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Erosion–corrosion behavior of Zr-based bulk metallic glass in saline-sand slurry

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ABSTRACT

Bulk metallic glass (BMG) is supposed to have a good erosion–corrosion (E–C) resistance due to its high hardness and good corrosion resistance. To reveal the E–C behavior, $Zr_{55}Cu_{30}Ni_{10}Al_5 \cdot$BMG is investigated using a slurry pot erosion tester. Experimental results show the volume loss rate of BMG increases with an increase in the particle size, sand concentration or impact velocity. The corrosion current density and the synergism rate increase with the increasing impact velocity. During E–C process, the surface microstructure transforms gradually from pure amorphous to composite mixture of crystalline and amorphous phases. The E–C resistance of BMG is better than that of 304 stainless steel, but not as expected as its high hardness.

1. Introduction

Bulk metallic glass (BMG) is a different category of material that is characterized by their amorphous structure and metallic bond. Because of their disordered structure, BMG has several unique properties that make it attractive for tribological and corrosive applications, [1,2]. Using pin-on-disc measurement, Tam [3] found Cu-based BMG had a better wear resistance with respect to the 304 stainless steel (SS). Zr-based bulk metallic glass was even fabricated as bearing rollers, which shows a better wear resistance than the commercial GCr15 ones [4]. However, due to the formation of tensile micro-cracks, the abrasive wear of BMG is not consistent with their high hardness [2]. Meanwhile, BMG has superior corrosion resistance. For example, 304L SS exhibits about 1000 times higher corrosion rate in 1 M H_2SO_4 solution and about four times higher corrosion rate in 3.5 wt% NaCl solutions compared with the Cu–Zr-based BMGs [5]. Moreover, in terms of incubation time and maximum rate of erosion, the cavitation erosion resistance of Zr-based BMGs is approximately 10 times higher than that of S30431 austenitic SS [6]. Therefore, regarding to good abrasion, corrosion and cavitation erosion resistance, BMG is supposed to have good erosion–corrosion (E–C) resistance.

To most of our knowledge, research work on E–C resistance of BMG is limited in published literatures. Because of the limitation of critical size, BMG is more applicable to fabricate as an amorphous metal coating than an end-use BMG part. Consequently, Fe-based amorphous metallic coatings were synthesized to resist E–C for marine pump in sand-containing NaCl solutions and their E–C rates were found only about 10% to 25% of 304 SS [7]. However, the microstructure of amorphous metal coating is not as same as that of BMG, regarding on pores or amorphous phase content. For this reason, the metallic glass coating on 304L SS exhibited marginally lower corrosion resistance than its metallic glass alloy [8]. Therefore, the BMG with pure amorphous structure is better for study on its E–C behavior. In this study, a casted Zr-based BMG rod without crystalline structure were used to investigate its E–C behavior in saline-sand slurry. And the E–C behavior was also compared with common AISI 304 SS.

2. Material and methods

2.1. Sample preparation

$Zr_{55}Cu_{30}Ni_{10}Al_5$ quaternary alloy ingots were prepared by arc-melting a mixture of pure element powders with the purity of 99.9% under a Ti-gettered argon atmosphere in a water-cooled copper crucible. Each of the ingots was melted four times to ensure uniformity in composition. Sample rods with a diameter of 4 mm were synthesized respectively by suction casting into a copper mold under a purified argon atmosphere. Then the BMG samples were cut into $\emptyset\ 4 \times 40$ mm. For comparison, AISI 304 SS was also cut into the same size. The mechanical properties of them are shown in Table 1 [9,10].

2.2. Erosion–corrosion test

E–C experiment were carried out in a slurry pot erosion tester (MSH erosion–corrosion system, China) equipped with an electrochemical detective system. The schematic diagram of this

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Table 1
Mechanical property of Zr-based BMG and AISI 304 SS.

Mechanical properties	$Zr_{55}Cu_{30}Ni_{10}Al_5$ [9]	AISI 304 SS [10]
Vickers hardness (kg/mm^2)	488	200
Elastic modulus (GPa)	103	193
Ultimate compressive stress (MPa)	1820	–
Ultimate tensile stress (MPa)	–	515
Percent of compression to fracture (%)	0.025	–
Percent of elongation to fracture (%)	–	40
Fracture toughness (MPa m$^{1/2}$)	40–55*	75–100

* Data come from $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10.0}Be_{22.5}$ · BMG [10].

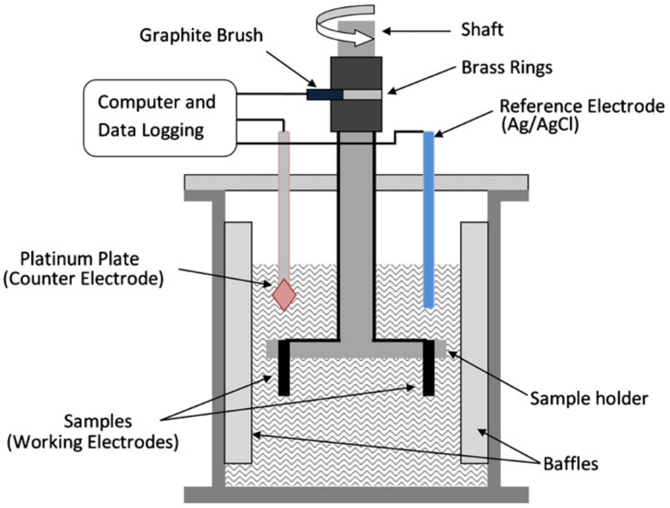

Fig. 1. Schematic diagram of slurry pot erosion tester.

