

Investigation on Microstructure and Wear Resistance of the Plain Carbon Steel Hardfaced by the Fe-Cr-C Electrodes Containing Mo, W, V Elements

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Abstract

In this investigate, plain carbon steel clad by SMAW in single, two and three- pass with two hardface electrodes containing molybdenum, tungsten, and vanadium. Scanning electron microscopy, X-ray diffraction, wear tests and microhardness test were carried out to evaluate the microstructure and wear properties of hardface layers. The results indicated that by increasing of molybdenum concentration in hardface layer, M_6C and M_7C_3 carbides were appeared in the microstructure. Moreover, by increasing the number of hardfaced layers and reducing dilution, the concentration of alloying elements, and the carbides coarser increased at microstructure. Also by increasing the percentage of the molybdenum the hardness of layers increased up to the 61 HRC and 1540 Vickers at the three-pass. In addition by increasing the number of passes the wear resistance of the hardfaced layers increased.

Keywords: Hardfacing, SMAW, Complex Carbide, Fe-C-Cr.

1. Introduction

Plain carbon steels are widely used in the manufacture of parts because they have good mechanical properties and machining capabilities. The most important disadvantage of this group of steels is their low resistance wear and corrosion. For this purpose plain, carbon steels are often subject to surface treatment. Accordingly, a layer of wear resistant materials deposited by welding techniques. This process is widely used to improve wear resistance [1, 2]. This is usually done for two purposes [3]:

- I- Providing special mechanical or physical properties of the surface or edge of the piece,
- II- Adding the dimensions of the workpiece to the desired size.

The cladding or hardfacing is usually done by welding process such as: OAW, GTAW, GMAW, SMAW, and SAW. Selection of welding method depends on the base metal as: chemical composition, melting point and thermal expansion of the clad layer and base metal. In cladding processes (or hardfacing) by welding operations numerous engineering materials and alloys are used as substrates. Different carbon steels, cast irons, low alloy steels and high alloy steels can be clad by

this process [4-5]. Adhesion, abrasion and contact fatigue are the three main mechanisms that lead to the separation of the material from the surface of a component. Other processes such as corrosion and abrasion are effective and highly destructive [3-5]. One of the most important hardfacing alloys is Fe-Cr-C. Different materials are used for hardfacing and choosing these materials choices depends on their application. Alloying elements such as chromium, tungsten, niobium and molybdenum are stronger carbide former element and increases the hardness and wears resistance of the surface [6].

Choteborsky et al [7] studied on the effect of Nb,V,W elements on the microstructure and wear resistance of the Fe-Cr-C hardface layer, their result showed that by increasing the niobium, the hardness and wear resistance of the hardface layer increases. By increasing vanadium and tungsten the hardness increases and the wear resistance improved considerably. The effect of adding tungsten on the microstructure and wear properties of the Fe-Cr-C hardface alloy on ASTM A36 steel plates by SMAW was investigated by Buchely et al [8]. Their result showed that the three layers of carbides deposit by the composite electrode (W and Cr) had highest wear resistance. The reason for the increased wear resistance due of appeared the primary MC and M_7C_3 carbides at microstructure was reported. The study of microstructure changes caused by $(Cr,Fe)_{23}C_6$ carbides in the Fe-Cr-C was studied by Fan et al[9]. Their result showed that the

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microstructure is formed of the initial solid solution (α) Cr-Fe and hypoeutectic structure $M_{23}C_6$. By adding carbon to 7 percent, the eutectic structure ($M_{23}C_6 + \alpha$) is appeared in microstructure.

The study of the microstructure and hardness test of steel St52 clad by Fe-Cr-C and Fe-Cr-Nb-C hardface alloys by GTAW was done by Shamanian et al [10], Their results suggested that in microstructure of the hardface layer with Fe-Cr-Nb-C alloy, the high volume fraction of the Cr_7C_3 and NbC carbides can be observed. Also, the clad layer by the Fe-Cr-Nb-C had higher hardness than that the Fe-Cr-C layer.

2. Materials and Methods

Six plates of plain carbon steel (St37) with dimensions of $10 \times 150 \times 150$ mm was used for hardfacing. The Fe-Cr-C welding electrode with chemical analysis as Table 1. used for fabricated the hardface layers.

