EFFECT OF RARE EARTH ELEMENT ON MICROSTRUCTURE OF FE-B CAST ALLOY

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Abstract

The microstructure of Fe-B alloys containing different boron and neodymium concentrations were investigated. The solidification microstructures of Fe-B cast alloy consist boride, pearlite and ferrite. Borides grow up along the grain boundary of austenite during the formation of eutectic. The results showed that the addition of neodymium caused a reduction of cell size and decreased the thickness of borides. However, neodymium addition at higher content (> 0.5 wt. %) in batch leads to no further reduction of cell size

Key words:
High boron cast iron, neodymium, microstructure, thickness of borides

1. INTRODUCTION

Current white cast irons exhibit excellent wear property, have low fracture toughness and are only used in those applications where a limited amount of impact occurs [1, 2]. The invention of high chromium white cast iron was considered a breakthrough, as its toughness was increased compared with white cast iron, which attributed to the improvement of carbide morphology. The matrix of high Cr white cast irons can be transformed into martensite by heat treatment; and the carbides are embedded in the martensitic matrix, hence, high Cr white cast iron has the appropriate toughness and excellent abrasion resistance [3, 4].

Fe–B alloy has high hardness and excellent wear resistance. Its impact toughness and fracture toughness are higher than those of white cast iron. The application of Fe–B alloy in high impact work condition is useful for the reduction of material consumption due to its high abrasion resistance and toughness. However, there exists an interconnected network of boride, which is not favourable to the improvement of the strength and toughness of Fe–B cast alloy. Gou [5] found that solubility of boron in iron can be changed with the addition of other elements such as Cr, Mo and V. Also Ma [6] found that the addition of Cr changed significantly the toughness of boride particles (Fe, Cr)2B in the system as well as mechanical properties of the matrix [7]. The significant effect of chromium in abrasive resistance and higher toughness contributes to wear resistance [8].

Generally, studies [9, 10, 11, 12] have shown that heat treatment of Fe-B alloys has 1 wt. % of boron. If the heat treatment is applied, the matrix of high boron cast steel transforms according to Fe-C system. But short time of heat treatment does not affect the shape of borides. A long time destabilization heat treatment has to be applied to change the morphology of borides and to influence secondary precipitation mechanism in matrix [13]. Also, forging leads to a change in the morphology of borides [14]. Addition of suitable amount of titanium and cerium rare earth changes the morphology and distribution of the eutectic borides in low carbon Fe–B cast steel increasing the overall mechanical properties [15].

This study aims to obtain a low carbon Fe-B cast steel that possesses granular boride structure through the addition of neodymium. In this study are discussed low carbon Fe-B cast steel with a different amount of neodymium.
2. EXPERIMENTAL PROCEDURE

The alloys used for this investigation were melted in a vacuum medium-frequency induction furnace of capacity 100 g. The alloys were poured at 1,650 °C into graphite mold (Fig. 1a) which was preheated up to 300 °C. The baths of metal were composed of steel wire (30 grams), ferroboron (0.8 and 1.6 grams) and Nd₂Fe₁₄B (0.1, 0.2, 0.4, 0.8, 1.6 grams of Nd). The chemical compositions of the alloys are shown in Table 1. Ingots were cut as shown in Fig. 1b. These samples were cast in metallographic resin, grinded by diamond disk and polished by OPS suspension. The samples were etched by Klemm I solution (supersaturate liquid solution of Na₂S₃O₃ in water + K₂S₂O₅) and optical metallography were used for observation.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Nd</th>
<th>Fe + C + B</th>
<th>Cell (μm²)</th>
<th>SD (μm²)</th>
<th>T (μm)</th>
<th>SD (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;0.3</td>
<td>&lt;0.4</td>
<td>1.1</td>
<td>-</td>
<td>Rest.</td>
<td>274</td>
<td>31</td>
<td>1.52</td>
<td>0.46</td>
</tr>
<tr>
<td>2</td>
<td>&lt;0.3</td>
<td>&lt;0.4</td>
<td>1.15</td>
<td>0.11</td>
<td>Rest.</td>
<td>257</td>
<td>29</td>
<td>1.09</td>
<td>0.31</td>
</tr>
<tr>
<td>3</td>
<td>&lt;0.3</td>
<td>&lt;0.4</td>
<td>1.1</td>
<td>0.32</td>
<td>Rest.</td>
<td>203</td>
<td>24</td>
<td>0.85</td>
<td>0.17</td>
</tr>
<tr>
<td>4</td>
<td>&lt;0.3</td>
<td>&lt;0.4</td>
<td>1.05</td>
<td>0.45</td>
<td>Rest.</td>
<td>168</td>
<td>9</td>
<td>0.67</td>
<td>0.13</td>
</tr>
<tr>
<td>5</td>
<td>&lt;0.3</td>
<td>&lt;0.4</td>
<td>1</td>
<td>0.65</td>
<td>Rest.</td>
<td>146</td>
<td>10</td>
<td>0.57</td>
<td>0.19</td>
</tr>
<tr>
<td>6</td>
<td>&lt;0.3</td>
<td>&lt;0.4</td>
<td>1.05</td>
<td>1.5</td>
<td>Rest.</td>
<td>148</td>
<td>11</td>
<td>0.55</td>
<td>0.12</td>
</tr>
<tr>
<td>7</td>
<td>&lt;0.3</td>
<td>&lt;0.4</td>
<td>1.15</td>
<td>-</td>
<td>Rest.</td>
<td>236</td>
<td>17</td>
<td>1.95</td>
<td>0.88</td>
</tr>
<tr>
<td>8</td>
<td>&lt;0.3</td>
<td>&lt;0.4</td>
<td>1.1</td>
<td>0.07</td>
<td>Rest.</td>
<td>193</td>
<td>21</td>
<td>1.94</td>
<td>0.57</td>
</tr>
<tr>
<td>9</td>
<td>&lt;0.3</td>
<td>&lt;0.4</td>
<td>1</td>
<td>0.3</td>
<td>Rest.</td>
<td>166</td>
<td>6</td>
<td>1.71</td>
<td>0.69</td>
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<tr>
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<td>&lt;0.3</td>
<td>&lt;0.4</td>
<td>1.05</td>
<td>0.38</td>
<td>Rest.</td>
<td>127</td>
<td>9</td>
<td>1.44</td>
<td>0.61</td>
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<td>11</td>
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<td>&lt;0.4</td>
<td>1</td>
<td>0.74</td>
<td>Rest.</td>
<td>88</td>
<td>9</td>
<td>1.16</td>
<td>0.53</td>
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<tr>
<td>12</td>
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<td>&lt;0.4</td>
<td>1.1</td>
<td>1.63</td>
<td>Rest.</td>
<td>81</td>
<td>11</td>
<td>1.32</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Fig. 1 Schema of graphite casting mold (a) and metallographic specimen (b)
Evaluation of microstructure was determined from thirty pictures of each sample according to procedures as shown in Fig. 1b (with 500 times magnification). Positions of picture were from core of ingot to their surface presented by black arrows in Fig. 1b, first picture was created 1 mm from the core cast and last picture was created maximal 2 mm under surface. The thickness of boride was measured using picture analysis software (QuickPhoto Industrial 2.3) as shown in Fig. 2c. Each image was determined number of cells and mean area $A$ of cells was calculated by equation (1).

