COHESIVE-ZONE MODEL IDENTIFICATION USING DIGITAL IMAGE CORRELATION

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ABSTRACT: Since a few years, cohesive-zone models have been formulated and used to simulate fracture of solid materials. The cohesive-zone models presented in the literature involve a 'jump' in the displacement field describing the crack onset within a predefined interface network which corresponds to interfaces between elements of the FE mesh. Nevertheless, the physical meaning of these displacement jumps is not obvious. Moreover, the forms of interface laws are often chosen in connection with the overall behavior and/or numerical considerations. In this study, we propose a simple one-dimensional analysis where an additive decomposition of strain into plastic hardening and damage is used to build an interface law. Displacement data obtained by digital image correlation (DIC) from tensile tests are used to identify cohesive-zone models for different materials. The proposed approach allows us to specify the physical sense of the usual forms of interface laws and the afore-mentioned displacement jumps introduced in the numerical simulations. Finally, we discuss the potentialities of DIC to assess the overall damage and its restriction to a surface damage in a cohesive-zone model.

1. INTRODUCTION

Cohesive-zone models (CZMs), first introduced by Dugdale [1] and Barenblatt [2], are relevant approaches to simulate dynamic fracture in a wide class of materials and to account for heterogeneities at various scales from grain up to the structure [3]. In the so-called Cohesive/Volumetric Finite Element framework, CZMs are introduced at interfaces between elements of a finite element discretization. Non-interpenetration of crack lips is accounted for in the cohesive zones upon debonding. CZMs have been successfully used to simulate and predict the entire fracture process from crack initiation to rupture (including crack growth, propagation, potential bifurcation...). Nevertheless, the identification of cohesive zone laws has to be further improved in order to get more reliable predictions in view of industrial applications. Some attempts have been proposed in the literature to extract cohesive law from experimental tests (*e.g.* inverse-problem based on elastic far-fields surrounding a crack tip [4], displacement fields along a predefined crack path [5]). In the following, we outline a new method based on strain field measurements during tensile tests on standard specimens to identify such cohesive laws.

2. EXPERIMENTAL SETUP AND CORRELATION TECHNIQUE

The experimental setup shown in Fig. 1 is composed of a uniaxial testing machine equipped with a 100 kN load cell and a fixed CCD camera set in front of the specimen (out-of-plane movements are prohibited) which records digital speckle images during the test.

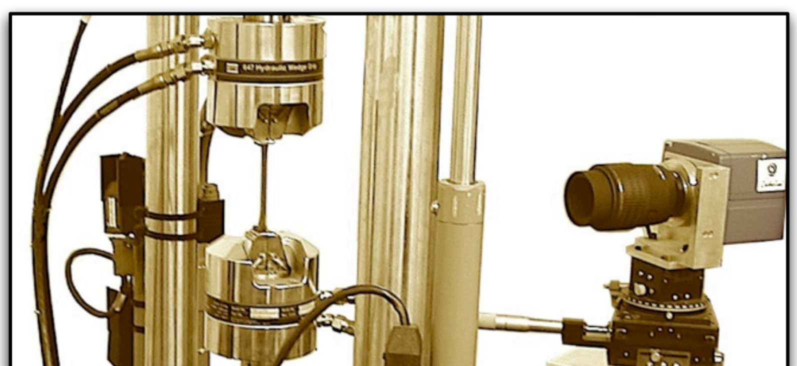

Figure 1 – A general view of the experimental setup

The in-plane displacement vectors are obtained by a direct digital image correlation method. A normalized discrete correlation function $\overline{\varphi}$ is computed at selected pixels (initially positioned on a regular grid) of consecutive images [6]. The locus of the maximum of $\overline{\varphi}$ gives the displacement *u* in the straining direction and the displacement *v* along the sample width. To reach a sub-pixel resolution, a local interpolation is performed around the discrete maximum of $\overline{\varphi}$ [7]. For this study, we used the image processing tools previously developed for the calculation of different kinematic fields by correlation techniques (displacements, Eulerian or Lagrangian strain, strain rate, kinetic energy, acceleration,...) [6].

