THREE-DIMENSIONAL MODELLING OF THERMO-ELASTO/VISCOPLASTIC SOLIDS CONTAINING ADIABATIC SHEAR BANDS

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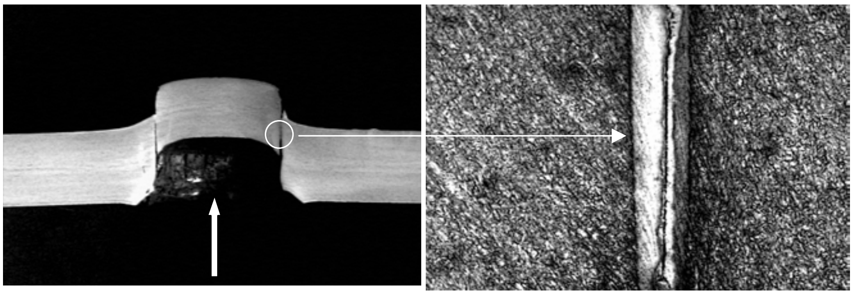
Summary The aim of the present contribution is to embrace salient features of the adiabatic shear banding (ASB) within the framework of three-dimensional finite strain modelling regarding viscoplastic flow coupled with ASB-related microdamage process. The ASB damage-induced anisotropy is being accounted for. An application of the model is given for the hat shape structure under impact loading.

INTRODUCTION

The main objective of the work presented is the numerical prediction of the adiabatic shear banding (ASB) induced degradation of a structural material under dynamic loading, including target/penetrator interaction. This phenomenon which occurs in particular in thermo/viscoplastic metals as the result of a thermal instability – bringing about discontinuity in the local velocity gradient and temperature - is actually known to lead to the ultimate fracture of the structure (see Fig.1).



a) Steel plate after impact b) Micrograph showing ASB and crack

Fig.1 : Impact of a flat end projectile onto a hard steel target (from GIAT Industries)

Though extensive investigation (metallurgical and mechanical, experimental and theoretical) has been devoted to the matter from the mid 20[th] century on, see f.ex. the references given in Longere et al.[1], only a few tentatives have been made to incorporate ASB phenomena into three-dimensional rigorous modelling involving viscoplastic flow coupled with specific ASB microdamage evolution, see Perzyna [2].

CONSTITUTIVE MODEL

In this work adiabatic shear banding is treated as an anisotropic damage process within the irreversible thermodynamics framework. In the approach proposed, the (system of) band(s) is incorporated in the representative volume element (RVE). With this viewpoint, informations relative to the variables characterizing the state of the band material (temperature, isotropic hardening, metallurgical transformation, …) together with geometric parameters related to the band itself (width and orientation) are all included in a single 2[nd] order tensorial internal variable $\mathbf{D}=d.\mathbf{N}$ whose norm d accounts for the intensity of adiabatic shearing (evolution of the variables mentioned before) and whose direction $\mathbf{N}=\mathbf{n}\otimes\mathbf{n}$ is collinear to the normal of the band plane **n**. While the 'damage' variable **D** governs the anisotropic degradation of the material (RVE), kinematic consequences of the presence of the bands, viewed as those of an idealised super dislocation, are dealt with by using the coresponding part of the velocity gradient – intervening in addition to the genuinely plastic part. A large deformation anisotropic plasticity and damage formulation based on the multiplicative decomposition of the deformation gradient is developed involving objective rates needed to ensure material frame indifference.

Constitutive equations integrating ASB-damage are derived from thermodynamic potentials namely the free energy and dissipative potentials in the general framework of the internal state variable formulation.

The reversible part of the free energy includes the initial isotropic linear thermo-elasticity of the sound material and damage induced anisotropic (orthotropic) elasticity for the ASB-degraded material. The form of the stored energy reflects the competition that takes place in the material between hardening and softening. Hardening is a consequence of the micromechanisms of plasticity in the material outside the band, while softening is due to heating on the one hand and to current ASB-related damage on the other one. During their evolution (formation and propagation), adiabatic shear bands modify the state of internal stresses. In this sense, one can assume that damage acts much like temperature to release stored energy.

Shear banding being in itself a singular viscoplasticity-like process, it is natural to consider it as rate dependent. Consequently, the existence of two dissipative potentials, which refer respectively to the homogeneous viscoplasticity and to the viscous damage, is supposed. The hypothesis of a single yield function has been put to describe the chronology of the dissipative viscous mechanisms mentioned and to account for the strong coupling between plasticity and damage.

An auxiliary indicator needed to determine the conditions for shear bands initiation and orientation has been obtained from a simplified analysis based on the linear theory of perturbations. This damage process incipience indicator is integrated within the constitutive model.

NUMERICAL SIMULATION AND COMPARISON WITH EXPERIMENT

The above constitutive model, including finite anisotropic elasto-plastic strains, rate sensitivity, strain hardening, thermal softening and anisotropic damage (by adiabatic shear banding), has been implemented as ‘user-material’ in the finite element code LS-DYNA. The numerical integration algorithm of the evolution equations is purely explicit combined with an adaptive time step procedure which controls the stability of the response. In addition, viscosity of the dissipative mechanisms – plasticity and damage – at stake favours regularization of the boundary value problem in the softening regime. A complementary mesh size dependence analysis is put forward ; it confirms much restrained sensitivity of the numerical results to the discretization, i.e. fair efficiency of the regularizing procedure involving finite difference scheme, see also Dornowski and Perzyna [3].

3D numerical simulations of adiabatic shear banding induced degradation in structural steels are performed considering the hat-shape structure dynamic test employing a direct Hopkinson pressure bar device (see Fig.2). The geometry of the hat-shape structure has been defined to localize deformation in a well-controlled area in which pressure remains quasi constant and uniform[4]. This test is used to study the sensitivity of metals to adiabatic shear banding.

Fig.2 : Dynamic hat-shape structure test employing a direct Hopkinson pressure bar device

CONCLUSION

A model coupling 3D viscoplastic response and damage evolution related to ASB process is put forward. Its numerical implementation and application allow to account for the ASB-induced degradation for the prediction of the post-localization response of the structure under dynamic loading. In the structural application shown for the hat shape structure one can see the propagation and/or the arrest of ASB-related damage bands being simulated with success. Numerical results show the evolution of the band tip velocity during the process. Numerical damage maps inside the hat shape structure and the load transmitted to the output bar are in good agreement with experimental evidence.

References

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