Rev.Adv.Mater.Sci. 18(2008) 27-29

Fe-(Cr, Mo)-(C, B)-Tm BULK METALLIC GLASSES WITH HIGH STRENGTH AND HIGH GLASS-FORMING ABILITY

Kenji Amiya[1] and Akihisa Inoue[2]

[1]R&D Institute of Metals and Composites for Future Industries, Sendai 980-8577, Japan
[2]Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan

Received: March 29, 2008

Abstract. The glass-forming ability and mechanical properties of (Fe, Co)-(Cr, Mo)-(C, B)-Tm glassy alloys have been investigated. The $(Fe, Co)_{48}Cr_{15}Mo_{14}C_{15}B_6Tm_2$ glassy alloys were prepared in a cylindrical form with a diameter of 18 mm. The largest supercooled liquid region before crystallization in $(Fe_{1-x}Co_x)_{48}Cr_{15}Mo_{14}C_{15}B_6Tm_2$ alloys is 90 K for $Co_{48}Cr_{15}Mo_{14}C_{15}B_6Tm_2$. These glassy alloys have high fracture strength of over 4100 MPa for the entire composition range and the strength level is almost independent of Co content. The combination of high strength and high glass-forming ability indicates high possibility of applying the (Fe, Co)-(Cr, Mo)-(C, B)-Tm glassy alloys to various industrial materials.

1. INTRODUCTION

Considering the engineering importance of Fe-based glassy alloys, there has been strong social demand of developing Fe-based bulk metallic glasses (BMGs) with higher glass forming ability (GFA) in conjunction with high strength. Recently, Fe-based BMGs with critical diameters up to 12 mm were formed in Fe-(Cr, Mo, Mn)-(C, B)-Y system [1,2] through the additional effect of small amounts of Y on the bulk glassy Fe-(Cr, Mo)-(C, B) alloys [3]. However, little is reported about the mechanical properties of Fe-(Cr, Mo)-(C, B)-Y glassy alloys because of their extremely brittle nature. We have found that Fe-(Cr, Mo)-(C, B)-Tm BMG exhibits simultaneously high strength above 4000 MPa as well as high GFA with a critical diameter of over 10 mm. We have further examined the effect of replacement of Fe by Co on the GFA and mechanical properties in (Fe,Co)-(Cr, Mo)-(C, B)-Tm system.

2. EXPERIMENTAL PROCEDURE

Multi-component alloys in (Fe, Co)-Cr-Mo-C-B-Tm system were examined because the significant additional effect of Y on $Fe_{50}Cr_{15}Mo_{14}C_{15}B_6$ alloy. Alloy ingots were prepared by arc melting in an argon atmosphere. The alloy compositions represent nominal atomic percentages of the mixtures. BMGs in a cylindrical form with a length of 50 mm and different diameters in the range of 2 to 18 mm were produced by a copper mold casting method. For comparison, glassy alloy ribbons with a thickness of about 0.03 mm were also prepared by melt spinning. The glassy structure was examined by X-ray diffraction (XRD). The specific heat associated with glass transition, supercooled liquid region and crystallization was measured by differential scanning calorimetry (DSC) at a heating rate of 0.67 K/s. Mechanical properties of cast rods were measured with an Instron testing machine at a

Corresponding author: Kenji Amiya, e-mail: rimcofak@imr.tohoku.ac.jp

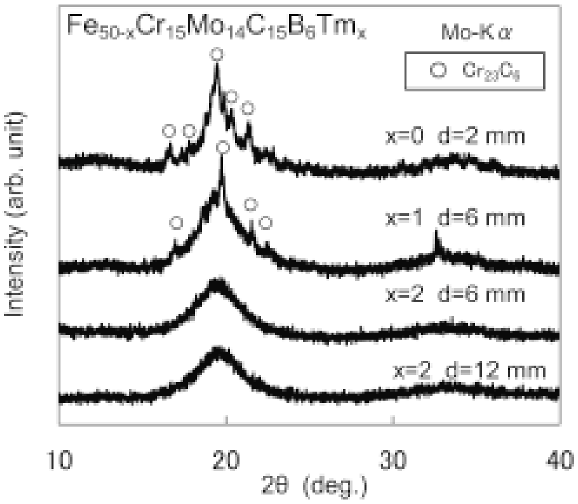

Fig.1. XRD patterns taken from the cross-section of the cast $Fe_{50-x}Cr_{15}Mo_{14}C_{15}B_6Tm_x$ (x=0, 1, 2) rods.

strain rate of 2.10-4s-1 under a uniaxial compressive load.

