Materials Science and Engineering A 527 (2010) 6800–6808

Contents lists available at ScienceDirect

Materials Science and Engineering A

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

Effect of chromium concentration on microstructure and properties of Fe–3.5B alloy

Shengqiang Ma[a,*], Jiandong Xing[a,*], Guofeng Liu[a], Dawei Yi[a], Hanguang Fu[b], Jianjun Zhang[a], Yefei Li[a]

[a] State Key Laboratory for Material Behavior of Materials, School of Materials Science and Engineering, Xi'an Jiaotong University, 28 Xianning West Road, Xi'an, Shaanxi Province 710049, PR China

[b] Research Institute of Advanced Materials Processing Technology, School of Materials Science and Engineering, Beijing University of Technology, Beijing 1000124, PR China

ARTICLE INFO

Article history:
Received 9 January 2010
Received in revised form 6 May 2010
Accepted 26 July 2010

Keywords:
Fe–B alloy
$(Fe,Cr)_2B$ boride
Fracture toughness
Solid solution

ABSTRACT

The cast low carbon Fe–3.5B alloys containing various chromium concentrations were prepared in a 10 kg medium frequency induction furnace and the effects of chromium concentration on microstructure and properties of Fe–3.5B alloys have been examined by means of optical microscope (OM), scanning electron microscope (SEM), back-scattered electron microscope (BSE), electron probe microanalyzer (EPMA), energy dispersive spectrum (EDS), X-ray diffraction (XRD), transmission electron microscopy (TEM) and Vickers hardness. As a result, the as-cast structures of Fe–3.5B–*X*Cr (*X* = 0, 2, 5, 8, 12, 18, mass fraction) alloys are mainly composed of dendrite ferrite, martensite, pearlite and boride. The boride in the alloy without chromium addition comprises the eutectic Fe_2B, which is continuous netlike or fish-bone structure distributed over the metallic matrix. With the increase of chromium concentration in Fe–3.5B alloy, matrix structure turns into the supersaturated α-Fe solid solution while the morphology of boride becomes dispersed due to the transformation of boride from simple Fe_2B to $(Fe,Cr)_2B$ when the chromium concentration in Fe–3.5B alloy exceeds 8 wt.%. Meanwhile, some primary M_2B-type borides may precipitate under this condition. The bulk hardness of the as-cast alloy ranges from 41.8 to 46.8 HRC. However, the bulk hardness of the heat treated alloy rises first and falls later mainly because of the morphology variation of structure. Fracture toughness of boride is improved gradually owing to the entrance of chromium into Fe_2B, which may be attributed to the change of spatial structure of boride.

1. Introduction

Considerable amount of economic loss is brought because of abrasion and corrosion in mechanical parts of machinery and equipment. Therefore, in order to reduce this loss, the research on superior wear-resistant and corrosion-resistant materials has been allotted a high priority in the field of material science recently [1–3]. It is of very important significance to develop excellent wear- and corrosion-resistant materials so as to meet the rigorous environment requirements. The invention of high chromium white cast iron was considered a breakthrough because of its increased toughness compared with plain white cast iron and Ni-hard white cast iron, which is attributed to the improvement of carbide morphology [4,5]. However, the high chromium white cast iron is still a kind of brittle material that cannot meet the requirement of demanding working conditions. Hence, constant research activities are being carried out to produce advanced materials, which are much better than existing wear-resistant materials [6,7].

Recently, much attention has been paid to high boron white cast iron owing to the unique characteristics of boron in steel [8–10]. Investigations have discovered that hardenability, toughness and wear resistance can be improved by adding boron as an alloying element. Since the borides exist in the high boron white cast iron, the study on high boron white cast iron has been widely emphasized by researchers [11–13]. Boride has a higher hardness than carbide when combined with the same element, which gives us the idea to replace the carbides in white cast iron with borides [14]. In addition, carbon is almost undissolved in boride, thus the properties of matrix can be adjusted by carbon content. This should in turn result in improving ductility and fracture toughness, while maintaining the inherently excellent wear resistance. The significance of this approach is that the matrix and hard phases can be adjusted independently by varying carbon and boron contents [4,15,16]. However, there exist many interconnect net-like borides in solidification structure of high boron white cast iron, which damages the continuity of matrix, reduces the toughness and results in fracture in impact environment. Thus, the application of high boron cast alloy is restricted to some extent.

* Corresponding authors. Tel.: +86 29 82665636; fax: +86 29 82665479.
E-mail addresses: shengqiang012@163.com (S. Ma), jdxing@mail.xjtu.edu.cn (J. Xing).

0921-5093/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.msea.2010.07.066

Heat treatment and hot deformation are the most common methods used to improve the toughness of cast alloys [17–20]. Nevertheless, heat treatment has little effect on morphology of boride because of lower boron solubility in high boron white cast iron. And hot deformation not only increases the production process and energy consumption, but also is only suitable for the simple-shaped work pieces. Guo and Wang [21,22] reported the solubility and diffusion of boron in Fe–Cr–B alloy. Unfortunately, there is little research about the influence of chromium concentration on the microstructure and properties of Fe–B alloy. The objective of present work aims to study the microstructures and properties of borides in Fe–3.5B alloys with different amount of chromium. As a result, the morphology and microstructure of the boride are improved and the fracture toughness is increased accordingly.

