NUMERICAL INVESTIGATION OF LOCALIZED FRACTURE IN POLYCRYSTALLINE MATERIAL (DH 36 STEEL) DURING DYNAMIC DOUBLE SHEAR LOADING UNDER ADIABATIC CONDITIONS

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The main objective of the present paper is to discuss procedure of the numerical investigation of localized fracture in polycrystalline material (particularly in DH 36 steel) generated by impact-loaded adiabatic processes. We take advantage of experimental results for DH 36 steel obtained by W.K. Nowacki and P. Gadaj. Particularly we based on the experimental observations of the double-shear specimen placed between two bars by using a Split Hopkinson Presser Bar in dynamic tests at high strain rates. Attention is focused on the proper description of a ductile mode of fracture propagating along the shear band for high impact velocities. This procedure of investigation is based on utilization the finite element method and ABAQUS system for regularized thermo-elasto-viscoplastic constitutive model of polycrystalline material.

1. Introduction

The properties of steel are strongly affected by the manufacturing process. In many processes in which large plastic deformation occurs, a large amount of heat is generated. The effect of the temperature increase on the mechanical behavior of the material can be significant and cannot be neglected in an accurate constitutive model. The understanding of high-strain-rate behavior of metals is essential for the modeling and analysis of numerous processes including high-speed machining, impact, penetration and shear localization. Recently, considerable progress has been made in understanding the role of rate controlling dislocation mechanisms on the temperature and strain rate dependence of the flow stress for metals and alloys.

In large plastic deformation that occurs in the simple shearing of sheet metal as well as in many other forming processes of polycrystalline material the microshear bands in material, resulting in a sever localized deformations, are generated.

In the present study a thermo-viscoplasticity model is used for investigating heat generation in steel with microshear banding is also studied. Special attention is directed at microshear bands generation associated with dynamic loading. In order to obtain a consistent microshear band generation and study its effects, the viscoplasticity model employed is formulated within a thermodynamic framework. In polycrystalline models, viscoplastic deformation takes place in the form of slip within a discrete slip system. A slip itself is a manifestation of dislocation motions. An increase in dislocation density results in a decrease in the mobility of the dislocations, due to pileups and to interaction with dislocation forests and other obstacles. The decrease in dislocation mobility can be seen as a plastic hardening or an increase in slip resistance. Any given dislocation is on a microscopic level surrounded by a stress field in which energy is stored. Since the viscoplastic flow is due to dislocation motion, the stored energy increases with an increase of viscoplastic deformation. The rate of stored energy is equal to the difference between the rate of plastic work and the dissipation of energy which leads to a heat generation. The heat generation is often measured by the fraction of plastic work dissipated as heat χ, which of course is also a measure of the rate of stored energy. Taylor and Quinney in 1934 made early attempts to measure this quantity. They concluded that the fraction of plastic work converted to heat is a constant lying somewhere between 0.8 and 0.95. Later experiments, on the other hand, have shown that the fraction is not a constant. Mason et al. (1994), for example, showed that for austenitic steel this fraction χ, varies between 0.6 and 1, depending upon the accumulated plastic strain. Rosakis et al. (2000) also showed that χ can be influenced by the strain rate.

2. Constitutive model

A general constitutive model of thermo-elasto-viscoplastic polycrystalline solids with a finite set of internal state variables is used. The model, formulated within a thermodynamic framework for large deformations is based on the flow rule proposed by Perzyna (2005). To obtain a thermodynamically consistent formulation here, however, account has been taken of the work of Pęcherski (1998), in which the microshear bands is incorporated on a total form in the strain rate deformation tensor. In the model that Perzyna (2005) developed the flow rule is considered to be of a power type. The set of internal state variables consists of two scalars, namely equivalent inelastic deformation and volume fraction of microshear bands. The equivalent inelastic deformation can describe the dissipation effects generated by viscoplastic flow phenomena and the volume fraction of microshear bands. The relaxation time is used as a regularization parameter. The evolution of the microshear banding related to slip resistance here is assumed to be local for each slip system and to be of a logistic function type. These assumptions turn out to be crucial for modeling the heat generation in a consistent way and also allowing it to be calibrated to experimental tests.

3. Numerical results

The capabilities of the model will be demonstrated in numerical example. The example concerns the simple shear response of polycrystalline steel, special emphasis being placed on the heat generation due to plastic work. As a numerical example we consider dynamic simple shearing and localized fracture in thin plate. We idealize the initial boundary value problem observed experimentally by assuming that the impact loading is simulated by a velocity boundary conditions which are the results of dynamic contact problem. The separation of the projectile from the specimen, resulting from wave reflections within the projectile and the specimen, occurs in the phenomenon.

A thin shear band region of finite width which undergoes significant deformation and temperature rise has been determined. Its evolution until occurrence of final fracture has been simulated. Shear band advance and the development of the temperature field as a function of time have been determined. Comparison of numerical results with experimental observation data has been presented. The numerical results obtained have proven the usefulness of the thermo-elasto-viscoplastic theory in the investigation of dynamic shear band propagations and localized fracture. The model can also be used for a fully coupled thermomechanical analysis.

4. References

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