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FORMATION AND MAGNETIC PROPERTIES OF Co-M-Ti-B (M=Fe, Nb) AMORPHOUS POWDERS BY MECHANICAL SOLID-STATE REACTION

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Abstract. Amorphous $Co_{70-x}M_xTi_{25}B_5$ (M=Fe, Nb) powders with x=5, 10, 25, 35 were synthesized by mechanical alloying technique. Substitution of Co with small amount of Fe or Nb element reduces the thermal stability of the amorphous powders. The milled amorphous $Co_{55}Nb_{15}Ti_{25}B_5$ powder has comparable supercooled liquid region as its ternary $Co_{70}Ti_{25}B_5$ counterpart. The milled $Co_{70-x}Fe_xTi_{25}B_5$ alloys have lower coercive force and higher saturation magnetization than the milled $Co_{70-x}Nb_xTi_{25}B_5$ alloys and show better soft magnetic properties.

1. INTRODUCTION

Co-based amorphous alloys have been known to possess excellent soft magnetic properties [1-3]. El-Eskandarany *et al*. [4] employed a high-energy ball milling technique to fabricate glassy $Co_{100-x}Ti_x$ ($25 \le x \le 67$) alloy powders at room temperature. Boron is one of the constituent atoms in most glassy alloys. Corrias *et al.* [5] reported that ball milling of Co-B mixtures induced solid-state amorphisation which became faster with increasing boron content. In the other study by El-Eskandarany *et al*. [6], they synthesized a single glassy phase of $Co_{71}Ti_{24}B_5$ alloy by mechanically alloying the elemental powders. The glassy powder obtained after 130 ks of ball milling exhibits soft magnetic properties with magnetization and coercivity of 1.01 T and 2.86 kA/m, respectively. This ternary alloy shows a large supercooled liquid region (ΔT_x=63K) and reduced glass transition temperature (ratio between glass transition temperature and liquidius temperature) of 0.55. However, Co is a strategic and expensive material. This study was intended to obtain good soft magnetic and thermally stable Co based powders by substituting some of the Co in the $Co_{71}Ti_{24}B_5$ alloys with Nb or Fe atom to reduce the usage of Co element.

2. EXPERIMENTAL

Mechanical alloying of the elemental powders at room temperature was employed to synthesize amorphous $Co_{70-x}M_xTi_{25}B_5$ (M=Fe, Nb) powders and their magnetic properties were investigated. Pure elemental powders of Co, Ti, B, Fe, and Nb with nominal compositions in atomic percent of $Co_{70-x}M_XTi_{25}B_5$, where X equals 5, 15, 25, and 35, were milled in a SPEX D8000 vibrator mill. The milling was stopped after selected milling times and a small amount of milled powders were taken out for analysis. The milled powders were characterized by means of X-ray diffraction employing Cu$K\alpha$ radiation, and a differential scanning calorimetry (DSC) at a constant heating rate of 10 °C/min. The magnetic magnetization and intrinsic coercive force of the milled powders were measured at room temperature using a Quantum Design MPMS7 superconducting quantum interference device (SQUID).

