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New insight on acoustoplasticity – Ultrasonic irradiation enhances subgrain formation during deformation

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ABSTRACT

Many industrial applications make use of ultrasonic vibration to soften metals. The existing understanding of such an acoustoplastic effect is one in which the ultrasonic irradiation either imposes additional stress waves to augment the quasi-static applied load, or causes heating of the metal, whereas the metal's intrinsic deformation resistance or mechanism is assumed to be unaltered by the ultrasound. In this study, indentation experiments performed on aluminum samples simultaneously excited by ultrasound reveal that the latter intrinsically alters the deformation characteristics of the metal. The deformation microstructures underneath the indents were investigated by a combination of cross-sectional microscopic techniques involving focused-ion-beam milling, transmission electron microscopy and crystal orientation mapping by electron backscattered diffraction. The softening effect of the ultrasound is found to constitute recovery associated with extensive enhancement of subgrain formation during deformation. By comparing the microstructures of samples deformed with and without simultaneous application of ultrasound, and those subsequently excited by ultrasound after deformation, the enhanced subgrain formation is proved to be one due to the combined application of the quasi-static loading and the ultrasound, but not a simple addition of the two. Similarly, by comparing with samples deformed while being simultaneously or subsequently heated up, the enhanced subgrain formation by the ultrasound is proved to be a lot greater than that due to the heat that it generates within the metal. Such effects of the ultrasound are interpreted by its ability to enhance dipole annihilation. The superimposed ultrasound causes dislocations to travel longer distances in a jerky manner, so that they can continuously explore until dipole annihilation.

1. Introduction

Ultrasonic vibration is used in many different machining and shaping processes, such as wire drawing (Graff, 1975; Eaves et al., 1975), drilling (Neugebauer and Stoll, 2004), impact peening to modify surface properties (Mordyuk and Prokopenko, 2007), lapping and turning of brittle materials (Zhang et al., 2005; Brehl and Dow, 2008), and welding of different metals (Joshi, 1971) or metallic glasses (Kreye et al., 1978). Many of these applications are based on the fact that the quasi-static stress required for deformation is reduced when ultrasonic vibration is applied. This phenomenon is called the Blaha effect (Blaha and Langenecker, 1955) or acoustoplastic effect.

The effect of ultrasound on materials under deformation has been studied since the 1950s (Blaha and Langenecker, 1955; Mason, 1955; Nevill and Brotzen, 1957). Langenecker (1963, 1966) reported that when ultrasonic vibration was

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