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Effect of carbonitride precipitates on the solid/liquid erosion behaviour of hardfacing alloy

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ABSTRACT

The present work reports the effect of carbonitride precipitates on the solid/liquid erosion behaviour of hardfacing alloy. Two kinds of Fe-Cr13-C hardfacing alloy (with and without nitrogen) were deposited on a carbon steel substrate. The microstructure of the hardfacing alloy was studied. Solid/liquid erosion tests were carried out with quartz sand particles under impact angles of 30°, impact velocity of 25 m/s for 45 min to explore the erosion behaviour of the hardfacing alloy. It is found that the erosion damages of hardfacing alloy were microcutting and impinging caused by the erosion of sand particles. Fine carbonitride precipitates can obviously refine the microstructure and make a dispersion strengthening effect on the matrix, leading to the enhancement of hardness of hardfacing alloy. In addition, lots of carbonitride precipitates can effectively protect the surface of hardfacing alloy against wearing of erosion sand particles. So the erosion resistance of hardfacing alloy could be improved significantly owing to the strengthening and protecting effect of carbonitride precipitates, and solid/liquid erosion mechanisms were found to be microcutting and impinging with shallow grooves, fine pits and tiny lips.

1. Introduction

A lot of mechanical equipment such as the dredges service in aggressive working environment for a long time can easily cause erosion damage and greatly shorten their service life [1–3]. Weld hardfacing technique is a kind of surface treatment to increase the wear life of erosion damaged parts, of which hardfacing alloy that has excellent resistance to wear is deposited onto the substrate [4]. Numerous hardfacing materials are available and they are being used in many applications. The martensitic stainless steel (Fe-Cr13-C) is a popular hardfacing material in weld hardfacing techniques because of the good properties of wear and corrosion resistances [5–7]. It is well known that a higher surface hardness is an essential condition for obtaining higher wear resistance in most kinds of hardfacing alloy. The hardness of the martensitic stainless steel increases with the increase of carbon content, but the welding crack resistance and the corrosion resistance decrease. Nitrogen is a gap-atom element like carbon and can improve many properties of stainless steel through combining with other alloy elements (Nb, V, and Ti) [8]. These properties include hardness, creep resistance, wear resistance and corrosion resistance. On the other hand, it has been reported that nitrogen may not adversely affect weldability during welding [9]. To further improve wear property and welding performance of martensitic stainless steel, the carbon content of steel decreases through nitrogen replacing parts of carbon, which can have a carbonitride hardened action on the matrix. Niobium, vanadium and titanium have been used as the most effective carbonitride alloying elements, which can cause much harder precipitation of carbonitride. These hard particles are regular form and distribute in the matrix, which can strengthen the bulk body and improve the wear property [10–12].

In view of the above, the present study is to compare the complex microstructures and solid/liquid erosion resistances of the new developed Fe-Cr13-C-N hardfacing alloy with that of the common commercial Fe-Cr13-C hardfacing alloy, and investigation is aimed at understanding the effect of carbonitride precipitates on the solid/liquid erosion behaviour of hardfacing alloy.

2. Experimental procedure

The submerged-arc hardfacing flux-cored wire was prepared using the flux-cored wire manufacturing equipment, and the wire was steel strip with diameter of 3.2 mm and consisted of alloying elements in iron powder. The hardfacing flux-cored wire was deposited on the substrate by the submerged-arc welding. The substrate used in this work was a 450 mm × 250 mm × 10 mm plate of low carbon steel. The welding flux used was agglomerated flux, and the alkalinity was 1.8–2.0. The welding conditions were as follows: welding voltage 30–35 V, welding current 400–450 A, wire extension 15–20 mm and welding speed 18–23 m/h. To ensure the

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Table 1
Chemical compositions of two hardfacing alloy (wt.%).

Hardfacing alloy	C	Si	Mn	P	S	Cr	Nb + V + Ti	N	Other
H1	0.10	0.40	1.51	0.009	0.007	13.5	1.2	0.12	–
H2	0.23	0.43	1.43	0.009	0.007	13.2			–

dryness of the agglomerated flux, it was baked in a furnace at 400 °C for 1 h. One common commercial Fe-Cr13-C hardfacing alloy of submerged-arc flux-cored wire has been made, and a new developed Fe-Cr13-C-N hardfacing alloy of submerged-arc flux-cored wire has also been designed through nitrogen replacing parts of carbon and adding nitrogen-fixed elements of Nb, V and Ti. The welds were deposited in six layers so that the undiluted hardfacing alloy could be got. Chemical compositions of the two hardfacing alloy (H1 and H2) were analysed, as shown in Table 1.

Rectangular shaped samples with dimension 20 mm × 10 mm × 5 mm were cut from the two hardfacing alloys at room temperature. And all of samples were heat treated at 550 °C for 1 h in an electric box furnace in order to precipitate carbonitrides. Microstructures of samples were observed by an optical microscope (OM) and a scanning electron microscope (SEM), after polishing and etching. The etching agent was composed of 4 ml hydrogen fluoride, 4 ml hydrogen nitrate, and 92 ml H_2O. And the carbonitride precipitate was determined using an energy dispersive spectroscopy (EDS). The macrohardness of the samples was measured with a Rockwell hardness machine. Five measurements were made on each sample, and an average of the five numbers was calculated and recorded.