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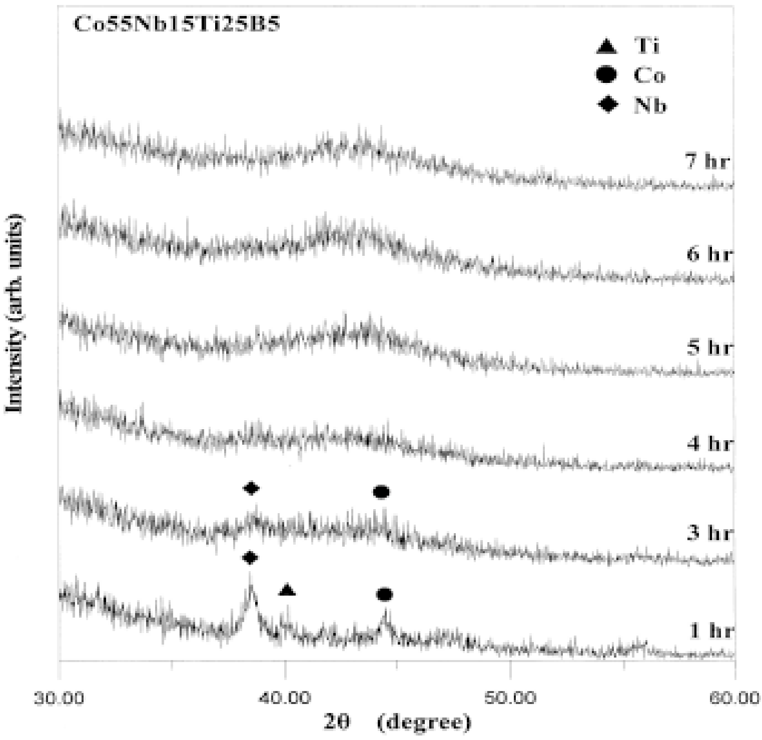

Fig. 1. XRD patterns of the milled $Co_{55}Nb_{15}Ti_{25}B_5$ powder at different milling times.

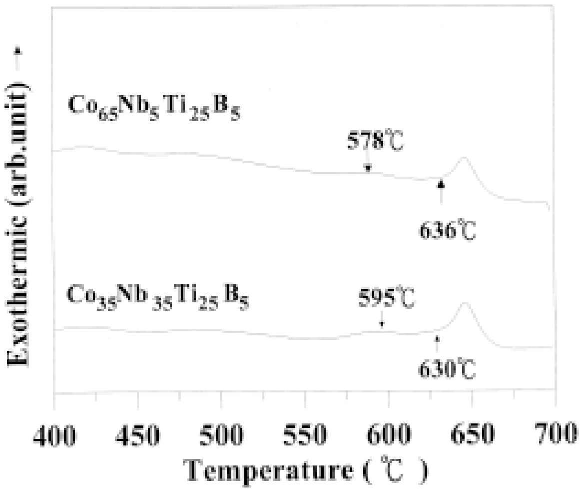

Fig. 2. DSC curves for the $Co_{65}Nb_5Ti_{25}B_5$ and $Co_{35}Nb_{35}Ti_{25}B_5$ alloys.

3. RESULTS AND DISCUSSIONS

The XRD patterns of the milled $Co_{55}Nb_{15}Ti_{25}B_5$ powder at different milling times are shown in Fig. 1. A broad, diffuse and smooth halo appearing after 5 h of milling indicates the formation of an amorphous phase. This amorphous phase maintains its structure and does not transform into other phases even after longer milling time. Except for the $Co_{35}Fe_{35}Ti_{25}B_5$ composition, all other XRD patterns show the amorphous features after a certain period of milling. The $Co_{35}Fe_{35}Ti_{25}B_5$ composition contains higher amount of Fe and cannot be amorphised even after prolonged milling.

The thermal stability of the milled powders, characterized by the temperature interval of the supercooled liquid region (ΔT_x) which is obtained by the difference between glass transition temperature (T_g) and crystallization temperature (T_x), was investigated by recording their DSC curves. Except for the $Co_{35}Fe_{35}Ti_{25}B_5$, all other milled powders exhibit two separate events in the DSC curves, as is shown in Fig. 2 for the $Co_{65}Nb_5Ti_{25}B_5$ and $Co_{35}Nb_{35}Ti_{25}B_5$ powders. The first endothermic peak is due to the glass transition reaction of the formed amorphous phase, whereas the second sharp exothermic peak is attributed to the crystallization of the amorphous phase. Contrary to the sharp exothermic crystallization peak, the endothermic glass transition peak is rather weak. From the DSC curves, the T_g, T_x, and ΔT_x can be determined. The determined ΔT_x values are listed in Table 1. The