Before welding, the surface oxides of the base metal were removed by sand blast process and then cleaned with acetone. hardfacing operation carried out by SMAW process(accordance with Table 2.) as single, two and three- pass.

After hardfacing specimens cuts from the samples and were tested by different method, the metallographic specimens etched by the Marble's etchant + HCL (50ml) + H_2O (50ml) + $CuSO_4$ (2.5gr) and the microstructure study by the scanning electron microscope, for identify the microstructure phases the XRD test was done with $\lambda=1.54 \text{ \AA}$, $Cu K\alpha$, Rockwell Hardness test was done according the ISO 6507-1 ASTM E18 [11] standard at Rockwell C

scale and Vickers micro-hardness testing was done according the ASTM E384 standard with a load of 500 g at 10 seconds [12].

Wear test was done according ASTM G99 standard (pin on disc) by the force of 130 N, rotary plate rotation speed of 50 mm/s and the wear distance of 1000 m by using bearing steel pins 52100 [13]. The weight loss was calculated by digital scale and precision of ten-thousandths of a gram.

3. Results and Discussion

3.1. Chemical Composition and Microstructure

Table 3. denote the chemical composition of the hardface layers of the specimens and the dilution of the different layers. In order to determine the dilution of each layer according to the chemical composition of the layer, Equation 1 was used [14]:

$$D = \frac{P_{x1} - P_{x2}}{P_{x2} - P_{x3}} \times 100 \quad (1)$$

Where: P_{x1} is concentration of element x in considered layer in weight percentage,

P_{x2} : concentration of x element in the consumable welding in weight percentage,

P_{x3} : concentration of x element in weight percentage in base metal

D: is dilution rate in percentage.

The change of the chemical composition of hardface layer (Table 3.) due the dilution of base metal and by increasing the number of hardface layer the concentration of base metal elements in the hardface layer decreases and changes the chemical composition of the layer.

Table 1. Chemical analysis (wt. %) of welding electrode (1623 and 1105V).

No	Electrode	C	Si	Mn	Va	W	Cr	Mo	Cr/C
1	1623	0.5	3.1	0.4	0.6	1.3	6.5	-	13
2	1105V	0.9	0.5	1.4-1.6	0.9	1.1	4.2	8.5	5

Table 2. Welding Parameters.

No	Electrode	Number of passes	Process	Voltage(V)	Current (A)	Welding speed (cm / min)	Polarity
A ₁	1623	1	SMAW	27-29	100-115	70-80	DCEP
A ₂	1623	2	SMAW	27-29	100-120	70-80	DCEP
A ₃	1623	3	SMAW	27-29	100-138	70-80	DCEP
B ₁	1105V	1	SMAW	27-29	110-125	70-80	DCEP
B ₂	1105V	2	SMAW	27-29	110-125	70-80	DCEP
B ₃	1105V	3	SMAW	27-29	110-135	70-80	DCEP

Table 3. Chemical composition (wt. %) and the degree of dilution of hardface layers.

Sample	Fe	C	Si	Mn	S	Cr	Mo	%Dilution
A ₁	92.7	0.4	0.49	0.41	0.003	4.48	0.3	33
A ₂	90.9	0.48	0.64	0.4	0.009	5.51	0.48	16
A ₃	89.5	0.5	0.79	0.4	0.008	6.39	0.53	3
B ₁	88.7	0.64	0.41	0.5	0.011	3.44	6.22	19
B ₂	86.51	0.67	0.39	0.56	0.015	3.69	6.33	12
B ₃	85.0	0.74	0.44	0.54	0.015	3.81	7.32	9

Fig. 1. shows the Fe-0.5Mo-Cr-C phase diagrams. According to this diagram and the specified points, it is expected that the iron carbide and M_7C_3 carbides are formed in the mentioned temperature and in room temperature the carbides at the matrix of the martensite and austenite appeared for all of the specimens group A.