slurry erosion tester is shown in Fig. 1. It is mainly consisted of a rotating device. The specimens were mounted in holders at the edge of the rotating disk and the motor drove the sample rotary in the slurry at room temperature. The rotation velocity was varied at four values 200, 300, 500 and 800 rpm in this study, which corresponding to impact velocities of ca. 2.09, 3.14, 5.23 and 8.37 m s^{-1}, respectively. All the samples were firstly polished by SiC paper in a grit of ♯800 and degreased in acetone, then cleaned by alcohol and air-dried. Angular quartz particles with the mean size of 26–40 mesh (about 370–570 μm), 80–120 mesh (about 120–180 μm) and 150–200 mesh (about 75–100 μm) obtained from Yangtze Delta were used in these E–C tests. The morphology of the typical sand particles with 80–120 mesh is shown in Fig. 2. For each E–C test, the slurry pot was filled with 10 L aqueous solution containing 3.5% NaCl with 1 wt%, 3 wt% and 5 wt% sand particles, respectively. The pH value was detected with a pH meter (PHS-25CW, Shanghai), and the average pH value of the aqueous solution with 3.5% NaCl and 3 wt% sand particles is 6.84. All the specimens were ultrasonically cleaned in acetone before and after each test and weighted for the total mass loss using a precision electronic balance with a sensitivity of 0.1 mg. For all samples, three replicate tests were conducted for at least 2 h and each value reported in this paper was an average of three measurements. The old slurry was replaced by fresh one for every three tests. To compare the E–C rates of BMG and 304 SS, the mass losses were transformed to their volume loss. The densities of 304 SS and $Zr_{55}Cu_{30}Ni_{10}Al_5$ · BMG are 8.03 and 6.787 g cm^{-3} [11], respectively. In this present study, the volume loss caused by pure erosion (V_e) was assumed to be equal to volume loss in distilled water-containing sand particles. To the volume loss caused by pure corrosion (V_c), the test was carried out in 3.5% NaCl solution without sand particles. The synergism between erosion and corrosion (ΔV_{ec}) was expressed as the difference between the total volume loss (V_t) and the sum of V_e and V_c.

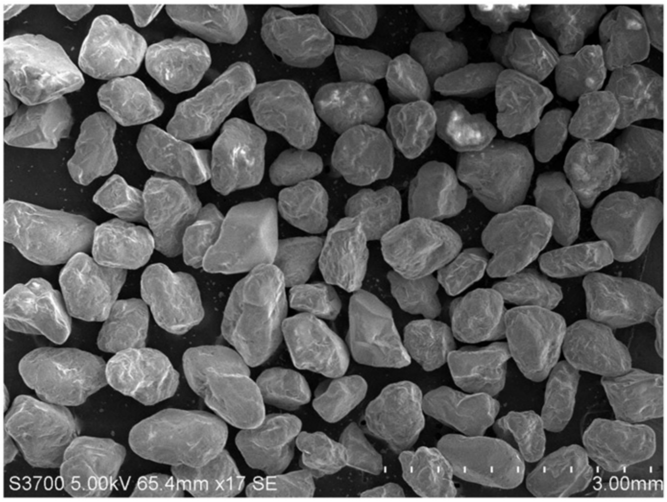

Fig. 2. Morphology of the sand particles with 80–120 mesh (about 120–180 μm).

2.3. Material characterization

X-ray diffraction (XRD) measurements of the Zr-based BMGs were made before and after E–C with a Rigaku D/max 2500PC using Cu K_α radiation. The surface morphologies of the test samples were observed by HITACHI S2400-N SEM to obtain a physical understanding of the E–C mechanisms. A Potentiostat/Galvanostat Model 268A electrochemical analyzer (Beijing, China) was applied to collect electrochemical data on a three-electrode cell, where the steel electrode was used as working electrode (WE), a saturated calomel electrode (SCE) as reference electrode and a platinum plate as counter electrode. The electro-chemical corrosion behaviors of the BMG and 304 SS were characterized by the polarization measurement, which were conducted at a scan rate of 1 mV s^{-1}, starting from -600 mV vs. E_{corr} to 700 mV vs. E_{corr} in saline-sand slurry for dynamic corrosion.

3. Results and discussion

3.1. Effect of particle size

The relationships between sand particle size and the volume loss rate of BMG and 304 SS under E–C and pure erosion conditions are shown in Fig. 3. As can be seen, the volume losses increased with the increase of particle size. When the particle size increased from 88 to 470 μm, the E–C rate of 304 SS increased from 0.10 to 0.71 mm^3 h^{-1} and BMG's E–C rate also increased from 0.05 to 0.63 mm^3 h^{-1}. BMG shows better E–C resistance than 304 SS. The pure erosion rates of BMG and 304 SS are lower than their corresponding E–C rates. However, both pure erosion rates of BMG and 304 SS are very close, especially when they eroded by big particles. Although BMG erosion resistance is limited under high energy impact, compared with 304 SS, BMG exhibits better corrosion resistance and better resistance to the synergy between corrosion and erosion. So in a certain range of particle size, large amount of big particles will lead to worse erosion of BMG and vice-versa.