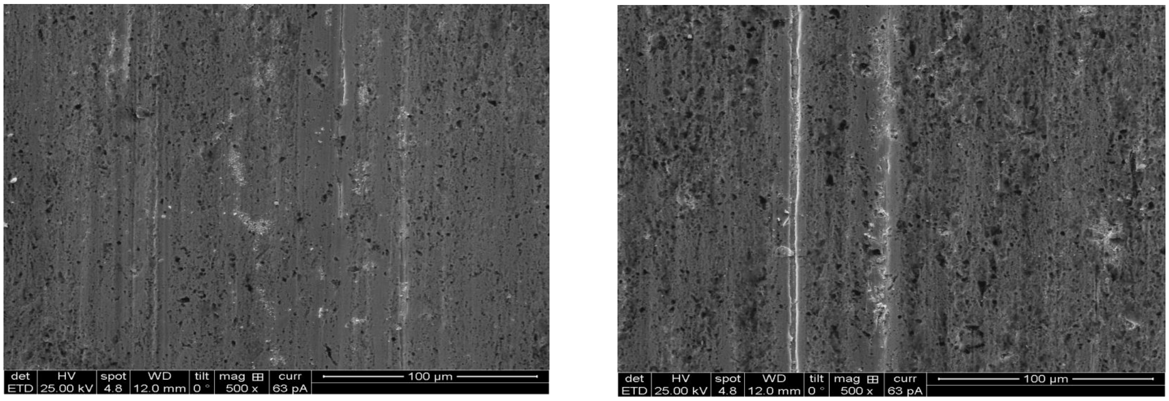


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Fig. 6 Worn surface features of sample 5(a) 15 min (b) 30 min.

Table 3: 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 4: 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