Fig. 2. shows Fe-8Mo-Cr-C diagram at 1000 ° C. The point B1, B2, B3 is shown according to the chemical composition B1, B2, B3. According to the diagram and marked spots, it is expected that the iron carbide and M_7C_3 and M_6C (Fe_3W_3C , Fe_3Mo_3C) carbides are formed in the mentioned temperature and in room temperature the carbides at the matrix of the martensite and retained austenite appeared for all of the specimens group B.

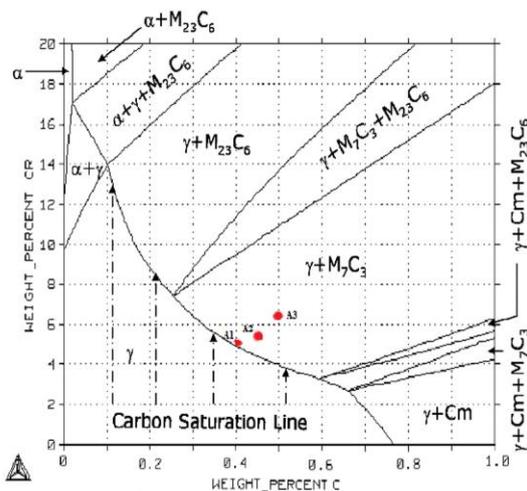


Fig. 1. Fe-0.5Mo-Cr-C diagram at a temperature of 1000 ° C .

Fig. 3. shows the SEM image of the specimens' hardfaced by 1623 and 1105V electrodes. As shown in Fig. 3a the needle martensitic structure in the austenite matrix is clear. Fine and dispersed chromium carbides are evident in the matrix (white areas).

In Fig. 3b it can be observed that by adding molybdenum and tungsten to the M_6C carbides are appeared in austenite and martensite phase in small

amounts and lead to the higher presence of alloying elements in the austenite phase. Also, adding molybdenum and tungsten to this alloy leads to the formation of spherical and elongated complex M_6C carbides [15].

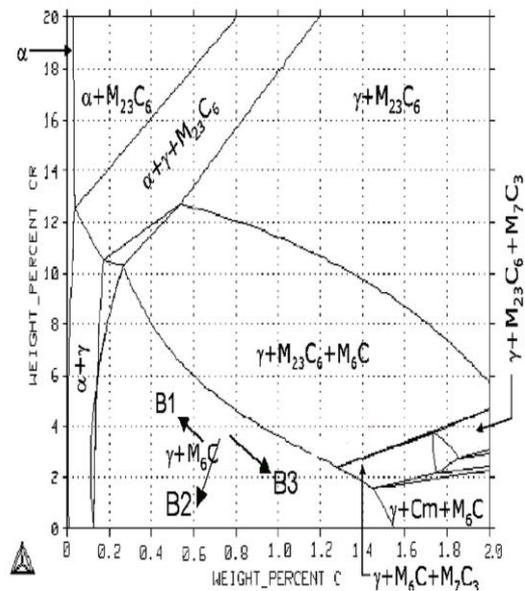


Fig. 2. Fe-8Mo-Cr-C diagram at a temperature of 1000 ° C .

Fig. 4. shows the analysis of an element of the three passes hardfaced layer by 1623 electrode. The analysis is specified inside the point (1) formed in Fig. 4. Also, Table 4. denote the results of the elemental analysis test of this point. According to the results of Table 4., this phase is chromium carbide at the point.

Table 4. Weight and atomic % of the elements in the elemental analysis in point 1.

