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A combined experimental-numerical investigation of the failure mode of thin metal foils

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Abstract

A combined experimental and numerical analysis of the mechanical response of the thin aluminum foils employed in beverage packaging has been performed using 3D digital image correlation and non-linear finite element techniques. The present contribution focuses on the significant amount of out-of-plane displacements that develop in tensile tests as fracture propagates across the investigated specimens. The influence of this phenomenon on the actual failure mode of the considered metal samples is further discussed.

Keywords: pipeline steel; material aging; mechanical characteristics; indentation

1. Introduction

Thin metal foils are employed in several technological fields related to the production of micro-devices, flexible electronics and beverage packaging (Read and Volinski, 2007; Wong and Salleo, 2009; Bolzon et al., 2015). In these applications, the metal thickness is of the order of a few microns or even less. The foil properties are influenced by the lamination processes and differ from those of the corresponding bulk materials. In particular, the apparent material brittleness increases as the thickness is reduced. At the same time, thin samples are difficult to handle and their mechanical response is sensitive to local imperfections, size and geometric effects (Klein et al., 2001; Hu, 2003; Wang et al., 2003). Thus, for instance, the overall load versus displacement output recorded during uniaxial

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tensile tests may not be directly correlated with the local stress-strain response.

The interpretation of the results can be enhanced by full-field monitoring techniques complemented by simulation models of the experiment (Avril et al., 2008; Bolzon, 2014). This approach has been applied to the case of thin aluminum foils employed in beverage packaging.

A three-dimensional digital image correlation (3D-DIC) technique has been exploited to measure the displacement distribution and the configuration changes of non-conventional metal samples subjected to tensile load. The performed measurements evidence the significant amount of out-of-plane displacements that develop as fracture propagates across the investigated specimens. The influence of this phenomenon on the actual failure mode of the considered metal samples is discussed in this contribution with the aid of non-linear finite element models of the experiment validated in former investigations (Bolzon et al., 2015).

2. Experimental investigation

Tensile tests have been performed on notched specimens cut from thin aluminum foils (9 µm nominal thickness). The considered material configurations are shown in Fig. 1. The sample dimensions are approximately 250 mm length and 100 mm width, comparable with those considered in former investigations (Andreasson et al., 2014). The deformation of the specimens and the crack propagation has been followed by a 3D-DIC technique.

The resolution achievable with 3D-DIC permits to detect phenomena like material separation and crack propagation at early stage, well in advance with respect to visual inspection (Mathieu et al., 2012). The measurement accuracy of DIC depends on the experimental conditions (Zappa et al., 2014): it can be optimized by the specimen preparation and by image pre-processing (Mazzoleni et al., 2015).

In the considered experimental set-up, a stereo camera system mounted on a tripod points the specimen, which is connected with the loading machine by clamps. Two LED-based lighting devices are mounted nearby. The light intensity and projection angle with respect to the metal sample are tuned in order to avoid specular reflection and to get the optimal quality of the image observed in a monitor. An external trigger is used to synchronize the two cameras. The image acquisition frequency is 1Hz.

The stereoscopic vision system allows to detect the spatial deformation of the foil under the increasing applied load. The dimensions of the field of view are set to 220x160 mm in order to acquire images of the full area of the specimen. A pair of GX3300 cameras equipped with 50 mm focal length optics (Zeiss Makro Planar T 2/50) are used to acquire the images for DIC. The full resolution thus achieved is 3296×2472 pixels (px), with about 15px/mm in the camera field of view.

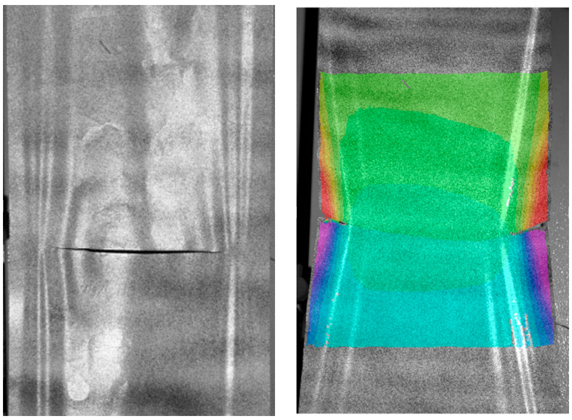

Fig. 1. Snapshots of the notched material specimens subjected to tensile test and DIC reconstruction of the displacement distribution in the loading direction (vertical in the images).