2. Experimental procedure

2.1. Preparation for Fe–3.5B cast alloy

The investigated alloys in present work are hypoeutectic high boron white cast iron. The alloys were prepared in a 10 kg medium frequency induction furnace. Initial charge materials were clean low silicon pig iron and steel scrap. Ferro-alloys such as Fe–63 wt.% Cr and Fe–16.28 wt.% B were added to a slag-free molten alloy so as to minimize the oxidation loss and slag formation. When all the alloys were melted in the furnace, 0.10 wt.% pure aluminum was added into the molten alloy to deoxidize at the temperature of 1520–1540 °C. The melt was subsequently super-heated to 1560 °C and transferred into a pre-heated teapot ladle. After removal of any dross and slag, the melt was poured at 1430 °C into the sodium silicate–CO_2 bonded sand moulds, obtaining Y-block ingots following ASTM A781/A 781-M95. The test specimens were cut from the lower part of the Y-block and surface ground to remove 3 mm from the surface and eliminate any oxidized layer. Some of the as-cast specimens were treated at 980 °C for 1 h, quenched in water and then tempered at 200 °C, followed by air cooling. The chemical compositions of Fe–3.5B alloys are listed in Table 1.

2.2. Microstructure examination

The microanalysis of the specimens was carried out using a scanning electron microscope (SEM), a back-scattered electron image (BSE), an X-ray diffraction (XRD), an electron probe microanalysis (EPMA), a transmission electron microscopy (TEM) and an energy dispersive spectrum (EDS) to identify microstructures. For metallographic observations, all specimens were etched in a 4 vol.% nital solution. XRD was performed on a MXP21VAHF diffractometer with Copper Kα radiation coupling continuous scanning at 40 kV and 200 mA as an X-ray source. The specimen was scanned in the 2θ ranging from 20° to 100° with scanning speed of 2°/min and step space of 0.02°.

Table 1
Chemical compositions of Fe–3.5B alloys.

Elements (wt.%)	B	C	Si	Cr	Balance
Specimen C0	3.5	0.22–0.29	0.6–0.8	0	Fe
Specimen C1	3.5	0.22–0.29	0.6–0.8	2.0	Fe
Specimen C2	3.5	0.22–0.29	0.6–0.8	5.0	Fe
Specimen C3	3.5	0.22–0.29	0.6–0.8	8.0	Fe
Specimen C4	3.5	0.22–0.29	0.6–0.8	12.0	Fe
Specimen C5	3.5	0.22–0.29	0.6–0.8	18.0	Fe

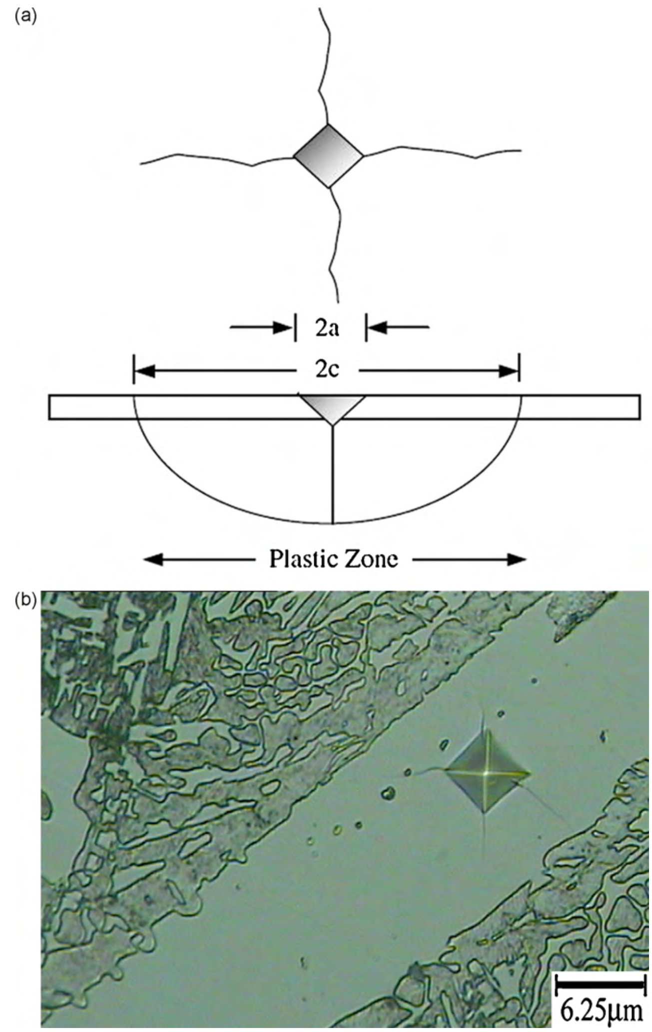

Fig. 1. (a) Schematic representation of a Vickers indent in boride and (b) optical micrograph of boride in Fe–3.5B alloy.

2.3. Vickers microindentation fracture toughness test

The bulk hardness was measured on an HR-150A Rockwell-hardness tester. The microhardness of boride in Fe–3.5B alloy was also measured by using an HXD-type 1000 Vickers-hardness tester with a load of 100 gf, according the ASTM E384 standard. The indentation cracking method proposed by Palmqvist in 1957 [23] was utilized and the equation used for calculating fracture toughness was as follows [24–29]:

$$K_{IC} = X \cdot \frac{P}{c^{3/2}} \quad (1)$$

where X is the residual indentation coefficient, which depends on hardness to modulus ratio (H/E) of the boride. The constant X is 0.064 $(E/H)^{1/2}$, where E and H are the Young's modulus and microhardness, respectively. P is the applied load and the value of E is approximately 290 GPa [24–30] for fracture toughness calculation, and c is the indentation radial cracking length as shown in Fig. 1.

3. Results

3.1. Solidification microstructure of Fe–3.5B alloys with various chromium concentrations

The as-cast solidification microstructures of Fe–3.5B alloys containing various chromium concentrations are shown in Fig. 2.