[at%]	[Wt%]	Element
29.6694	8.033	C
38.2372	44.8424	Cr
32.0933	40.4248	Fe

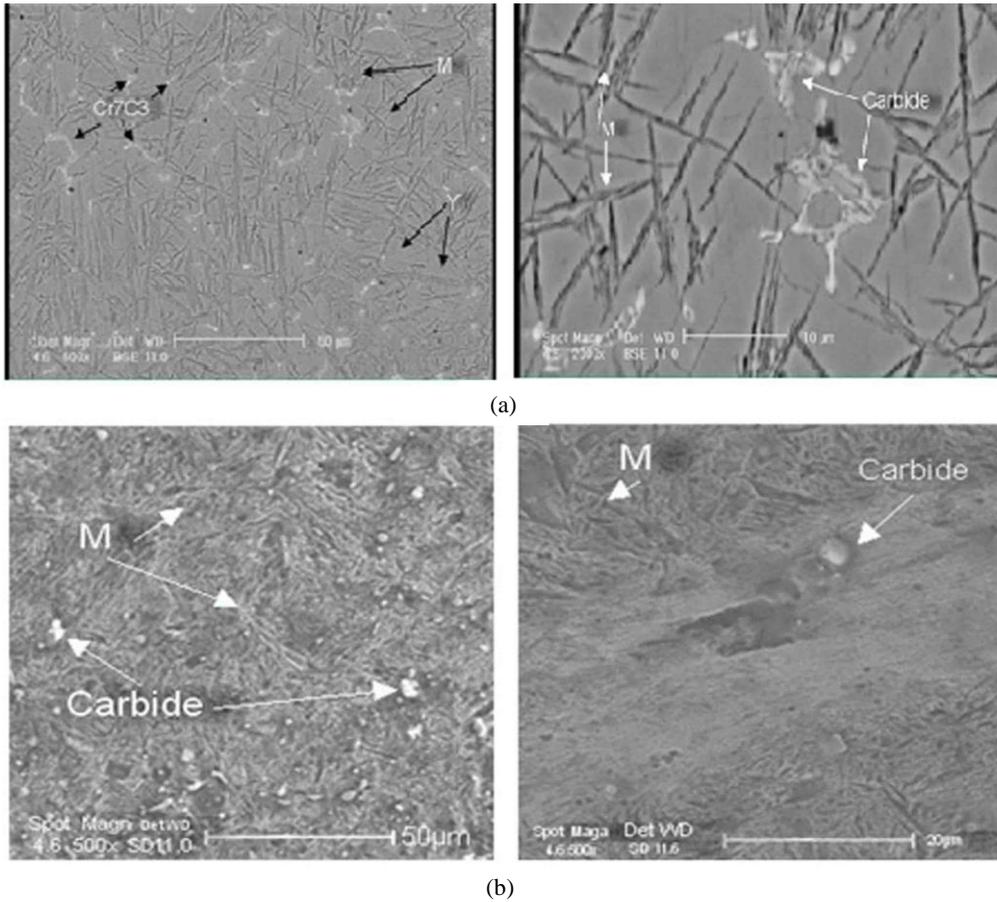


Fig. 3. SEM images of the third pass layers. a) hardfaced by electrode 1623, b) hardfaced by electrode 1105V.

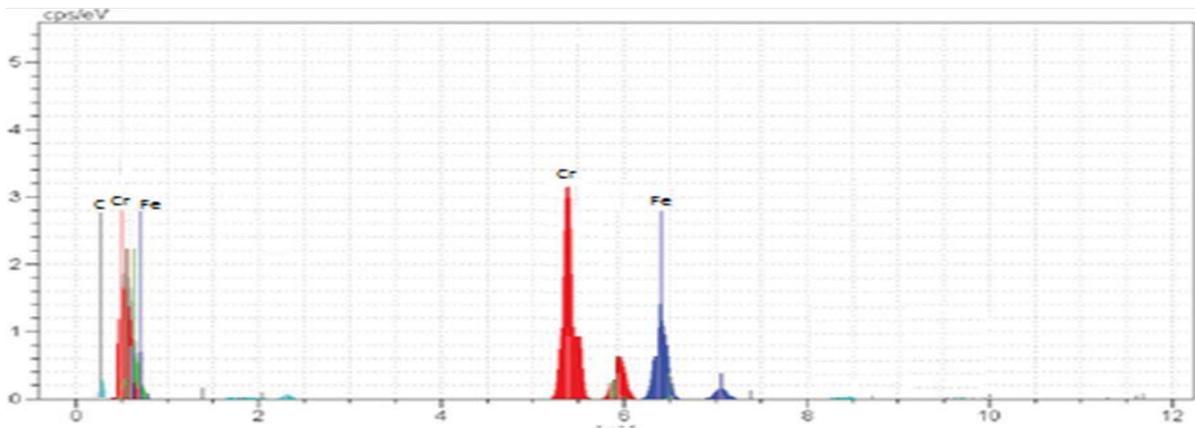


Fig. 4. Elemental analysis of the test results within point 1 of the specimen A3.

