Effect of B element on Fe-10Cr-B alloy

Jing Gao¹, a, Yingfan Zhao¹, b, Weiping Tong¹, c, Chu Chen², d, Lin Zhu², e
¹Key Laboratory of Electromagnetic Processing of Materials, Northeastern University, Shenyang, 110819, China
²TianJin Heavy Industries Research ZDevelopment CO., LTD. No.16, Luo Da Street, TEDA, Tianjin
¹email: 467014557@qq.com, bemail: 2166898454@qq.com, demail: chenchu1986@163.com, eemail: zl508@126.com
*Corresponding author: cemail: wptong@mail.neu.edu.cn

Abstract: In this paper, Fe-10Cr-B alloys with different B content were prepared by the method of liquid phase sintering. Optical microscope (OM), scanning electron microscope (SEM), X-ray diffraction (XRD), Rockwell hardness tester were used to investigate the influence of B element on the structure, phases and macro-hardness of the Fe-10Cr-B alloys. The results show that the hardness of alloys with different B content gradually increases with the increase of B content in the alloy. When the B content is 2.5 wt.%, the hardness of the alloy reaches the maximum value of 61.8 HRC. A further increase in the B content will lead to a decrease in the macroscopic hardness of the alloy sample. The alloy with B content of 2.5wt.% is mainly composed of metal matrix and M₂₃(C, B), boron-carbides. The Cr and B elements are mainly enriched in boron-carbides.

1. Introduction:
As a kind of wear-resistant alloy, Fe-Cr-B alloy has been widely researched in recent years due to its good comprehensive mechanical properties [1-4]. Scholars [5] have found that the atomic radius of Cr element is larger than that of Fe element, so the addition of Cr element can increase the solid solubility of B. The addition of B can significantly improve the hardenability of steel [6]. This is because during the nucleation process, B atoms hinder the diffusion of grain boundary atoms on the grain boundary, thereby slowing down the formation of ferrite on the grain boundary, and then significantly improving the hardenability of steel [7]. The addition of B element can form borides in the alloy, and the hardness and elastic modulus of borides are higher than carbides. B element is rich in resources and low in price. The use of B element can reduce production costs [8]. Generally speaking, the higher the hardness of the alloy, the better the wear resistance it should be. The content of B element directly affects the hardness and wear resistance of the alloy.

In this paper, Fe-10Cr-B alloys with different B content were prepared by the method of liquid phase sintering. A Rockwell hardness tester was used to measure the macroscopic hardness of each alloy, and the alloy with the best hardness was selected to analyze the structure and phase of the alloy using an optical microscope (OM), a scanning electron microscope (SEM), and an X-ray diffraction (XRD). At the same time, the preparation method has simple process and low cost, and the content of each element component can be accurately controlled.
2. Materials and Methods

In this study, high-carbon ferrochrome powder, boron-iron powder, manganese powder, and iron powder were used to prepare Fe-10Cr-B with the content of 1wt.%, 1.5wt.%, 2wt.%, 2.5wt.% and 3wt.%. The sample code of each alloy is shown in Table 1.

| Alloy | C     | Mn | Cr | B    | Si   | Fe    |
|-------|-------|----|----|------|------|-------|
| 1B    | 1.2725| 2  | 10 | 1.0  | 0.2075| Balance|
| 1.5B  | 1.2726| 2  | 10 | 1.5  | 0.3075| Balance|
| 2B    | 1.2728| 2  | 10 | 2.0  | 0.4075| Balance|
| 2.5B  | 1.2728| 2  | 10 | 2.5  | 0.5075| Balance|
| 3B    | 1.2731| 2  | 10 | 3.0  | 0.6075| Balance|

According to the ratio, the weighed powder was loaded into the powder mixer and mixed evenly. Then the mixed powder was put into a cylindrical corundum crucible with the size of 50×50 mm. Then put the corundum crucible into the BLMT-1600 argon gas protection furnace for sintering. The heating rate used in this experiment is 9°C/min. The sintering process is: heat preservation at 850°C for 30 min, then heat up to 1300°C, hold for 30 min, continue to heat up to 1380°C, hold for 30 min, and finally cool down in the furnace. The samples were cut into 10×10×10 mm cubes from the centre of the samples by wire cutting. Each sample was ground with sandpaper and mechanically polished, and the macro-hardness of each alloy was measured with a Rockwell hardness tester, and each sample was scored at 5 points to get the average value. The alloy with the best hardness was selected to be further analyzed: X-ray diffraction analysis, optical microscope, and scanning electron microscope observation.

