Available online at www.sciencedirect.com
ScienceDirect
Materials Letters 62 (2008) 1707 – 1710
materials letters
www.elsevier.com/locate/matlet

(Ni–P)/graphite composite film plated on bulk metallic glass

Yanbin Han, Mingzhen Ma, Gong Li, Jinku Yu, Guangyi Liu, Qin Jing, Xiaobo Chen, Qiang Wang, Riping Liu *

State Key Laboratory of Metastable Materials Science & Technology, Yanshan University, Qinhuangdao 066004, China

Received 10 November 2006; accepted 25 September 2007
Available online 2 October 2007

Abstract

Zr-based bulk metallic glass was subjected to electro-less plating of (Ni–P)/graphite composite film in order to avoid cold welding in ultrahigh vacuum condition. The plated film consisted of Ni–P amorphous phase, fine nickel crystals and fine graphite particles. Measurements of the adhesion coefficient between the two sample surfaces contacted in high vacuum indicated that the cold welding phenomenon appeared for the naked surfaces of the Zr-based metallic glass was essentially depressed after the deposition treatment on the surfaces.

Keywords: Chemical synthesis; Cold welding; Adhesion coefficient; Amorphous alloys

1. Introduction

The study and application of bulk metallic glasses have attracted increasing attention due to their high yield strength, hardness, elastic strain limit, anti-fatigue and anti-corrosion properties, etc. [1]. Especially for the past 20years, new breeds of multi-composition bulk metallic glasses have been discovered, such as Zr–Ti–Cu–Ni–Be [2] and Mg–Cu–Y [3], which greatly improve the glass-forming ability and the formation of glass is therefore unnecessary with ultrahigh cooling rates. Breaking of the limitation of cooling rates emits vital force and energy for the development of bulk metallic glasses. Many academic and basic studies have been done, such as in the invention of new glassy alloy systems, glass-forming ability [4], thermal stability [5], supercooled liquid region [6], crystallization of amorphous alloy [7], mechanical performance [8], etc. But little has been done on the cold welding phenomenon between two contacting parts used under ultrahigh vacuum conditions, such as in the case of space. Under the high vacuum condition in outer space [9–11], two clean contacting surfaces of metallic parts will possibly be adhered together for the increasing load and friction. This is the so-called "cold welding" phenomenon and often observed for metallic materials. In order to realize the application of bulk metallic glasses in space environment, the cold welding phenomenon between metallic glasses should be studied and the ways to avoid the cold welding should be investigated. In this paper, we report the results of the cold welding experiments between Zr-based metallic glasses. And avoiding of the cold welding is realized by

Table 1
Solutions and parameters for electro-less composite plating

	Solution A	Solution B	Solution C
Nickel sulphate	20–60 g/L	20–40 g/L	20–60 g/L
Sodium hypophosphite	10–40 g/L	18–36 g/L	10–40 g/L
Sodium acetate	0–60 g/L	0–60 g/L	0–60 g/L
Kaliumiodate	10–20 mg/L	–	10–20 mg/L
Sodium citrate	–	0–70 g/L	–
$CH_3(CH_2)_{10}CH_2SO_3Na$	–	0.01 g/L	–
Lactic acid	0–10 mL/L	0–30 mL/L	0–10 mL/L
pH	3–14	3–14	3–14
Temperature	70–90 °C	70–95 °C	70–90 °C
Graphite powder	–	2–30 g/L	2–30 g/L
Plating time	0.5–1 h	0.5–3 h	0.5–1 h

* Corresponding author. Tel.: +86 335 8074723; fax: +86 335 8074545.
E-mail address: riping@ysu.edu.cn (R. Liu).

0167-577X/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.matlet.2007.09.067