Fig. 5. presents the XRD pattern of the specimens' hardfaced by electrode 1623 at single, two and three-pass (A1, A2, and A3). The results of XRD indicated that the Cr_7C_3 , austenite, and martensite phases appeared in all specimens microstructure.

Fig. 6. shows the XRD pattern of the specimens' hardfaced by electrode 1105V at single, two and three-pass (B1, B2, and B3). The results of XRD indicated that austenite with martensite phases and M_6C such as molybdenum carbide and tungsten carbides are formed.

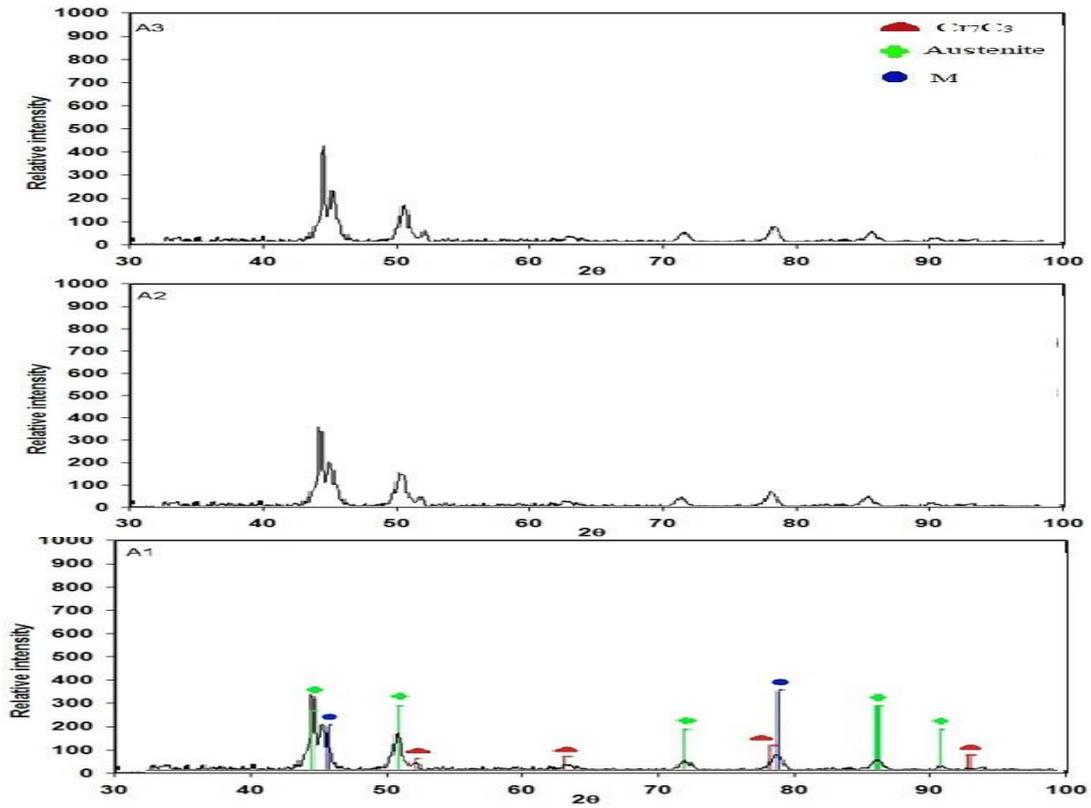


Fig. 5. XRD pattern of the hardfaced sampled by electrode 1623 in single-two and three pass layer.

