Title	Measurement of fracture behavior of Zr-based metallic glass by thermography
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Citation	Transactions of JWRI. 2010, 39(2), p. 319-321
Version Type	VoR
URL	https://doi.org/10.18910/24795
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Measurement of fracture behavior of Zr-based metallic glass by thermography[†]

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KEY WORDS: (Zr-based metallic glass) (High speed tensile test) (Thermography) (Fracture) (Spark) (Hot oxide particle) (Liquid droplet)

1. Introduction

Since metallic glass is an amorphous solid, it offers approximately three times the strength of crystalline materials and it breaks without plastic deformation in tensile tests[1)]. Therefore, it is considered that enormous adiabatic deformation will occur. Molten particles or liquefied fractures are often observed after tensile tests on metallic glass. Recently, Wang et al. conducted fatigue tests on Zr-based metallic glass and reported the occurrence of sparking at fatigue fracture, which was photographed using an IR thermograph camera[1]. In the present study, the high-speed tensile tests were performed on Zr-based metallic glass at various strain rates from low to high speed using a high-speed tensile test unit of the dynamic structural testing system. The sparking phenomenon at tensile fracture was photographed using a IR thermograph camera. We also elucidated a mechanism generating the sparking phenomenon by examining fracture surfaces and using material science methods such as X-ray analysis[2].

2. Experimental

Zr-based metallic glasses of $Zr_{48}Cu_{36}Al_8Ag_8$ and $Zr_{55}Cu_{30}Al_{10}Ni_5$ were prepared at Tohoku University by casting. **Figure 1** shows a photograph of a tensile test specimen. The specimen was smooth and rod-shaped. The specimen geometries were 5 mm in diameter, 30 mm in gauge length and 60 mm in overall length. The amorphous nature of the structure was confirmed by halo pattern detection through X-ray diffraction (XRD).

The tensile crosshead speed was varied from 0.001 to 1200 mm/s. The strain rate ranged from 1.7×10^{-5} s^{-1} to 2.3×10^{1} s^{-1}. The test temperature was room temperature. To observe the sparking phenomenon of the metallic glass at fracture, the infrared (IR) thermograph was used. An infrared thermograph camera (Titanium 530L, Cedip) was used for thermograph detection; the sensor was made of mercury cadmium telluride (MCT) with 7.6–9.1 μm wavelength and 25-mK temperature resolution. A 128×128-pixel area (4×4 cm) was measured at 700 Hz by an IR thermograph camera. A thin submicron graphite coating was provided to reduce the heat reflection on the measurement sample surface. After fracture, amorphous structures and crystallization of $Zr_{48}Cu_{36}Al_8Ag_8$ metallic glass specimens were analyzed using SEM observation of the fracture surface and XRD analysis.

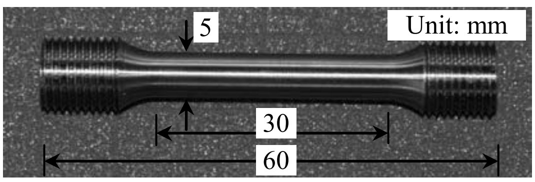

Fig. 1 Photograph of specimen.

3. Sparking Phenomenon

The sparking phenomenon was observed in all $Zr_{48}Cu_{36}Al_8Ag_8$ and $Zr_{55}Cu_{30}Al_{10}Ni_5$ metallic glass specimens regardless of strain rate.

Figure 2 shows IR thermograph camera photographs of high-speed tensile fracture of $Zr_{48}Cu_{36}Al_8Ag_8$ metallic glass at 10 mm/s crosshead speed. It was detected at 1/700 second per frame. While fracture has not yet started in (a), the fracture section is indicated in red by the sparks in (b), and rough flying particles are seen at the moment of fracture. Particles are also seen in (c) and (d). This indicates that the fracture occurred instantaneously and that the oxide particles or liquid droplets appear as particles. Although this can only be seen as a momentary spark when observed visually, it could be detected with an IR thermograph camera.

