A STUDY ON MICROSTRUCTURE AND WEAR BEHAVIOR OF FE-BASED HARD FACING ALLOYS

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ABSTRACT: *The hardfacing process is an effective tool for cost reduction and maximizing the wear resistance and thus increasing the life of machinery components by overcoming the severe destructive wear conditions. Fe-based Hardfacing alloys which contain a high volume fraction of hard phases are suitable materials to be deposited as wear resistant thick coatings. The present research focused on the microstructural evolution, hardness variation and wear resistance of Fe-based hard layers produced by welding deposition. The wear test results were discussed in relation to chemical composition, microstructure and hardness. Three Fe-based alloys with different compositions which are commercially available were used to deposit on DIN 1.2714 die steel substrates by gas metal arc welding method.*

Keywords: Hardfacing, Fe-based alloy, wear, microhardness, carbides

1. INTRODUCTION

Many engineering components work against very aggressive conditions such as abrasion, adhesion, erosion, corrosion and so on. Hardfacing is one of the most useful and economical techniques employed to protect the severe wear of tools and machines. [1]. The Fe–based hardfacing alloys have high hardness and high resistance to corrosion and wear and is often deposited on the surfaces of engineering components subjected to wear [2-3]. The microstructures of such alloys are composed of alpha ferrite and complex carbides, which makes the matrix harder and resistant to wear [4-6].

The objective of this work is to study the influence of the Fe-based hardfacing alloys with different compositions on microstructure, microhardness and abrasive wear resistance. Fe-based alloy was deposited using gas metal arc welding (GMAW) on the substrate was DIN 1.2714 tool steel which is widely used for hot forging die components.

2. MATERIAL AND METHODS

DIN 1.2714 tool steel having dimensions 30 mm x 30 mm x 80 mm was used for hardfacing purpose by means of gas metal arc welding (GMAW) process. The chemical compositions of tool steel and commercial hardfacing electrodes were presented in Table 1. Hardfacing coating procedure is that was as follows; samples were heated in a furnace about 300 0C – 450 0C. Fe-Cr-C alloy was deposited using gas metal arc welding (GMAW). Welding parameters were given in Table 2. Samples were cooled slowly and then stress relieved process was applied in a furnace at 450 0C for 6 hrs.

Table 2. Welding parameters for hardfacing applications

Parameters	Values
Current (A)	180
Gas pressure (bar)	15
Gas composition	75-95% Ar + 4-22% CO_2 + 1-3% O_2

Each hardfacing specimen was ground with SiC emery paper and polished with diamond paste. The metallographic specimens were etched with 4% nitric acid alcohol solution. The microstructures were observed on the surface by optical microscopy (OM) and on the cross-section by scanning electron microscopy (SEM). X-ray diffraction (XRD) analysis was performed with radiation of Cu-Kα and wavelength of 1.542Å between 30°-110°.

Vickers microhardness determinations on transverse sections were carried out. The load was 300 g. Both of load time and dwell time were 10 s. The abrasive wear tests were performed using ball-on-disc CSM tribometer where counterface was alumina ball with the diameter of 6 mm. The rotation velocity of the disc was of 543 rpm and applied load was 10N. The total sliding distance was 500 m. The wear rate was calculated by Eq. (1). W is the wear rate (mm^3/N m). ΔV is the wear volume (mm3). N is the normal load during testing (N). L is the wear distance (m).

$$W = \frac{\Delta V}{N.L} \qquad (1)$$

Table 1. Chemical compositions of tool steel and hardfacing electrodes

	C	Si	Mn	Cr	Ni	W	V	Mo	Fe
Alloy-1	0.1	0.9	0.8	29	9	-	-	-	Bal
Alloy-2	0.7	0.6	0.7	10	-	-	7	-	Bal
Alloy-3	0.25	0.3	0.7	7.5	-	4.5	-	-	Bal
Tool steel	0.50 - 0.60	0.10 - 0.40	0.60 - 0.90	0.80 - 1.20	1.50 - 1.80	-	0.05 - 0.15	0.35 - 0.55	Bal

3. RESULTS AND DISCUSSION

The OM morphologies of the hardfacing coatings with different alloying elements are shown in Fig. 1. The microstructures of the hardfacing coatings consisted of the primary Fe-rich dendrites and an interdendritic eutectic comprising Fe–Cr solid solution with $M_{23}C_6$, M_6C or M_7C_3 carbides [7]. It is noted that the micrographs were similar for three hardfacing, but Alloy-1 showed finer microstructure.