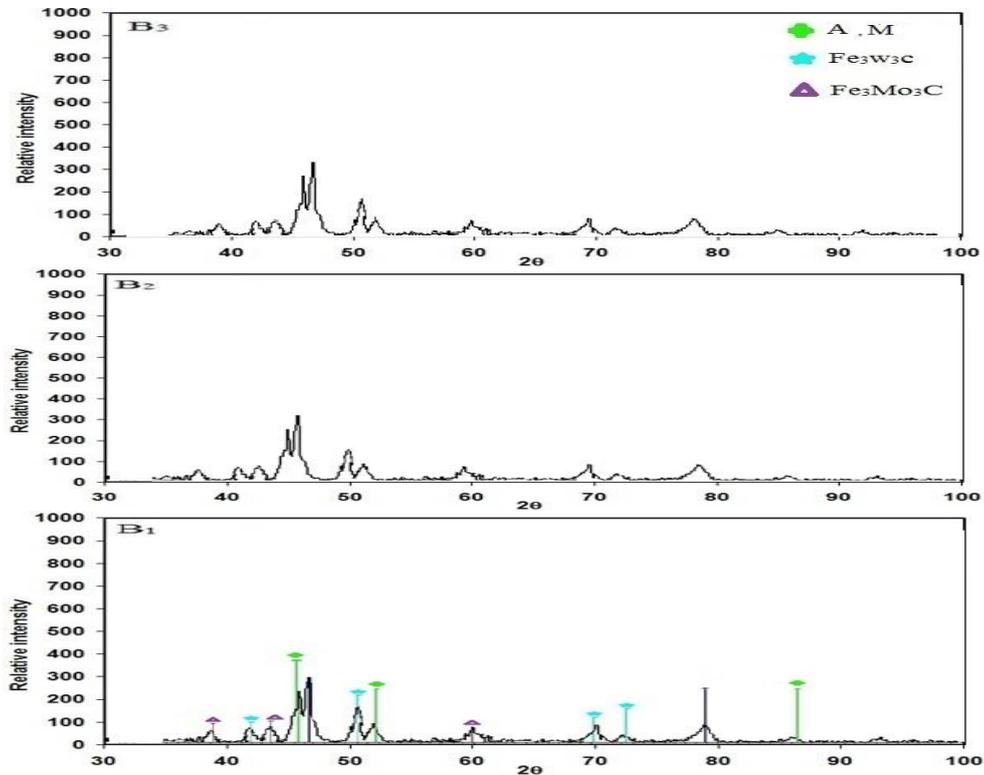


Fig. 6. XRD diagram of the hardfaced sampled by electrode 1105V in single-two and three-pass layer.

3.2. Hardness test

As can be seen in Fig. 7. the least hardness is associated by the electrode 1623 in a single pass mode (sample A 1). This is due of lower amounts of chromium and carbon in chemical composition. By increasing the number of hardface layers, due to decreased the dilution, the concentration of alloy elements in chemical composition of hardface layer is increased and increases the volume fraction of carbides with more uniform distribution in the matrix and the hardness is increased. In addition by increasing the Mo concentration in hardface layer, the volume fraction of the M_6C carbides in microstructure and hardness of hardface layer has increased. This factor increased the hardness of sample B3 up to 61 HRC.

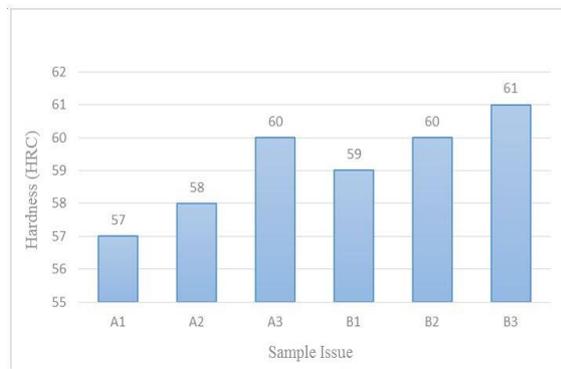


Fig. 7. The hardness test results of the specimens.

By comparing the hardness test results in Fig. 7. with the results of Buchely et al [8], it is denoted that the specimens containing molybdenum carbides have the higher hardness than the specimens containing chromium carbide. Finally, it can be concluded that the matrix hardness, carbides and the size and distribution of carbides determine the hardness of hardface layers [16,17].

