The Effect of Ni Addition on the Microstructure and Glass Forming Ability of Fe-Mo-P-C-B Bulk Amorphous Alloy

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1. Introduction

Fe-based bulk metallic glasses (BMGs) are of special interest among metal-based BMGs due to their excellent mechanical and physical properties such as high yield strength, good soft magnetic properties, high thermal stability, and good corrosion resistance and, at the same time, abundant natural resources and low material cost. However, all these materials are extremely brittle in tension, have poor toughness and are brittle or quasi-brittle in compression. These can undermine their use for potential engineering applications. It is thus desirable to improve the glass forming ability (GFA) of Fe-based amorphous alloys and to fabricate large size bulk amorphous alloys.

In this study, with the aim of understanding the effects of Ni addition on the glass forming ability and structural of Fe-Mo-P-C-B BMGs, we added Ni by replacement of Fe into a $Fe_{77}Mo_5P_9C_{7.5}B_{1.5}$ BMG, and the thermal stability, GFA, and hardness of $(Fe_{1-x}Ni_x)_{77}Mo_5P_9C_{7.5}B_{1.5}$ (x=0.05, 0.1, 0.15) glassy alloy series were systematically investigated.

2. Materials and Method

Multi-component master alloys with nominal compositions of $(Fe_{1-x}Ni_x)_{77}Mo_5P_9C_{7.5}B_{1.5}$, with x = 0.05, 0.1 and 0.15, were prepared by induction melting in a quartz crucible under purified argon atmosphere. Pieces of the master alloys were re-melted under induction in a quartz crucible and injected into a water-cooled copper mold to form 2 mm diameter rods. The length of the cast samples was 60 mm. The thermal behaviors related to glass transition, crystallization events of the alloys were investigated using a differential scanning calorimeter (PerkinElmer, DSC-7) under the flow of purified argon, at a heating rate of 20 K/min. The structure of the cylindrical rods was investigated by X-ray diffraction (XRD, Philips X'Pert PRO) using Co Kα radiation and high resolution transmission electron microscopy (HRTEM, Tecnai F30 operating at 300 kV).

3. Results and Discussion

Figure1 shows the XRD patterns of the $(Fe_{1-x}Ni_x)_{77}Mo_5P_9C_{7.5}B_{1.5}$ (x=0.05, 0.1, 0.15) samples. The specimens with x=0.05 Ni show a number of sharp crystalline peaks on the main diffraction maximum, suggesting that the samples are partially amorphous with some crystalline phases. In contrast, there are no discernible crystalline peaks on the XRD pattern of the as-cast $(Fe_{0.9}Ni_{0.1})_{77}Mo_5P_9C_{7.5}B_{1.5}$, suggesting that the alloy with x=0.1 Ni is amorphous. Further increasing in the Ni content to x=0.15 leads to a number of crystalline peaks superimposed on the main halo, indicating that the sample consists of both amorphous and crystalline phases. The addition of Ni increases the number of alloy components. Therefore, due to the confusion principle, proper Ni addition may tighten the atomic structure of the super cooled liquid and increase the atomic packing density, which would lower the ground-state energy of the super cooled liquid and thus destabilize compound formation (i.e., new competing crystalline phases).

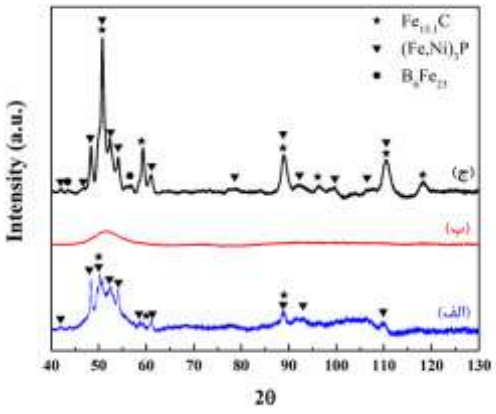

Figure 1. XRD pattern of $(Fe_{1-x}Ni_x)_{77}Mo_5P_9C_{7.5}B_{1.5}$ (x=0.05, 0.1, 0.15) samples

The microstructure of the $(Fe_{0.9}Ni_{0.1})_{77}Mo_5P_9C_{7.5}B_{1.5}$ alloy has been carefully examined with TEM. A typical high-resolution TEM (HRTEM) image is shown in Figure 3. Except for the short-range or medium-range ordered clusters, no crystalline phase has been observed. The inset of Figure 2 is the corresponding selected area electron

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diffraction (SAED) pattern. Except for diffraction halos, no sharp diffraction ring or spots was observed. It confirms that the $(Fe_{0.9}Ni_{0.1})_{77}Mo_5P_9C_{7.5}B_{1.5}$ alloy possesses a full glass structure, in agreement with the XRD pattern (Figure 1).