3. Results & Discussion

The hardness of alloys with different B content is shown in Figure 2. The Rockwell hardness of Fe-10Cr-B alloys with B content of 1wt.%, 1.5wt.%, 2wt.%, 2.5wt.% and 3wt.% are 57.3, 58.9, 61, 61.8 and 60.1 HRC, respectively. From the measured macroscopic hardness data, it can be seen that with the increase of the B content in the alloy, the hardness gradually increases. When the B content is 2.5wt.% , the hardness of the alloy reaches the maximum value of 61.8HRC. A further increase in the B content will lead to a decrease in the macroscopic hardness of the alloy sample. It shows that the macro hardness of 2.5B sample is the maximum value in this range. Therefore, the 2.5B sample was selected for further organization and phase analysis.

The OM photo of the 2.5B sample is shown in Figure 2(a), and the SEM photo of the 2.5B sample is shown in Figure 2(b). It can be seen from Figure 2 that the microstructure of this alloy is mainly composed of two phases. Using EDS of SEM for component analysis, the components of point A and point B in Figure 2(b) are shown in Table 2. On the low-magnification OM photo, as shown in Figure 2(a), boron-carbides are distributed in a chrysanthemum shape. Microscopically, on a high-magnification SEM photo, as shown in Figure 2(b), $M_{23} (C, B)_6$ boron-carbides are distributed in a "road-like" shape, and the width of the "road" ranges from 4 to 15 μm. In addition, the XRD analysis results of the 2.5B sample are shown in Figure 3, further verifying the phase composition of the alloy. Perform EDS energy spectrum analysis on the A and B area in Figure 2(b). The analysis results are shown in Table 3. Combining the data in Figure 2, Table 2 and Figure 3, it can be seen that the boron-carbides in the OM and SEM of the 2.5B sample in Figure 2 are mainly $M_{23} (C, B)_6$ boron-carbides. The structure of 2.5B sample is mainly composed of $M_{23} (C, B)_6$ boron-carbides (point A) and metal matrix (point B). $M_{23} (C, B)_6$ boron-carbides are evenly distributed in the 2.5B alloy matrix, and the boron-carbides occupy a larger volume fraction. The production of $M_{23} (C, B)_6$ boron-carbides increase the macroscopic hardness of the alloy. The metal matrix is mainly $\alpha$ (Fe, Cr, Mn).
Fig.1 Hardness of each alloy

![Graph showing hardness vs. B content](image)

Fig.2 OM and SEM of the 2.5B alloy: (a)OM; (b)SEM

![OM and SEM images](image)

Table 2 EDS analysis of 2.5B sample

| Element | A         | B         |
|---------|-----------|-----------|
|         | wt.%      | at.%      | wt.%      | at.%      |
| Fe      | 77.29     | 59.29     | 90.11     | 79.69     |
| Mn      | 1.84      | 1.43      | 1.53      | 1.37      |
| Cr      | 13.35     | 11        | 4.78      | 4.54      |
| Si      | 0         | 0         | 0.25      | 0.44      |
| C       | 3.91      | 13.93     | 2.82      | 11.59     |
| B       | 3.62      | 14.35     | 0.52      | 2.37      |
| Total   | 100.00    | 100.00    | 100.00    | 100.00    |

It can be seen from Table 3 that Cr element and B element are mainly enriched in M_{23} (C, B)_{6} boron-carbides. Boron-carbides have a high B content, which in turn has good hardness and wear resistance. M_{23} (C, B)_{6} boron-carbides have a higher microhardness, about 2400HV [8]. M_{23} (C, B)_{6} boron-carbides can be directly precipitated in the alloy matrix during the solidification process. Mn and Cr are dissolved in the Fe matrix to form a solid solution. The uniform distribution of the matrix between the boron-carbides provides good toughness for the alloy as a whole.
4. Conclusions
1. The hardness of alloys with different B content gradually increases with the increase of B content in the alloy. When the B content is 2.5wt.%, the hardness of the alloy sample reaches the maximum value of 61.8HRC. A further increase in the B content will lead to a decrease in the macroscopic hardness of the alloy sample.
2. The alloy with B content of 2.5wt.% is mainly composed of metal matrix α (Fe, Cr, Mn) and M23(C, B)6 boron-carbides.
3. The Cr and B elements are mainly enriched in boron-carbides.

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