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Static mechanical properties for $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glass by ultrasonic velocity measurement

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Static Mechanical Properties for $Ca_{48}Mg_{27}Cu_{25}$ Bulk Metallic Glass by Ultrasonic Velocity Measurement

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Abstract. The static mechanical properties of a $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glass were investigated using a technique of ultrasonic measurement and compressive test. The Young's modulus (*E*), Poisson's ratio (*v*), shear modulus (*G*) and bulk modulus (*B*) for the $Ca_{48}Mg_{27}Cu_{25}$ alloy at room temperature are significantly smaller than those for Zr- and Pd-based bulk metallic glasses. The values of *E*, *v*, *G* and *B* for the $Ca_{48}Mg_{27}Cu_{25}$ alloy are 29.8GPa, 0.230, 12.1GPa and 18.4GPa, respectively. The results of compression test for the $Ca_{48}Mg_{27}Cu_{25}$ alloy have been also described.

1. Introduction

Recently, the relationships between the mechanical constants and the some essential properties for metallic glasses have been investigated. It has been reported that the Poisson's ratio (*v*) or the ratio of bulk modulus (*B*) to shear modulus (*G*) of glass is correlated to the fragility of a glass-forming liquid [1]. It is important to examine a correlation between the *v* (or *B*/*G*) and the fragility of metallic glasses. A low liquid fragility of metallic glass is expected to enhance the glass forming ability (GFA) of the alloy. The *v* (or *B*/*G*) of metallic glasses becomes to be an useful tool for the design of metallic glasses with a high GFA. It has been reported that there is an universal correlation between the *G*/*B* ratio and the fracture toughness for metallic glasses [2]. Metallic glass with a low *G*/*B* ratio exhibits the high fracture toughness. The relationship between the Young's modulus (*E*) and the glass transition temperature (T_g) for Zr-TM-Al (TM: Cu, Ni, or Co) bulk metallic glasses has been investigated [3]. The *E* of Zr-TM-Al alloys increases with increasing the T_g of alloys. The mechanical constants of metallic glasses are key parameters for the development of new metallic glasses or the improvement of mechanical properties for metallic glasses such as fracture toughness.

Recently, Ca-Mg-Cu metallic glasses, which have a remarkable low *E* and T_g, have been developed [4]. In this paper, we show the results of static mechanical properties for a $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glass measured by a continuous ultrasonic method. The mechanical constants of the $Ca_{48}Mg_{27}Cu_{25}$ alloy were compared to those of Zr- and Pd-based bulk metallic glasses.

2. Experimental Procedures

An alloy ingot of $Ca_{48}Mg_{27}Cu_{25}$ was prepared from pure Ca, Mg and Cu metals using an induction melting technique in an argon atmosphere. The $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glasses were fabricated using a copper-mold casting technique in an argon gas atmosphere. The plate-shaped bulk metallic glass with a width of 10 mm and thickness of 4 mm was fabricated. The rod-shaped bulk metallic glass with a diameter of 4 mm was fabricated. The plate- and rod-shaped samples were used for ultrasonic measurements and a compression test, respectively. The amorphous structure of the samples was examined by X-ray diffraction with Cu K_α radiation. The thermal stability of the samples was measured using a differential scanning calorimeter (DSC) under a flowing argon gas atmosphere with a heating rate of 20K/min. The density of sample was measured by an Archimedes method at room temperature. The compression test was performed by an Instron testing machine with a strain rate of 1×10^{-4} s^{-1} at room temperature. The ultrasonic velocities for specimen were measured using mechanical resonance of continuous ultrasonic waves [5, 6]. The longitudinal and transverse ultrasonic waves propagating through the sample were generated by $LiNbO_3$ transducers with 36 deg. Y cut and 41 deg. X cut, respectively. The transducers with a diameter of 5 mm and fundamental frequency of 10 MHz were used for the ultrasonic velocity measurements.

A wave length (λ_r) of ultrasonic wave with a mechanical resonance frequency (f_r), which propagates into sample have a relationship to thickness of sample (L) as $\lambda_r = 2L/m$ where m is a constant associated with the resonance order. Velocity of ultrasonic wave (V_s) is given as $V_s = \lambda_r x f_r$. Therefore, the V_s is rewritten as $V_s = 2L x f_r / m$. The ultrasonic velocity is obtained by the measurements of a series of resonance frequencies. The elastic stiffness constants of c_{11} and c_{44} are related to the velocities of longitudinal and transverse waves (V_l and V_t) as $c_{11} = \rho(V_l)^2$ and $c_{44} = \rho(V_t)^2$ where ρ is a mass density of sample. In general, E, v, G and B depend on elastic stiffness constants of c_{11}, c_{44} and c_{12} ($c_{12} = c_{11} - 2c_{44}$). For isotropic materials such as amorphous materials, the E, v, G and B are presented as $E = (c_{11} - c_{12})(c_{11} + 2c_{12})/(c_{11} + c_{12})$, $v = c_{12}/(c_{11} + c_{12})$, $G = c_{44} = (c_{11} - c_{12})/2$ and $B = (c_{11} + 2c_{12})/3$, respectively.

