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# Effects of vanadium additive on structure property and tribological performance of high chromium cast iron hardfacing metal

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ABSTRACT

Hard and wear-resistance layer of high chromium cast iron (HCCI) with vanadium additive was prepared by surfacing technology. Using DSC the phase transition temperature curve of surfacing alloy layer was examined. The content of carbide in hardfacing layer was further determined through microstructure analysis. Meanwhile, iron–carbon equilibrium phase diagram of hardfacing layer was calculated. In addition, the wear-resistance of hardfacing layer was carried out. The results show that the carbide precipitated from hardfacing layer is the type of M7C3. Primary, eutectic and secondary carbides are approximately hexagonal structure, long rods and fine spherical, respectively. However, the secondary carbide VC is precipitated from the hardfacing layer when vanadium additive was added into flux cored wire. As the content of vanadium additive increases in the flux-cored wire, the size of primary carbide significantly reduces and the amount of eutectic and secondary carbides gradually increase. Therefore, the improvement of wear-resistance of surfacing layer was mainly due to the vanadium additive in flux-cored wire.

## 1. Introduction

High chromium cast iron exhibits (HCCI) excellent wear resistance at low-stress state when its microstructure contains M7C3-type carbides [1,2]. Therefore, HCCI has been widely used in machinery, metallurgy, mining and other fields. Carpenter and Carpenter [3] studied M7C3 carbide within a high chromium white iron by X-ray diffraction. Wu et al. [4] analyzed the effect of titanium on the morphology of primary M7C3 carbides in hypereutectic high chromium white iron. Wang et al. [5] discussed the precipitation and transformation of secondary carbides in a high chromium cast iron. Wiengmoon et al. [6] conducted the microstructural and crystallographical study of carbides in 30 wt.% Cr cast irons. Failed workpieces can be repaired by surfacing technology to restore their shape, size and performance to a certain extent [7–9]. Chatterjee and Pal [10] studied the wear behavior of hardfacing deposits on cast iron Sapate and Rama Rao [11] analyzed the effect of carbide volume fraction on erosive wear behavior of hardfacing cast irons. Hao et al. [12] discussed effect of rare earth oxides on the morphology of carbides in hardfacing metal of high chromium cast iron. However, the bulk M7C3-type primary carbides in the hardfacing layer were usually concentrated together during hardfacing process [13], which leads to the relative decrease of wear-resistance of the hardfacing alloy layer [14,15]. Compared with that of original workpiece, the service life of HCCI with hardfacing layer is reduced.

Recent literatures have reported that the carbides can be refined by adding vanadium element into cast iron or cast steel [16,17]. Shizhong et al. [18] researched the effects of vanadium and carbon on microstructures and abrasive wear resistance of high speed steel. Tokaji et al. [19] research the fatigue behavior of cast irons with spheroidal anadium carbides dispersed within martensitic matrix microstructure. Xu et al. [20] optimized the chemical composition of high speed steel with high vanadium content for abrasive wear using an artificial neural network. To solve the above problems, as described in this paper a new type of self-shielded flux-cored wire was used in welding HCCI in this paper. The effect of vanadium additive on the carbide and wear resistance of the hardfacing layer was analyzed in details.

**Table 1**
Composition of the flux-cored wire.

| Alloy | Ferrochromium | Ferromanganese | Ferrosilicon | Aluminum powder | Graphite |
|---|---|---|---|---|---|
| Content (wt.%) | 65–85 | 3–5 | 4–6 | 2–4 | 10–15 |

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**Table 2**
Chemical compositions of steel Q235.

| Element | C | Si | Mn | P | S |
|---|---|---|---|---|---|
| Content (wt. %) | 0.18 | 0.15 | 0.45 | 0.02 | 0.02 |

**Table 4**
Composition of high chromium cast iron hardfacing metal.

| Element | C | Cr | Mn | Si | Al | O | S | P |
|---|---|---|---|---|---|---|---|---|
| Content (wt.%) | 3.5 | 23 | 1.2 | 0.5 | 0.04 | 0.0015 | 0.013 | 0.021 |

## 2. Experimental materials and methods

### 2.1. Experimental materials

In the present work, some alloying elements such as carbon, chromium, manganese and silicon were added into the flux-cored wire. When C content (wt%) is 3.5–4.0% and the Cr content (wt.%) is 25–30%, M7C3-type carbide can be precipitated from the hardfacing layer on the surface of HCCI. Various alloying elements added into flux-cored wire are shown in Table 1. In order to investigate the effect of vanadium additive on microstructure and wear-resistance of the hardfacing layer, the mass fraction of ferrovanadium added into flux-core wire is 0 wt.%, 1.5 wt.%, 2 wt.%, and 3 wt.%, respectively. The purpose of adding aluminum powder in the wire was deoxidization.