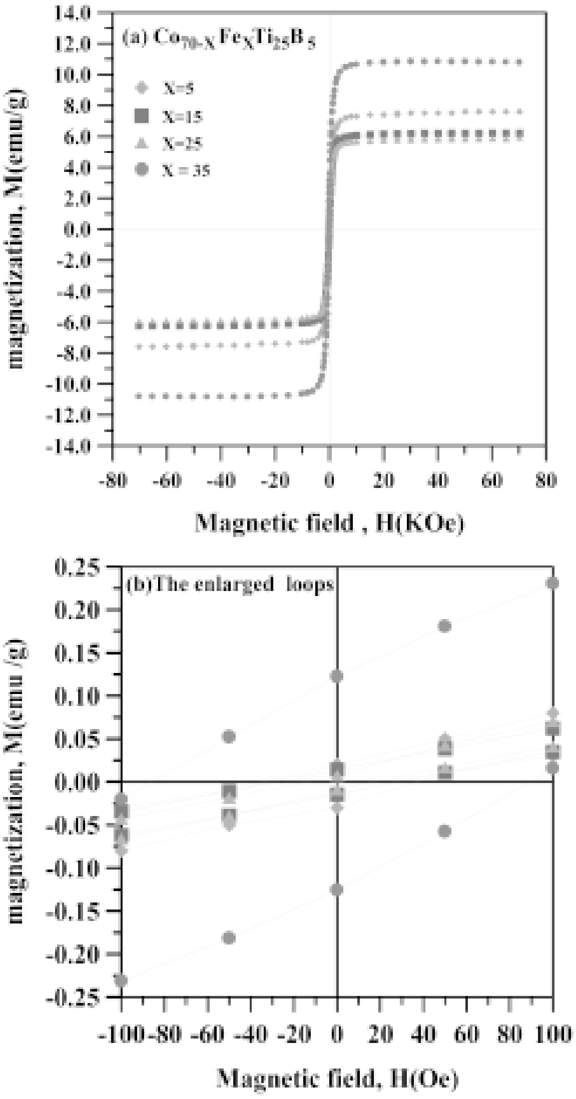

Fig. 3. (a) M-H loops of the milled $Co_{70-x}Fe_xTi_{25}B_5$ powders, and (b) the same M-H loops in an enlarged scale.

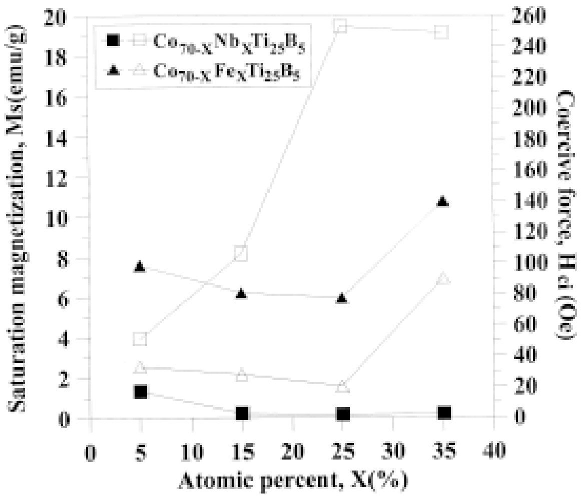

Fig. 4. Variations of saturation magnetization and intrinsic coercive force with Fe or Nb atomic percent for the $Co_{70-x}Fe_xTi_{25}B_5$ and $Co_{70-x}Nb_xTi_{25}B_5$ powders. Full symbols represent saturation magnetization and open symbols represent coercive force.

Table 1. The ΔT_x of the milled amorphous powders investigated in this study.

