

## EFFECT OF VOLUME FRACTION OF $(Cr,Fe)_7C_3$ CARBIDES ON CORROSION RESISTANCE OF THE Fe-Cr-C HARDFACING ALLOYS

$$\text{AT } \frac{Cr}{C} = 6$$

Hamed Sabet<sup>1\*</sup>, Shamsedin Mirdamadi<sup>2</sup>, Shahram Kheirandish<sup>2</sup>,  
Masoud Goodarzi<sup>2</sup>

<sup>1</sup>Department of Materials Engineering, Karaj Branch, Islamic Azad University,  
Karaj, Iran, P.O. Box: 31485-313

<sup>2</sup>School of Materials Engineering, Iran University of Science and Technology,  
Tehran, Iran. Z.P: 1648613114

Received 24.09.2012

Accepted 03.01.2013

### Abstract

In this investigation, three different chemical compositions of Fe-Cr-C alloys were fabricated on AISI 1010 steel substrates by gas tungsten arc welding (GTAW). The optical emission spectroscopy (OES), optical microscopy (OM), scanning electron microscopy (SEM), techniques and corrosion test were used for determining chemical composition studying the microstructure and corrosion behavior of the Fe-Cr-C alloys. The OM and SEM results show that the microstructure of these alloys consisted of  $(Cr,Fe)_7C_3$  carbides with austenite, and by increasing of the carbon and chromium content in hardfacing alloys, the volume fraction of  $(Cr,Fe)_7C_3$  carbides in microstructure was increased. The polarization curves of the corrosion tests show that the increase of the volume fraction of  $(Cr,Fe)_7C_3$  carbides in the microstructure promotes the corrosion resistance of the Fe-Cr-C hardfacing alloys. The corrosion mechanism of the Fe-Cr-C hardfacing alloys was intergranular and galvanic corrosion.

*Keywords:* Fe-Cr-C;  $\frac{Cr}{C} = 6$ ;  $(Cr,Fe)_7C_3$  carbides; Austenite; Corrosion resistance

### Introduction

---

\* Corresponding Author: Hamed Sabet, [h-sabet@kiaau.ac.ir](mailto:h-sabet@kiaau.ac.ir)

The Fe-Cr-C is the most popular type of hardfacing alloys because it has relatively low cost than that the others as: Fe-Ni-Co (X: carbides forming elements) [1, 2]. The Fe-Cr-C alloys are used in severe abrasive conditions [3]. The excellent abrasion wear resistance of the Fe-Cr-C alloys depends on: type, morphology, volume fraction, distribution pattern of  $(\text{Cr,Fe})_7\text{C}_3$  carbides, and the type of matrix structure around the carbides [3,4].

The three types of carbides such as:  $\text{M}_3\text{C}$ ,  $\text{M}_7\text{C}_3$  and  $\text{M}_{23}\text{C}_6$  in Fe-Cr-C alloys depend upon the  $\frac{\text{Cr}}{\text{C}}$  ratio. Therefore, this ratio determines the applicability of these alloys in different wear conditions [5, 6]. It was reported [6] that the excellent abrasive wear resistance with good corrosion and oxidation resistance can be obtained with the ratio of  $\frac{\text{Cr}}{\text{C}}=5-8$ . In this ratio range, the hypoeutectic, eutectic and hypereutectic structure with the austenite phase is formed including  $(\text{Cr,Fe})_7\text{C}_3$  carbides [5, 6].

The Fe-Cr-C alloys are used widely in extractive oil equipments where erosion-corrosion might cause serious problems. Handling and processing of essentially silica-based solids results in extremely severe corrosion and wear conditions [7]. A few investigations were focused on the behavior of the Fe-Cr-C hardfacing alloys in the corrosive environments. Buchanan [8] reported that the abrasion-corrosion of the Fe-Cr-C alloy in an slurry of sand and sugarcane juice was lower than that Fe-C-B alloy and this behavior of the Fe-Cr-C alloy was due to chromium carbides that exist in the microstructure. Chang et al. [9] reported that the increment of carbon content can improve the corrosion resistance of the hypereutectic Fe-Cr-C cladding alloys and with increase of the carbon content the corrosion potential is moved towards the noble side.

