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Glass forming ability and magnetic properties of $Co_{(40.2-x)}Fe_{(20.1+x)}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$ (x=0–10) bulk metallic glasses produced by suction casting

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ABSTRACT

The effect of Fe concentration on the glass forming ability (GFA) and magnetic properties in $Co_{(40.2-x)}Fe_{(20.1+x)}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$ (x=0–10) bulk metallic glasses were investigated. By suction casting method, the bulk metallic glasses with diameters up to 2 mm were produced. We try to find out which Fe concentration makes an influence on Co based system's magnetic properties and glass forming ability. The curves of thermal analysis, obtained using differential scanning calorimetry (DSC), show that the $Co_{(40.2-x)}Fe_{(20.1+x)}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$ (x=0–10) have a supercooled liquid region (ΔT_x) of about 44 K. The saturation magnetizations (J_s) for as-cast BMG alloys were in the range of 0.62 T – 0.81 T.

1. Introduction

High saturation magnetization, low coercivity and high electrical resistivity are the most desirable properties for the soft magnetic materials [1,2]. Since we are dealing with bulk metallic glasses (BMGs), glass forming ability (GFA) of the alloy should also be high [3]. It is important to realize that it is quite difficult to achieve a good combination of all the properties mentioned above in one alloy composition [4]. Co- and Fe- based glassy alloys are expected to show good soft magnetic properties such as high saturation magnetization and lower coercive force [5,6]. According to their promising future application Fe- and Co-based BMGs development have not been as rapid as the other systems [7,8]. Fe–Co–Ni–B–Si, as it is pseudoternary system that does not show glass transition phenomenon [9]. But addition of Nb to Fe- and Co- based alloys improves their glass forming ability by increasing stability of supercooled liquid region. Many researchers try to find out which element and concentration ratio are suitable for replacing Nb [10,11]. It was reported earlier that addition of Fe to Co-based BMG alloys was affective to improve not only GFA but also the magnetic properties [12]. In this work, $Co_{40.2-x}Fe_{20.1+x}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$($x$=0–10) glassy rod with a diameter of 2 mm was prepared by arc melting and suction casting, and we also investigated the required maximum possible amount of Fe to achieve the good soft magnetic properties.

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2. Experimental procedure

The Co based multi-component alloy ingots with compositions of ($Co_{40.2-x}Fe_{20.1+x}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$) ($x$=0–10) were prepared by arc-melting the mixtures of pure elements in Zr-gettered argon atmosphere for at least four times. From the prealloys cylindrical rods were suction-cast in a Buhler MAM-1 arc melting system into a copper mold with a length of 30 mm and a diameter of 2 mm.

The structures of as-quenched samples were identified by X-ray diffraction (XRD) with CuKα radiation. The glass transition temperature (T_g), crystallization temperature (T_x), and liquidus temperature (T_l) were measured with Seteram SETSYS 16/18 differential scanning calorimetry (DSC) under flowing high purity argon gas with 15–20 mg samples at a ramp rate of 0.67 K/s. The $\Delta T_x = T_x - T_g$ and reduced glass transition temperature $T_{rg} = T_g / T_l$ were calculated accordingly. Magnetic hysteresis measurements were conducted with an ADE Magnetics EV9 vibrating sample magnetometer (VSM) with maximum magnetic field strength of 1750 kA/m, real-time field control and dynamic gauss range capable of reaching a resolution of 0.08 A/m at low fields.