Compositions	ΔT_x (K)	Compositions	ΔT_x (K)
$Co_{65}Fe_5Ti_{25}B_5$	44	$Co_{65}Nb_5Ti_{25}B_5$	58
$Co_{55}Fe_{15}Ti_{25}B_5$	53	$Co_{55}Nb_{15}Ti_{25}B_5$	65
$Co_{45}Fe_{25}Ti_{25}B_5$	40	$Co_{45}Nb_{25}Ti_{25}B_5$	50
$Co_{35}Fe_{35}Ti_{25}B_5$	-	$Co_{35}Nb_{35}Ti_{25}B_5$	35

ΔT_x of ternary $Co_{70}Ti_{25}B_5$ was also measured in this study for comparison purpose and is equal to 64 K. It can be seen from Table 1 that all the measured ΔT_x values, except for the $Co_{55}Nb_{15}Ti_{25}B_5$ powder, are lower than their ternary $Co_{70}Ti_{25}B_5$ counterpart. This implies that substitution of Co with small amount of Fe or Nb element will reduce the thermal stability of the amorphous alloys.

The magnetization vs. magnetic field properties were measured for all the milled powders and typical M-H loops from the $Co_{70-x}Fe_xTi_{25}B_5$ powders are shown in Fig. 3. Similar curves were obtained from the milled $Co_{70-x}Nb_xTi_{25}B_5$ powders. All the alloy powders exhibit magnetic hysteresis loop. The intrinsic coercive forces of the $Co_{70-x}Fe_xTi_{25}B_5$ and $Co_{70-x}Nb_xTi_{25}B_5$ alloys are in the range of 20 to 90 Oe and 51 to 253 Oe, respectively. The saturation magnetization for the $Co_{70-x}Fe_xTi_{25}B_5$ powders varies from 5.95 to 10.7 emu/g whereas for the $Co_{70-x}Nb_xTi_{25}B_5$ powders it changes from 0.13 to 1.33 emu/g. The variations of the saturation magnetization and coercive force with Fe or Nb content for the $Co_{70-x}Fe_xTi_{25}B_5$ and $Co_{70-x}Nb_xTi_{25}B_5$ powders are plotted and shown in Fig. 4. This figure indicates that the values of saturation magnetization of $Co_{70-x}Fe_xTi_{25}B_5$ powders are higher than those of $Co_{70-x}Nb_xTi_{25}B_5$ powders. For both alloy powders, the saturation magnetization decreases slightly with increasing Fe or Nb content, except for the $Co_{35}Fe_{35}Ti_{25}B_5$ alloy. The rising in magnetization of the $Co_{35}Fe_{35}Ti_{25}B_5$ alloy might result from its non-amorphous structure. It is well known that the saturation magnetization is determined only by the composition of the material. The saturation magnetization of a ferromagnetic material corresponds to the product of the net magnetic moment for each atom and the number of atoms in the material. The net magnetic moment of Fe atom is known to be larger than that of Nb atom. Therefore, for a given $Co_{70-x}M_xTi_{25}B_5$ composition, alloy with M=Fe gives higher saturation magnetization than that with M=Nb.

It is also found from Fig. 4 that the coercive forces of $Co_{70-x}Nb_xTi_{25}B_5$ powders are higher than those of $Co_{70-x}Fe_xTi_{25}B_5$ powders. Since soft magnetic materials are used in devices in which hysteresis energy loss must be low, lower coercive force is preferable. In this regard, this study indicates that the milled $Co_{70-x}Fe_xTi_{25}B_5$ alloys show better soft magnetic properties than the $Co_{70-x}Nb_xTi_{25}B_5$ alloys.

4. CONCLUSIONS

With an aim of developing ferromagnetic Co-based amorphous alloys by replacing some of the Co with Fe or Nb, the thermal stability of produced alloy powders is reduced. The milled $Co_{70-x}Fe_xTi_{25}B_5$ alloys have lower coercive force and higher saturation magnetization than the milled $Co_{70-x}Nb_xTi_{25}B_5$ alloys and show better soft magnetic properties.

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