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PROPERTIES OF BULK GLASSY ALLOYS AS A TRIBO-MATERIAL

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Abstract. In order to clarify the outstanding wear resistivity of metallic glasses, two kinds of wear tests under sliding and rolling conditions were carried out. Under the rolling condition, MG exhibits much superior wear resistivity than tool steel, while MG exhibits much lower wear resistivity than tool steel under sliding condition. Under both conditions, wear mechanism of MG is dominated by adhesive wear due to plastic flow. Relaxation of applied load due to plastic flow encourages wear resistance of MG. It is concluded that MGs are expected to be new Tribo-materials by understanding their unique deformation and wear behavior which is quite different from those of conventional crystalline alloys.

1. INTRODUCTION

By utilizing of useful properties for industries such as ultrahigh strength, large elastic elongation, low Young's modulus, high corrosion resistance, good soft magnetic properties, super-smooth surface and viscous deformability, Metallic glasses (MGs) are expected to be new industrial materials. At present, MGs are applying to MEMS parts, sensors. In particular, world's smallest microgeared motor for driving source of advanced medical equipments is mostly expected as an innovative product. We have developed mass-production process of precision gear parts made of MGs. MGs gear parts exhibit higher performance than conventional gear parts made of tool steel. The microgeared motor assembled by MGs gear parts exhibits 313 times longer durability than commercial one assembled by tool steel gears [1]. This superior durability is difficult to understand in the framework of abrasive wear, that is, wear resistivity has almost linear relation to material hardness [2]. In the present study, we intend to investigate the wear mechanism and to clarify the reason for the outstanding wear resistivity of MGs. Furthermore, possibility of MG applications to Tribo-materials will be discussed.

2. EXPERIMENTAL PROCEDURES

In order to clarify the exceptional high wear resistance of metallic glasses, two kinds of fundamental wear tests under sliding and rolling friction conditions were investigated. As schematically shown in Fig. 1, sliding test was carried out by putting in contact a fixed plate to a rotating disk. On the other hand, the rolling test was carried out by putting in contact a passive disk to an active rolling disk. All the metallic glass disks and plates with an atomic nominal composition of $Ni_{53}Nb_{20}Ti_{10}Zr_8Co_6Cu_3$ (Ni-MG) [3] were made by an injection casting method [4]. The disks and the plates made of commercial tool steel (SK4) were also used for comparison. The revolution of the active rotating disk was 300

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rpm, the applied stresses were 0.5 and 5.0 N and the testing time was 12 hours. The wear loss (ΔV) in volume was evaluated by weighing the active and passive rotating disks and fixed plate. In addition, the worn surfaces were examined by scanning electron microscopy (SEM) and confocal scanning microscopy (CSM).

3. RESULTS AND DISCUSSION

Initially, ΔV under sliding friction condition with an applied load of 0.5 N were investigated. For the Ni-MG, ΔV of the active rolling disk and the fixed plate was 0.68 and 0.18 mm^3, respectively. On the other hand, ΔV of the active rolling disk and the fixed plate for SK4 was undetectable and 0.05 mm^3, respectively. These results suggest that the wear resistivity of SK4 is much superior to that of Ni-MG. Fig. 2 show the friction surface and the worn debris of the Ni-MG samples. Carved dents with a region of about 10 μm and worn debris adhered on the surface can be observed on the friction surface of the active rolling disk shown in Figs. 2a and 2b. As seen in Figs. 2c and 2d, plastic flow region developed to the rolling direction of active disk can be observed on the friction surface of the fixed plate. In addition, morphology of the worn debris shown in Fig. 2e generated by sliding friction is divided into two types, that is, milled-like debris with a width of about 10 μm and flake-like debris with a diameter of about 50 mm. The character such as flaky morphology with high aspect ratio and deformed by plastic flow can be observed in both of the debris. These results indicate that the wear behavior of the Ni-MG is dominated by plastic flow and adhesive wear. On the other hand, the worn debris of the SK4 sample is shown in the Fig. 2f for comparison. It is quite different from the Ni-MG debris. The morphology of the SK4 debris mainly consists of fine powder with a diameter of less than 1 μm. In anyway, heavy wear behavior of Ni-MG under sliding friction may be related to the plastic flow observed on the friction surface and the debris.

