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Dislocation density based constitutive model for ultrasonic assisted deformation

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Abstract

The mechanical behaviour of metallic materials subjected to plastic deformation is altered with the superposition of ultrasonic vibrations. A significant effect is the reduction of flow stress or acoustic softening. This phenomenon is utilized in metal forming and other deformation based manufacturing processes. Experimental investigations on ultrasonic assisted tensile tests focuses on the effect of ultrasonic vibrations along the longitudinal axis of the specimen, whereas the manufacturing processes employs in transverse directions. In the present work, transverse ultrasonic vibrations are imposed during a uniaxial tensile test using an aluminium alloy during tensile test. The trend of acoustic softening due to transverse direction vibrations is similar to that along longitudinal direction. A dislocation density based constitutive model is extended to model the softening due to ultrasonic effect. The predicted results agree well with the experimental observations.

Keywords: Ultrasonics, amplitude, plasticity, constitutive model

1. Introduction

The effect of ultrasonic vibrations during plastic deformation of metallic materials has been studied for several decades [1–4]. A significant drop in flow stress in the presence of ultrasonic vibrations [5](referred as acoustic softening) and change in hardening even after the removal of vibrations [1], especially at high acoustic intensity are its typical characteristics. This residual acoustic hardening or softening has been attributed to the changes in dislocation interactions, multiplication or annealing [4, 6]. The mechanisms related to ultrasonic softening has been subjected to considerable experimental and theoretical study in the past. In addition to the change in dislocation mobility, the softening effect is also attributed to friction effect, thermal softening and stress superposition [5, 7]. Recent investigations have demonstrated the significance of ultrasonic vibrations on the dislocation annihilation and subgrain formation [4, 7, 8] that cannot be accommodated through the classical approaches. Advanced models relating the dislocation dynamics and ultrasonic vibrations are increasingly gaining attention [3, 8].

The effect of ultrasonic vibrations in reducing the flow stress is utilized in many deformation based manufacturing processes such as ultrasonic assisted forming[9] and machining[10]. Most of the investigations using tensile tests applied the ultrasonic vibrations along the specimen axis [5, 11]. However the induced vibrations in the forming processes are in the transverse direction [7, 12] to the plane of the sheet. Depending upon the contact between the tool and the deforming sheet, the nature of induced vibrations could be longitudinal and/or shear wave.

In the present work, tensile tests were performed by subjecting the specimen to transverse vibrations, which is a closer representation of the envisaged manufacturing processes. A dislocation density based model is developed to describe the constitutive behaviour. It was found that the effect of transverse and longitudinal vibrations are similar and can be described using the same mathematical model. The predicted results using the proposed model correlate very well with the experimen-

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