Materials and Design 58 (2014) 491–498

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Wear behavior–hardness–microstructure relation of Fe–Cr–C and Fe–Cr–C–B based hardfacing alloys

Yüksel N. *, Şahin S.

Celal Bayar University, Faculty of Engineering, Materials Engineering Department, Manisa, Turkey

ARTICLE INFO

Article history:
Received 17 December 2013
Accepted 12 February 2014
Available online 20 February 2014

Keywords:
Hardfacing
Wear test
Ferroboron
Ferrochromium
Welding

ABSTRACT

The aim of this study is the investigation of the effect of ferroboron and the amount of powder mixture (ferroboron + ferrochromium) on wear resistance of Iron (Fe)–Chromium (Cr)–Carbon (C) based hardfacing alloys. Powder mixture, consisting of ferrochromium (FeCr) and ferroboron (FeB), was added to massive wire during welding process. Hardfaced layers were obtained by three different powder mixtures and two different powder/massive wire proportions. Hardfacing was applied to AISI 1020 steel substrate by open arc welding. Hardness test, Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD) analysis, dry sand/rubber wheel abrasion test were executed. Test results showed that increasing ferroboron content and increasing powder mixture amount enhanced the wear resistance.

1. Introduction

Abrasive wear happens when a hard object is burdened against particles of a substance that contain identical or superior rigidity. Any material, even if the bulk of it is very soft, may cause abrasive wear if hard particles are in attendance [1]. Wear resistance of materials can be improved through bulk treatment and applying a wear resistant surface onto a cheaper core material [2,3]. While bulk treatment has been practiced for a long time, surface treatment is fairly recent and attains growing importance [2]. Thus the use of coatings is an extremely attractive means of providing inexpensive, easy to fabricate metals with the special properties of materials that may be expensive, and often unworkable, at little increase in cost [4].

Hard surfacing is the application of a durable surface layer to a base metal to impart properties like resistance to metal-to-metal sliding with high contact stress, impact wear, abrasion, erosion or pitting and corrosion or any combination of these factors [5,6]. Hard surfacing can be applied by several techniques, such as plasma spraying, laser cladding, welding and thermal spraying methods [5,7–11].

Improvement of the wear resistance of machine components may be achieved by an adequate selection of abrasion resistant materials for the deposition of hardfacing layers on the bulk parts [12]. The addition of alloying elements and rapidly solidified fine crystalline microstructure containing finely distributed hard phases can exhibit an excellent combination of hardness and toughness of the hardfaced alloys [13]. Coarse hard phases and high hardness are important to achieve high abrasion resistance. The hardness of the hard phases and/or the hardness of the matrix should be higher than the hardness of the abrasive [13,14].

Iron-based alloys with niobium (Nb), titanium (Ti), molybdenum (Mo) in combination with boron (B) and carbon have been selected as hardfacing alloys due to their high hardness and wear resistance gained by the precipitation of different abrasion resistant hard phases [15,10]. The high chromium irons are widely used for hardfacing of industrial components in mining, cement plants, thermal power plants and iron and steel industries due to their higher hardness and excellent abrasive resistance which attributed to the formation of chromium carbides [16,17]. The wear properties are affected by the microstructures and weight fraction of carbide phases. The coarser microstructures and lower carbide weight fraction result in more weight loss [18]. However, the control of carbide sizes and distributions became an important challenge for Fe–Cr–C hardfacing alloys due to the brittleness of large block primary carbides. Primary carbides often form in Fe–Cr–C hardfacing alloy that deteriorates the continuity between the carbides themselves and the matrix [19]. So the wear resistance of a hardfacing alloy depends on many factors such as the type, shape and distribution of hard phases, as well as the toughness and strain hardening behavior of the matrix [9]. For this reason, the concordance between the carbide and matrix should be investigated, so

* Corresponding author. Address: Celal Bayar University, Faculty of Engineering, Materials Engineering Department, 45140 Muradiye-Manisa, Turkey. Tel.: +90 236 201 24 06; fax: +90 236 241 21 43.

E-mail addresses: nilay.yuksel@cbu.edu.tr (N. Yüksel), salim.sahin@cbu.edu.tr (S. Şahin).

http://dx.doi.org/10.1016/j.matdes.2014.02.032
0261-3069/

the relation of microstructure and wear behavior can be determined according to their distribution and morphology.

