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WEAR RESISTANCE OF METALLIC GLASS BEARINGS

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Abstract. A new microgeared-motor assembled by Ni-based metallic glasses (MGs) bearing was constructed. The durability of the microgeared-motor improved about 4 times longer than that of the microgeared-motor assembled by the sintered alloy bearing. As compared with that of the sintered alloy bearing, higher hardness of Ni-based MG encourages excellent wear resistance of bearing. In order to clarify the relation between hardness and wear resistance of MG bearings, we conducted wear tests for the conventional sintered alloy, Zr-, Ni-, and Fe-based MG bearings. As a result, it was found that the worn loss in volume were 2.7%, 1.8%, 0.2%, and 0.0% for the sintered alloy, Zr-based MG, Ni-based MG and Fe-based MG, respectively. This result suggests that the wear resistance of bearings is mainly dominated by hardness. The wear mechanism of MG bearing will be also discussed.

1. INTRODUCTION

It is well known that the metallic glasses (MGs) exhibit excellent properties such as high strength, high elastic limit, good imprintability and so on [1]. By utilization of these properties, industrial applications for micromachine parts are expected.

In our previous studies [2,3], we have reported that the durability of the microgeared-motor with a diameter of 2.4 mm was drastically improved by assembling of Ni-based ($Ni_{53}Nb_{20}Ti_{10}Zr_8Co_6Cu_3$) MG microgears. The Ni-based MG exhibits relatively high GFA, ultra-high strength of 2700 MPa, large elastic elongation of 2% and excellent corrosion resistance [4-7]. The durability of the geared-motor using Ni-based MG microgears is reaching about 313 times longer than that of the commercial geared-motor using conventional carbon tool steel gears. The worn loss of the MG gear tooth was evaluated to be only 3% and this small worn loss may contribute to the long durability of the geared-motor [3]. However, it is revealed that the reason for rotation stopping of the microgeared-motor was mainly due to the wear of the sintered alloy bearing, not due to the wear of the MG gears. Therefore a MG bearing with high strength is possible to improve the product durability.

In this paper, we intend to examine the effect of a MG bearing for the durability of the microgeared-moter and to clarify the relation between hardness and wear resistance of MG bearings through sliding-wear tests for the conventional sintered alloy, Zr-, Ni- and Fe-based MG bearings. In addition, the wear mechanism of MG bearing will be also discussed.

2. EXPERIMENTAL PROCEDURE

The ingots of Zr-, Ni-, and Fe-based MG, with a composition of $Zr_{55}Cu_{30}Ti_{10}Ni_5$ [8], $Ni_{53}Nb_{20}Ti_{10}Zr_8Co_6Cu_3$ [2], and $Fe_{36}Co_{36}B_{20}Si_4Nb_4$ (at.%) [9], respectively, were used in this study. The conventional plane bearing was formed from a copper and an iron powder. The Vickers' hardness of each material was 60,520,760, and 1100, for the sintered alloy, Zr-, Ni- and Fe-based MG, respectively. The load in Vickers' hardness measurements was 5 N. From the master alloy ingots, the cylindri-

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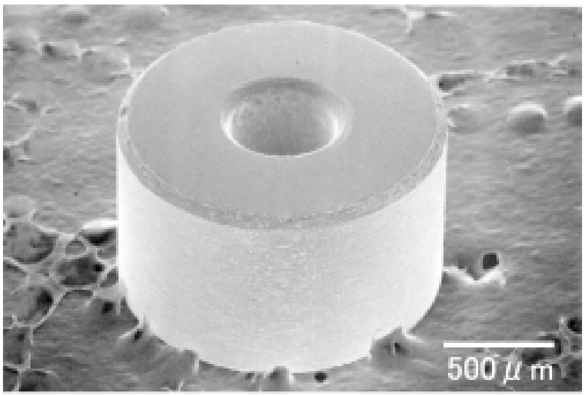

Fig. 1. SEM image of the MG bearing with outside diameter of 1.5 mm, inside diameter of 0.5 mm, and length of 1.0 mm by machining.