3. RESULTS AND DISCUSSION

Fig. 1 shows the XRD patterns taken from the cross-section of the cast $Fe_{50-x}Cr_{15}Mo_{14}C_{15}B_6Tm_x$ (x=0, 1, 2) alloy rods. Although the $Fe_{50}Cr_{15}Mo_{14}C_{15}B_6$ with a diameter of 2 mm consists of glassy and crystalline $Cr_{23}C_6$ phases, the addition of Tm is effective for the suppression of the precipitation of the crystalline phase, leading to the formation of a single glassy phase with a diameter of 12 mm at the Tm concentration of 2 at.%. The crystalline phases of the cast $Fe_{50-x}Cr_{15}Mo_{14}C_{15}B_6Tm_x$ (x=0, 1) rods are identified as only a $Cr_{23}C_6$ phase. The partial crystallization phase is independent of Tm addition up to 1 at.%.

The compositional dependence of the critical diameter for formation of the single glassy phase (d_{max}) was examined for (Fe, Co)-(Cr, Mo)-(C, B)-Tm alloys. Fig. 2 shows the plots of the diameter for glass formation as a function of Co content for the $(Fe_{1-x}Co_x)_{48}Cr_{15}Mo_{14}C_{15}B_6Tm_2$ alloys. The d_{max} of the glassy alloy rod was 12 mm for x=0, increase to 16 mm at x=0.2-0.4 and decreases to 10 mm at x=1.0, indicating the composition dependence of GFA. The DSC curve of the cast Co-based $Co_{48}Cr_{15}Mo_{14}C_{15}B_6Tm_2$ rod with a diameter of 10 mm is shown in Fig. 3, together with the data of the melt-spun ribbon. It is seen that the cast alloys

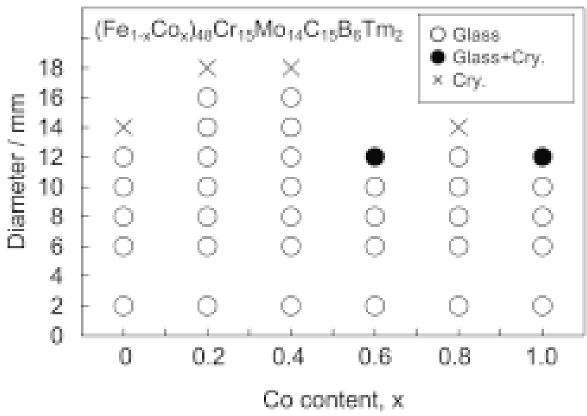

Fig. 2. Change in the structure of the cast $(Fe_{1-x}Co_x)_{48}Cr_{15}Mo_{14}C_{15}B_6Tm_2$ rods with sample diameter and Co content.

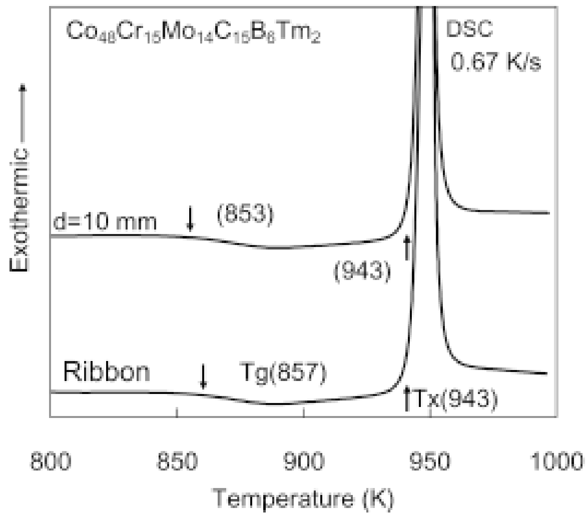

Fig. 3. DSC curves of the cast $Co_{48}Cr_{15}Mo_{14}C_{15}B_6Tm_2$ rods with a diameters of 10 mm.

exhibited the distinct glass transition at 853K, followed by a large supercooled liquid region of 90K. Furthermore, there is no appreciable difference of T_g and T_x between the cast and melt-spun samples. The previous data indicate that the largest ΔT_x for Co-based glassy alloys is 98K for $Co_{40}Fe_{22}Nb_6Zr_2B_{30}$ alloy, while the d_{max} of the alloy is 1.5 mm [4]. The present results of the $Co_{48}Cr_{15}Mo_{14}C_{15}B_6Tm_2$ glassy alloy are believed to be the first evidence for the good combination of the large ΔT_x of over 90K and high GFA leading to the formation of a single glassy phase even in the 10 mm cylindrical sample for Co-based BMGs.

