Effect of crystal anisotropy on the deformation behavior of copper under scratching process

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In this study, we investigate the anisotropy behavior from in-situ micro-scratch performed along three different crystal directions on copper samples. A diamond spherical tip is used to avoid asymmetries from indenter geometry. Imprint morphology is then observed using a scanning electron microscope (SEM) and the lattice rotation is captured using an electron backscatter diffraction (EBSD) on the sample surface. Our experimental strategy aims to capture the anisotropy behavior from different scratch directions, to better understand the deformation mechanisms of single crystal copper under scratching process.

Keywords: anisotropy, deformation mechanisms, single crystalline copper, scratch

1. Introduction

With the extensive development of micromechanical testing instruments, scratch tests can now be performed on small volumes of materials (e.g. single grains in a metal) to access local mechanical properties such as hardness, friction, and wear characteristics of materials [1]. These properties may be direction dependent (anisotropic), which requires complete directional characterization of complex behavior models. The abstract describes scratch testing of a strong anisotropic material. Scratch forces measurement is complemented with bulge geometry measurement by profilometry and material rotation estimation by Electron Back-Scattering Diffraction (EBSD), whereas finite element simulations using Abaqus 2016 will be used to identify constitutive model parameters from the whole set of observables. The present work aims to answer the following fundamental question: in a given oriented grain, how much will the crystal deform differently when it is scratched along different directions? For this, it is interesting to relate the anisotropy on the scratch behavior with the intrinsic constitutive anisotropy of a material such as copper.

2. Methods

Single crystal configuration is chosen as the simplest case, moving away from crystal heterogeneities and their influence on local mechanical behavior.

2.1. Sample preparation

High purity (99.999%) single crystal Cu samples with normal surface (111) and (001) were mechanically polished with abrasive paper down to 4 µm grit size and finally electropolished.

2.2. Micro-scratches

Scratches were performed *in-situ* in a Scanning Electron Microscope (SEM) using the Alemnis micro-indentation platform [2] (Alemnis GmbH, Thun, Switzerland) and a diamond conico-spherical indenter with tip radius of 1 µm and 100 µm. Scratch lengths up to 200 µm were performed varying velocity up to 100 µm s^{-1}.

3. Experimental results and discussion

Preliminary scratch results (1µm tip radius and 3,2 µm scratch length) performed with high dynamic mode at 100 µm s^{-1} on (111) Cu sample (Fig1), have pointed to a strong anisotropy scratch behavior as a function of scratch direction. It is highlighted by a difference on pile-up morphology formed on the right side or in front of the track. Also by an ovate loop symmetry of lattice rotation on the EBSD map direction2. Finally, by a maximum scratch force values: 5mN to direction1 versus 3,3mN to direction2; the latter being a low atomic density direction.

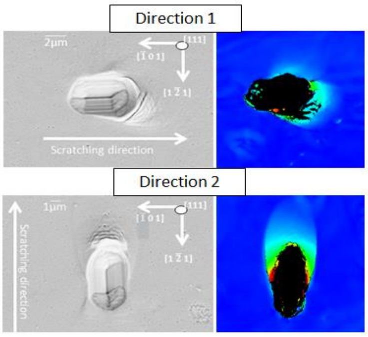

Figure 1: SE-SEM (left) and EBSD misorientation map (right) highlighting strong anisotropy evolution during scratch on (111) single crystal Cu sample.

The mechanisms generated on this scratching study are still under investigation. The physical meaning of the results from such a scratch test are fairly open to interpretation. Despite these difficulties, the developed strategy allows comparative tests with some degree of confidence. Experimental strategy development is ongoing with longer scratches lengths to reach scratch stabilization. Scratch forces, imprint morphology, as well as lattice rotation prove to be the good witness of anisotropy allowing us to answer the fundamental raised question: Does a crystal deform in the same way when it is scratched along different directions?

4. References

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