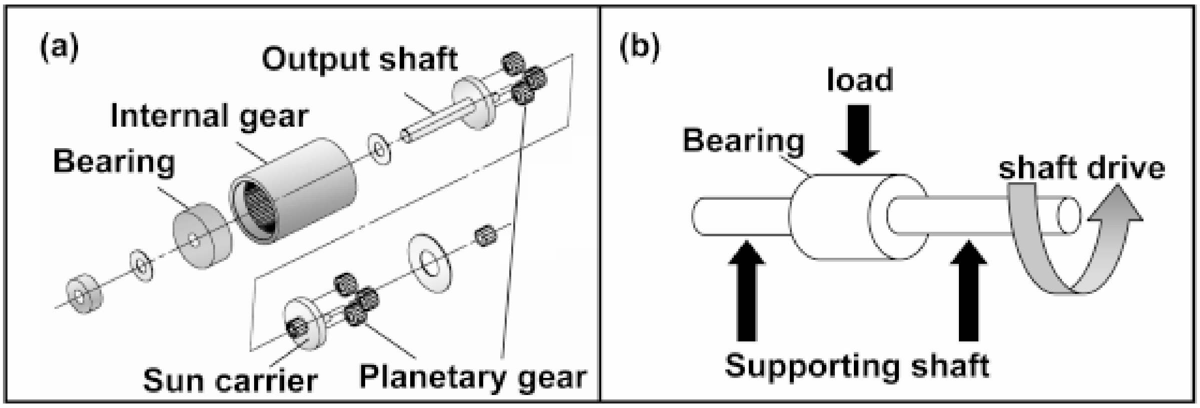

Fig. 2. Schematic set-up illustrations of the (a) product durability test of the microgear, (b) sliding-wear test for bearings.

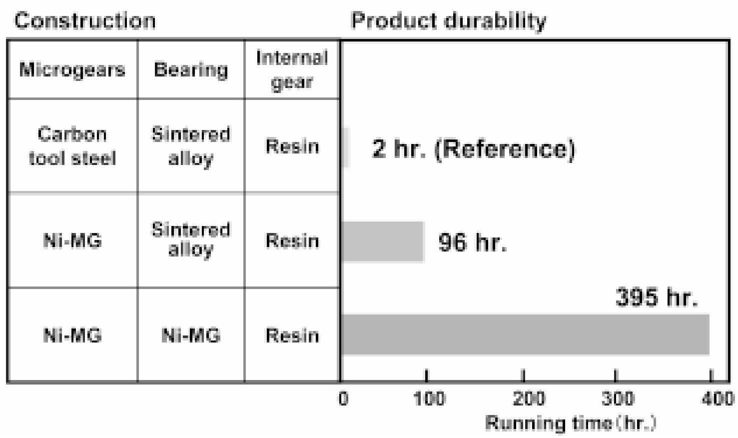

Fig. 3. The durability test for the microgeared-motor assembled by MG gears with MG bearing or sintered alloy bearing. The data of conventional product assembled by carbon steel gears is also shown.

cal rods with diameters up to 2 mm were produced by copper mold casting in an Ar atmosphere. MG bearings with an outer diameter of 1.5 mm, an inner diameter of 0.5 mm, and a length of 1.0 mm were prepared by machining, as shown in Fig. 1.

Fig. 2 shows schematic set-up illustrations of the (a) product durability test of the microgear, (b) sliding-wear test for bearings. To clarify the product durability, three kinds of microgears (a sun-carrier, an output-shaft and 6 pieces of planetary-gear) made of Ni-based MG were assembled into the commercial geared-motor with a diameter of 2.4 mm, as shown in Fig. 2a. The applied torque and rotation speed were 200 μNm and 2000 rpm, respectively. Oil was applied as a lubricant for all gear-parts. The durability test was performed by con-

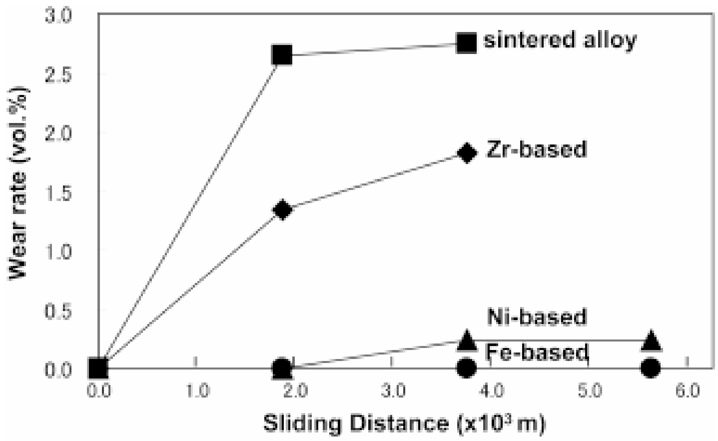

Fig. 4. Wear loss in volume of the sintered alloy bearings, Zr-, Ni-, and Fe-based MG bearing for sliding distance.