The interdendritic zone eventually solidified as rich by alloying element resulting intermetallics formation, such as carbides [8]. The formation of microstructures composed of α-Fe, γ-Fe and complex carbides, such as M_3C, M_7C_3 and $M_{23}C_6$, depending on the chemical concentration of the deposit weld metal [9]. For example, the chemical composition of Alloy-1 (wt%) is 0,1C, 29Cr, 9Ni, 0,9Si, 0,8Mn, bal. Fe, and it comprised largely of austenite to somewhat M23C6 and ferrite (Fig.2).

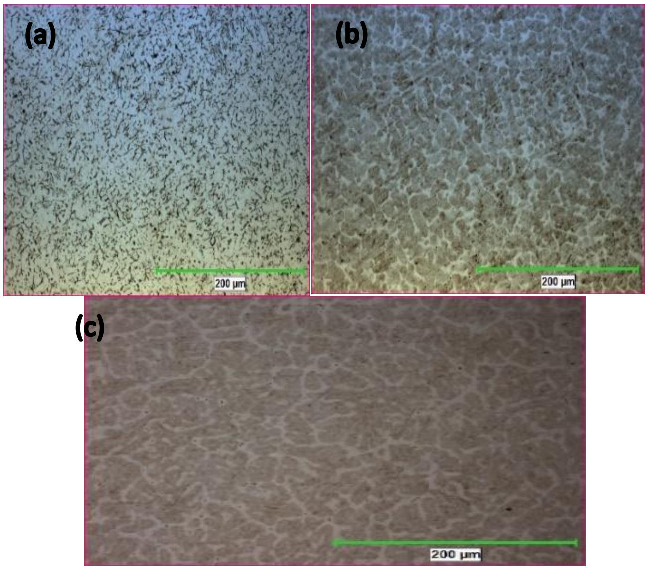

Fig 1. The surface micrographs of the hardfacing alloys: (a) Alloy-1 (b) Alloy-2 (c) Alloy-3

The main microstructures of Alloy-3 which includes W and Cr were ferrite to a degree $M_{23}C_6$ and M_6C. Alloy-2 which has highest C content with Cr and V composed of ferrite and M_7C_3 and M_7C_3 content of Alloy-2 was higher than other hardfacings.

E. Badisch *et al.* [10] stated that type, content, size and morphology of the hard phases occurring play a major role in the final wear properties of the individual alloys and contribute to their abrasion resistance.

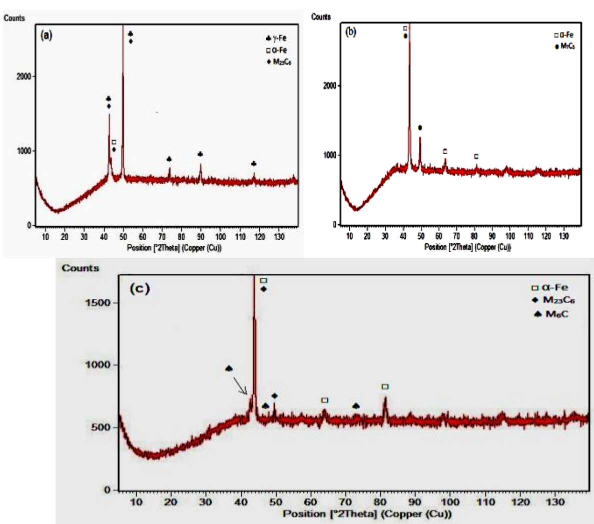

Fig. 2. XRD patterns for the different conditions: (a) Alloy-1 (b) Alloy-2 (c) Alloy-3

The shift of the peaks from their own positions due to excessive foreign atoms causes to change the lattice constant. Alloying atoms distort the FCC or BCC lattice, causing an expansion of the lattice and producing a solid solution strengthening [11]. The interplanar spacing for cubic structures was given in Equation (2).