$$A = \frac{1}{n} \times \sum_{i=1}^{n} \frac{N_i}{A_{image} \times R_i},$$

where $N_i$ is number of cells, $A_{image}$ is total area of image, $n$ is number of images and $R_i$ is volume of cells.

A general linear method was used for statistical evaluation.

RESULTS

The as-cast macrostructures of high boron cast iron and microstructures are shown in Fig. 1b and Fig. 2a and Fig. 2b. It can be seen from Fig. 2 that the high boron cast iron comprises a borides continuous network. The matrix is made up of martensite and a small amount of ferrite and the ferrite is mainly distributed in the boundary of cells. It can be see that peritectic reaction leads to increasing carbon content in borides which explains the reason why there is no effect of martensite around borides.

Between both groups of samples with different content of boron have significant differences of mean area $A$ and differences thickness of borides presented in Fig 3. It was found that increasing cell size grows...
thickness of borides. Neodymium was used as an addition element for changes number of nuclei in liquid state. The results show that neodymium has significant effect on number of nuclei as a result of cell size reduction. But a higher content than 0.5 wt. % in batch leads to no further reduction of cell size. The effect is seen in Fig. 4 and Fig. 5. In Fig. 4 is presented dependency between thicknesses of borides and weight of neodymium content for both groups of samples. Dependency between cell area (µm²) and content of boron and neodymium (to 0.6 wt. %) in batch is described by equation (2), $R^2=0.96$, $F=67$, $p<0.001$.

$$\text{cell area} = 317 - 112 \times \text{wt.} \% \text{B} - 270 \times \text{wt.} \% \text{Nd}$$

In Fig. 5 is presented dependency between cell size and weight of neodymium content for both groups of samples. It is seen that effect of neodymium independent on boron content and reduction of cell size is similar for both of groups of samples with different boron content. The same tendency can be objective for mean thickness of borides. Dependency between thickness of borides and content of boron and neodymium (to 0.6 wt. %) in batch is described by equation (3), $R^2=0.95$, $F=48$, $p<0.001$.

$$\text{Thickness of borides} = 0.606 + 1.81 \times \text{wt.} \% \text{B} - 1.69 \times \text{wt.} \% \text{Nd}$$

The results are important for the development of wear resistance of high boron cast iron. These alloys can be forged and heat treated [14] and lower thickness of borides is useful for better forging. Lower cell size leads to alloys with higher wear resistance because of homogeneity of hard phases in the metal matrix and size of the hard phase according to Badisch’s [16] and Polak’s [17] results showed significant influence on wear resistance of alloys.

Based on the results obtained, it can be prepared samples for analysis of abrasive wear resistance. These samples can be expected at different microstructure of metal matrix.

![Fig. 3 Relationship between thickness of borides and cell area](image-url)
CONCLUSION

The present work investigated the effect of neodymium on the microstructure of the high boron cast steel. The main conclusions include the following: Thickness of borides in alloys was reduced by neodymium in batch.
Optimal content of neodymium in the batch was 0.5 wt.% and at higher content there was no reduction of cell size and thickness of borides.

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REFERENCES