Figure 3 shows IR thermograph camera photographs of high-speed tensile fracture of $Zr_{55}Cu_{30}Al_{10}Ni_5$ metallic glass at 1200 mm/s crosshead speed. While fracture has not yet started in (a), the fracture section is indicated in red. Particles are seen in (c) and (d) as same as $Zr_{48}Cu_{36}Al_8Ag_8$, but the size of particles is very small, and they are few in number compared to those for $Zr_{48}Cu_{36}Al_8Ag_8$ metallic glass.

As discussed above, it is considered that the particles are flying and these are observed as sparks at the moment of fracture of Zr-based metallic glass. However the number and size of particles are different for compositions of Zr-

† Received on 30 September 2010
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Transactions of JWRI is published by Joining and Welding Research Institute, Osaka University, Ibaraki, Osaka 567-0047, Japan

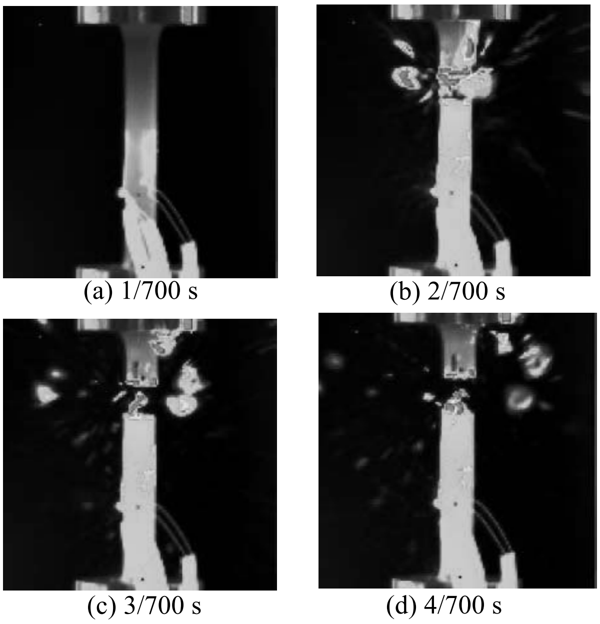

Fig. 2 Moment of fracturing of $Zr_{48}Cu_{36}Al_8Ag_8$ metallic glass (Crosshead speed 10 mm/s).

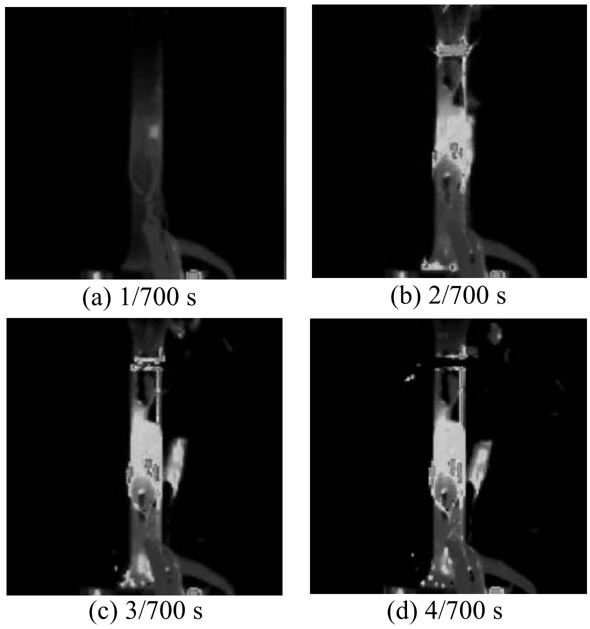

Fig. 3 Moment of fracturing of $Zr_{55}Cu_{30}Al_{10}Ni_5$ metallic glass (Crosshead speed 1200 mm/s.)

based metallic glass.