3. Results and Discussion

Figure 1 shows the X-ray diffraction patterns for the $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glasses. The broadened diffused-diffraction peak for both of the alloys is the typical characterization of amorphous structure. Figure 2 shows the DSC curves for the $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glasses. Table 1 shows the thermodynamic parameters for the $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glasses. Both of the alloys exhibit almost the same thermal stability.

Figure 3 shows the compressive stress-strain curve for the $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glass. The compressive fracture strength ($\sigma_{c,f}$) and compressive fracture strain ($\varepsilon_{c,f}$) of the $Ca_{48}Mg_{27}Cu_{25}$ alloy are 411 MPa and 1.4 %, respectively. The $\sigma_{c,f}$ for a $Ca_{57}Mg_{19}Cu_{24}$ alloy has been reported to be 545 MPa [4]. The $\sigma_{c,f}$ measured for the $Ca_{48}Mg_{27}Cu_{25}$ alloy is smaller than that for the $Ca_{57}Mg_{19}Cu_{24}$ alloy. The larger $\sigma_{c,f}$ value of $Ca_{57}Mg_{19}Cu_{24}$ alloy seems to mainly result from the increase of strong metallic bonding for Ca-Cu pair. The heats of mixing for the constituent elements affect the bonding force between the constituent elements. The negative heats of mixing are 20 kJ/mol for Ca-Mg pair, 20 kJ/mol for Mg-Cu pair and 39 kJ/mol for Ca-Cu pair [7]. Therefore, the Ca-Cu pair has the strongest bonding force among the pairs. The bonding number of Ca-Cu and Ca-Mg pairs increases with the Ca content for Ca-Mg-Cu alloy increases.

Table 2 shows the static mechanical properties for the $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glass. The E estimated for the $Ca_{48}Mg_{27}Cu_{25}$ alloy is in the range from 20GPa to 35GPa for Ca-based bulk metallic glasses. The v for the $Ca_{48}Mg_{27}Cu_{25}$ alloy is remarkably smaller than those reported for metallic glasses. The v of many metallic glasses is 0.30~0.42 [2]. The v of the $Ca_{48}Mg_{27}Cu_{25}$ alloy is between the v of 0.211 for window glass and the v of 0.266 for toughened glass [10]. The measurement results indicate that the $Ca_{48}Mg_{27}Cu_{25}$ alloy with the v of 0.230 and G/B of 0.658 is brittle. Metallic glasses with v <0.31~0.32 (or, equivalently, with G/B > 0.41~0.43) have been pointed out to be brittle [2]. On the other hand, compared to the $Zr_{50}Cu_{40}Al_{10}$ and $Pd_{44}Cu_{31}Ni_8P_{17}$ alloys, the features of mechanical constants for the $Ca_{48}Mg_{27}Cu_{25}$ alloy are as follows. (1) The E for the $Ca_{48}Mg_{27}Cu_{25}$ alloy is less than one third of those for the Zr- and Pd-based alloys. (2) The *ν* for the $Ca_{48}Mg_{27}Cu_{25}$ alloy is about two thirds of those for the Zr- and Pd-based alloys. (3) The *G* for the $Ca_{48}Mg_{27}Cu_{25}$ alloy is about one third of those for the Zr- and Pd-based alloys. (4) The *B* for the $Ca_{48}Mg_{27}Cu_{25}$ alloy is less than one fifth of those for the Zr- and Pd-based alloys.

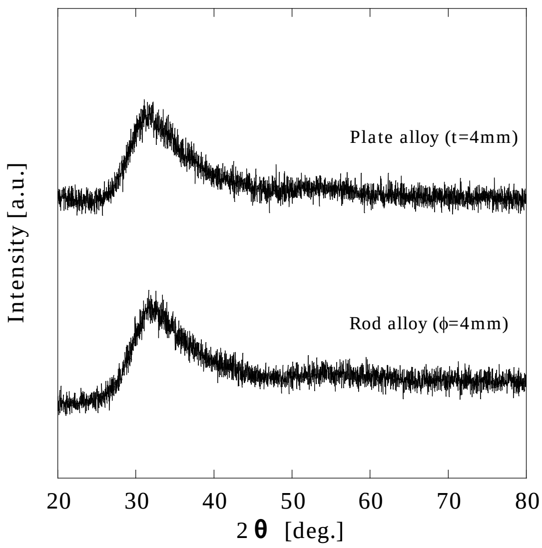

Figure 1. X-ray diffraction patterns for the $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glasses.

