Strong dependence of relative humidity on the tribological behavior of Cu-Zr based BMGs in ambient air

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Bulk Metallic Glasses (BMGs) are recent materials (1980s) of great interest for industrials thanks to their exceptional mechanical properties, including high elastic limit and fracture toughness. However, their tribological behavior is still highly debated and misunderstood, with erratic conclusions between studies. The present study aims at demonstrating the influence of the relative humidity of ambient air on the friction and wear of BMGs. Results confirm that an environment with high humidity causes a significant decrease of the coefficient of friction, thanks to the formation of a specific tribolayer at the interface.

Keywords: tribology, bulk metallic glasses, friction, relative humidity, oxide tribolayer

1. Introduction

Bulk Metallic Glasses are alloys with amorphous structure, that confers them a very different mechanical behavior compared to crystalline alloys [1], opening new fields of applications. The wear resistance of BMGs is however weakly studied and seems to deliver conflicting results. Existing tribological studies analyze the impact of parameters such as chemical composition, relaxation, mechanical properties and contact conditions, but very few look into environmental conditions (argon, oxygen, vacuum) [2-3], and none of them considers relative humidity. The present study highlights the significative impact of humidity on friction and wear rate of BMGs.

2. Methods

Four different Cu-Zr-based BMG were chosen in this study, with different Cu/Zr ratio and microalloyings of Nb or Ti. BMG plates were tested through reciprocating linear ball-on-plate friction tests (5000 friction cycles of ± 1 mm magnitude at 1 Hz, with an applied normal force of 1 N). The counterparts used were 100Cr6 balls of 5 mm diameter. The relative humidity (RH) was controlled by means of NaOH solutions with variable concentrations.

Surface topography characterization of friction tracks was performed using a variable focus optical microscope. Wear volumes of the ball and the plate were calculated. SEM observations and EDS analyses were also carried out on the wear tracks.

3. Results and discussion

The coefficient of friction (COF) is strongly correlated to the RH of ambient air: the COF decreases (from 0.9 to less than 0.6) as RH increases (fig 1). The steel ball undergoes a severe wear (despite its higher hardness) following the same dependency to RH. However, the BMG wear volume remains extremely low (nearly zero) whatever the RH. This is due to the formation of a protective tribolayer on the BMG friction track. This layer appears to be mostly composed of iron oxides coming from the wear debris of the ball, compacted into patches that support the load thanks to its especially high hardness.

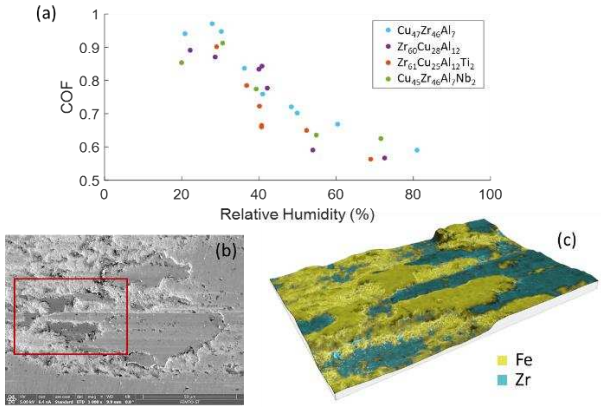

Figure 1: Friction coefficient depending on RH (a), SEM image of the wear track (b) and combined representation of 3D-SEM image and EDS mapping

This study gives an explanation of the high wear resistance of Cu-Zr-based BMGs: wear particles of the harder counterpart compact into a protective third body whose morphology depends on the relative humidity of ambient air.

From an engineering perspective, this study highlights the strong influence of relative humidity on the friction and wear of these alloys. It also provides a possible explanation of the conflicting results reported in literature.

4. References

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