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Internal friction induced by interstitial atoms in multicomponent glassy alloy and composite

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Abstract

Effects of the 2 at.% Nb addition on the stability and hydrogen-induced internal friction behavior of the $Ti_{34}Zr_{11}Cu_{47}Ni_8$ multicomponent glassy alloy have been investigated. Thermal analysis indicates that the supercooled liquid region decreases by adding Nb, indicating that 2 at.% Nb addition reduces glass forming ability. On the other hand, there is no effect of the Nb addition on the hydrogen content dependence of the peak internal friction and the peak temperature. Nb has no attractive interaction with Ti and Zr but is attracted to Ni atoms. The contrasting effects of Nb addition are thus attributable to its alternative effects on the local atomic structure, i.e. no effect of Nb on the local atomic structure around Ti and Zr having high affinity with hydrogen but strong effect on the environment of Ni.

Keywords: Internal friction; Glassy alloy; Damping material; Hydrogen; Local atomic structure

1. Introduction

Internal friction induced by interstitial atoms, especially hydrogens in multicomponent glassy alloys and their composites is interesting from the viewpoint of the local atomic structure of the glassy alloys because it is sensitive to the local anisotropic strain in the structure. In addition, multicomponent glassy alloys and composites are of interest as new candidate damping materials by using their-induced internal friction because they have high mechanical strength and available in a bulk form by a copper-mold casting [1,2].

Several groups have already reported studies of internal friction of the hydrogenated glassy alloys (HGAs) [3–6]. They have reported internal friction behaviors of the Zr-based HGAs because the Zr-based glassy alloys are the most available bulk glassy alloys. Ti-based glassy alloys can also absorb hydrogen. In addition, high damping Ti-based alloys open new damping application field since they are much lighter and less expensive than Zr-based ones. We have investigated the hydrogen-induced internal friction of Ti-rich glassy alloys [7–9]. For example, the effects of a small amount of Si addition on the stability and hydrogen-induced internal friction behavior of $Ti_{34}Zr_{11}Cu_{47}Ni_8$ HGAs were reported [8]. It was found that a $(Ti_{34}Zr_{11}Cu_{47}Ni_8)_{98}Si_2$ glassy alloy containing 14.4 at.% H showed high internal friction, Q^{-1} of about 4×10^{-2}. It was also found that the addition of such a small amount of Si was effective to increase the peak temperature. Besides, they had almost the same potential at about 250 K for the damping as crystalline Mn–Cu–Al and Cu–Al–Ni alloys at room temperature. Recently, the effects of the Pd addition below 10 at.% Pd on the stability and hydrogen-induced internal friction behavior of $Ti_{34}Zr_{11}Cu_{47}Ni_8$ glassy alloys were also investigated [9]. It was found that the internal friction peak temperatures of the $Ti_{34}Zr_{11}Cu_{47}Ni_8$–Pd HGAs with hydrogen content below about 30 at.% H were higher than those of the mother $Ti_{34}Zr_{11}Cu_{47}Ni_8$ HGAs, especially at the lower hydrogen contents below about 10 at.% H. The peak internal frictions of the $Ti_{34}Zr_{11}Cu_{47}Ni_8$–Pd HGAs increased with increasing hydrogen content below about 15 at.% H and then tended to saturate. These are in contrast to the effects of the Si addition mentioned above. It should be noted that Si and Pd have large negative mixing enthalpies with Ti and Zr which have high affinity with hydrogen, as shown in Table 1. This characteristic is easily expected to be effective to change local structure of the glassy alloy and the interstitial site distribution for hydrogen and the local strain anisotropy which strongly affect the hydrogen-induced internal friction. In this manuscript effects of 2 at.% Nb addition to the $Ti_{34}Zr_{11}Cu_{47}Ni_8$ glassy alloy have been described and compared to the reported Si and Pd effects. Contrary to the later cases, Nb has almost zero mixing enthalpy

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Table 1
Mixing enthalpy (kJ/mol) of Nb, Si and Pd against Ti, Zr, Cu and Ni

	Ti	Zr	Cu	Ni
Nb	2	4	3	−30
Si	−49	−67	−2	−23
Pd	−65	−91	−14	0

with Ti and Zr, as shown in Table 1 and the atomic radius of Nb (1.43 Å) is almost the same as that of Ti (1.47 Å).