Borides and carbides are the common hard phases in hardfacing alloys [20]. Borides that form with the transition metals have long been known to possess high potential for extreme applications because of their high hardness and excellent wear, friction and corrosion resistance [21]. In literature some studies revealed that boron promoted the development of primary hard phases such as boride or carbide and increased the volume fraction of these wear resistant hard phases [21–23,17]. The study of Liu et al. suggested that boron influences directly not only on the formation of carbides, but also the bulk hardness, as well as the wear resistance of alloys [22].

Boride-rich cored wires are used widely in cladding or hard surfacing of some industrial applications by spraying or welding methods [24]. In the present study FeB powder was used as boron source with various proportions.

The aim of this study is to investigate the effect of massive wire/additional powder proportion and FeCr/FeB ratio in this powder mixture on microstructure, hardness and wear behavior of hardfacing alloys.

2. Experimental study

2.1. Production of wear plates

Two different massive wire/powder ratios and three different FeCr/FeB powder compositions were used and six different hardfacing coatings were obtained (Table 1).

Hardfacing can be applied with various welding techniques. In the current study wear plates were produced by open arc welding (Table 2) using massive wire 1.6 mm in diameter, ferrochromium and ferroboron powders. Chemical compositions of massive wire, ferroboron and ferrochromium powders were given in Table 3, Table 4 and Table 5 respectively. Hardfacing coatings were applied to AISI 1020 steel without preheating.

The size analyses of FeB and FeCr powders were given in Fig. 1 and Fig. 2 respectively. According to the size analyses, the size range of FeB powder is between 74 and 352 μm and the size range of FeCr powder is between 18.5 and 497.8 μm.

Table 1
Compositions of powder mixtures.

Sample No.		Composition of powder mixture	
		FeB (%wt.)	FeCr (%wt.)
50% Massive wire + 50% powder mixture	50/50-1	–	100
	50/50-2	10	90
	50/50-3	30	70
30% massive wire + 70% powder mixture	30/70-1	–	100
	30/70-2	10	90
	30/70-3	30	70

Table 3
Chemical composition of massive wire.

C %	Si %	Mn %	Fe %
0.08	0.8	1.45	Rest

Table 4
Chemical composition of ferroboron.

B %	Fe %
17	Rest

Table 5
Chemical composition of ferrochromium.

C %	Cr %	Si %	Fe %
6	55	2	Rest

2.2. Hardness and microstructure of hardfacing deposits

Macro Vickers hardness measurements were carried out by Emco-Test DuraVision hardness tester under 10 kgf loads according to ASTM: E-384. Hardness values were obtained as mean of three different measurements taken from the top surface of grinded hardfacing layer. Also micro hardness values of different phases of samples were obtained under 50 gf loads for 10 s dwell time.

Microstructure and volume fraction of hard phases were investigated by Nikon Eclipse LV 100 optical microscope using Clemex Software. Samples were polished and etched with Kalling's reagent (33 ml H_2O, 33 ml methyl alcohol, 33 ml HCl, 1.5 g $CuCl_2$) for quantitative analysis of the carbide–boride/matrix phases. Calculation of the volume fraction was carried out from the mean of three different areas. X-ray diffraction (XRD) of hardfacing coatings were carried out on grinded top surface of hardfaced layers with Cu Kα radiation and scanning angles between 20° and 90° (Fig. 3). Chemical compositions of hardfacing alloys were obtained by optical emission spectroscopy (Table 6).

2.3. Wear test

Dry sand/rubber wheel abrasion test was carried out according to ASTM: G-65 to investigate the wear behavior of hardfaced layers. The schematic representation of dry sand/rubber wheel

Table 2
Welding parameters.

Parameter	Sample No.					
	50/50-1	50/50-2	50/50-3	30/70-1	30/70-2	30/70-3
Wire feeding rate (g/min)	62	62	62	62	62	62
Powder feeding rate (g/min)	62	62	62	145	145	145
Voltage (V)	27.5	27.5	27.5	27.5	27.5	27.5
Current (A)	280–300	280–300	280–300	350	350	350
Traveling Speed (mm/min)	170	170	170	170	170	170
Wire extension (mm)	20–25	20–25	20–25	20–25	20–25	20–25
Oscillation width (mm)	41	41	41	41	41	41