$$d = \frac{a}{\sqrt{(h^2+k^2+l^2)}} \qquad (2)$$

Where a is the lattice constant and h, k, l are the Miller indices [12]. Using the Eq. (2), the lattice constants can be calculated for samples by using crystallographic parameters and peak list derived from XRD pattern. The results were given in Table 2. Based on the observed *d*-spacings of the XRD pattern, α or γ is a saturated solution alloying elements in Fe. The calculated lattice expansions were about 0.82% in γ-Fe lattice and 2.42 % in α-Fe lattice for Alloy-1. However the main phase was γ-Fe for Alloy-1, therefore it was concluded that the lattice expansion resulted from α-Fe lattice had no significant effect. Even that, as the expansion in γ-Fe lattice was in very small quantities, it can be said that the solid solution strengthening was not a significant contribution to Alloy-1. Alloy-2 and Alloy-3 had mainly α-Fe, therefore the lattice expansions occurred in α-Fe lattice were 2.37% and 1.4% for Alloy-2 and Alloy-3 respectively. It can be concluded that the solid solution strengthening contributed to the hardness of Alloy-2 and Alloy-3.

Table 2. The Lattice constants for untreated and treated samples

	Alloy-1	Alloy-2	Alloy-3
Phase	γ-Fe	α-Fe	α-Fe
Reference lattice parameters (a, Å)	3.623	2.866	2.866
Average lattice parameters (a, Å)	3.653	2.934	2.907
Lattice expansion (%)	0.82	2.37	1.4

The hardfacing showed dendrites oriented in the direction normal to the interface between the hardfacing and the substrate providing a good bonding (Fig.3). The substrate had tempered martensite. The hardfacing exhibited some voids and porosities.

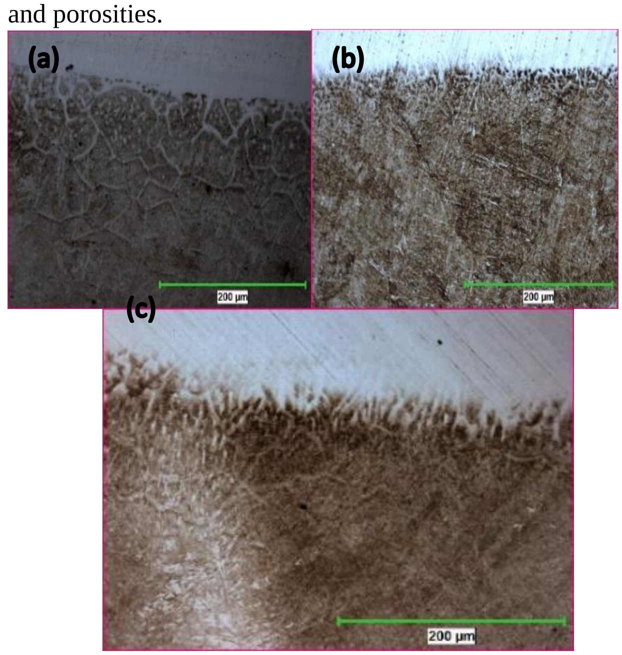

Fig.3. SEM of the hardfacing layers (a) Alloy-1 (b) Alloy-2 (c) Alloy-3

The hardness of various phases encountered in this study is presented in Table 3. Formation of M_7C_3 or M_6C type carbides will contribute to the increase of hardness more than

$M_{23}C_6$. This result agreed with the hardness profile measured along the cross-section of the substrate-hardfacing (Fig.4). As can be seen, Alloy-2 and 3 had higher hardness, while Alloy-1 had a lower hardness than the substrate. Alloy-2 had the highest hardness because it had the highest lattice expansion resulting in solid solution hardening and highest amount of carbide formation. Table 3 demonstrates that M_7C_3 is an important factor in increasing hardness value. Alloy-3 had a higher hardness than Alloy-1 due to M_6C type carbides. The substrate hardness originated from tempered martensite.