2. Experimental procedure

Alloy ingots were prepared in an arc-melting furnace in purified argon atmosphere. Glassy alloys were prepared by the conventional single-roll melt spinning in purified argon atmosphere. The as-prepared ribbons were of about 1 mm in width and 20 μm in thickness. The glassy nature was verified by the X-ray diffraction using monochromatized Cu Kα radiation. Hydrogen was inserted by an electrochemical method using 1N H_2SO_4 solution. Hydrogen contents of the samples were determined by an inert gas carrier melting thermal conductimetric method. Internal friction was measured using a reed method between about 90 and 380 K in vacuum ($\sim 10^{-2}$ Pa). All samples were in ribbon shape. Measured length of the samples was about 14 mm. An electrostatic force was used for oscillation excitation of the sample. Electric capacity of the sample was measured to detect the oscillation of the sample. Internal friction was measured using a resonance oscillation method. Measurement frequency was about 120 Hz. Measurement strain width was about 1.0×10^{-6}. The details on the instrumental setup and measurement procedure were described elsewhere [6].

3. Results and discussion

The X-ray diffraction pattern of as-spun ribbons shows a halo pattern, indicating a single glassy phase. Fig. 1 shows the DSC curves of glassy $(Ti_{34}Zr_{11}Cu_{47}Ni_8)_{98}Nb_2$. The result of the mother $Ti_{34}Zr_{11}Cu_{47}Ni_8$ glassy alloy is also shown in the figure for comparison. A small endothermic phenomenon occurs before a large first exothermic peak. These correspond to the glass transition T_g (and passage to a supercooled liquid region) and crystallization, respectively. The glass transition temperature T_g and crystallization T_x are at 715 and 761 K, respectively.

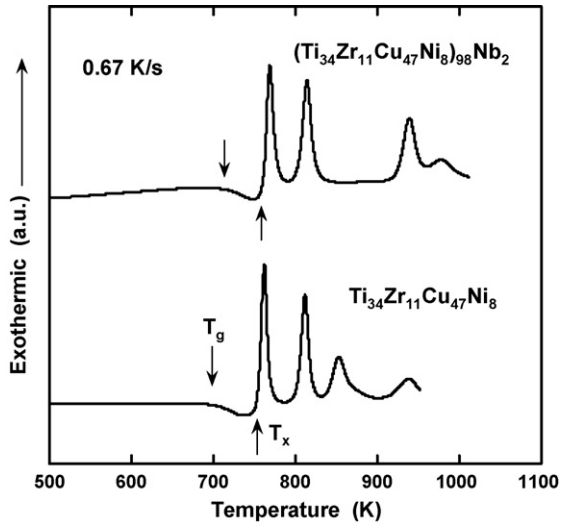

Fig. 1. DSC curves of $Ti_{34}Zr_{11}Cu_{47}Ni_8$ glassy with and without 2% Nb addition.

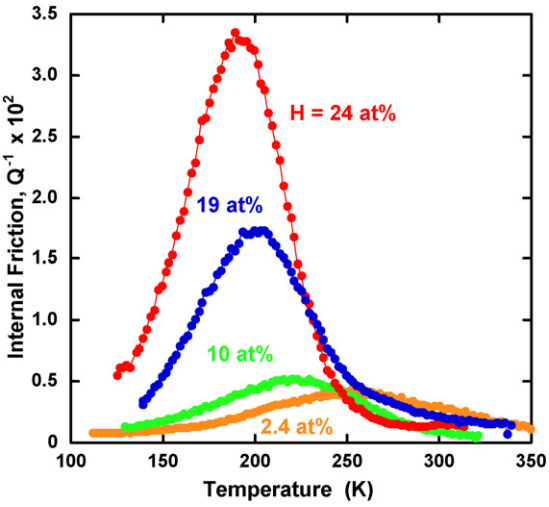

Fig. 2. Temperature dependence of internal friction of glassy alloy $Ti_{34}Zr_{11}Cu_{47}Ni_8$ with and without 2% Nb addition hydrogenated with various content of hydrogen.

Both are different from those of the $Ti_{34}Zr_{11}Cu_{47}Ni_8$ glassy alloys. The ΔT_x ($=T_x - T_g$) is 46 K and smaller than that of the $Ti_{34}Zr_{11}Cu_{47}Ni_8$ glassy alloy (56 K), indicating that 2 at.% Nb addition decreases the stability of the glassy state. There are other distinct exothermic peaks in the measured temperature range. It should be noted that the third and fourth peak temperatures are highly different from those of the $Ti_{34}Zr_{11}Cu_{47}Ni_8$ glassy alloy. These results indicate that the 2 at.% Nb affects the glass stability and simultaneously the local atomic structure.