### 2.2. Experimental details

The matrix material was selected as Q235 steel, the composition of which is shown in Table 2. The manual arc hardfacing method was applied and three layers were welded on each specimen. The interpass temperature was 450 °C and no oscillation was applied. Welding process parameters are shown in Table 3.

The microstructure of the hardfacing metal was observed by using the optical microscope of type XJG-05. The carbides were determined by X-ray diffraction (XRD) of type D/max-2500/PC, whose parameters are listed in Table 4. The contents of Cr and V elements were measured by fluorescence analysis apparatus of type EDX3000D.

The microhardness of the hardfacing metal was measured by the sclerometer of type XHY11-7000 (accuracy: ± HV2). The load used in the microhardness measurement of primary carbides was 300 N and six readings were taken.

The wear-resistance of the hardfacing metal was performed by the belt sander of type BSH-150C, whose schematic diagram is shown in Fig. 1. Six replicate wear tests of the hardfacing metals for each composition were carried out so as to minimize data scattering and enhance the accuracy of data, and the average of the six replicate test results are reported in this work.

The phase transformation temperature curve of the hardfacing metal was determined by the differential scanning calorimetry (DSC: accuracy: ± 1 °C) of type STA449C and Fe–C equilibrium phase diagram with different content of vanadium additive was calculated by using Thermo-Calc software. The version and database used in this work are Thermo Calc version P and the databases TCFE2.

## 3. Experimental results

### 3.1. Carbides of the hardfacing metal

#### 3.1.1. Process of carbide precipitating in hardfacing metal

The phase transformation temperature curve during cooling process of the hardfacing metal is shown in Fig. 2. The temperature of the specimen was recorded from 1400 °C. The first exothermic peak appeared when the specimen is cooled to 1327.2 °C, which is caused by the primary carbides precipitated from the liquid phase. At the temperature of 1183.5 °C, the second exothermic peak of the specimen appeared, which is caused by the eutectic reaction, and the eutectic austenite and carbides are formed. When the specimen is cooled to 755.7 °C, the third exothermic peak appeared, which is caused as the transformation temperature from gamma to alpha.

#### 3.1.2. Carbide morphology of the hardfacing metal

The microstructures of hardfacing metal on the welded surface of Q235 steel and cross-section of the specimen are shown in Fig. 3. The primary carbide of the hardfacing metal on welded surface is approximately bulk hexagonal, which is shown in A zone of Fig. 3 (a). The eutectic carbide is mainly distributed with long rod, which is shown in B zone of Fig. 3 (a). The secondary carbide is fine spherical around primary ones, which are shown in C zone of Fig. 3 (a). The primary carbide on the cross-section is column and grown vertically to the welded surface, which are shown in Fig. 3 (b). The average microhardness of the primary carbides on the welded surface is 1784 HV, and that on the cross-section is 1128 HV respectively. However, the average micro-hardness of eutectic carbides on the welded surface is 1452 HV, and that on the cross-section is 860 HV, respectively. Why is there a difference in microhardness of primary and eutectic carbides? The primary carbides of the hardfacing metal on welded surface are approximately bulk hexagonal, while those on the cross-section are column. Both on the welded surface and cross-section, the eutectic carbides are mainly distributed with long rod shape, and the secondary carbides are fine spherical around the primary ones.

#### 3.1.3. Carbides type of the hardfacing metal

The X-ray diffraction spectrum of the hardfacing metal is shown in Fig. 4. The microstructure of hardfacing metal is composed of martensite, retained austenite and M7C3-type carbide.

### 3.2. Effect of vanadium additive on carbide of the hardfacing metal

#### 3.2.1. Effect of vanadium additive on carbide morphology

The microstructures of the hardfacing metal with 0 wt.%, 1.5 wt.%, 2 wt.% and 3 wt.% vanadium additives, respectively, are shown in Fig. 5, respectively. Bulk primary carbide of M7C3-type is precipitated from the hardfacing metal with free vanadium additive, which is shown in Fig. 5 (a). With the increase of vanadium additive, the microstructure of the hardfacing metal is refined obviously and the dimension of the carbide is reduced gradually. However, the amount of the eutectic carbide is increased, which are shown in Fig. 5 (b), (c) and (d) respectively.

#### 3.2.2. Effect of vanadium additive on carbide type

The XRD with 3 wt.% vanadium additive in the flux-cored wire is shown in Fig. 6. The phase structures of the hardfacing metal are

**Table 3**
Paramaters of XRD by D/max-2500/PC.

| Maximum power | Stability | Focal spot size | Goniometer | | | |
|---|---|---|---|---|---|---|
| | | | Angle of radius | Minimum stepping | Setting repeatability | Slit |
| 60 kv × 300 mA | ± 0.01% | 0.5 × 1 mm | − 60 to + 145° | 1/1000° | 1/1000° | 0.01-1.7 mm |