ON THE MODELING OF DAMAGE AND DUCTILE FRACTURE IN ADVANCED HIGH STRENGTH STEEL SHEETS USING VOID CELL CALCULATIONS

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Summary A micromechanical analysis based on three-dimensional void cell calculations is carried out to model the evolution of damage and the mechanisms responsible for ductile fracture in a TRIP steel sheet. Micrographs of material submitted to different stress states and increasing amounts of accumulated plastic strain have revealed that the critical mechanism responsible for ultimate failure is the localization of the plastic deformation in a shear band which initiates from the boundaries of an isolated void. Using FE analysis, a void-containing RVE is submitted to loading histories measured in the experiments through hybrid experimental-numerical analysis to reproduce the observed fracture mechanisms. Simulation results show a good agreement with experiments and permit to model qualitatively the dependence of the material ductility to the first and third stress invariants, i.e. the stress triaxiality and Lode parameter, as well as the plastic strain rate.

INTRODUCTION

Damage mechanisms responsible for ductile failure of materials are generally described as the nucleation and growth of voids. During deformation, microcracks eventually appear after void coalescence by internal necking, which leads to macroscopic material fracture. However, in sheet materials where only small stress triaxialities can be reached, alternative mechanisms have been identified, such as localisation of the plastic flow into shear bands [1].
In this work, the damage and fracture mechanisms of a TRIP steel sheet are investigated experimentally for different stress states by micrograph analysis. Subsequently, Finite Element void cell calculations are carried out to model the identified failure mechanisms. Simulation results show a good agreement with experiments and permit to model qualitatively the dependence of the material ductility to the first and third stress invariants, i.e. the stress triaxiality and Lode parameter.

EXPERIMENTAL IDENTIFICATION OF DAMAGE

The evolution of damage and the mechanisms responsible for ductile fracture are identified in a TRIP steel sheet material. Experiments are performed on flat notched tensile specimens with different notch radii and on disk specimens submitted to out-of-plane hemispherical punching, thereby covering stress states from uniaxial to equi-biaxial tension. For each specimen geometry, experiments have been interrupted prior to fracture at different stages of deformation: onset of through-thickness necking and 95%, 98% and 99% of the displacement at which fracture initiates. Micrographs of samples extracted from the deformed specimens permit to evaluate the material damage for increasing amounts of accumulated plastic strain, and to identify the fracture mechanisms. It is shown that the critical mechanism responsible for ultimate failure is the localization of the plastic deformation in a shear band which initiates from the boundaries of an isolated void. Very high strains are reached inside the shear band which lead to the nucleation of secondary voids ("void sheet" mechanism) and eventually result in the slant fracture of the sheet material. The orientation of the fracture surface is controlled by the shear band direction.

In addition, high strain rate experiments are performed on notched tensile specimens. A newly-developed dynamic tensile testing device is employed in conjunction with a modified split Hopkinson pressure bar system to perform the dynamic experiments. It is found that damage and failure mechanisms are similar at high strain rate ($\approx 10^3$/s) and low strain rate ($\approx 10^{-3}$/s)

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MODELING OF THE FRACTURE MECHANISMS

A micromechanical analysis based on three-dimensional void cell calculations is carried out to model the observed damage and fracture mechanisms. A void-containing RVE is submitted to loading histories measured in the experiments through hybrid experimental-numerical analysis [2]. In particular, the increase of triaxiality occurring after the onset of localized necking and prior to fracture is taken into account. Fully periodic boundary conditions are applied to the cell and no symmetry is considered in order to allow for plastic localization into shear bands to occur. The matrix material is modeled as incompressible rate-dependent elastic-plastic, where the plastic behavior is described by a planar isotropic yield surface and a non-associated quadratic orthotropic flow rule [3]. The material parameters of the plasticity model are identified through an inverse calibration method.

Simulation results show a good agreement with experiments and permit to model qualitatively the dependence of the material ductility to the first and third stress invariants, i.e. the stress triaxiality and Lode parameter, as well as to the plastic strain rate.

CONCLUDING REMARKS

a. Damage and failure mechanisms are identified in a TRIP steel sheet by micrograph analysis for a wide range of stress states,
b. The critical mechanism responsible for ultimate failure is the localization of the plastic deformation in a shear band which initiates from the boundaries of an isolated void,
c. A micromechanical model based on void cell calculations is developed to model the identified damage and failure mechanisms
d. The model permits to describe qualitatively the dependence of the material ductility to the stress triaxiality, the Lode parameter, and the plastic strain rate.

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