Friction Anisotropy and Deformation in Copper Subjected to Sliding

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The idea that the coefficient of friction at metal sliding interface is dependent on mechanical properties and thus plasticity dates back many years to Bowden & Tabor's work in 1950. Today, modern electron microscopy and diffraction techniques in conjunction with suitable instrumentation enable a much closer look at the interconnection between friction and plasticity. In the present work, the anisotropy of both the coefficient of friction and plastic deformation in high-purity copper is investigated. This is achieved by changing the orientation of the crystal lattice at the sliding interface with respect to the direction of sliding.

Keywords: friction, deformation, anisotropy, copper, electron microscopy

1. Introduction

In their seminal work first published seventy years ago in 1950, F. Bowden and D. Tabor were the first researchers in the field of tribology to postulate a dependence of the coefficient of friction on the mechanical properties of metallic sliding interfaces [1]. This interdependence of friction and plastic deformation has been further investigated across length scales ever since, both experimentally as well as using simulations. Especially in recent years, as the public's awareness for global energy expenditure and the imminent climate crisis has steadily increased, the potential of fundamental tribological research has become even more widely recognized.

The present work is thus focused on further unraveling the fundamental aspect of frictional anisotropy and deformation in an unlubricated copper-sapphire ball on flat model system, a detailed understanding of which remains elusive to date. Both the frictional response as well as microstructure development inside the face-centered cubic copper sample material are investigated with respect to different crystallographic orientations of the copper lattice at the sliding interface.

2. Methods

In order to enable an investigation of the interdependence of friction and plastic deformation, single crystalline high-purity copper samples with different crystallographic normal orientations were used. A custom micro-tribometer specifically developed for this purpose was employed to repeatedly and unidirectionally slide sapphire spheres with a diameter of 5-10 mm along specific crystallographic directions of the copper lattice in a controlled dry nitrogen environment. According to Bowden, a difference in friction is expected for sliding along different crystallographic orientations [2].

The tribologically loaded copper was then characterized both on the macro- and micro-scale using modern state of the art techniques not yet available to Bowden and Tabor, such as optical 3D profilometry as well as detailed electron microscopy, including scanning transmission electron microscopy (STEM), electron backscatter diffraction (EBSD) and transmission Kikuchi diffraction (TKD).

3. Discussion

3D profilometry reveals an anisotropic average profile shape after 1000 unidirectional sliding cycles for sliding in the [0-11] and [1-21] directions on a (111) single crystal (Figure 1). The different profile peak heights left and right of the wear track indicate anisotropic plastic deformation, as expected.

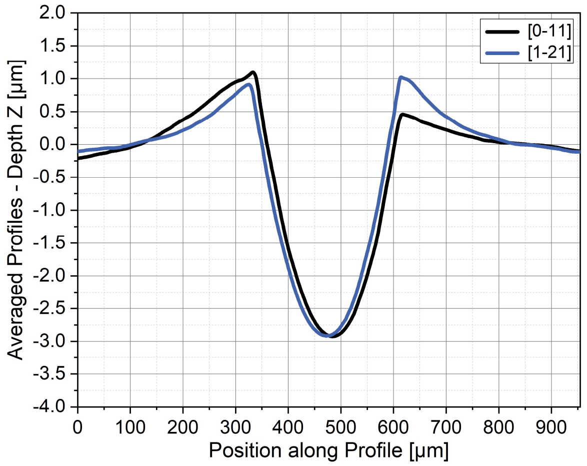

Figure 1: Anisotropic average wear track profile for sliding in [0-11] direction as opposed to [1-21] direction on a (111) single crystal

This observation is analyzed in relation to the initial crystallographic orientation of the copper lattice as well as the microscopic plastic deformation as observed by electron microscopy. Furthermore, the interconnection between the plastic deformation observed and the evolution of the coefficient of friction measured during the corresponding experiments is discussed.

4. References

[1] Bowden, F. P. et al., "The Friction and Lubrication of Solids". Vol. 1. Oxford University Press, 2001.

[2] Bowden, F. P. et al., "Anisotropy of Friction in Crystals" Nature 203.4940 (1964): 27-30.