3. IDENTIFICATION PROCEDURE

Traditionally, CZMs describe the material cohesion through a relationship between the local stress tensor σ (or a related variable) and a displacement jump [*u*] between two contiguous elements of the finite element mesh. From a more physical point of view, this jump can be interpreted at the macroscopic scale as the displacement resulting from the entire fracture process (growth of microvoids, coalescence, onset and opening of a crack), and not only as the gap between two crack lips. The proposed identification approach is based on the knowledge of the cross-section within the gauge part of the sample where damage develops preferentially. This cross-section can be defined as the locus where the material point acceleration changes its sign (see dashed line in Fig. 2(a); this area is observed well before strain localization). The overall uniaxial stress-strain relation $\sigma - \varepsilon$ is thus split into a bulk behavior $\sigma - \varepsilon_b$ outside this cross-section and a 'surface' behavior $\sigma - \varepsilon_s$ inside this cross-section where the strain and damage concentrate. This splitting is based on the additive decomposition of strain: $\varepsilon = \varepsilon_b + \varepsilon_s$. Then, the CZM associated with this localized damaged zone is derived by introducing a characteristic length consistent with the energy of rupture.

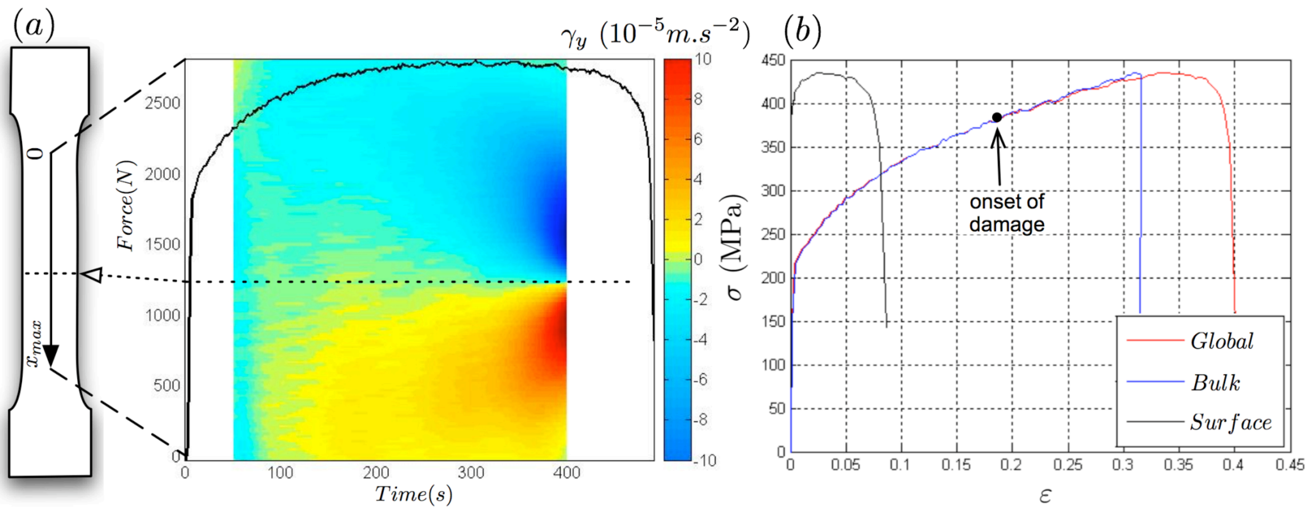

Figure 2 – Uniaxial tensile test on a ductile steel: from DIC analysis to surface damage model identification. (a) Evolution of the axial force (solid line) and spatiotemporal representation of material point accelerations (isovalues) along the straining direction; (b) Identified stress-strain plots.

Assuming no volume change during the plastic hardening without damage and considering that elastic strains remain small even at finite strain, the tensile stress can be classically approximated by $\sigma \approx (F/S_0)e^{\varepsilon}$, where *F* is the load, ε the true tensile strain and S_0 the initial cross-section of the specimen gauge part. The overall and bulk stress-strain diagrams are plotted in Fig. 2(b) by setting several optical extensometers. Outside the damaged zone, the range of the extensometer length ensures that the uniaxial stress-strain responses remain on a master curve (independent of the length and position of the extensometer). When this master curve deviates from the bulk curve, a significant damage takes place and a positive 'decohesion' strain ε_s is obtained according to the uniaxial strain decomposition. After the peak stress, the strain increase in the localized damaged zone is associated with elastic unloading in the bulk part.

It is interesting to notice that these preliminary results present notable similarities with usual (empirical) cohesive zone models in the literature: trapezoidal shape (door-like) for ductile materials and bilinear shape (triangle) for brittle materials.

4. REFERENCES

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