Although the object of these few papers was to study the corrosion resistance of the Fe-Cr-C hardfacing alloys, but their results were not directed solely on the effect of carbides on the corrosion behavior of these alloys. This study is particularly focused on the effect of volume fraction of  $(\text{Cr,Fe})_7\text{C}_3$  carbides on the corrosion resistance of Fe-Cr-C hardfacing alloys at  $\frac{\text{Cr}}{\text{C}}=6$ .

## Experimental

AISI 1010 low carbon steel (C=0.1wt.%) specimens with  $200 \times 100 \times 10$  mm dimensions were used for the substrate. The surface of the samples were thoroughly cleaned, dried and rinsed by acetone. The powders mixture (in wt.%) of the ferrochromium (70 Cr and 30 Fe) and crystalline graphite (98% purity) were used as a coating alloys. The ratio of ferro-chromium and graphite powder corresponds to that of stoich-ometric  $\text{M}_7\text{C}_3$  carbides.

Three different amounts of the ferrochromium and graphite powders were mixed in ball mill for 1h in argon atmosphere. Then each mixture of powders was mixed with 20 wt.% sodium silicate, were pre-placed on the substrate with 1 mm thickness, and dried in electrical furnace at  $120^\circ\text{C}$  for 1h.

Hardface cladding was carried out by using the gas tungsten arc welding (GTAW) heat source to produce series of multiple hardface clad tracks. The chemical analysis of hardfacing alloy was determined by optical emission spectroscopy (OES). For metallography, the samples were cut and polished by  $1\mu\text{m}$  diamond paste and

chemically etched in a freshly prepared 2% nital solution. The microstructure was observed using a VEGA/TESCAN scanning electron microscope (SEM) equipped with back-scattered electron (BSE) detectors. In addition, in order to determine the volume fraction of phases in each sample optical microscope (Olympus BX51 M) equipped with image analysis software was used.

For corrosion test each sample was covered with the waterproof tape, leaving an exposed area of 1cm<sup>2</sup> on the material surface. Less than 3.5 wt.% NaCl solution at 30°C was used as a corrosion medium for performing the potentiodynamic polarization tests in order to evaluate the overall corrosion behavior of the samples. The working electrode polarization was measured as a potential difference between the reference and working electrode. The polarization resistance was measured with potential scanning rate of 0.5 mVs<sup>-1</sup> within the potential range of E<sub>oc</sub>±10mV. The silver-silver chloride electrode was regarded as a reference electrode. After polarization test, the corroded surface was observed by optical microscope.

## Results and Discussion

Table 1 gives the chemical analysis of different hardface samples. Three types of different Fe-Cr-C hardfacing alloys were fabricated with the constant ratio of  $\frac{Cr}{C} \cong 6$ .

Table 1 Chemical composition (wt.%) of the hardfacing alloys.

Sample	C	Si	Mn	P	S	Cr	Fe	$\frac{Cr}{C}$
A	1.94	0.13	0.14	0.002	0.003	12.21	Bal.	6.2
B	3.52	0.13	0.12	0.002	0.003	21.32	Bal.	6.1
C	4.02	0.12	0.13	0.002	0.003	24.22	Bal.	6.0

Fig.1 illustrates the microstructure of hardfacing alloys with different chemical compositions. (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides and austenite were obtained in all samples. Fig.1 denotes that sample A has hypoeutectic microstructure with primary austenite and eutectic ((Cr,Fe)<sub>7</sub>C<sub>3</sub>+austenite) structure. Sample B has eutectic ((Cr,Fe)<sub>7</sub>C<sub>3</sub>+austenite) structure, whereas sample C has hypereutectic microstructure with primary (Cr,Fe)<sub>7</sub>C<sub>3</sub> and eutectic ((Cr,Fe)<sub>7</sub>C<sub>3</sub>+austenite) structure.