3. Results and discussion

The XRD patterns exhibited by BMGs are given in Fig. 1a and Fig. 1b. Those patterns show us that the alloy systems produced by the suction casting method are in an amorphous structure. It can be observed that a mixed structure of amorphous matrix together

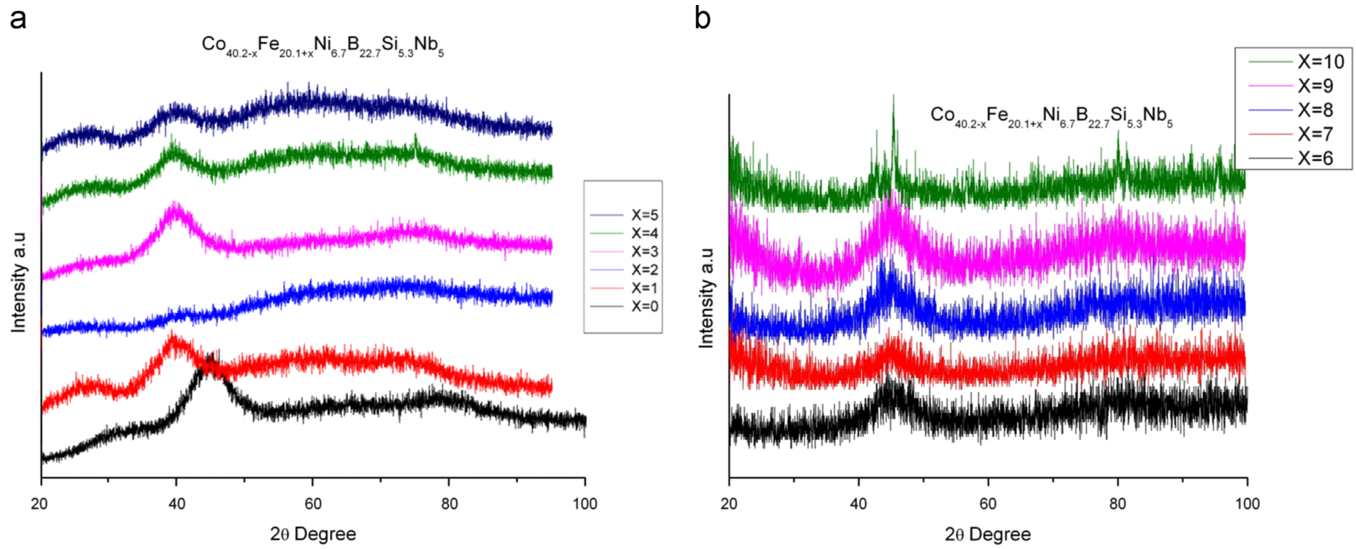

Fig. 1. (a) XRD patterns of $Co_{40.2-x}Fe_{20.1+x}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$ (x=0–5) BMG alloys and (b) XRD patterns of $Co_{40.2-x}Fe_{20.1+x}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$ (x=6–10) BMG alloys.