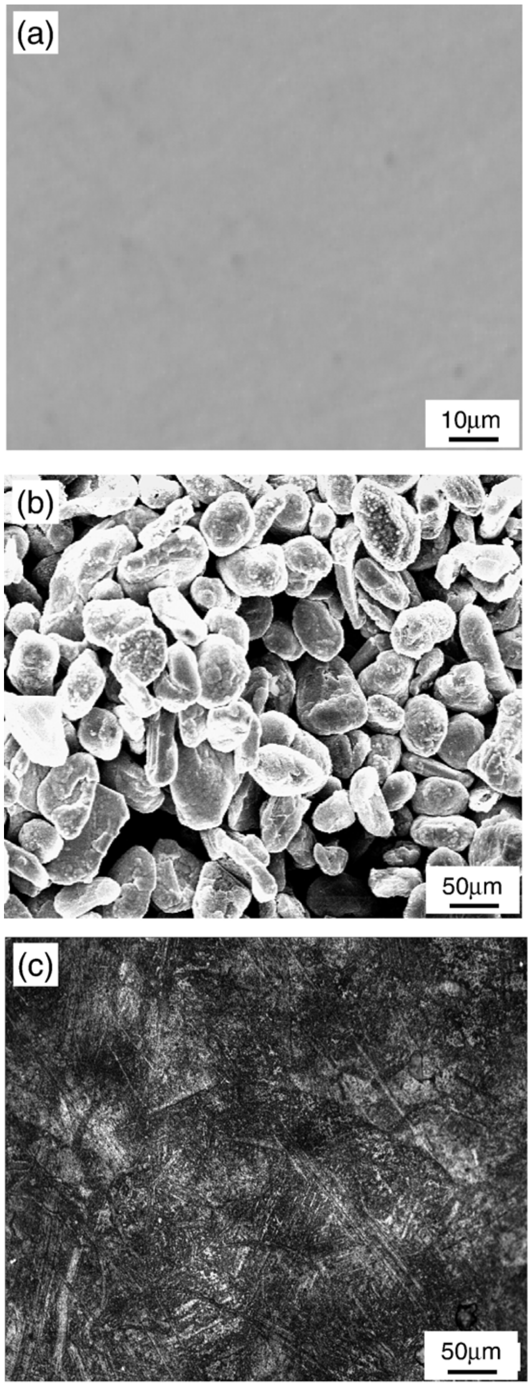

Fig. 1. Surface morphologies of the samples: (a) with Ni–P film, (b) with (Ni–P)/graphite film by solution B, and (c) with (Ni–P)/graphite film by solution C.

plating (Ni–P)/graphite composite film on the surface of the metallic glass.

2. Experimental methods

$Zr_{41}Ti_{14}Cu_{12.5}Ni_{10}Be_{22.5}$ bulk metallic glass rods were prepared by casting of the alloy melt into a copper-mould in an argon atmosphere. The sample cut from the rods had a plate-like shape with a thickness of 6mm. A smooth surface is necessary for the following film deposition and for measurement of the adhesion coefficient. The sample surfaces were thus polished with water-fast sand paper (1200#).

The tidy surface of the bulk metallic glass was firstly electroless plated with a film of Ni–P amorphous alloy. Then graphite particles were co-plated with Ni–P amorphous alloy. The plating solutions adopted are shown in Table 1.

Three different films were plated, Ni–P alloy film by solution A, (Ni–P)/graphite film by solution B [12,13], and (Ni–P)/graphite film by solution C, respectively. SEM observation, X-ray diffraction analyses and adhesion coefficient measurement were performed in the present study. The adhesion coefficient measurement was performed by Ultra-High Vacuum Space Environment Simulator (Type LW-1) in Lanzhou Institute of Physics.

3. Results and discussion

The surface morphologies of the bulk metallic glass with Ni–P film and (Ni–P)/graphite films plated by different solutions are shown in Fig. 1. The surface of the sample plated with Ni–P alloy film is bright and shining (Fig. 1a). The surface of the sample with (Ni–P)/graphite film by solution B shows apparently accumulation of the graphite particles with a dimension of about 8–12µm in diameter (Fig. 1b). Such a kind of film is easy to be scratched away from the base metallic

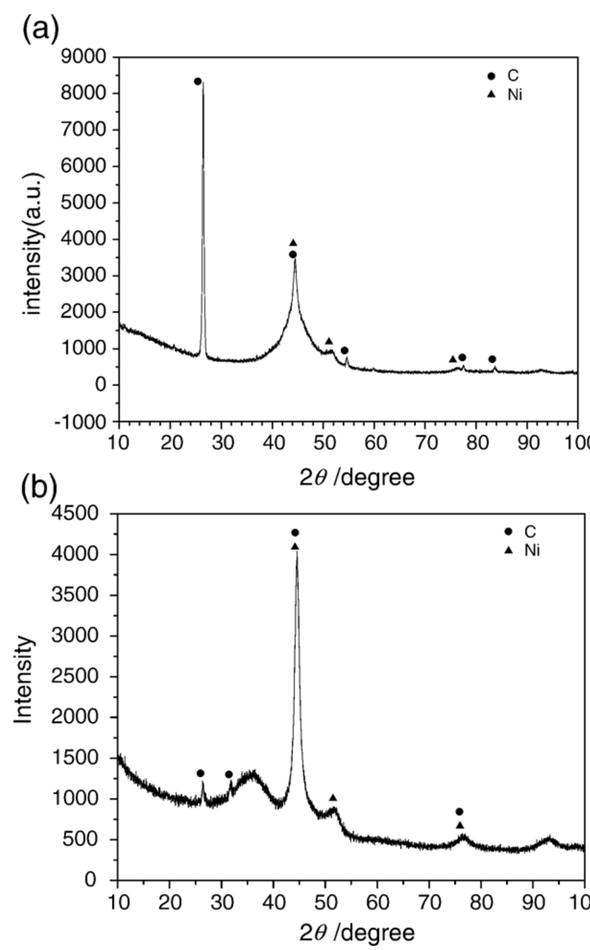

Fig. 2. XRD spectra of (Ni–P)/graphite films plated (a) by solution B and (b) by solution C.