ΔV under rolling friction condition with an applied load of 0.5 N were investigated. For the Ni-MG, ΔV of the active and the passive rolling disks were both undetectable. On the other hand, ΔV of the active and passive rolling disks for SK4 was 0.005 and 0.01 mm^3, respectively. In this rolling condition, the values of ΔV were small. Therefore, accelerated tests by increasing the applied load to 5 N were carried out. As a result, ΔV of the active and the passive rolling disks for Ni-MG was 0.03

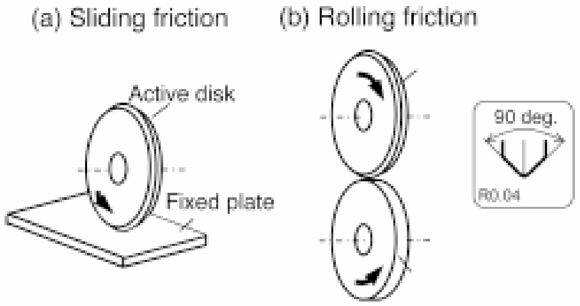

Fig. 1. Schematic illustration of fundamental wear tests under sliding and rolling conditions.

and 0.02 mm^3, respectively. On the other hand, *DV* of the active and passive rolling disks for SK4 was 0.18 and 0.07 mm^3, respectively. Oppositely to the results under sliding condition, wear resistivity of the Ni-MG is superior to that of the SK4 under rolling condition. In the case of sliding friction, rotating energy of the active disk will be easily transform into dynamic friction energy generated against the fixed plate, then the dynamic friction energy might be consumed as temperature raising and wear. However, temperature raising or wear is difficult to occur under rolling conditions because the rotating energy of the active disk should be mainly consumed as rotating of the passive disk. Figs. 3a and 3b show the surface morphology of Ni-MG active rolling disk. Neither caved dents nor adhesive debris can be observed as it appeared in the sliding wear test. Only slight plastic flow developed at right angle to the rotating direction can be observed. Fig. 4a shows the surface CSM image of the Ni-MG active disk. The average surface roughness (R_a) of the Ni-MG active disk is evaluated to be 0.05 μm, which is the same as the one before test. Only protrusion of the disk is flattened. Ribbon-like debris observed in Fig. 4b might be formed by the shear fracture of the plastic flow region shown in Fig. 3b. Fig. 4c shows the surface CSM image of the SK4 active disk. The average surface roughness (R_a) of the active disk is evaluated to be 0.42 μm, which is drastically coarser than before test (0.04 μm). Worn debris of the SK4 shown in Fig. 4d is similar to that shown in Fig. 3f. Even with different friction condition, wear behavior of SK4 is the same. This result suggests that the wear behavior of SK4 is mainly dominated by abrasive wear.

Throughout the different friction wear tests, it is found that the wear behavior of the Ni-MG and SK4

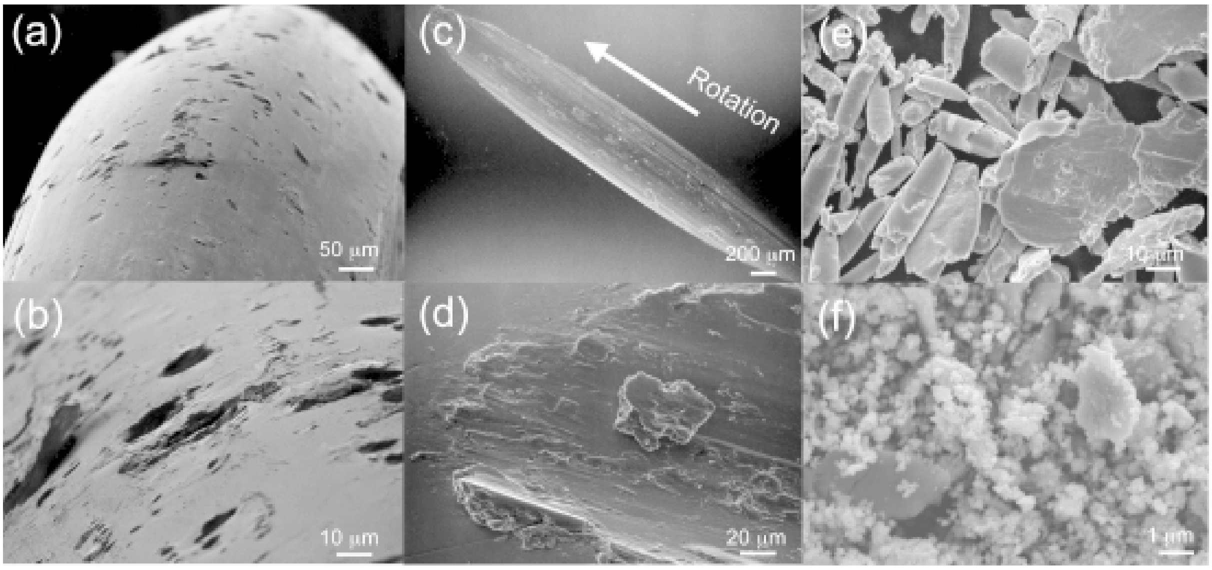

Fig. 2. SEM images of a,b) worn surface active disk, c,d) worn surface of fixed plate, e) worn debris of Ni-MG under sliding condition. Worn debris of SK4 under sliding condition e) is also shown for comparison.