The mechanism generating this sparking phenomenon has been suggested as follows: (1) thermal insulation phenomenon, (2) spattering of hot oxide particles, (3) spattering of liquid droplets, (4) process of vanishing or elimination of excess electrons specific to metallic glass, and so on. This sparking phenomenon seems to be unique to amorphous metallic glass.

Considering that the flying particles are also attached to the fracture surface, we examined the fracture surface using SEM observation and XRD analysis. **Figure 4** (a) and (b) shows the fracture surface of $Zr_{48}Cu_{36}Al_8Ag_8$ metallic glass in the tensile test at a low and high strain rate. Regardless of the strain rate, smooth dimples (A) and smooth areas (B) are observed, in addition to the rough dimple fractures normally observed that indicate ductile fracture. The smooth dimples (A) are regarded as attached marks of flying particles due to sparking. These indicate that the hot oxide particles collided with the fracture surface and become attached. The smooth areas (B) are regarded as melting and solidification cracking. This indicates that it was heated to the melting temperature of metallic glass, which is 900°C or higher, by thermal insulation change, etc., during the tensile fracture of the metallic glass, causing it to melt, and then generate high-temperature cracks during cooling. The large localized deformation and the remelting feature are believed to be due to the high strength, large elastic energy and low melting temperature of the alloy, which are common characteristics of bulk metallic glass.

As for the results of XRD analysis, most of the fractures had a halo pattern indicating an amorphous structure. However, a peak for ZrO_2 oxide film or oxide particles or a crystallization peak for substances such as $ZrNi_2$ were observed in some parts along with the halo patterns. Thus, some of the fracture particles become attached to the fracture surface as flying particles at the moment of fracture and the fracture surface was heated to high temperatures, which caused oxidation.

From these observations, the flying particles, that are observed as the sparks, are hot oxide particles and liquid droplets.

4. Conclusions

The conclusions of this study are summarized as follows.

(1) The sparking phenomenon was also observed in $Zr_{48}Cu_{36}Al_8Ag_8$ and $Zr_{55}Cu_{30}Al_{10}Ni_5$ metallic glass specimens regardless of strain rate at the moment of fracture. However the amount of sparks are different,

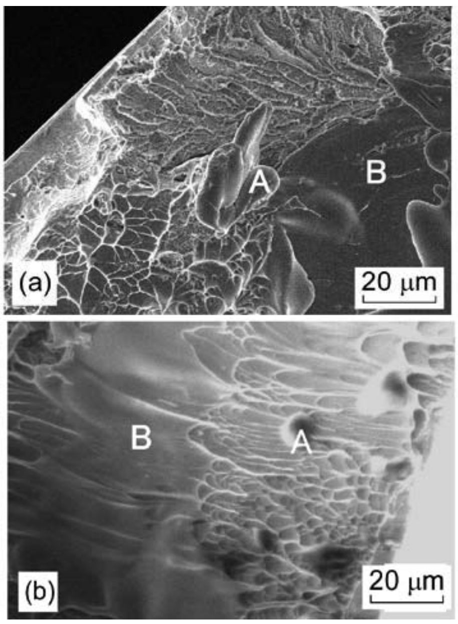

Fig. 4 Fracture surfaces of tensile test. (a) Crosshead speed 0.001 mm/s. (b) Crosshead speed 1200 mm/s.

depending on the components of Zr-based metallic glass.

(2) It is revealed by SEM observation and XRD analysis of the fracture surface that the flying particles of hot oxide particles and liquid droplets are observed as sparks at the moment of fracture. Although this can only be seen as a momentary spark when observed visually, it could be detected with an IR thermograph camera.

Acknowledgements

The authors sincerely thank Professor Inoue and Associate Professor Kimura, Tohoku University for supplying the samples for this study. The authors also thank Technical Specialist Mr. Nakatsuji, for his assistance with the experiment. This work was supported by Grant-in-Aid for Cooperative Research Project of Nationwide Joint-Use Research Institute on Development Base of Joining Technology for New Metallic Glasses and Inorganic Materials from The Ministry of Education, Culture, Sports, Science and Technology, Japan.

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