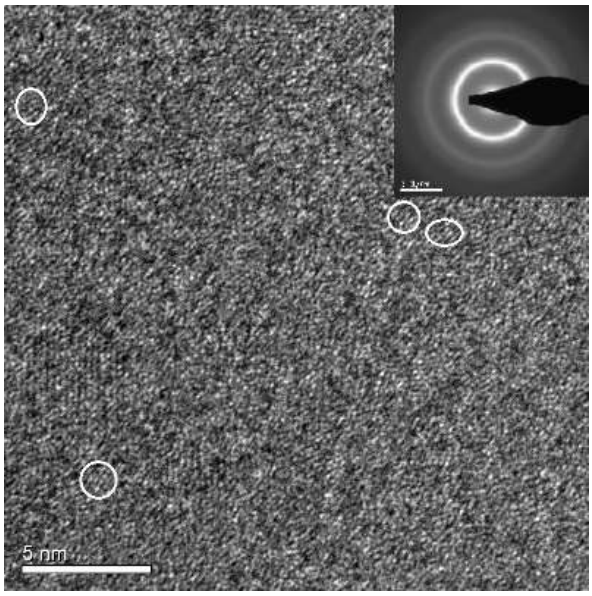

Figure 2. HRTEM image and the selected area electron diffraction pattern of $(Fe_{0.9}Ni_{0.1})_{77}Mo_5P_9C_{7.5}B_{1.5}$ alloy

Figure 3 shows the DSC trace of $(Fe_{1-x}Ni_x)_{77}$ $Mo_5P_9C_{7.5}B_{1.5}$ (x=0.05, 0.1, 0.15) alloys measured at 20K/s heating rate, (a-c, respectively).

To predict the relatively easy, different alloy systems to form glassy materials, many of indicators of glass forming ability (GFA) have been evolved. Characteristic temperature, such as liquidious temperature (T_l), glass transition temperature (T_g), and crystallization temperature (T_x) include these indicators.

It should be remarked again that samples with x=0.05 and 0.15 are amorphous matrix composites. Therefore, the computational methods such as γ ،β ،α and etc. are characteristic to the matrix, which certainly has a different chemical composition than the overall sample composition(s). This explains why apparently the alloy with x=0.1 should show a lower GFA (lower γ ،β ،α and etc.), but in fact, it is the only one which is amorphous (Figure 2).

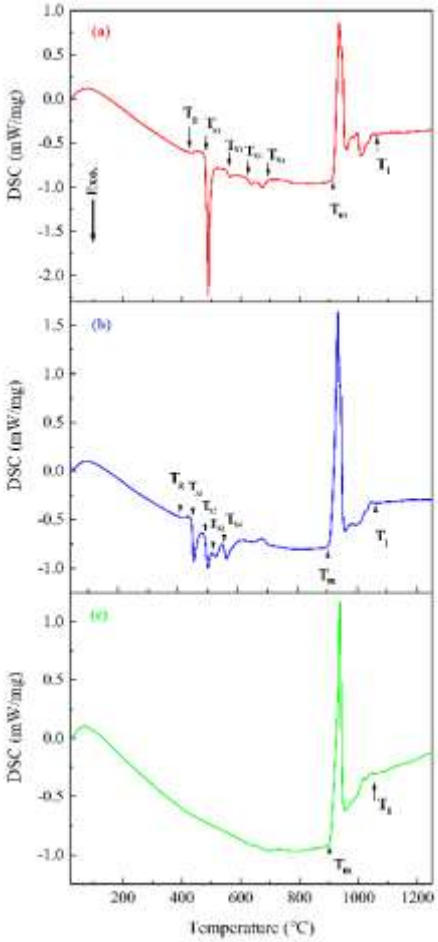

Figure 3. DSC trace of $(Fe_{1-x}Ni_x)_{77}$ $Mo_5P_9C_{7.5}B_{1.5}$ (x=0.05, 0.1, 0.15) alloys, (a-c respectively)

4. Conclusion

Ni additions have a major influence on the GFA of the base alloy. The appropriate addition of Ni to the $(Fe_{1-x}Ni_x)_{77}$ $Mo_5P_9C_{7.5}B_{1.5}$ (x=0.1) alloy shifts the composition closer to the eutectic, lowers the liquidus temperature, and significantly enhances the GFA of the alloys.

The computational methods such as γ ،β ،α and etc. are characteristic to the matrix, which certainly has a different chemical composition than the overall sample composition(s). Therefore, the results of the computational methods regardless of the experimental results don't are enough accurate.