The erosion test was carried out using a solid/liquid erosion testing machine. Fig. 1 shows the schematic representation of the test. Specimens were tested under solid/liquid conditions by mixing 5 wt.% quartz sand (size: 400–700 μm) and 95 wt.% water injected at the angle of 30°, and the erosion experiments were performed at a velocity of 25 m/s for 45 min. The erosion tests were performed on 20 mm × 15 mm face of the specimen. Three testing specimens were made from each sample and were tested separately. A microbalance with an accuracy of 0.1 mg was used to weigh each specimen before and after erosion, and an average of weight losses was calculated and recorded. The erosion rate was determined by the ratio of weight loss per unit of tested surface per unit of sliding time. And the pattern of worn samples was observed by SEM.

3. Results and discussion

Microstructural features of sample H1 and H2 are shown in Fig. 1. There are two main phases of lath martensite and precipitate in the hardfacing alloy. Fig. 1a exhibits lots of fine precipitates distributing homogeneously in the grain boundaries and martensite bulk, and Fig. 1b shows a network of precipitate phase only in the grain boundaries. Meanwhile, it is found that sample H1 has a finer grain with refinement martensite lath structure than sample H2. So the nitrogen and nitrogen-fixing elements (Nb, V and Ti) have an obvious effect on precipitation reactions of hardfacing alloy resulting in hindering the austenite grain growth, refining the martensite lath and dispersion strengthening.

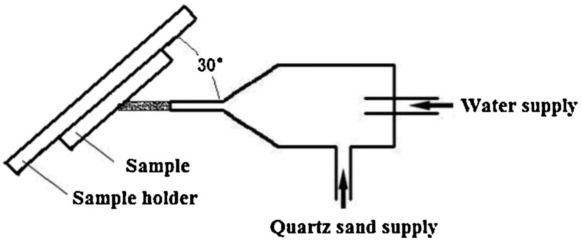

Fig. 1. Schematic diagram of erosion test.

The pattern and chemical composition of precipitated particles in the sample H1 are shown in Fig. 3. These particles are characteristic cubical or rod shape and the size is smaller than 3.5 μm, as shown in Fig. 3a. The EDS analysis shows the presence of nitrogen, carbon, niobium, vanadium and titanium peaks (Fig. 3b). So it is determined that these precipitate particles homogeneously distributed in the sample H1 are complex carbonitrides of Nb, V and Ti [13,14]. While in the sample H2, a continuous network of precipitates with coarse size was precipitated from grain boundaries (Fig. 2b). So carbonitride precipitates can prevent the formation of chromium-rich phase at grain boundaries and contribute to strengthening the matrix. Table 2 gives the hardness and erosion rate of the two samples. Compared with the sample H2, the sample H1 has about a 7 HRC increase in the hardness value and over 50% decease in the erosion rate. Therefore, the carbonitride precipitates play an important role in the microstructure, hardness and erosion property of hardfacing alloy.

The typical scanning electron morphology of the worn surface of the sample H1 and H2 is shown in Fig. 4. Both surfaces revealed grooves, craters and lips, which indicated the microcutting and impinging action of sand particles. In the solid/liquid erosion, the sand particles have great mobility in the fast transporting liquid at lower concentration (5 wt.%). Accordingly, motion of sand particles in transporting liquid results in rotation [15]. The abrasive wear is more likely to occur when these sand particles with high rotational speed flow to the surface of samples at the angle of 30°, and cuts a series of grooves on the surface of sample. And the material removal is caused by microcutting. When the sand particles have no or lower rotational speed, the erosion damage is due to deformation (craters and lips) caused by impinging. Deformation by impinging results in surficial fracture and subsequent removal of material [16].

Fig. 5 gives the higher SEM magnification observations of the worn surface. Grooves induced by sand particle wear produces a wavy surface at erosion. As shown in Fig. 6a, the worn surface of the sample H1 exhibits minimum depth of grooves; this is responsible for its minimum material removal. By comparison, the worn surface of the sample H2 seems maximum depth of grooves (Fig. 5b). In addition, some fine block desquamation can be seen in the sample H1 (Fig. 5a), indicating hard particles of carbonitride was detached from the already worn matrix. It is evident that the carbonitride particles have a protecting effect on the matrix to keep the sample from microcutting due to their finely dispersed distribution in the matrix [17]. The impinging damage caused by the sand particles resulting in indentation pits and extrusion lips on the worn surface is presented in Fig. 6. The extent, size and depth of indentation pits and the extent and size of extrusion lips on the sample H1

Table 2
Hardness and erosion rate of sample H1 and H2.

Sample	Hardness (HRC)	Erosion rate (gm m^{-2} s^{-1})
H1	42.8	0.78×10^{-7}
H2	35.5	2.07×10^{-7}