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IDENTIFICATION OF COHESIVE ZONE MODELS USING THERMOMECHANICAL IMAGING TECHNIQUES

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ABSTRACT: Since several years, cohesive zone models have been developed and used to numerically simulate the fracture of solid materials. These models are often written and identified in a mechanical framework introducing a displacement "jump" related to the virtual opening of the crack. In this work, we propose to split the overall volumic damageable plastic behaviour of the material into a purely elastoplastic behaviour related to the bulk response (hardening) and a purely damageable behaviour associated with the cohesive zone (softening). The aim of this paper is to propose an experimental approach combining Digital Image Correlation and Infrared Thermography techniques to characterize the thermo-mechanical response of the material, the bulk, and the cohesive zone.

1. INTRODUCTION

Cohesive-zone models (CZM), which were first introduced through the pioneering work of Dugdale [1] and Barenblatt [2], are suitable to simulate fracture in a wide range of materials and to account for heterogeneities at various scales from the grain up to the structure [3]. In the cohesive/volumetric finite element framework, CZMs are introduced at interfaces between adjacent elements of a finite element discretization. They have been successfully used to simulate and predict the entire fracture process from crack onset to rupture [3].
In recent years, substantial progress has been achieved from a numerical point of view and CZM predictions have been regularly improved. Although CZMs are becoming increasingly robust, their application is somewhat arbitrary and several difficulties remain, notably regarding the identification of the constitutive equations. This paper aims to propose an experimental methodology to enhance the choice of CZM constitutive equations and improve their identification. This methodology does not assume either any particular shape or any predefined crack path, but focuses on the experimental validity of the projection of volumic (micro) damage onto a simple surface. The study is restricted to overall ductile materials (copper specimens) and the local effect of the stress triaxiality on the volumic damage is neglected (uniaxial tension).
Local energy balances are constructed combining kinematic measurements obtained by DIC and thermal data given by Infrared Thermography. This information is then used to derive the cohesive response from the volumic response of the material at the observation scale.
In what follows, the experimental setup is briefly described, and then some recent results illustrate the potentiality of such an experimental approach.

2. EXPERIMENTAL SETUP

The experimental setup includes a mechanical testing machine, a CCD camera and an infrared camera. The cameras are set perpendicularly to the flat specimen surface. Each camera is controlled by a separate computer. A specific electronic device was designed to synchronize the frame grabbing of the two cameras. The principle of this device is as follows. A frequency generator is used to produce the trigger signal of the master camera. This frequency is divided or multiplied by an integer factor to generate the trigger signal of the slave camera. Each time an image acquisition is completed, the analogical signals provided by the machine sensors (force, displacement) are digitized, and the time is given, on each acquisition computer, by a common clock having a 0.1 ms period.
Before starting the tests, the specimen surfaces are painted. The surface facing the CCD camera is speckled with black and white paints in order to obtain the contrast necessary to perform DIC. The surface facing the infrared camera is coated with a thin layer of black paint in order to homogenize and to increase its emissivity.
The displacement field is computed using the *KelKins* image processing software [4]. The thermal data are processed *via* the local heat equation. The particular derivative is computed by combining kinematical and thermal data as presented in [5].

3. RESULTS

In this work we assume that the material behavior corresponds to damageable elastoplasticity. As soon as strain and damage localize, the sample must be considered as a structure where structural and material effects are superimposed. In this work, we propose a protocol to derive the uniaxial cohesive zone response associated with the loading direction (*i.e.* x_1) during a tensile test. The Figure 1 represents the basic stretch of the strain partition used to deduce the bulk and the

cohesive zone response from the material response obtained experimentally. The local axial Cauchy stress σ_1 is obtained supposing a transverse isotropic response (ε_2=ε_3). The uniaxial effective stress σ_{eff} is computed introducing the damage variable *D* (associated with volume variations measured by DIC and with an isotropic damage model). The bulk response corresponds to isochoric elastoplasticity, and is associated with the incompressible stress σ_{inc}.