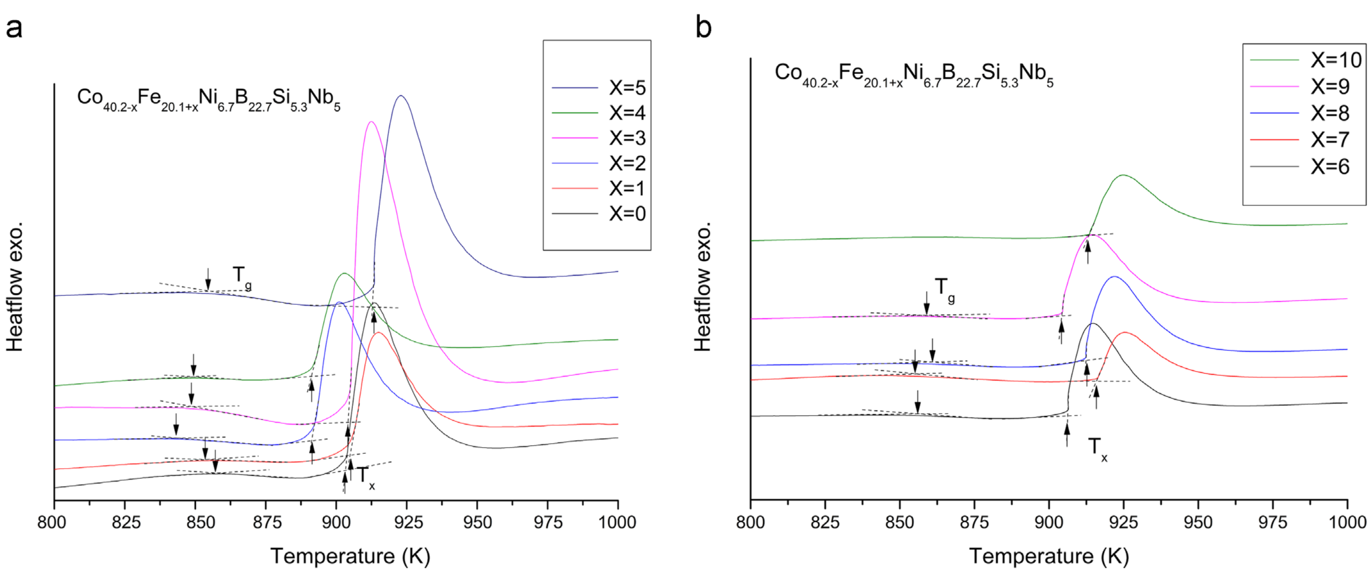

Fig. 2. (a)DSC curves of $Co_{40.2-x}Fe_{20.1+x}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$ (x=0–5) BMG alloys and (b) DSC curves of $Co_{40.2-x}Fe_{20.1+x}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$ (x=6–10) BMG alloys.

with a little amount of crystalline phase was formed in the x=10 alloy, indicating that this alloy cannot be fully amorphized in our casting condition. On the contrary, the alloys with x=1, 2, 3, 4, 5, 6, 7, 8 and 9 can be cast into fully amorphous as no Bragg peaks, except for a broad diffraction hump, can be detected in their X-ray diffraction patterns, indicating that the substitution of an appropriate amount of Fe for Co affected the glass forming ability of the Co-based system. However, with further increasing Fe content up to x=10, some diffraction peaks appeared, indicating that an excessive substitution of Fe deteriorated GFA of the system. The crystalline phase in the sample with x=10 Fe is most likely α-(Fe, Co) solid solution [13].

Fig. 2a and b shows the DSC curves of as-cast $Co_{40.2-x}Fe_{20.1+x}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$ (x=0, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10) alloys with different Fe contents at temperatures up to 1000 K. It can be seen that, each alloy exhibits a distinct glass transition followed by a supercooled liquid region before crystallization. Based on the DSC curves, T_g, T_x and ΔT_x are derived and summarized in Table 1. It can be seen that the ΔT_x and T_g of all alloys are exceeding 40 and 840 K, respectively. Fig. 3a and Fig. 3b shows the DSC curves at temperatures higher than 1000 K, which illustrate the melting reaction of different $Co_{40.2-x}Fe_{20.1+x}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$ (x=0–10) alloys. Table 1 also shows us that the Fe amount in the composition system affect the T_l value. The T_{rg}, which is taken as the gauges for glass forming ability, is calculated and also presented in Table 1. T_{rg} values are in the range of 0.634 and 0.669. Actually, the alloys with x=1–9 Fe content could be cast into fully amorphous of 2 mm diameter, except for the $Co_{30.2}Fe_{30.1}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$ alloy, elucidating clearly the role of Fe substitution up to x=10 in the enhancement of GFA for the present BMGs.

To investigate the effect of Fe substitution on magnetic properties of the as-cast $Co_{(40.2-x)}Fe_{(20.1+x)}Ni_{6.7}B_{22.7}Si_{5.3}Nb_5$ (x=0–10) BMGs, the hysteresis J–H loops of all as-cast alloys were measured with VSM under the applied magnetic field of 1750 kA/m. Fig. 4a and Fig. 4b shows the J–H loops of the alloys. The J values have been calculated using the data of density and magnetization (M) for each measurement. The shape of J–H loops for all alloys shows a typical ferromagnetic feature. The saturation magnetization (J_s) and coercivity (H_c) of each alloy derived from the corresponding J–H loop are listed in the last two columns of Table 1. It is found