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The positive effect of non-inert casting atmospheres on the glass-forming ability of FeMoPCBSi bulk metallic glass

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A B S T R A C T

In order to utilize non-inert casting atmospheres to improve the glass forming ability (GFA) of Fe-based bulk glassy alloys, in this work, dependence of GFA, composition and soft magnetic properties on casting atmosphere species is observed for $Fe_{77}Mo_2P_{10}C_4B_4Si_3$ glassy alloy. Firstly, it was found that GFA can be significantly improved by some non-inert atmospheres, as when cast under N_2/air/O_2, its critical diameter can reach to 3.5 mm, which is larger than that of sample cast in inert Ar. Moreover, the component contents on the alloy surface vary greatly with the casting atmospheres while the whole bulk composition remains almost unchanged. In addition, this Fe-based glassy alloy exhibits identical soft magnetic properties regardless of the applied casting atmospheres. The mechanism for the positive effect of non-inert atmospheres on the GFA of $Fe_{77}Mo_2P_{10}C_4B_4Si_3$ glassy alloy may be involved with the surface properties of alloy liquid such as surface tension and the modified superficial composition.

1. Introduction

Fe-based metallic glasses are candidates for magnetic functional applications since they possess considerably magnetic properties including high saturation magnetization (B_s), low coercive force (H_c), high effective permeability, good frequency stability and low loss, etc [1–3]. However, one of the biggest obstacles for its development and application is its poverty of glass forming ability (GFA). In order to enhance the GFA, great effort and many strategies have been devoted since the first Fe-based bulk metallic glass (BMG) was founded in 1995 [4]. Generally, when the Fe-based BMGs were prepared by similar method or equipment, these strategies can be divided into two categories: one is to scavenge heterogeneous nucleation sites out of the undercooled alloy liquids (such as pure raw materials, flux melting), and the other is through adjusting the alloy composition. In addition, it is found that the casting atmospheres also have a great impact on the GFA as the alloy composition can be modified by absorbing O or other elements from the atmosphere, and O or other elements may induce formation of harmful oxides which act as heterogeneous nucleation sites or trigger the nucleation of metastable phases [5–13]. A representative and well-known example is the GFA of Zr-based BMGs could be dramatically deteriorated when the casting atmosphere contains even a small amount of O [14]. For the same reason, some non-inert atmospheres are usually discarded and pure inert Ar is widely adopted during the preparation of BMGs. Compared with Zr-based, Cu-based, rare-earth-based and Ti-based BMGs, it seems Fe-based metallic glasses are likely less sensitive to oxygen-contained casting atmosphere during the casting procedure [15] since the manufacture of Fe-based ribbons can be performed in air [16]. However, with regard to the preparation of Fe-based BMGs, using pure inert Ar as the casting atmosphere is still the most common choice. Although a few researchers have managed to prepare Fe-based BMGs in air through the formation of harmless rare earth oxides, however, unfortunately, it is at the expense of GFA [17,18].

According to Tumbull' theory [19,20], the heterogeneous

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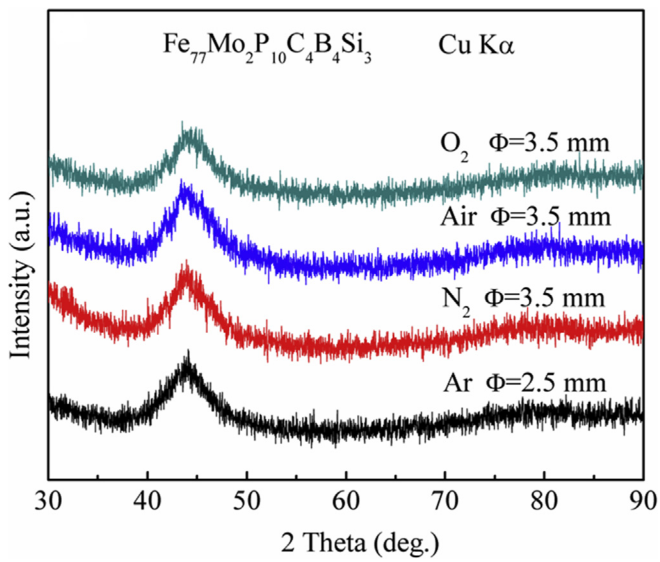

Fig. 1. XRD patterns of as-cast $Fe_{77}Mo_2P_{10}C_4B_4Si_3$ rods prepared in Ar, N_2, air and O_2 atmospheres.

nucleation rate *I* is related to surface tension which can be significantly influenced by the species of the atmospheres [21,22], meaning the species of the atmosphere may be involved with *I* or the GFA. It was also reported that O contamination (even at ppm levels) can have a dramatic effect on the surface tension of a metal alloy [23]. Inspired by this result, we decided to investigate the influence of non-inert casting atmospheres on Fe-based BMGs. An $Fe_{77}Mo_2P_{10}C_4B_4Si_3$ alloy was reported to exhibit a critical diameter (D_{cr}) of 2.5 mm in pure Ar [24]. Subsequently, it was adopted to examine the variations of GFA, composition and soft magnetic properties with kinds of casting atmospheres in this paper. It was found that the O_2, N_2 and air benefit equivalently the GFA of $Fe_{77}Mo_2P_{10}C_4B_4Si_3$ alloy without deteriorating the soft magnetic