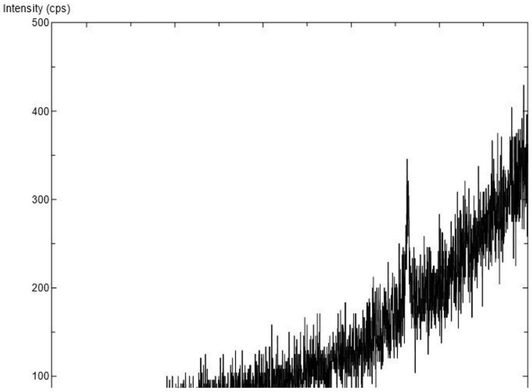

Figure 6.4 Diffractometer trace for the specimen no. 1 before wear test

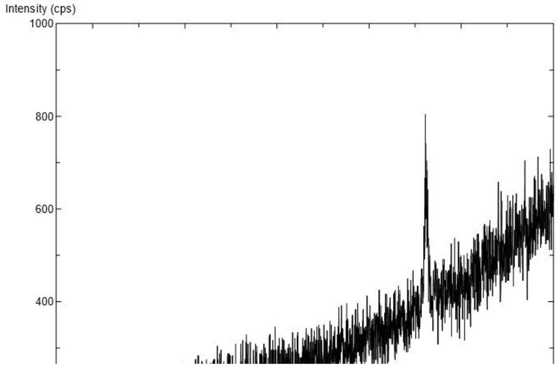

Figure 6.4 Diffractometer trace for the specimen no. 1 after wear test

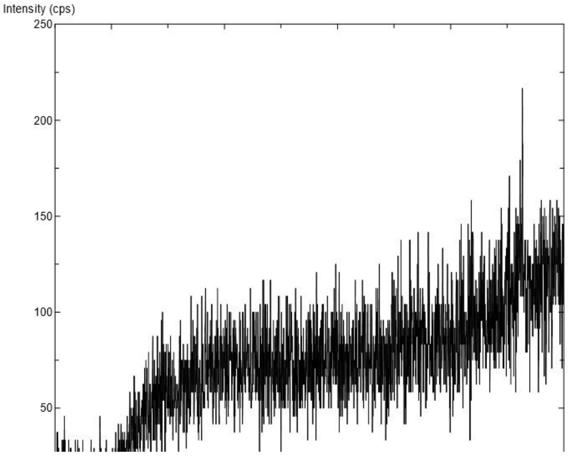

Figure 6.4 Diffractometer trace for the specimen no 5 before wear test

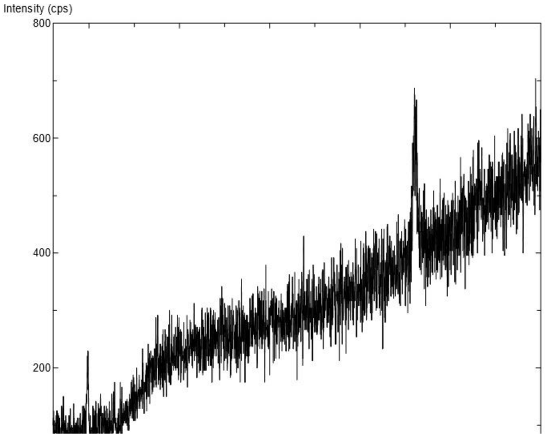

Figure 6.4 Diffractometer trace for the specimen no. 5 after wear test

B. X-ray Diffraction Analysis (XRD)

X-ray diffraction is used to recognise the phases and determining lattice parameter of microstructure components[7]. By thorough investigation selecting the low and high abrasion resistance wear test specimens (specimen no. 1 and specimen no. 5) for this analysis. The selected samples are milled and ground to the required dimension by milling and grinding operation (10x10x1 mm) by retaining the weld deposited layer. The respective 10mm square faces were polished by 1µm diamond paste and electro polished to remove any mechanically deformed layer at the surface. The electro polishing solution used consisted of 10% oxalic acid in water. XRD was observed using a STAPI MP diffractometer equipped with high score. Before and after the wear test for both the low and high abrasion resistance specimens were conducted and the constituents of alloy compositions are shown in the respective peaks.

The investigation of XRD test for the low wear resistance (specimen no. 1) and high wear resistance (specimen no. 5) before and after wear test were analysed that the percentage of chromium showing maximum peak values both in specimen 1 and specimen 5. The chromium carbide is lesser in percentage distributed on the specimen 1 before and after wear test as shown figure 6.4, 6.5, 6.6 and 6.7 respectively.

The chromium carbide is uniformly distributed on the weld surface of specimen 5 as shown in figure 6.8, 6.9 and 6.10 respectively. The X-ray diffraction of the coating was executed on the outer layer for both specimen 1 and specimen 5 as shown in figure 6.4 - 6.10 . Hence the microstructure of HAZ consists of the coarse grain caused by the heat input energy and the substrate contains ferrite [69]. Several researchers have found that increasing volume fraction of carbides improves the abrasion resistance.With the aid of XRD and optical microscopy, the hypoeutectic and eutectic composites were formed to consists of Cr-Fe solid solution (α) and $(Cr,Fe)_{23}C_6$ carbide. In hypoeutectic structure, $(Cr,Fe)_{23}C_6$ is fine lamellar structure (specimen no. 5). In eutectic structure, $(Cr,Fe)_{23}C_6$ is equi-axed dendrite. The investigation of XRD clearly shows that the percentage of chromium is high peaks both in specimen 1 and 5 before and after wear test. The lower peaks correspond to the percentage of manganese, carbon and silicon.

V. CONCLUSIONS

1. SEM results indicates that typical wear surface morphologies of specimens 1, 3 and 5 are the worn out specimens consists of low, medium and high abrasion resistance at the entry and exit.
2. The examination of the wear scars indicate that morphologies for all the samples were similar consisting of three zones, a short entrance and exit area and the main wear zone in middle.
3. It is evident that the main wear mechanism is microcracking and microploughing which is involved in producing the large abrasion grooves. For microploughing, the substantial mechanism of metal removal is fracture resulting from plastic flow.
4. Wear surface topography suggests that microploughing is the predominant mechanism for metal removal. SEM photographs showing as weld dendritic structure of the Fe-Cr-C hardfacing alloy, eutectic carbides, mapping elements Fe-Cr-C of austenite and eutectic carbide.
5. 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.
6. 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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