As can be seen in Tables 5 and 6, by increasing the number of hardface layer the microhardness of microstructure is increased. The reason due that by increasing the number of hardface layers, dilution is reduced and the concentration of the elements such as: chromium, carbon and molybdenum increases in harface layer and the volume fraction of carbides with microhardness increases

By increasing the concentration of the molybdenum element at hardface layers ,leads to the formation of complex carbides in the matrix , since the hardness of complex carbides is higher than that the chromium carbides , also by in increasing the Mo concentration the hardness of microstructure increases and this means that in B1, B2, and B3 specimens have the higher microhardness than that

A1,A2, A3 specimens . This factor has increased the hardness of sample B3 up to 1540 Vickers.

Table 5. Micro-hardness (HV) test results of the matrix and the carbides (electrode 1623).

No	Chromium Carbide	Matrix
A1	801.5 ± 20	690.1 ± 23
A2	1010.8 ± 39	815.4 ± 28
A3	1300.1 ± 50	830.4 ± 28

Table 6. Micro-hardness (HV) test results of the matrix and the complex carbides (electrode 1105V).

No	molybdenum carbides	Matrix
B1	815.2 ± 20	705.4 ± 23
B2	1155.4 ± 39	840.7 ± 28
B3	1540.6 ± 50	860.4 ± 28

3.3. Wear test

Formation of carbides and martensite increase wear resistance because they have higher hardness. Carbides increase the worn mass by cutting and reducing the depth of the scratches [14,17].

During the wear process, the austenite phase is converted into martensite as the result of hardening phenomenon [14]. In addition, the presence of martensite blades of the carbides created in the matrix indicates the higher wear resistance [14].

Fig. 8. shows the results of the wear test on the specimens A3 and B3. A sudden change of gradient in the weight reduction graph after a distance of 100 meters in specimen A3 indicates that in this specimen the dislocations are accumulated rapidly and the residual stress has led to crack on the surface sooner than B3 and by continuing this process the cracks in the surface increase. As result determined that the wear resistance of hardface layer fabricated by 1105V electrode (B3) in three-pass is more than the fabricated specimen by electrode1623 (A3)

Fig. 9. presents the SEM images of worn surfaces of different specimens (electrodes 1623 and 1105V)

The groves on the specimens harfaced by 1105V electrode have less depth than that the specimens hardfaced by 1623 electrode, the reason of which is the distribution of particles in different specimens such that in the specimens hardfaced by 1623 electrode the Cr_7C_3 particles present low resistance particles when dealing with abrasive particles and thus the abrasive particles have created grooves on the surface easily.

In the sample B hardface layer with better morphology and distribution make difference in abrasion resistance.

The worn surfaces of both specimens have micro cuts and microcracks. In specimen A3 the cracks are more continuous and are scattered across the lattice.

Moreover, the specimen has semi-deep lines. The predominant wear mechanism is micro cutting+ micro ploughing. But in the case of B3, the cracks are not as large as previous specimens and are scattered on the surface. So the wear mechanism of this specimen is micro cutting + micro cracking.

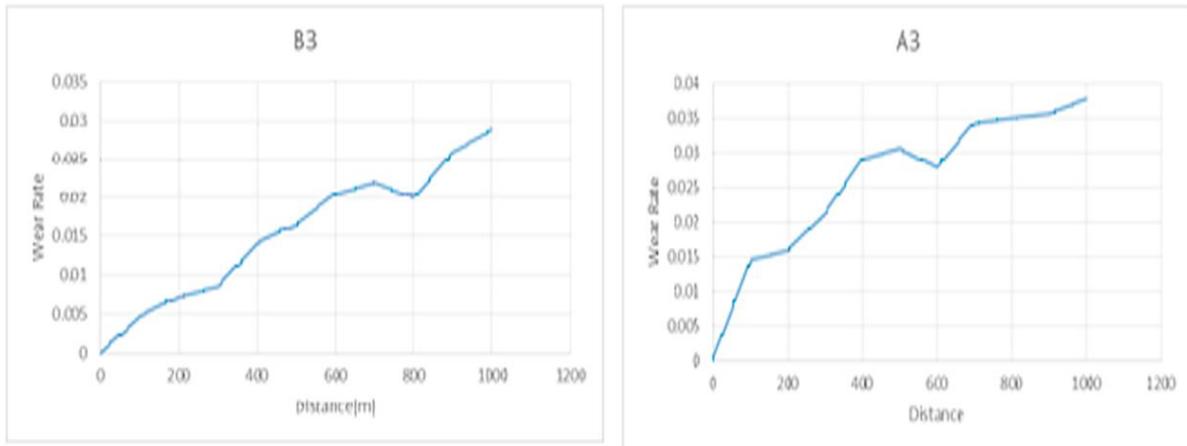


Fig. 8. The wear rate of the specimens A3 and B3.