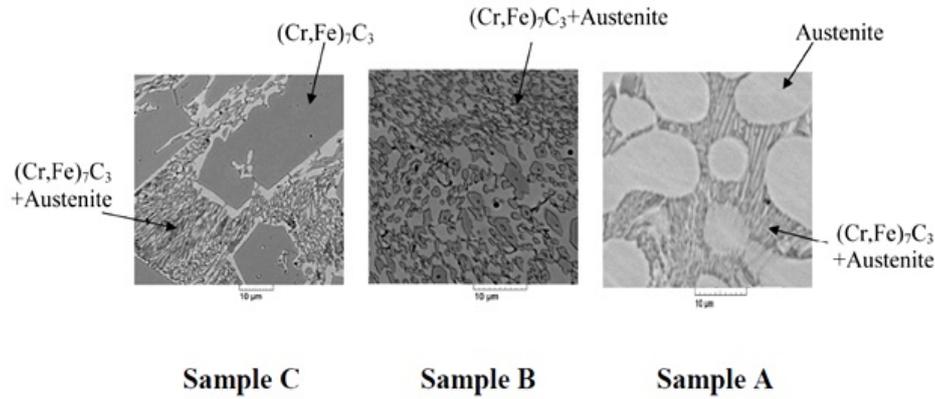


Fig.1 SEM micrographs of hardface alloys with different chemical compositions.

Table 2 shows the microstructural characteristics of the different samples. The results of Table 2 indicate that by increasing of the carbon and chromium contents in the Fe-Cr-C hardface alloys, the total volume fraction of  $(Cr,Fe)_7C_3$  carbides was increased and the volume fraction of total austenite was decreased.

Fig.2 shows potentiodynamic polarization curves of hardfacing alloys with different volume fraction of  $(Cr,Fe)_7C_3$  carbides in 3.5wt% NaCl at 30°C.

Table 2 The microstructure characteristics of the different samples

Sample	Chemical composition (wt.%)		Microstructure	Phases characteristics (wt.%)						
	C	Cr		Primary austenite	Eutectic austenite	Total austenite	Eutectic carbide	Primary carbide	Total carbide	Total Phases
A	1.94	12.22	hypoeutectic	45	14	59	41	-	41	100
B	3.52	21.32	eutectic	-	23	23	77	-	77	100
C	4.02	24.22	hypereutectic	-	15	15	40	45	85	100

Table 3 gives the corrosion current and potential with polarization resistance of hardfacing alloys. It is clear that when the  $(Cr,Fe)_7C_3$  carbides were increased from 41 (sample A) to 85 wt.% (sample C), the values of the corrosion potential ( $E_{corr}$ ) was increased from -594.0 to -486.1 mV, and the values of the corrosion current ( $I_{corr}$ ) was reduced from 34.99 to 1.239  $\mu$ A, and the values of the polarization resistance ( $R_p$ ) was increased from 1.49 to 30.43  $\Omega$ cm<sup>2</sup>. The higher  $R_p$  and  $E_{corr}$  or lower  $I_{corr}$  indicate that the corrosion resistance is excellent. Therefore, the best corrosion resistance was obtained in sample C with total of 85 wt.%  $(Cr,Fe)_7C_3$  carbides.