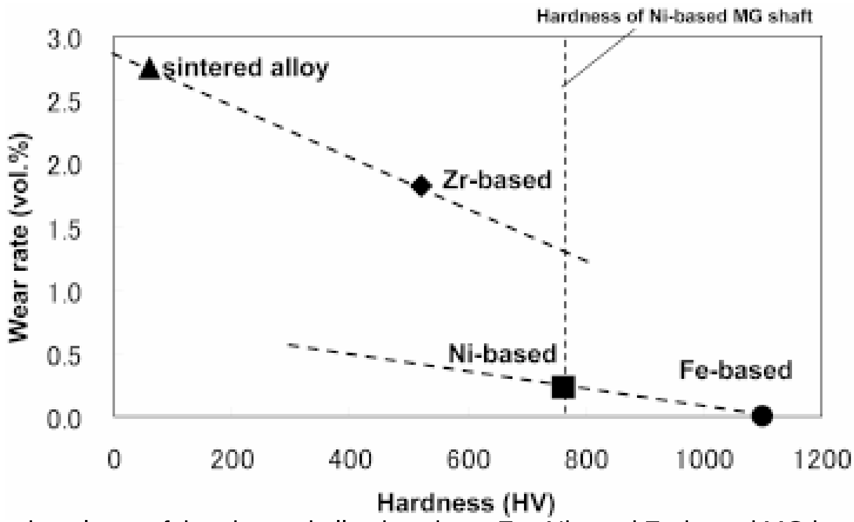

Fig. 5. Wear loss in volume of the sintered alloy bearings, Zr-, Ni-, and Fe-based MG bearing for Vickers hardness.

tinuous clockwise rotation till scuff or stuck. Ni-based MG, the same material as MG microgears, was used as a material of MG bearing for the microgeared-motor.

The sliding wear tests were performed by driving the Ni-based MG output shafts and an applied load of bearings and a shaft rotation speed were 0.3 N and 4000 rpm, respectively, as shown in Fig. 2b. The amount of the wear loss in bearings was measured by analytical balance (Mettler Toledo; AG245) with a measurement resolution of 0.01 mg. The wear loss is represented in volume. Roughness profiles and morphologies of worn surface of bearings were examined by confocal scanning microscopy (CSM) and scanning electron microscopy (SEM).

3. RESULT AND DISCUSSION

The lifetime of the microgeared-motor using Ni-based MG bearing was 395 hours, while that of the microgeared-motor using the sintered alloy bearing was only 96 hours, as shown in Fig. 3. The durability of it improved about 4 times longer than that of the microgeared-motor assembled by the sintered alloy bearing. As compared with that of the sintered alloy bearing, higher hardness of Ni-based MG encourages excellent wear resistance of bearing. Consequently, the durability of the microgeared-motor is enhanced.

In order to discuss the mechanism of the good wear resistance of the MG bearing, the sliding wear tests for the sintered alloy and MG bearings were examined. Fig. 4 summarizes the worn loss in volume of bearings for the sliding distance. As a result, it was found that the worn loss in volume at the sliding distance of $1.9 \cdot 10^3$ m were 2.7%, 1.8%, 0.2%, and 0.0% for the sintered alloy, Zr-based MG, Ni-based MG and Fe-based MG, respectively. Fe-based MG bearing has the highest wear resistance and the higher durability of the microgeared-motor using it will be expected. The worn loss is roughly proportional to hardness of materials, as shown in Fig. 5. This result suggests that the wear resistance of bearings is mainly dominated by hardness. Considering the hardness of Ni-based MG shaft, wear behavior of Ni- and Fe-based MG bearings is possible to be different from that of sintered alloy and Zr-based MG bearing. Because the sintered alloy and Zr-based MG bearing have lower hardness compared with Ni-based MG shaft, it is assumed that the wear rate of these is much larger than that of Ni- and Fe-based MG bearing.