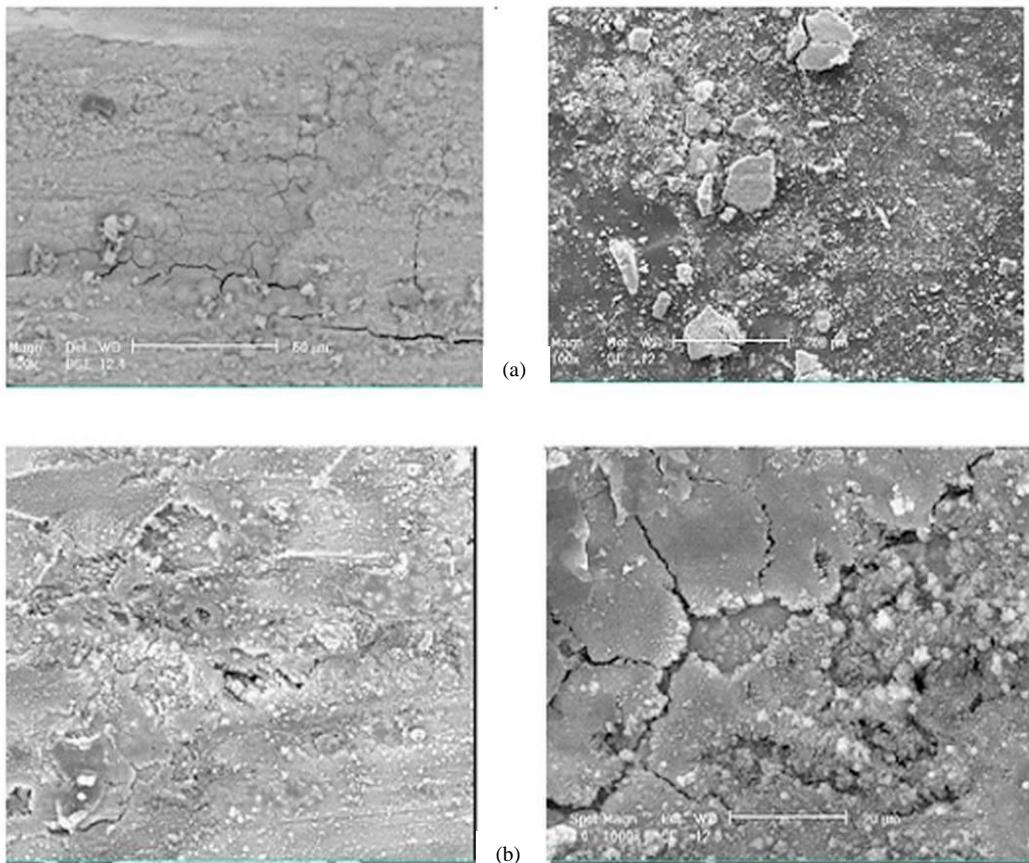


Fig. 9. SEM images of the worn surface. a) specimen A3 , b) specimen B3.

4. Conclusions

1. The Fe-Cr-C base hardface layer formed on plain carbon steel containing martensite, austenite and chrome carbides on the retained austenite.
2. By adding molybdenum and tungsten to the alloy system Fe-Cr-C phase M_6C , martensite and austenite are formed.
3. By reducing the amount of dilution caused by the increase in the number of hardfaced layers, the concentration of alloying elements on the specimen is increased which makes the carbides coarser and formation of complex carbides.
4. By increasing molybdenum the hardness of the hardface layers is increased and this hardness in 3-pass mode up to 61 HRC and 1540 Vickers.
5. The formation of hard M_6C carbides can cause a significant increase in wear resistance. In addition by increasing the number of passes the wear resistance of hardfaced layers increased.

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