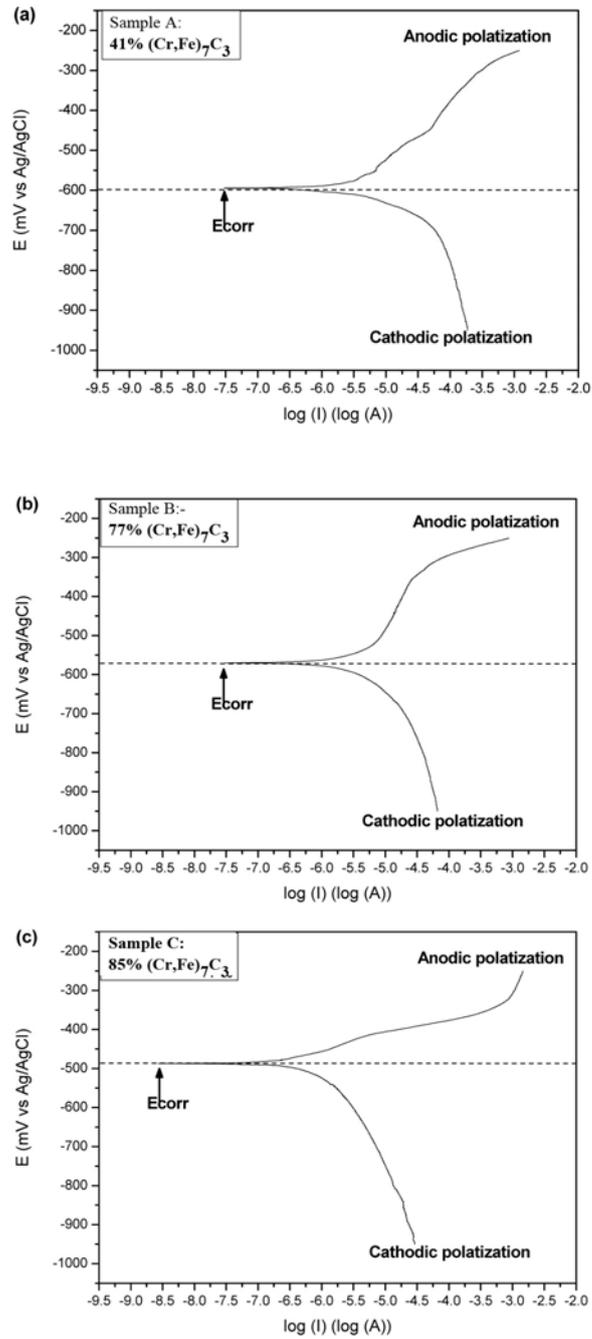


Fig.2 Potentiodynamic polarization curves of hardfacing alloys with various volume fraction of  $(Cr,Fe)_7C_3$  carbides in 3.5wt% NaCl at 30°C.

Table 3 The corrosion current ( $I_{corr}$ ), corrosion potential ( $E_{corr}$ ) and polarization resistance ( $R_p$ ) of hardfacing alloys in 3.5wt.% NaCl solution.

Sample	Total (Cr,Fe) <sub>7</sub> C <sub>3</sub>	$E_{corr}$ (mV)	$I_{corr}$ ( $\mu$ A)	$R_p$ ( $\Omega$ cm <sup>2</sup> )
A	41%	-594.0	34.99	1.49
B	77%	-570.0	8.128	7.88
C	85%	-486.1	1.239	30.43

The corrosion potential of (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides was higher than the austenite because the (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides have excellent chemical stability [10, 11]. (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides are corrosion resistant, but the surrounding chromium-depleted alloy in the matrix (austenite) was aggressively corroded. When the volume fraction of (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides was increased, the corroded area (austenite) was decreased. Therefore, the corrosion resistance of hardfacing alloy (sample C) was enhanced by increasing of the volume fraction of (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides.

Especially, the  $R_p$  was abruptly increased from 1.49 to 7.88  $\Omega$ cm<sup>2</sup> when the volume fraction of (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides was increased from 41% (sample A) to 77% (sample B). These results suggest that the corrosion resistance was controlled by the matrix (in sample A), while the volume fraction of (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides was 41%, when the volume fraction of (Cr,Fe)<sub>7</sub>C<sub>3</sub> was increased to 77% (in sample B) the influence of rapidly carbides with good corrosion resistance was predominant. Therefore, the  $R_p$  was rapidly increased by increasing of the volume fraction of (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides.

Fig.3 shows the corroded surface of sample C with the hypereutectic microstructure after potentiodynamic test. It can be seen that in sample C the (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides were not corroded by 3.5% NaCl solution. However, the austenite (from eutectic) was attacked and the form of corrosion is intergranular, because (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides had higher corrosion potential than that the austenite. Therefore, since (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides are more noble and austenite became more active, a galvanic couple was formed. It should be noted that all samples are prone to galvanic corrosion.