glass by a sand paper. A smooth surface morphology is seen for the sample plated with (Ni–P)/graphite film by solution C (Fig. 1c). The surface is uniform and the graphite particles cannot be distinguished. The thickness of the film is about 2–3μm in this case, which is measured by AMBIOS TECHNOLOGY INC XP-2TM. The film is stable even ground by a sand paper, with no evident scratches left on a macro-scale, which indicates an improved quality in comparison with that plated with solution B.

In order to identify the phases and the composition of the composite film, X-ray diffraction analysis was used and the results are shown in Fig. 2. It can be seen that the film plated with solution B consists of graphite phase and fine nickel crystalline phase, which can be confirmed by the broadening of the nickel peak. Graphite phase can also be obviously seen with high peak intensity. The film plated by the solution C consists of amorphous phase, fine nickel crystalline phase and graphite phase.

To imitate the real working condition in space, the coated films were exposed to wear resistant test under different load and rotation speed. The composite film did not flake away, which indicated good bonding strength.

Under the vacuum of 10^{-7}Pa, which was used to imitate the vacuum condition in space in this work, the adhesion coefficients, which is defined as $\alpha=F_c/F$ ($F_c=K_d\times(V_s-V_z)$), $F=K_a\times V_{ma}$, α is adhesion coefficient, F_c is adhesion force or cold welding force, F is loading force, K_d is unloading sensitivity, V_s is separating voltage, V_z is zero voltage, K_a is loading sensitivity, were tested for two different kinds of surface contacts, Zr-based bulk metallic glass to Zr-based bulk metallic glass and Zr-based bulk metallic glass coated with the composite film to Zr-based bulk metallic glass coated with the composite film respectively.

Normally cold welding may occur when the adhesion coefficient is bigger than 10^{-2}. Consequently application of the material is not suitable if cold welding is required be avoided. On the other hand, when the adhesion coefficient is smaller than 10^{-4}, cold welding phenomenon will basically not take place. Thus application of the material in space is safe with respect to cold welding. In the present work, the adhesion coefficients measured were shown in Fig. 3. Apparently, cold welding may occur in space for the contact of two naked glassy surfaces, because the adhesion coefficient measured is bigger than 10^{-2}. For the contact of two surfaces coated with Ni–P/graphite films, the adhesion coefficient is smaller than 10^{-4}, which indicates that such a contact will be free of cold welding. Thus it can be used in space.

4. Conclusion

For the potential applications of the bulk metallic glasses in space, cold welding of two contacting surfaces in ultrahigh