Fig. 2 shows the temperature dependences of the internal friction of the $(Ti_{34}Zr_{11}Cu_{47}Ni_8)_{98}Nb_2$ HGAs with various contents of hydrogen. The main feature is a broad peak of the internal friction. This is one of typical characteristics of the hydrogen-induced internal friction of multicomponent HGA. Fig. 3(a) shows the hydrogen content dependence of the peak temperature of the $(Ti_{34}Zr_{11}Cu_{47}Ni_8)_{98}Nb_2$ HGAs. Data of the $Ti_{34}Zr_{11}Cu_{47}Ni_8$ HGAs [7] reported before are also plotted in this figure to compare. The peak temperatures of the $(Ti_{34}Zr_{11}Cu_{47}Ni_8)_{98}Nb_2$ HGAs decrease with increasing hydrogen content hyperbolically as do those of the mother $Ti_{34}Zr_{11}Cu_{47}Ni_8$ HGAs and the results are almost the same as that of the latter. In other words, there is no effect of the Nb addition on the peak temperature. Fig. 3(b) shows the hydrogen content dependences of the peak internal friction. Data of the $Ti_{34}Zr_{11}Cu_{47}Ni_8$ HGAs [7] are also plotted in this figure. The peak internal friction of the $(Ti_{34}Zr_{11}Cu_{47}Ni_8)_{98}Nb_2$ HGAs increases with increasing hydrogen content and the hydrogen content dependence of the peak internal friction is almost the same as that of the latter. In other words, there is again no effect of the Nb addition as for the peak temperature. These results are in contrast to the effective results of the Si or Pd addition reported before [8,9].

As mentioned above, Nb addition affects the glass stability. On the other hand, it does not affect the peak internal frictions and peak temperatures. These contrasting effects of the Nb addition are noteworthy to discuss. As shown in Table 1, Nb has

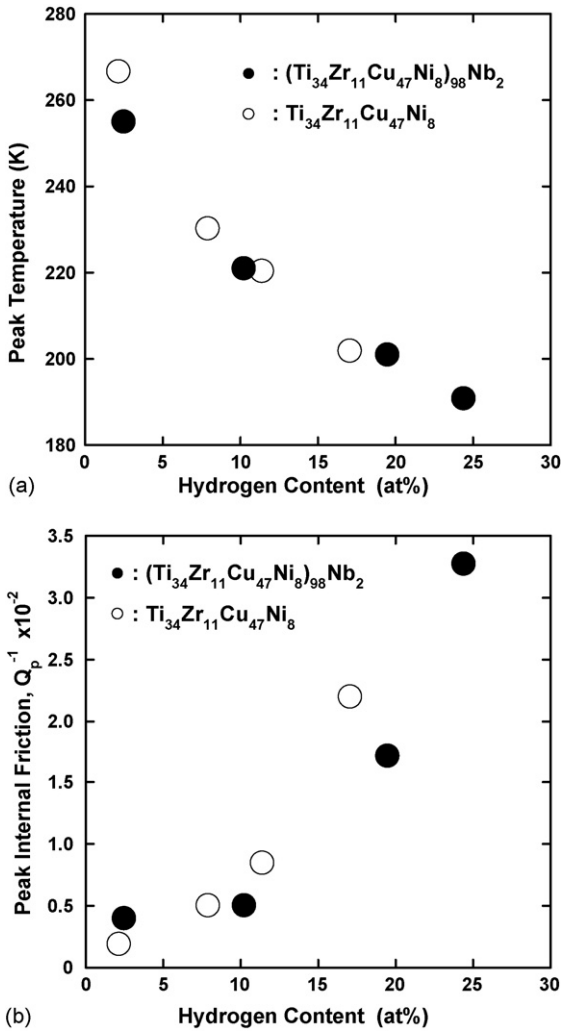

Fig. 3. Hydrogen content dependence of the internal friction of hydrogenated glassy $Ti_{34}Zr_{11}Cu_{47}Ni_8$ with and without 2% Nb addition: (a) peak temperature; (b) peak internal friction.

almost the same atomic radius as Ti and almost zero mixing enthalpy with Ti and Zr, which are elements having high affinity with hydrogen. Accordingly, it is expected that the Nb addition induces non or little change of the local atomic structure around Ti and Zr in the $(Ti_{34}Zr_{11}Cu_{47}Ni_8)_{98}Nb_2$ glassy alloy and just induced changes of that around Cu and Ni, probably around Ni because of the large negative mixing enthalpy between Nb and Ni, as shown in Table 1. The above contrasting effects of the Nb addition are attributable to these alternative effects on the local atomic structure.

4. Conclusion

Effects of 2 at.% Nb addition on the stability and hydrogen-induced internal friction behavior of the $Ti_{34}Zr_{11}Cu_{47}Ni_8$ glassy alloy have been investigated using the X-ray diffraction, DSC and the temperature dependence of the internal friction above 90 K. The thermal analysis indicates that the supercooled liquid region decreases by adding Nb, indicating that the 2 at.% Nb addition destabilizes the glass. It is found that there is no effect of the Nb addition on the hydrogen content dependence of the peak internal friction and the peak temperature. These contrasting effects of the Nb addition, i.e. an effect on the glass stability but no effects on the hydrogen-induced internal friction, are attributable to its effects on the local atomic structure and in particular, non-interaction Ti and Zr which have high affinity for hydrogen and likely strong interaction. These results are in contrast with those of Si or Pd addition reported before.

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