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Effects of B addition on glass forming ability and thermal behavior of FePC-based bulk metallic glasses

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ABSTRACT

The FePC-based bulk metallic glasses (BMGs) have been demonstrated to possess high plasticity and good soft magnetic properties. However, the relatively poor glass forming ability (GFA) and thermal stabilities limited their application in industries. The effects of microalloying with B in FePC-based BMGs on the GFA and thermal behaviors were systematically investigated. It was found that a small amount of B addition can dramatically enhance the GFA of FePC-based BMGs, which in turn leads to the critical maximum diameter up to 2 mm for full glass formation even using low cost raw materials. The underlying mechanism of the enhancement of GFA from the competing crystalline phase with amorphous phase, the average thermal expansion coefficient and dynamic viscosity were discussed in detail.

1. Introduction

As a diverse family of novel materials, bulk metallic glasses (BMGs) exhibited a strong promising potential for structural and functional applications owing to their disordered structure and unique performances, such as ultrahigh strength, large elasticity, and excellent corrosion resistance[1-4]. In the early stage, the majority of BMGs synthesis was focused on the precious metal systems, such as Zr-based and Pd-based ones[3]. However, the high raw material costs severely restricted the development and application of these BMGs. Unlike other BMG systems, Fe-based BMGs usually displayed more attractive potentials because of the combination of ultrahigh strength, excellent soft magnetic properties, good corrosion resistance and relatively low material cost[5-10].

Recently, the authors proposed that most of the Fe-based BMGs can be reasonably clarified into three types: FeC(B)-based, FeB-based, and FeP(C)-based BMGs[11] and demonstrated that the different types of BMGs were linked with their different glass forming ability (GFA), different physical properties and different thermal behaviors. Among the three types of BMGs, the FeP(C)-based BMGs often possess a lower glass transition temperature T_g, a lower shear modulus G, and a higher Poisson′s ratio υ, resulting in a lower shear flow barrier and a higher ductility at room temperature. In addition, the FeP(C)-based BMGs also exhibited a good corrosion resistance in HCl solutions and soft magnetic properties at room temperature[12,13]. Therefore, the FeP(C)-based BMGs were very attractive materials for the practical industry applications in the future. However, most of the FeP(C)-based BMGs currently still have a very poor GFA[11], which hinders their widespread use and mass production. In order to enhance the GFA of FeP(C)-based BMGs, high purity raw materials or fluxing method have always been introduced[14-17], whereas the high-cost materials and the critical fabrication process directly blocked their practical application. Therefore, improving the GFA of FeP(C)-based BMGs by using low purity raw materials and a simple preparation technology (such as copper mould casting) has been a deserved issue to study[18].

Moreover, it has been shown that three types of Fe-based BMGs with different GFA exhibited differ-

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ent thermal properties[11,19]. The authors proposed that a low glass transition temperature and a low activation energy of glass transition were generally associated with a high plasticity at room temperature[19]. However, for a particular FeP(C)-based BMGs, the underlying mechanism of the correlation between the GFA and the thermal behaviors remained poorly understood. In this work, the effects of B addition on the GFA and thermal properties of $(Fe_{75}Mo_5P_{13}C_7)_{100-x}B_x$ BMGs were investigated. Among these alloys, the thermal properties, such as the thermal expansion behavior and the dynamic viscosity of these FeP(C)-based BMGs were also in-depth studied.

2. Experimental Methods

The master alloy ingots of $(Fe_{75}Mo_5P_{13}C_7)_{100-x}B_x$ (x=0, 0.3, 0.5, 1.0, 1.5, 2.0 at.%) were prepared by arc-melting the mixtures of low purity Fe (99.5%), Mo (99.9%), C (99.9%), B (99.5%), and industrial Fe-P alloy (72.6 wt.% Fe, 25.3 wt.% P and other impurities) under a Ti-gettered argon atmosphere[19]. The specimen rods with a diameter from 1 mm to 3 mm were prepared by copper mould suck casting with water cooling. The microstructure of alloys was identified by X-ray diffraction (XRD, SHIMADZU XRD-6100) with CuKα radiation operated at 40 kV and 30 mA and scan speed of 4 (°)/min, and scanning electron microscopy (SEM, JSM-6610), respectively. The thermal expansion experiment was carried out in a thermal expansion instrument (NETZSCH DIL 402C) under the high purity nitrogen atmosphere with a flow rate of 80 mL/min at the heating rate of 5 K/min. The specimen rod was 1.5 mm in diameter and approximately 9 mm in length. The thermal properties were also studied by using a thermal mechanical analyzer (TMA Q400) under flowing purified nitrogen with flow rate of 20 mL/min. In this test, a fixed compression load of 50 mN was applied and the sample rod with 1.5 mm in diameter and 0.9 mm in length under the compression mode was operated at a heating rate of 10 K/min.