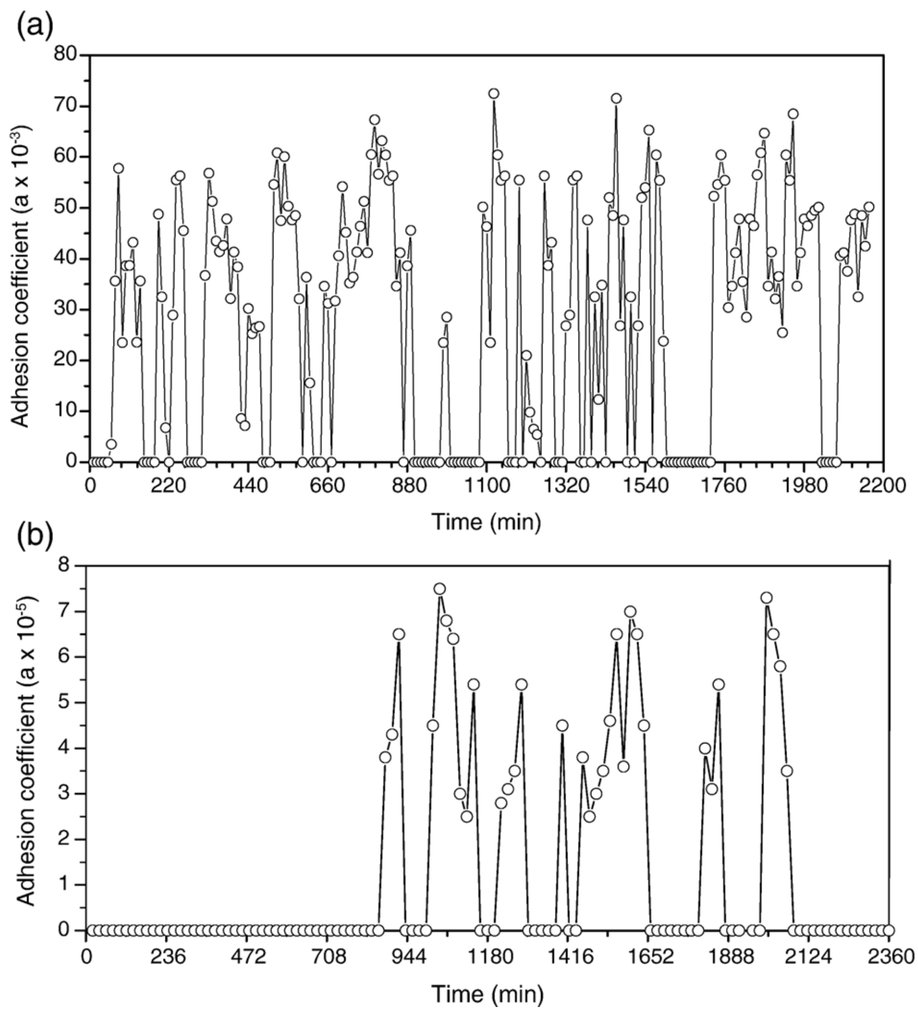

Fig. 3. Adhesion coefficient test results for two contacting surfaces of (a) naked Zr-based bulk metallic glassy samples and (b) samples plated with (Ni–P)/graphite composite films.

vacuum was tested. It was found that cold welding of two naked tidy glassy surfaces was easily to be welded. To overcome this disadvantage, (Ni–P)/graphite composite film was plated on the surface of bulk metallic glass by electro-less plating with a selected solution. The existence of this self-lubricant composite film indeed avoids the cold welding phenomenon.

Acknowledgements

This work was supported by the NSFC (Grant No. 50325103/50731005), SKPBRC (Grant No. 2006CB605201-2/2007CB616915), PCSIRT (Grant No. IRT0650) and Hebei NSF (Grant No. E2004000209). The authors are very grateful to Lanzhou Institute of Physics.

References

[1] Q.S. Zhang, H.F. Zhang, Y.F. Deng, Bulk metallic glass formation of Cu–Zr–Ti–Sn alloys, Scrip Mater. 49 (2003) 273.
[2] A. Peker, W.L. Johnson, A highly processing metallic glass $Zr_{41.5}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5}$, Appl Phys. Lett. 63 (17) (1993) 2342.
[3] A. Inoue, T. Nakamura, N. Nishiyama, T. Masumoto, Mg–Cu–Y bulk amorphous alloys with high-tensile strength produced by a high-pressure die-casting method, J. Mater Trans. JIM 33 (10) (1992) 937.
[4] Z.P. Lu, Y. Li, S.C. Ng, Reduced glass transition temperature and glass forming ability of bulk glass forming alloys, J. Non-Cryst. Solids 270 (1-3) (2000) 103.
[5] D. Fatay, J. Gubicza, P. Szommer, Thermal stability and mechanical properties of a Zr-based bulk amorphous alloy, Mater. Sci. Eng., A Struct. Mater.: Prop. Microstruct. Process. 7 (2004) 387.
[6] A. Inoue, T. Zhang, T. Masumoto, Al–La–Ni amorphous alloy with a wide super cooled liquid region, J. Mater. Trans. JIM 30 (1989) 965.
[7] C. Li, J. Saida, M. Kiminami, A. Inoue, Dynamic crystallization process in a supercooled liquid region of $Cu_{40}Ti_{30}Ni_{15}Zr_{10}Sn_5$ amorphous alloy, J. Non-Crystal. Solids 261 (1-3) (2000) 108.
[8] H. Kimura, M. Kishida, T. Kaneko, A. Inoue, T. Masumoto, Physical and mechanical-properties of Zr-based metallic glasses, J. Mater. Trans JIM 36 (7) (1995) 890.
[9] D. Wyn-Roberts, New frontiers for space tribology, Tribol. Int. 23 (1990) 149.
[10] R.L. Fursaro, Self-lubricating polymer composites and polymer transfer film lubrication for space application, Tribol. Int. 23 (1990) 105.
[11] L.V. Santos, V.J. Trava-Airoldi, E.J. Corat, J. Nogueira, N.F. Leite, DLC cold welding prevention films on a Ti_6Al_4V alloy for space applications, Surf. Coat. Technol. 200 (2006) 2587.
[12] X.X. Jiang, W. Shen, Theoretics and Practice of Electroless Plating, National Defence Industry Press of Peking, vol. 4, 2000 (In Chinese).
[13] N. Li, G.W. Yuan, D.Y. Li, Theoretics and Technology of Ni-based Alloys by Electroless Plating, Harbin Institute of Technology Press, 2002, p. 57, (In Chinese).