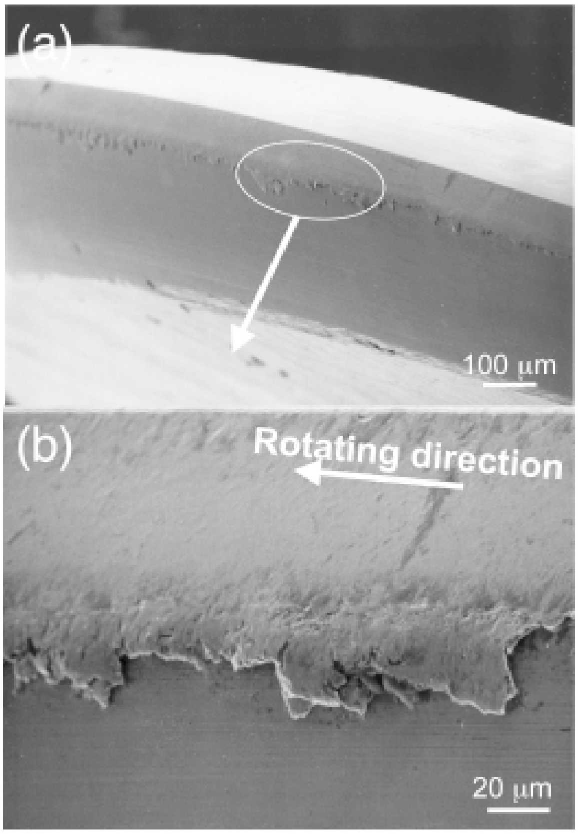

Fig. 3. SEM images of a,b) worn surface of Ni-MG active disk under sliding condition.

is dominated by adhesive and abrasive wear, respectively. However, opposite results in wear resistance were obtained as depending on the friction modes. This is attributed to the difference in

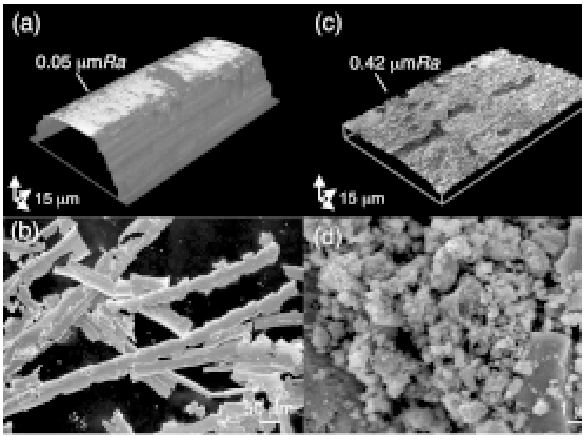

Fig. 4. CSM images of worn surface of a) Ni-MG active disk and b) SK4 active disk under rolling condition. SEM images of worn debris of c) Ni-MG active disk and d) SK4 active disk under rolling condition.

their deformation behaviors. Generally, crystalline alloys are hardened by deformation. Worn debris may be generated by carving of hardened deformation region, and the hardened debris accelerates abrasive wear. On the other hand, it is known that metallic glasses exhibit localized work softening due to deformation [5,6]. This work softening will accelerate adhesive wear. In the case of sliding friction, a vicious sequence, that is, softening, adhesion of worn debris, stress concentration at debris and higher softening degrades wear resistivity of Ni-MG. Moreover, localized friction heat will accelerate plastic flow. On the contrary, plastic flow occurred at the right angle against the rotating direction under the rolling condition. Then, the flowed region was pushed out from friction plate, which has no effect on the friction wear. In addition, the flattened protrusion should relax the applied load. Consequently, Ni-MG exhibits much superior wear resistance than expected by its hardness. It is therefore concluded that MGs are expected to be new Tribo-materials by understanding their unique deformation and wear behavior which is quite different from those of conventional crystalline alloys.

4. CONCLUSIONS

From fundamental wear tests under sliding and rolling friction conditions, it is found that metallic glasses exhibit unique wear resistivity, which is quite different from ordinary crystalline alloys. Metallic glasses exhibit adhesive wear because of their work softening behavior. In spite of worse wear resistivity under sliding friction conditions, metallic glasses show superior wear resistivity under rolling condition than expected by its hardness. Such superior wear resistivity of metallic glasses under rolling condition is attributed to the large stress relaxation by their low Young's modulus, large elastic limit and work softening behavior. From tribological point of view, it is concluded that the metallic glasses exhibit exceptional high wear resistivity by the suppression of adhesive wear.

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