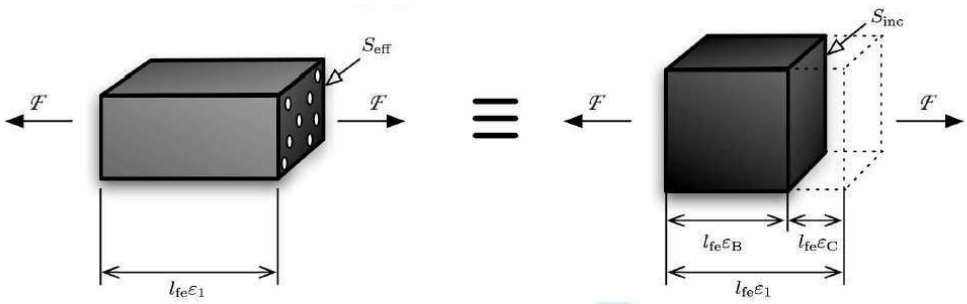

Figure 1- Basic sketch of the strain partition

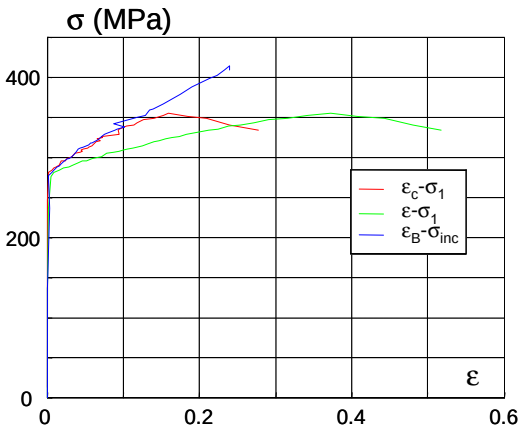

Figure 2- Mechanical response

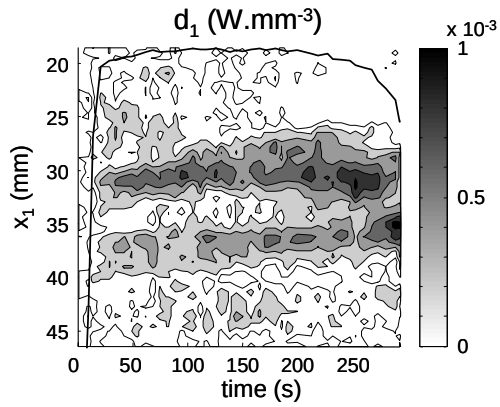

Figure 3- evolution of d_1 during the test

Figure 2 shows the apparent tensile stress σ_1 in the localization zone as a function of the overall and cohesive zone axial strains, respectively ε_1 and ε_C. The stress-strain relation σ_{inc} *vs.* ε_B associated with the virtual isochoric straining is also plotted on the same graph. This relation corresponds to the bulk behavior that should be resolved at the Gauss points in a FE method for each material, and therefore it should be used for determining the bulk parameters of constitutive equations. The relation σ_1 *vs.* ε_C provides access to the cohesive zone response and corresponds to the CZM, which can be directly used in CZM-based simulations through incorporation of the length l_{fe} corresponding to the link between the displacement jump [*u*] and the cohesive strain ε_C.

The intrinsic dissipation d_1 is computed as the difference between the overall heat source and the heat source related to the thermoelastic coupling ($\dot{w}_{thel} = -\lambda T_0 \mathrm{tr}(\dot{\sigma})$, with T_0 being the room temperature and λ the linear thermal dilatation coefficient). Its evolution during the deformation process is plotted in Figure 3. It shows the progressive concentration of dissipative heat sources in the strain localization zone (around x_1 = 32 mm). This dissipation is associated with plasticity and damage. Matching the kinematic and calorimetric responses enables us to validate the thermomechanical consistency of the proposed approach.

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