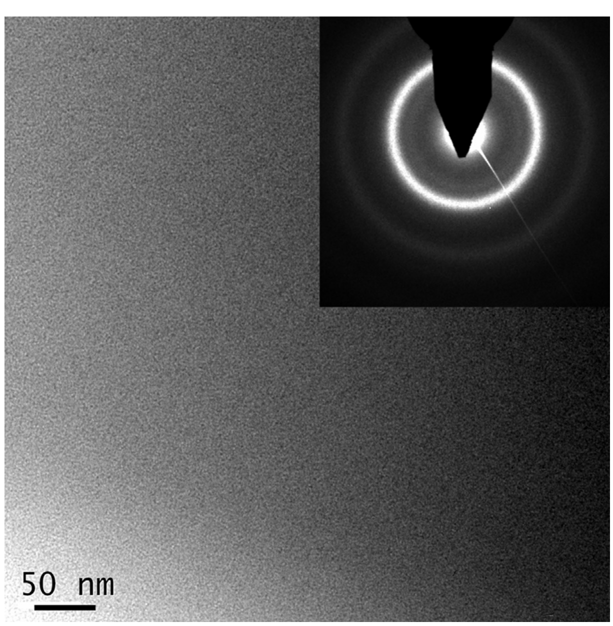

Fig. 2. TEM image and corresponding SAED pattern taken from the cross section of the as-cast $Fe_{77}Mo_2P_{10}C_4B_4Si_3$ rod with a diameter of 3.5 mm prepared under O_2 atmosphere.

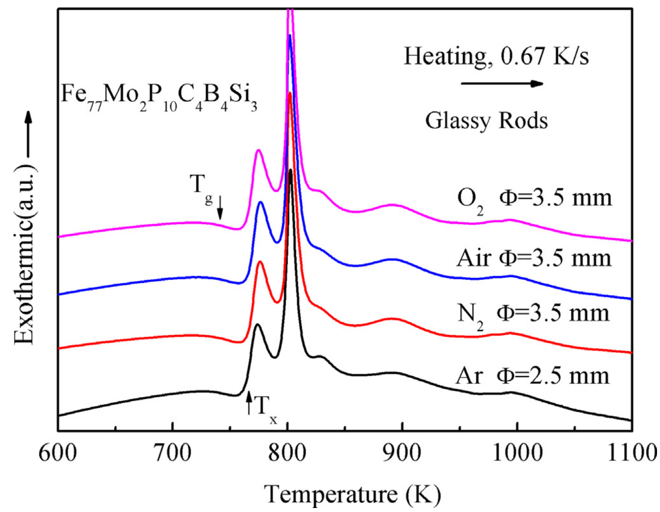

Fig. 3. DSC curves of as-cast $Fe_{77}Mo_2P_{10}C_4B_4Si_3$ glassy rods prepared in Ar, N_2, air and O_2 atmospheres.

properties. The underlying mechanism concerning the effect of non-inert casting atmospheres on the GFA was also clarified.

2. Experimental

A multi-component alloy ingot with a nominal composition of $Fe_{77}Mo_2P_{10}C_4B_4Si_3$ was prepared by induction melting the mixtures of pure Fe metal (99.99 wt%), pure Mo metal (99.99 wt%), pure B (99.9 wt%) and Si crystals (99.999 wt%), Fe-P alloy (99.9 wt%, 18 wt% P) and Fe-C alloy (99.9 wt%, 4.6 wt% C) under a high purified Ar atmosphere.

Cylindrical rods with a length of about 40 mm and different diameters of 2–4 mm were produced with a Rapid Quench Machine System. The casting chamber of the Rapid Quench Machine System was evacuated to ~4×10^{-3} Pa, then filled with high pure Ar, air, O_2 or N_2 to 9×10^4 Pa, respectively. Finally, the molten alloy liquid was cast into the cylindrical copper mold. In order to ensure the reproducibility, the D_{cr} was determined only after three glassy rods with the D_{cr} were obtained. Glassy ribbons with a thickness of about 20 μm were produced by melt spinning.

The as-cast rods were ground to powder at first, and then their microstructures were examined by X-ray powder diffractometer (XRD) with Cu-Kα radiation. Glass transition temperature (T_g) and crystallization temperature (T_x) were estimated by differential scanning calorimetry (DSC) at a heating rate of 0.67 K/s. The C and P atomic concentration in the surface of alloy cast in Ar and air atmospheres were determined by Auger Electron Spectroscopy (AES, PHI 700) with a referential sputter speed of 4 nm/min of SiO_2. The contents of O and N in the master alloy and BMG samples were also measured using an EMGA-620W oxygen/nitrogen analyzer. Magnetic properties of B_s and H_c were measured at room temperature with a vibrating sample magnetometer (VSM) under an applied field of 800 kA/m and a B-H loop tracer under a field of 800 A/m, respectively.

3. Results

Fig. 1 depicts the XRD patterns of as-cast $Fe_{77}Mo_2P_{10}C_4B_4Si_3$ rods prepared in Ar, N_2, air, and O_2 atmospheres under chamber pressure of 9×10^4 Pa. From Fig. 1, it can be found all the XRD patterns with different diameters prepared in corresponding atmosphere consist of only a typical halo peak and have no any sharp diffraction