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NUMERICAL INVESTIGATION OF DYNAMIC SHEAR BANDS IN INELASTIC SOLIDS AS A PROBLEM OF MESOMECHANICS

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The main objective of the present paper is the numerical investigation of dynamic shear bands in inelastic solids generated by impact–loaded adiabatic processes. Particular attention is focused on the proper description of a ductile mode propagating along the shear band for high impact velocities.

PROBLEM OF IMPACT-LOADED PRENOTCHED PLATE

An idea of this investigation has been inspired by recent experimental observations presented in [2,6]. These experimental works have been brought deep understanding of the initiation and propagation characteristic as well as the temperature field evolution of dynamic shear bands in C 300 maraging steel. Pre–fatigued single edge notched specimens were asymmetrically impacted on the edge under the notch to initiate adiabatic shear band. The advance of the shear band and its velocity as a function of time were presented and a sequence of thermal images revealing the development of the temperature field as a function of time were showed. A photograph of an arrested shear band in the specimen showed that the thickness of the band is about 40 μm (so it is mesoscale size range). A scanning electron microscope image of the specimen surface that failed by shear band propagation showed (presented) elongated voids, with shear edges that are characteristic of such a failure mode. The presence of voids reveals the development of triaxial tensile stresses that led to void growth and eventual a ductile fracture mode.
Numerical simulation of dynamic shear band propagation in an asymmetrically impact–loaded prenotched plate have been presented in [3,7]. However many problems at the moment are not clear and many are still open for investigation.
Applications of metals and polymers at mesoscale (a size scale that ranges from a fraction of micrometer to 100 μm) are recently multiplying rapidly. It is considerable experimental evidence that plastic flow and particularly fracture phenomena in crystalline solids are inherently size dependent over mesoscale range. However, conventional continuum mechanics models of inelastic deformation processes are size scale independent. The relatively large numbers of dislocations governing plastic deformation at the micron scale motivate the development of a continuum theory of plasticity incorporating size–dependence. The elastic viscoplastic theory can be developed for this purpose.

ELASTO–VISCOPLASTIC CONSTITUTIVE MODEL

A general constitutive model of elasto–viscoplastic damaged polycrystalline solids is developed within the thermodynamic framework of the rate type covariance structure with a finite set of internal state variables. The set of internal state variables consists of two scalars, namely equivalent plastic deformation and volume fraction porosity. The equivalent inelastic deformation can describe the dissipation effects generated by viscoplastic flow phenomena and the volume fraction porosity take into account the microdamage evolution effects, cf. [5].
The relaxation time is used as a regularization parameter. By assuming that the relaxation time tends to zero the thermo–elasto–plastic (rate independent) response of the damaged material can be obtained. Fracture criterion based on the evolution of microdamage is formulated.
It is noteworthy to stress that viscosity introduces implicitly a length–scale parameter into the dynamical initial–boundary value problem, i.e. $l = \alpha c T_m$, where T_m is the relaxation time for mechanical disturbances and is directly related to the viscosity of the material, c denotes the velocity of the propagation of the elastic waves in the material. The factor α depends on the particular initial–boundary value problem under consideration and may also depend on the microscopic properties of the material.
The thermo–elasto–viscoplastic theory developed takes account of (i) plastic non–normality; (ii) softening effects generated by microdamage mechanisms; (iii) thermomechanical couplings (thermal plastic softening and thermal expansion); (iv) influence of stress triaxiality on the evolution of microdamage; (v) rate sensitivity; (vi) dissipation and dispersion effects; (vii) synergetic effects generated by cooperative phenomena; (viii) length scale sensitivity; (ix) finite plastic deformation; (x) invariance with respect to diffeomorphism.
The identification procedure for the material functions and constants involved in the constitutive equations is developed basing on the experimental observations of adiabatic shear bands in HY–100 steel presented in [1]. We take here advantage of our previous numerical investigation presented in [4]. We consider dynamic shear band propagation in an asymmetrically impact–loaded prenotched plate (similar to that experimentally investigated in [2]).

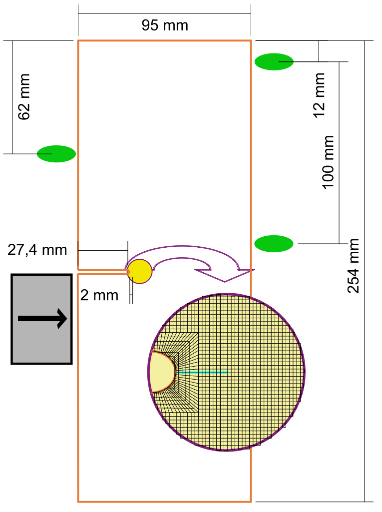

Figure 1. Specimen geometry, impact arrangement and finite discretization. Thickness of the specimen is 12 mm.

NUMERICAL EXPERIMENT

The plate is made of HY–100 steel. A notch (260 μm wide) is situated symmetrically on the edge, which is further extended by 2 mm as has been shown in Fig. 1. The specimen is supported at three points and is initially stationary. The constant velocity V_0 (13 $\div$ 39 m/s) is imposed for projectile. The projectile comes into contact with the specimen over the width of 50 mm. The impact loading is simulated by a velocity boundary condition which are the results of dynamic contact problem. The velocity imposed in specimen in front of projectile increases from zero for the initiation of contact between the projectile and the specimen and increases during the process. The contact surface is assumed to be traction–free. The separation of the projectile from the specimen, resulting from wave reflections within the projectile and the specimen, occurs in the phenomenon. All surface areas have traction free boundary conditions except where the velocity boundary condition is applied. Utilizing the finite element method and ABAQUS system for regularized elasto–viscoplastic model the numerical investigation of dynamic shear band propagation in an asymmetrically impact–loaded prenotched plate is presented. We idealize the initial boundary value problem observed experimentally in [2] by assuming the velocity boundary condition and different material of the specimen.

FINAL REMARKS

The elaborated numerical algorithm satisfies the material objectivity principle with respect to diffeomerphism (any motion). The discretization parameters are assumed in such a way, cf. Fig. 1, to solve the problem of mesomechanics properly. The dimension of the accepted mesh is of order 20 μm. 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, shear band velocity and the development of the temperature field as a function of time have been determined. Qualitative 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 numerical investigation of dynamic shear band propagation.

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