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Measuring high strain rate behavior of metals at the contact mechanics scale

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Under high speed tribological contact or impacts, metals react according to their strain rate sensitivity. This paper aims at defining a methodology to identify such a behavior at the right scale , i.e. the grain scale. The identification procedure is based on high-speed micro-compression testing with full pillar geometry finite element simulations. Microcompression tests are performed on single crystal copper to provide inputs for crystal plasticity strain rate sensitive parameters inverse identification. A strain rate sensitive behaviour in the [100] crystal orientation is observed. The higher the strain rate the better the identification sensitivity due to to high strain rate induced localization.

Keywords: Micromechanical testing, Micropillar, High strain rate, Crystal plasticity, Micro-impacts

1. Introduction

Increasing wear resistance of materials in severe conditions is one of the most important challenge to reduce energy losses. Such investigations require a thorough understanding of mechanical properties at the scale of tribological contacts (up to a few microns). Most of the published experimental works remained however limited to low strain rate (0.1 s^{-1}) due to both experimental and computational challenges. Nonetheless, in many surface engineering applications related to wear resistance, such as erosive wear or impact wear, strain rate can reach up to 10000 s^{-1} and beyond. High strain rate indentation, not to be confused with ballistic/impact indentation test, received a particular attention in the past few years thanks to the new capabilities of piezo-based micromechanical tester capable of simultaneous high speed actuation and sensing [1]. Based on these new capabilities, we developed an approach to investigate the high strain rate behaviour of metals at their grain scale, i.e. the micron scale [2].

2. Methods

2.1. High strain rate micro-compression

Microcompression tests are performed on single crystal copper at 0.01 s^{-1} and 100 s^{-1} in the [100], [110] and [111] orientations to provide inputs for crystal plasticity strain rate sensitive parameters inverse identification. Figure 1 shows a typical displacement profile imposed to the indenter during a microcompression test. For high strain rate tests, the pillar is not in contact with the indenter at its initial position. The indenter accelerates progressively to reach the targeted constant displacement rate without triggering the piezoStack actuator natural frequencies.

An overall good repeatability of the stress-strain curves suggest that the strain-rate dependency observed does not depend on the pillar size, owing to the statistical nature of size-effects.

2.2. Identification procedure

The identification procedure using the real pillar geometry is applied to the experimental load-displacement curves obtained with the [100] crystal orientation at two different strain rates. An identifiability indicator based on the cost function Hessian matrix approximate close to the minimum is used to assess the uniqueness and stability of the identified coefficients [2].

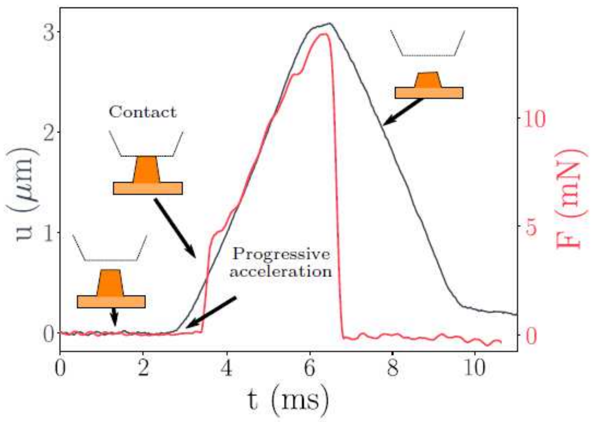

Figure 1: Example of a typical high dynamic imposed displacement profile and resulting measured load.

3. Results and discussion

The solution represents well the copper specimen hardening strain-rate sensitivity in the [100] orientations. The identifiability indicator [2] computed after identification is I = 1.31. It confirms the well-posedness of the inverse problem. It appears to be related to a structural effect, which enhances the apparent strain rate sensitivity influence on the load-displacement curve. Modeling the pillar as single element or using the experimental stress-strain curve for strain-rate sensitivity direct estimation cannot account for such structural effects. Crystal plasticity parameters identified through this methodology are shown to allow reproducing with success experimental micro-impact results obtained using a canon-based test rig designed on purpose.

4. References

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