3. Results

Fig. 1(a) shows the XRD patterns of as-cast $(Fe_{75}\text{-}Mo_5P_{13}C_7)_{100-x}B_x$ (x=0.3, 0.5, 1.0, 1.5 and 2.0 at.%) alloy and the corresponding critical maximum diameter (D_{max}) for the full glass formation. It can be seen that all the XRD patterns of the specimens reveal only the broad smooth peaks, and no peaks correspond to the crystalline phases, demonstrating the amorphous nature. Obviously, the GFA of FePC-based alloys can be enhanced by the B addition, which is consistent with previous results[19]. The corresponding D_{max} of FeMoPCB alloys (x=1.0 and x=1.5) can be achieved to 2 mm even they were produced by the low purity raw materials. However, an excessive addition of B degraded the GFA. The critical D_{max} for x=2 alloy was decreased into 1.5 mm in diameter. Fig. 1(b) shows the XRD patterns of $(Fe_{75}Mo_5P_{13}C_7)_{100-x}B_x$ (x=0, 0.3, 0.5, 1.0, 1.5 and 2.0 at.%) alloys when the sample rods are above their critical D_{max}. Some Fe_3C phase, Fe_3P phase and α-Fe phase were clearly precipitated in the B-free alloy, even when the sample rod was reduced to 1 mm in diameter. The FeMoPC alloy exhibited a very poor GFA, which was very different from the previous report for that prepared by fluxing method with high purity materials[20]. This demonstrated again that the purity of raw materials and the preparation method could affect the GFA dramatically[21]. Moreover, the α-Fe phase disappeared from the XRD patterns of the B-bearing alloys. Also, the precipitation of Fe_3P phases was relatively decreased after the B addition. These implied that precipitated phases were changed after the addition of B into the FeMoPC alloys.

For the more detailed microstructure of FePC-based alloys, Fig. 2 shows the cross-sectional microstructure of as-cast alloys when the sample rods are over their maximum diameter. All the samples were

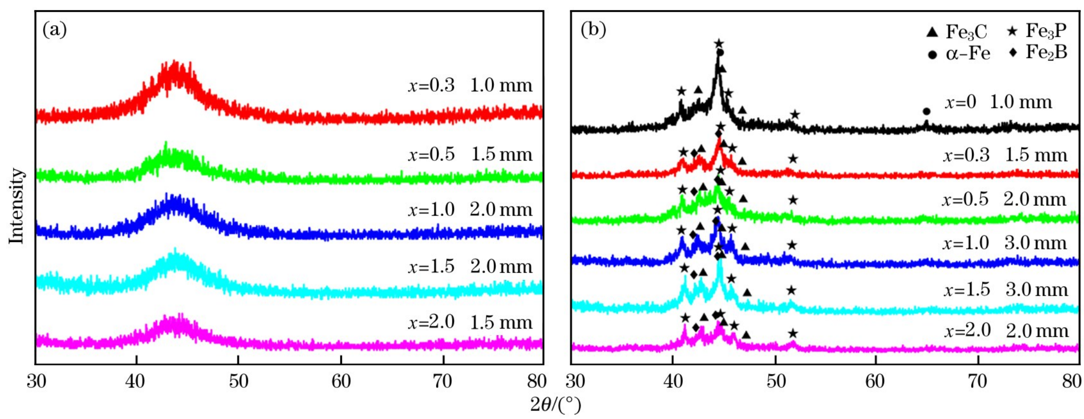

Fig. 1. XRD patterns of $(Fe_{75}Mo_5P_{13}C_7)_{100-x}B_x$ (x=0.3, 0.5, 1.0, 1.5 and 2.0 at.%) BMGs with critical diameter for full glass formation (a) and alloy rods over their corresponding maximum diameter (b).