Mechanical properties of the cast $(Fe_{1-x}Co_x)_{48}Cr_{15}Mo_{14}C_{15}B_6Tm_2$ (x=0-1) rods with a diameter of 2 mm were measured by the compression test. The (Fe, Co)$_{48}$Cr$_{15}$Mo$_{14}$C$_{15}$B$_6$Tm$_2$ alloys exhibit the compressive strength of over 4100 MPa and elastic elongation of 1.7% to 1.9%, being independent of Co content. It is again noticed that the high strength of 4340 MPa in conjunction with large d_{max} above 10 mm is achieved for the (Fe$_{0.2}$Co$_{0.8}$)$_{48}$Cr$_{15}$Mo$_{14}$C$_{15}$B$_6$Tm$_2$ BMGs.

We discuss the reason for the significant increase in the d_{max} for glass formation above 10 mm by the addition of 2 at.%Tm to the previously reported Fe-(Cr, Mo)-(C, B) alloy. The addition of Tm element is effective for the increase in the degree of the satisfaction of the three empirical rules for the achievement of high GFA [5] and causes the difficulty in the rearrangement of the constituent elements on a long-range-scale. Furthermore, it is known that the glassy alloy of Fe-B-Ln system with high GFA consists of network-like structures in which triangular prism are connected densely with each other [6]. The Ln element plays an important role in the formation of the dense random packing structure with the difficulty of rearrangement of atoms. The $Cr_{23}C_6$ phase which contains the triangular prism structure precipitates as the partial crystallization phase in the Fe-B-Ln glassy alloy. The partial crystallization phase is identified as $Cr_{23}C_6$ phase in the Fe$_{50}$Cr$_{15}$Mo$_{14}$C$_{15}$B$_6$ and Fe$_{49}$Cr$_{15}$Mo$_{14}$C$_{15}$B$_6$Tm$_1$ alloys. The triangular prisms structure may exist in the glassy phase of Fe-(Cr, Mo)-(C, B) and Fe-(Cr, Mo)-(C, B)-Tm systems. The main difference between both alloy systems whether Tm element exist in between the triangular prisms or not. The addition of Tm element is indispensable to make difficulty of rearrangement of atoms during quenching, thereby leading to improve GFA in Fe-(Cr, Mo)-(C, B) system.

4. CONCLUSION

The maximum diameter for formation of a glassy phase exceeds 10 mm for all alloys in (Fe$_{1-x}$Co$_x$)$_{48}$Cr$_{15}$Mo$_{14}$C$_{15}$B$_6$Tm$_2$ system. The GFA of (Fe$_{1-x}$Co$_x$)$_{48}$Cr$_{15}$Mo$_{14}$C$_{15}$B$_6$Tm$_2$ alloys was found to increase with increasing Co content up to 19.2 at%, and the maximum diameter of the rod was 16 mm for (Fe$_{0.8}$Co$_{0.2}$)$_{48}$Cr$_{15}$Mo$_{14}$C$_{15}$B$_6$Tm$_2$. The highest ΔT_x in the (Fe$_{1-x}$Co$_x$)$_{48}$Cr$_{15}$Mo$_{14}$C$_{15}$B$_6$Tm$_2$ alloys is 90K for Co$_{48}$Cr$_{15}$Mo$_{14}$C$_{15}$B$_6$Tm$_2$. These glassy alloys have high fracture strength above 4100 MPa which is independent of Co content. The high GFA is attributed to the retardation of precipitation of the crystalline phases caused by the formation of the stabilized glassy local structure in which trigonal prisms may be connected densely with each other. The simultaneous achievement of high strength and high GFA indicates the possibility of applying the (Fe, Co)-(Cr, Mo)-(C, B)-Tm glassy alloys to various engineering materials.

ACKNOWLEDGEMENT

This study is funded by the New Energy and Industrial Technology Development Organization (NEDO) under "Processing Technology for Metallic Glasses" project.

REFERENCES

[1] Z.P. Lu, C.T. Liu and W.D. Porter // *Appl. Phys. Lett.* **83** (2003) 2581.
[2] Z.P. Lu, C.T. Liu, J.R. Thompson and W.D. Porter // *Phys. Rev. Lett.* **92** (2004) 245503-1-4.
[3] S.J. Pang, T. Zhang, K. Asami and A. Inoue // *Corrosion Sci.* **44** (2002) 1847.
[4] T. Itoi and A. Inoue // *Mater. Trans., JIM* **41** (2000) 1256.
[5]A. Inoue // *Mater. Trans., JIM* **36** (1995) 866.
[6] A. Inoue and A. Takeuchi // *Mater. Trans.* **43** (2002) 1892.