Fig. 6 shows SEM images of the worn surface of MG bearings contacted with rotating shaft. On the surface in the edge part of all MG bearing, scratches were remarkably observed. Area of worn scratches was the largest in Zr-based MG bearing. These scratches show plastic flow or abrasive wear. Plastic flow of MG in the edge part was caused by the stress that locally exceeded the yield stress of the MG bearings. In Ni- and Fe-based MG bearing with same or higher hardness compared with that of Ni-based MG shaft, the worn loss was little. Therefore, the worn debris of MG bearing and shaft caused by stress adhered on surface again by stress and it was assumed that scratches were mainly caused by plastic deformation and adhered debris. But in Zr-based MG bearing with lower hardness compared with that of Ni-based MG shaft, the worn loss was large. Therefore, the worn debris with higher hardness from shaft is possible to induce abrasive wear. It was assumed that scratches were spread by plastic deformation and abrasive wear in Zr-based MG with low yield stress.

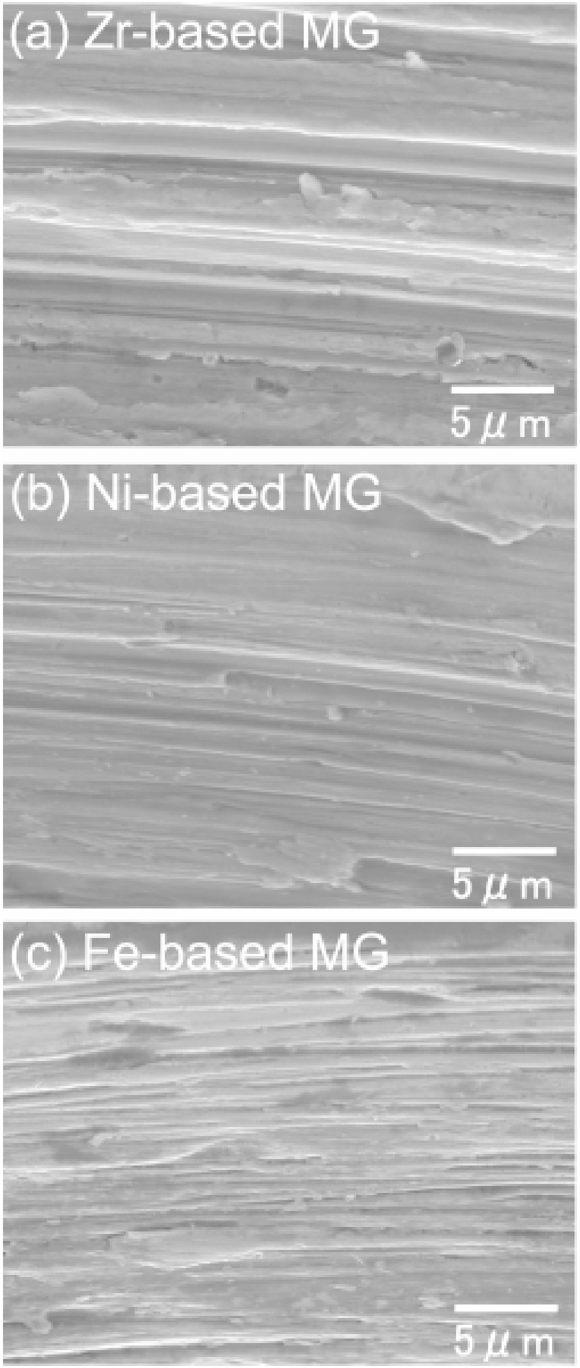

Fig. 6. SEM images of Surface morphologies of the (a) Zr-based MG bearing, (b) Ni-based MG bearing, and (c) Fe-based MG bearing after the sliding-wear tests.

4. SUMMARY

We evaluated the durability of the microgeared-motor by assembling the Ni-based MG bearing, and investigated the relation between hardness and wear resistance of MG bearings through the sliding wear tests for MG bearings. The results obtained are summarized as follows;

(1) The durability of the microgeared motor using the Ni-based MG bearing improved about 4 times longer than that of one assembled by the sintered alloy bearing. The excellent wear resistance of the Ni-based MG bearing contributes the superior durability of product.

(2) The worn loss in volume of bearings under sliding tests was 2.7%, 1.8%, 0.2%, and 0.0 % for the sintered alloy, Zr-based MG, Ni-based MG and Fe-based MG, respectively. The wear resistance of bearings is mainly dominated by hardness.

(3) Scratches were observed on the worn surface in the edge of all MG bearings. It was assumed that scratches were mainly caused by plastic deformation and adhered debris and in Zr-based MG bearing with low yield stress, harder worn debris induced abrasive wear.

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