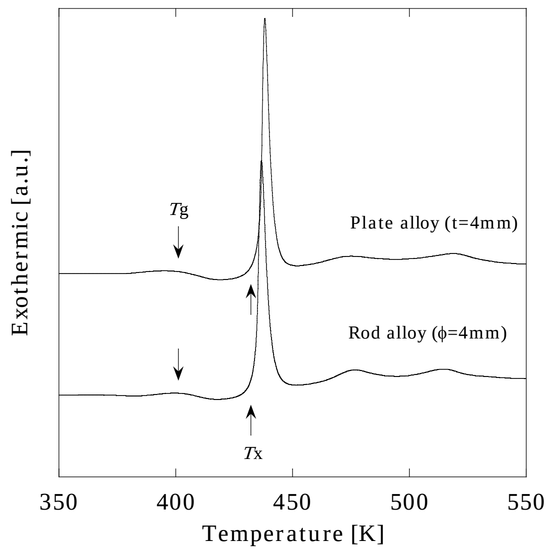

Figure 2. DSC curves for the $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glasses.

Table 1. Thermodynamic parameters for the $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glasses.

Samples	T_g (K)	T_x (K)	ΔT_x (K)
Plate-shaped alloy	401	433	32
Rod-shaped alloy	402	432	30

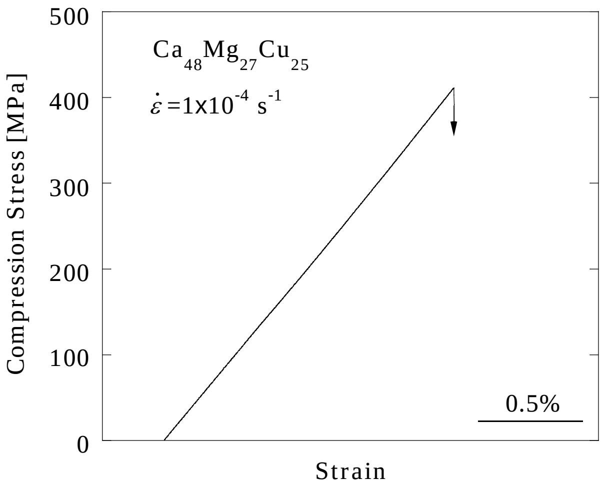

Figure 3. Compressive stress-strain curve for the $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glass.

Table 2. The mass density, ultrasonic velocities and mechanical constants for $Ca_{48}Mg_{27}Cu_{25}$, $Zr_{50}Cu_{40}Al_{10}$ and $Pd_{44}Cu_{31}Ni_8P_{17}$ bulk metallic glasses.

	$Ca_{48}Mg_{27}Cu_{25}$	$Zr_{50}Cu_{40}Al_{10}$ [a]	$Pd_{44}Cu_{31}Ni_8P_{17}$ [b]
ρ (g/cm^3)	2.428	6.853	9.549
V_l (km/s)	3.77	4.62	4.46
V_t (km/s)	2.23	2.21	1.90
c_{11} (GPa)	34.5	146	190
c_{44} (GPa)	12.1	33.4	34.6
c_{12} (GPa)	10.3	78.6	121
E (GPa)	29.8	90.7	96.2
v	0.230	0.352	0.389
G (GPa)	12.1	33.3	34.6
B (GPa)	18.4	101	144
B/G	1.52	3.03	4.16
G/B	0.658	0.330	0.240

[a] Reference [8]

[b] Reference [9]

4. Conclusions

The mechanical constants of a $Ca_{48}Mg_{27}Cu_{25}$ bulk metallic glass were measured by a continuous ultrasonic method. The $Ca_{48}Mg_{27}Cu_{25}$ alloy exhibits Young's modulus (E) of 29.8GPa, Poisson's ratio (v) of 0.230, shear modulus (G) of 12.1GPa, bulk modulus (B) of 18.4GPa, compressive fracture strength of 411MPa and compressive fracture strain 1.4%. Compared to $Zr_{50}Cu_{40}Al_{10}$ and $Pd_{44}Cu_{31}Ni_8P_{17}$ bulk metallic glasses, the E, v, G and B for the $Ca_{48}Mg_{27}Cu_{25}$ alloy at room temperature are remarkably smaller. The v of the $Ca_{48}Mg_{27}Cu_{25}$ alloy is close to those for window and toughened glasses.

Acknowledgments

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