Numerical simulation of non-standard tensile tests of thin metal foils

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Abstract

Tensile tests performed on notched material samples of non-standard dimensions permit to follow the evolution of the fracture processes occurring in thin metal foils. However, the load versus displacement record of these experiments does not always reflect directly the local stress-strain relationship and the fracture characteristics of the investigated material. In fact, the thin foils are usually difficult to handle and sensitive to local imperfections, size and geometric effects, which affect the overall response. Simulation models of the performed tests can support the interpretation of the experimental results, evidencing the role of the disturbances as shown in this contribution.

Keywords: thin metal foils, fracture characteristics, non-standard tensile test, simulation models

1. Introduction

Thin metal foils are used in several technological fields to produce components for micro-devices, flexible electronics and beverage packaging [4,10,13]. The constitutive properties of these materials are influenced by the lamination processes and differ from those of the corresponding bulk metals. The evaluation of the tensile properties is usually performed from the results of tests performed on thin material strips according to Standards (e.g., [3]). The geometry suggested by Standards does not permit to calibrate the fracture properties of the foils. In fact, material separation occurs almost instantaneously. The process progresses in a rather unstable way even on short specimens. Larger notched samples permit to follow the evolution of fracture [2,6-8,11]. Still, results are not always reliable due to the difficulties that are usually encountered handling the thin foils. Furthermore, the overall mechanical response of the samples reflects local imperfections and is sensitive to size and geometric effects [9,12]. Thus, the load versus displacement output recorded during uniaxial tensile tests does not always reflect directly the local constitutive (stress-strain) relationship. Simulation models of the performed tests can support the interpretation of the experimental results [5], evidencing the disturbance sources as shown in this contribution.

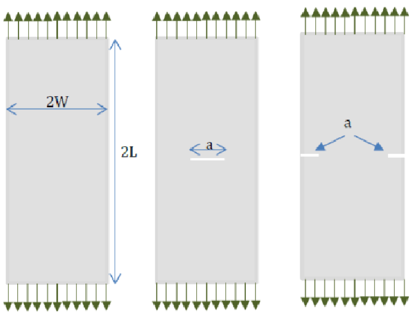

Figure 1: Geometrical configuration of the considered material samples.

2. The problem

The fracture processes developing in thin aluminium foils employed in beverage packaging have been investigated both experimentally and numerically. Metal samples shaped as shown by Fig. 1 have been subjected to tensile tests. The assumed dimensions (length 2L=250 mm, width 2W=100 mm, 9 μm nominal thickness) are comparable with those of former investigations [2, 8]. The experimental output shows that the in-plane deformation of the considered material is accompanied by warping [6]. Similar response was earlier documented by Kao-Walter [8].

The observed phenomena can be understood and reproduced in a finite element context, taking into account both material and geometric non-linearity [1].

In the present case, the metal response is described by the classical elastic-plastic constitutive law based on Hencky-Huber-von Mises criterion with isotropic hardening rule. The assumed material parameters define the uniaxial stress-strain curve shown in Fig. 2, which conforms to the output reported in [11].

Static analyses and plane stress models permit to recover the stress distribution visualized for instance in Fig. 3. This output justifies the appearance of wrinkles under tensile loading. In fact, a narrow compression band appears close and parallel to the notch. These relatively high stresses can lead to the geometrical instability of the thin structure.

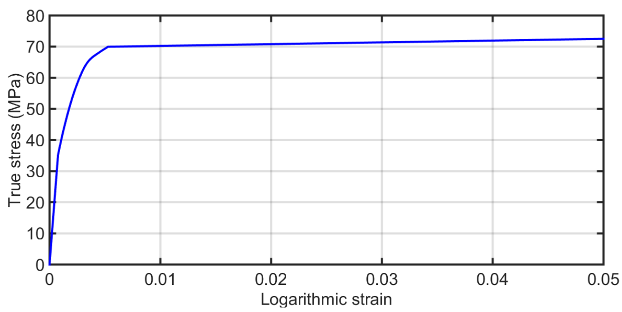

Figure 2: Uniaxial material response.

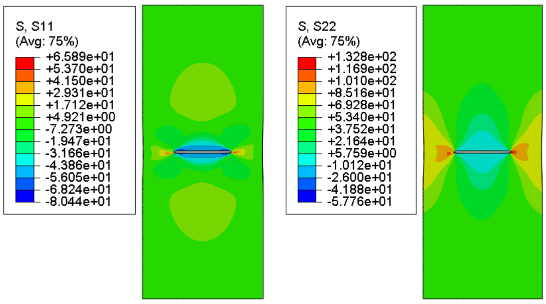

Figure 3: Stress distribution orthogonal (S11, left) and parallel (S22, right) to the loading direction.

The observed warping can be reproduced in a three-dimensional (3D) context. The initially flat material configuration is therefore modelled by shell elements. Quasi-static analyses stabilized by small damping coefficients are performed. No geometrical imperfections are introduced.

Figure 4 shows the load-displacement curves resulting from the simulations in the case of the metal sample with no notches. The damping coefficient influences the overall results, which are almost independent of this factor below a threshold level. For small or no damping, the numerical output matches the experimental results up to the peak load, whereas the material separation is not explicitly modelled. The dispersion of the softening branches returned by the physical tests, likely due to physical imperfections, is worth to be noticed.

The computations also shows that out of plane displacements develop since the beginning of the simulated tests, leading to the deformed configurations shown in Fig. 3.

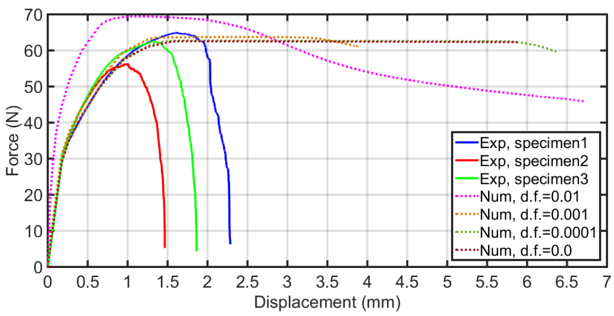

Figure 4: Overall load-displacement curves recovered from the 3D simulations of the plain metal sample compared to the experimental output.

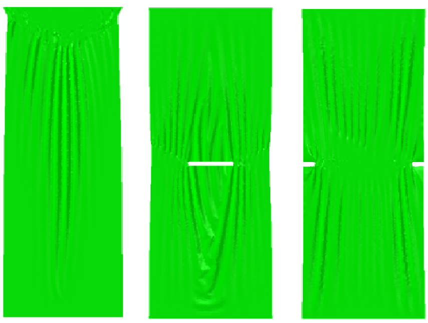

Figure 5: Wrinkles resulting from the 3D simulation of the tensile tests suggested by the sketches in Fig. 1.

3. Closing remarks

Non-standard tensile tests have been proposed to understand the fracture processes developing in thin metal foils. The experiments have been simulated in a finite element context, reproducing the observed warping phenomena. The numerical results are somehow influenced by the damping coefficient that permits to stabilize the quasi-static analyses but the results are consistent with the experimental output. The instability effects and the wrinkle formation are seen even more clearly in the notched specimens.

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