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Microstructure and wear resistance of Fe-Cr13-C-Nb hardfacing alloy with Ti addition

Ke Yang*, Yuan Gao, Kè Yang, Yefeng Bao, Yongfeng Jiang

College of Mechanical and Electrical Engineering, Hohai University, Changzhou 213022, China

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ABSTRACT

In order to achieve the maximum benefit from the carbide-forming elements Ti and Nb, it is very important to have a better understanding of the strengthening mechanism of the two carbide-forming elements in the hardfacing alloy.

The Fe-Cr13-C-Nb hardfacing alloy with and without Ti addition were deposited respectively on carbon steel substrates by shielded metal arc welding. The carbide-forming elements in the two hardfacing alloys were S1-0.158Nb and S2-0.156Nb+0.263Ti(wt.%). Optical microscope (OM), scanning electron microscope (SEM) and energy-dispersive spectrometer(EDS) were used to investigate the effect of titanium addition on the microstructure of the hardfacing alloy. The impact experiment was conducted using the Charpy impact testing machine. The wear resistance was tested through a slurry rubber wheel abrasion test machine, and the wear behaviour was also studied.

The results show that, the carbide precipitation of the Fe-Cr13-C-Nb hardfacing alloy was determined by Ti addition. Ti has greater affinity than Nb for carbon to form TiC, and the prior TiC precipitates act as nucleation sites for NbC to promote precipitation of complex carbides in the hardfacing alloy. The microstructure of the Fe-Cr13-C-Nb hardfacing alloy with titanium addition exhibited hard carbides dispersion in a tough martensite matrix, where the hard carbides provide the resistance to abrasion. So the Fe-Cr13-C-Nb hardfacing alloy with titanium addition showed a better wear resistance, and the wear mechanism was mainly interrupted plastic grooves with minimum depth and desquamation of carbides.

1. Introduction

Weld hardfacing technique is commonly employed to extend or improve the service life of engineering components and to reduce their cost, because hardfacing alloy has excellent resistance to wear and corrosion when deposited onto the substrate [1–3]. In hardfacing alloys, Fe-Cr13-C martensite stainless steel has good wear and corrosion resistance properties and is often used for depositing on the surfaces of components subjected to abrasion [4–7]. In order to increase wear resistance, hard carbides are expected to be formed in the hardfacing alloy and act to shield the matrix from abrasion. In addition, a tough matrix that is required for the hardfacing alloy to prevent the falling off of carbides and to produce a resistance to cracking. The heat treatment is widely used to improve the precipitation of carbides and increase the toughness of hardfacing alloy after welding. However, it is difficult to manufacture a large heat treatment furnace and the cost of hardfacing is very high when the dimension of engineering components are large. In order to solve this problem, it was considered necessary to directly obtain the best wear resistant hardfacing alloy containing a high volume fraction of carbides and a tough matrix after welding.

Titanium(Ti) and niobium(Nb) are the strongest carbide-forming elements and can combine with carbon in the hardfacing alloy to form granular carbides with high hardness. On the other hand, formation of these carbides reduces the carbon concentration in the matrix of the hardfacing alloy, which is favorable for improving the toughness. Numerous published works [8–15] investigated the influence of strong carbide-forming elements on the microstructure and wear resistance of the Fe-based hardfacing alloy and as carbide-forming elements Ti and Nb were used. These Fe-based hardfacing alloys generally fall into two categories:

– Low-Cr Fe-based alloys, materials, containing up to 12% Cr content, MC carbides are formed by metallurgical reaction of alloying elements and carbon [8–10,14]. Four kinds of weld metal containing 1.4% Cr and different strong carbide forming elements were surfacing welded on 9Cr2Mo substrate. Forming tendency of VC is weaker than TiC and NbC [8,9]. In the analysis of microstructure and properties of TiC particles reinforced Fe-

* Corresponding author.
E-mail address: yangke_hhuc@126.com (K. Yang).

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based surface composite coatings (≤ 0.02% Cr) produced by manual shielded metal arc welding (SMAW), the results showed that TiC particles are produced by direct metallurgical reaction between ferrotitanium and graphite during welding [10].

- High-Cr Fe-based alloys, materials with 12–50% Cr content, M_7C_3 and MC primary carbides form at high carbon concentrations [11–15]. A series of high carbon Fe-Cr-C-Nb/Ti were investigated. Volume fractions of coarse hard phased of 6–41% of MC-type carbides, together with 0–28% chromium carbides of M_7C_3-type, were found in a hard eutectic microstructure [11]. Steels with 15 mass% Cr, 2 mass% Mo and varying contents of C, V, Nb and Ti were investigated, the results showed Nb is most suited to form MC carbides for wear resistance thus reducing the content of M_7C_3 [15].

However, the precipitation mechanism of the carbides between on the two elements of Nb and Ti in the Fe-Cr13-C hardfacing alloy remains unclear. In order to achieve the maximum benefit from the carbide-forming elements Ti and Nb, it is very important to have a better understanding of the detailed microstructural evolution and the precipitation mechanism on the two kinds of carbides within the Fe-Cr13-C hardfacing alloy.

In this study, the Fe-Cr13-C-Nb hardfacing alloy with and without Ti addition were made by shielded metal arc welding (SMAW). The effect of titanium addition on microstructure and wear resistance of the Fe-Cr13-C-Nb hardfacing alloy was studied. And the investigation is also aimed at understanding strengthening mechanism of the two carbide-forming elements in the Fe-Cr13-C hardfacing alloy.