Table 3. Hardness values of various carbides

Austenite	Ferrite	M_7C_3	$M_{23}C_6$	M_6C	Martensite	Ref
250-350	-	1200	-	-	-	[13]
-	100	-	-	-	-	[14]
190-350	70-190	1400 - 2150	-	-	-	[15]
-	-	1700	-	-	-	[16]
-	-	-	800	-	500-1010	[17]
-	-	1025 - 1500	800	1200 - 1800	-	[18]

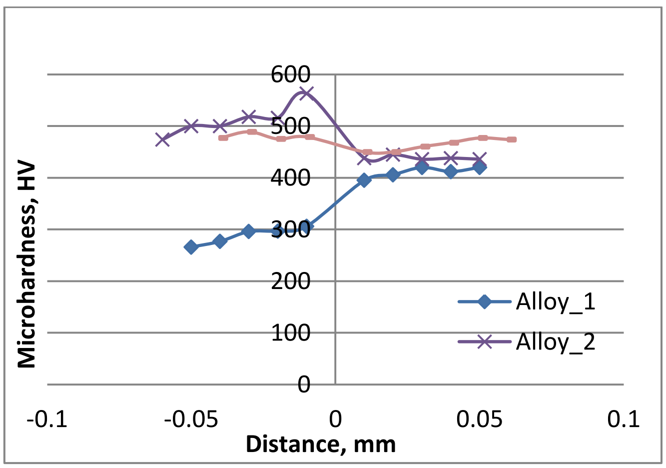

Fig. 4. The hardness curve of the hardfacing depth profile

Table 4 shows wear rate, average friction coefficient, hardness from the top of the hardfacing layer and hardness from wear scar comparatively. Hardness is considered as an important material property for alloys because it is often used to correlate to wear resistance of materials. As reported by KenchiReddy and Jayadeva [19], as the hardness increases, the loss of wear decreases. As it is seen in Table 4, Alloy-2 had higher surface hardness and lower wear rate. V.E. Buchanan *et.al* [20] compared the wear behavior of two hardfaced deposits produced from two commercial electrodes with that of an Fe–Cr–B based alloy deposited by electric arc spraying onto a gray cast iron substrate. They showed that variations in the morphology of the carbides and the structure of the weld deposits produced marked differences in resisting dry abrasive wear.

The hardness values from wear scar indicated that the most hardness enhancement after the wear test was in Alloy-1. Moreover, the average friction coefficient showed a significant decrease for Alloy-1. It should be related to the oxide formation and friction induced work hardening during wear test.

Table 4. Values of wear and hardness test for the hardfacing samples

	Wear Rate, x10-6 (mm3/N/m)	Average Fric.Coeff., µ	Average Hardness of Hardfacing ($HV_{0.3}$)	Hardness of wear scar ($HV_{0.3}$)
Alloy-1	1.617	0.568	288	749
Alloy-2	0.618	0.891	512	628
Alloy-3	1.9714	0.709	480	535

Cr_2O_3 layers have attracted a lot of attention because of its charming properties such as high hardness and mechanical strength, good optical characteristics, excellent chemical inertness, and low friction coefficient [21]. Cheng et al. exposed that the Cr_2O_3 particles generated during the pin-on-disc tests played a significant role in changing frictional behavior [22]. On the other hand, J.W. Yoo et al [23] stated that the worn surfaces were hardly work-hardened besides oxide formation. Na-Ra Park and Dong-Gyu Ahn [24] found that the remarkable work hardening takes place in the worn region of theStellite21 hardfaced layer. Ranjit Singh and Sudhanshu Kumar Pandey [25] also obtained a decrease of wear volume loss which is associated with work hardening of substrate. However, Alloy 1 had no good wear resistance related to its hardness after wear test. It was concluded that a hard oxide or hardly work hardened layers on a soft metal surface may be ineffective because the soft substrate will deform, allowing the oxide to break up. The broken oxides act as abrasive particles, increasing wear. Therefore, this hard layer is unable to a high load sliding contact.

4. CONCLUSION

The following observations and conclusions were obtained:

- The hardfacing process is an effective tool for wear resistance and thus increasing the life of machinery components by overcoming the severe destructive wear conditions.
- Compared with the substrate, the microhardness and wear resistance of the coating improved by means of solid-solution strengthening and second-phase particle hardening.
- Experimental investigation revealed that, weld metal chemistry & hardness have significant influence on wear property. There is a correlation between hardness values and wear resistance.
- Alloy-2 and Alloy-3 had a higher hardness than Alloy-1. The hardness value increased by M_7C_3 and M_6C content.
- In wear tests, average friction coefficient showed a significant decrease in Alloy-1 which has highest Cr content. Alloy-1 had the lowest friction coefficient due to oxide formation and/or friction induced work hardening layers during wear test. And also, Alloy-2 which has high Cr and C content has lowest wear rate and this result is related to M_7C_3.

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