Study of the corroded surface and corrosion test results show that when the corroded area (austenite) became lesser the corrosion resistance became excellent. This is the consequence of the increase of the volume fraction of (Cr,Fe)<sub>7</sub>C<sub>3</sub> carbides resulting in increase of the corrosion resistance of the Fe-Cr-C hardfacing alloys.

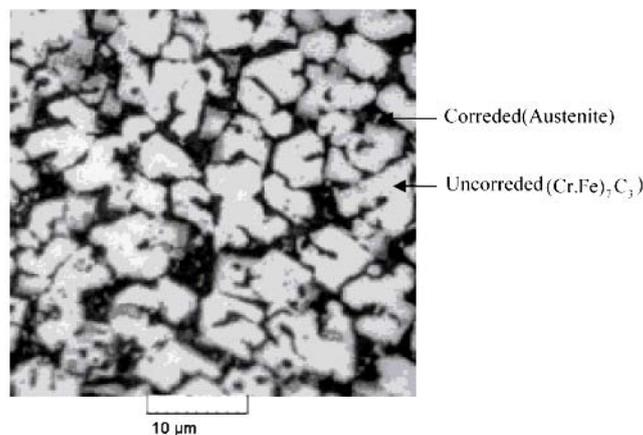


Fig.3 Optical micrograph of surface corroded of the sample C with hypereutectic microstructure.

### Conclusions

In this study different Fe-Cr-C hardfacing alloys were fabricated (at  $\frac{Cr}{C} = 6$ ) on steel substrate to investigate the effect of volume fraction of  $(Cr,Fe)_7C_3$  carbides on corrosion resistance. The following conclusions are obtained:

1. The series of Fe-Cr-C hardfacing alloys have different chemical composition and microstructure consisting of  $(Cr,Fe)_7C_3$  carbides and austenite with different volume fraction of phases.
2. By increasing of the carbon and chromium content of the Fe-Cr-C at constant ratio of  $\frac{Cr}{C} = 6$ , the volume fraction of  $(Cr,Fe)_7C_3$  carbides in microstructure was increased.
3. By increasing the volume fraction of  $(Cr,Fe)_7C_3$  carbides in microstructure, the corrosion potential and corrosion resistance were increased and the corrosion current was reduced. Therefore, by increasing the volume fraction of  $(Cr,Fe)_7C_3$  carbides the corrosion resistance of the Fe-Cr-C hardfacing alloy was increased.
4. The corrosion mechanism of the Fe-Cr-C hardfacing alloys was intergranular and galvanic corrosion.

### References

- [1] R. Chotěborský, P. Hrabě, M. Müller, J. Savková, M. Jirka, Res. Agr. Eng, 54 (4) (2008) 192–198.
- [2] S. Buytoz, M. M. Yildirim, H. Eren, Mat. Let. 59 (2005) 607-614
- [3] J. Liu, L. Wang, J. Huang, J. Univ. Sci. Tech. Beij., 13 (6) (2006) 538-542.
- [4] C.M. Chang, C.M. Lin, C.C. Hsieh, J.H. Chen, W. Wu, J. Alloys Comp., 487 (2009) 83-89.

- [5] C.M. Lin, C.M. Chang, J.H. Chen, W. Wu, *Met. Mat. Trans. A*, 40A (2009) 1031-1038.
- [6] H. Sabet, S. Khierandish, S. Mirdamadi, M. Goodarzi, *Trib. Let.*, 44 (2011) 237-245.
- [7] R.B. Davis, *Microstructural Relationship to Flow Accelerated Corrosion*, Code and Standard for Quality Engineering, ASME Minneapolis, MN 1994, U.S.A.
- [8] V.E. Buchanan, *J. Mat. Eng. Perform.*, 21(2)( 2012 ) 231-239 ,
- [9] C.M. Chang, C.C. Hsieh, C.M. Lin, J. H. Chen, C.M. Fan, W..Wu, *Mat. Chem.*
- [10] B.Lu, J. Luo, S. Chiovelli, *Met. Mat. Trans A*, 37A (2006) 3029-3038.
- [11] D.A. Jones, *Principles and Prevention of Corrosion*, Upper Saddle River, NJ 1996, U.S.A.