2. Experimental procedure

The hardfacing alloy was deposited on the substrate by manual shielded metal arc welding (SMAW). The substrate used in this work was a 300 mm × 100 mm × 10 mm plate of low carbon steel. The hardfacing electrode was made by using a core of Fe-Cr13-C-Nb martensite stainless steel and a coating of CaO-CaF_2-TiO_2 slag system. Two electrode coatings (S1 and S2) were prepared. And ferrotitanium (FeTi) was added into one kind of electrode coatings. In order to obtain the undiluted hardfacing alloy, six layers of welds were deposited on the substrate. The welding process parameters were as follows: welding speed 9–13 m/h, welding current 100–130 A and welding voltage 24–26 V. The chemical compositions of hardfacing alloy S1 and S2 were analyzed by using a direct-reading spectrometer (Q4 Tasman, Bruker, Germany), as shown in Table 1. It is can be clearly found that the chemical composition of hardfacing alloys belonged to one of the Fe-Cr13-C martensitic stainless steel series.

Rectangular shaped samples were cut from the hardfacing coating at room temperature. After the samples were polished and eroded by a solution of H_2O92 mL+$HNO_3$4 mL+HF4 mL, the microstructures were observed by an optical microscope (OM, XJG-05, Nanjing Jiangnan Novel Optics Co., Ltd. China) and a scanning electron microscope (SEM, S-4800, Hitachi, Japan). And carbide precipitations present in the samples were analyzed by energy-dispersive spectrometer (EDS, equipped by SEM). The hardness of the samples was measured by a Rockwell hardness machine (HRC, HR-150AL,Shanghai Zhongyan Instrument Manufacturing Factory, China). The impact experiment was conducted using the Charpy impact testing machine(JB-300B, Yongke Test Machine, China). And the size of specimens was 5 mm × 5 mm cross section and 50 mm length and an average of three observations was reported.

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

Hardfacing alloy	C	Si	Mn	Cr	Nb	Ti	Fe
S1	0.152	0.632	0.330	12.31	0.158	–	Balance
S2	0.152	0.689	0.334	12.41	0.156	0.263	Balance

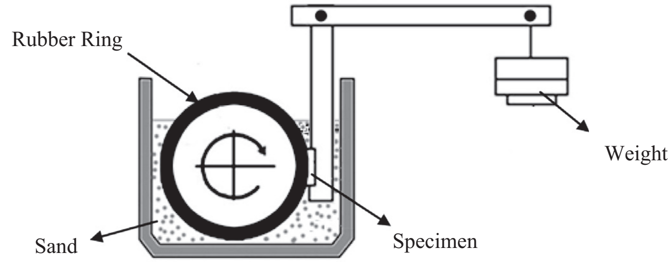

Fig. 1. Schematic diagram of the wear tester.

The wear resistance of hardfacing alloy was measured by a sand-rubber wheel testing machine(MLS-225, Jinan Yihua Tribology Testing Technology Co.,Ltd. China). Fig. 1 shows the schematic representation of the test. Wear testing specimens were machined into a size of 57 mm × 25.5 mm × 6 mm. The 57 mm × 25.5 mm face of the specimen were worn in contact with wet sands (1 kg water and 1.5 kg quartz sand with size: 380–830 μm). Wet sands carried by the rubber wheel under a testing load of 300 N, and the running distance was 1118 m. Three testing specimens were prepared from each sample and tested separately. A microbalance with ± 0.1 mg precision (ME104E, Mettler Toledo, China) was used to weigh each specimen before and after wearing, and an average of weight losses was calculated and recorded. After the measurement, And the worn surface was characterised by SEM. The specific relative wear resistance ratio (R) was obtained using the following Eq [16]:

$$R = \frac{W_j}{W_o}$$

where W_j is the weight loss of sample (g), W_o is the weight loss of sample S1. The sample has the higher value of R, which means the sample has the better wear resistance.

3. Results and discussion

Microstructure of the sample S1 and S2 are shown in Fig. 2. The sample S2 shows a finer grain with refinement martensite lath structure than the sample S1. In addition, there are a number of precipitate particles with size about 0.5–2 μm distributing homogeneously in the matrix of the sample S2(Fig. 2c and d), which cannot be obviously observed in the sample S1(Fig. 2a and b). Fig. 3 shows EDS surface scanning images. According to the particles sites of the enrichment of Ti and Nb (as marked by circles), it could be identified these precipitated particles presented in the sample S2 are complex carbides of Ti and Nb. Fig. 4 shows the elements distribution of carbide particles in the sample S2, The morphology of carbide particles are characteristic cubical, as shown in Fig. 4a. The EDS line scanning images (Fig. 4b and c) show the peak values of Ti and Nb correspond to the carbide particles sites. So it is indicated that these precipitated particles homogeneously distributed in the hardfacing alloy are a type of complex carbide which consists of TiC and NbC [17–19].

It is well known that Ti and Nb have strong affinities for carbon to forming carbide particles in liquid metal, and TiC is more likely to be formed than NbC based on the thermodynamic theory (free energy of carbide formation). Therefore, it is evidential that carbon first combine Ti form TiC and then TiC acts as nucleates of NbC,