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Detecting the beginning of the *shear* band formation in uniaxial tensile tests by out-of-plane displacement measurements

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Abstract

We have used both electronic speckle-pattern interferometry (ESPI) and whole-field Subtractive Moiré (WSM) to follow the thickness reduction of sheet metal specimens subjected to uniaxial tensile tests. By analyzing the out-of-plane displacements induced between close load stages, we evaluated nonlinear effects linked to the progression of the thickness necking or transverse reduction in area of the sample. We observed that, during the transition zone of the test, long before reaching instability, the samples were thinned mainly along a relatively broad band. Due to its remarkable degree of localization, we identified this band as the *diffuse necking*. This diffuse necking preceded the development of the local neck and indicated the beginning of *shear* band formation.

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1. Introduction

A metal specimen subjected to a tensile test initially undergoes elastic deformation that is followed by a transition to plastic deformation. Although during this stage of the test the deformation is stable, the strains begin to localize within a relatively broad zone known as diffuse necking. The stable deformation, with continuously rising load, is followed by the instability whereby a local neck or *shear* band is produced due to strong localization of deformation. Because in-plane strains are associated with out-of-plane deformations, the monitoring of the thickness reduction of tensile specimens can be used to detect the beginning of the localized necking and the onset of the shear band formation.

The deformation progression can be followed through the use of high-sensitivity whole-field optical techniques; speckle-based techniques as shearography [1–4] and electronic speckle-pattern interferometry (ESPI) [5–7] as well as optical techniques based on the Moiré effect [7–14] yield fringe patterns that are contour maps of the deformation fields induced by the application of load. In particular, ESPI and whole-field subtractive Moiré (WSM) [8] have been used to visualize the onset of strain localization by using interferometers with in-plane sensitivity [5,13,14].

In this work, we have used an interferometer with out-of-plane sensitivity to follow the thickness reduction of sheet metal specimens subjected to uniaxial tensile tests. We utilized both ESPI and WSM to obtain contour maps of the out-of-plane displacement fields induced on the illuminated sample during the test. These maps allowed us to monitor different trends in the deformation process and to evaluate nonlinear effects linked to the progression of the thickness necking.

By analyzing the induced out-of-plane relative displacements between close load stages, we observed that, the sheet metal specimen was thinned along a relatively broad band during the transition zone to the plastic deformation. This band enabled us to predict the orientation of the shear

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band before reaching instability. Due to its remarkable degree of localization, we identified the detected band as the diffuse necking. This diffuse necking preceded the development of the local neck on this area and indicated the beginning of shear band formation.

We conclude that the localization of the necking began during the transition zone to the plastic deformation, long before the maximum of the tensile force. At the position where the onset of the localization was determined, we observed thickness reductions up to about 7%.

2. Measuring out-of-plane displacements

The out-of-plane displacements, W, induced on an illuminated sample can be measured by using the interferometer shown in Fig. 1. This optical arrangement is the same as the well-known Michelson interferometer, but we used in this interferometer a collimated coherent input beam.

If the illuminated surface is rough, the camera in Fig. 1 captures speckle patterns. The digital subtraction of two speckle patterns, registered while the illuminated specimen surface undergoes mechanical deformation, generates a fringe pattern. The generated fringe pattern documents the induced changes in the shape of the illuminated surface. This technique is referred-to as electronic speckle-pattern interferometry (ESPI) [1].

Instead, if the illuminated specimen is specular, or mirror-like, the coherent addition of the collected beams generates a pattern of fringes by constructive and destructive interference. This fringe pattern is a contour map of the z-coordinate of the specimen surface, where the contour interval is $\lambda/2$ per fringe order [8]; λ is the illuminating source wavelength. The digital superposition of two fringe patterns registered while the illuminated specimen surface undergoes mechanical deformation generates a Moiré fringe pattern. The generated Moiré pattern encloses information on the induced changes in the topography of the specimen. This technique is referred-to as whole-field subtractive Moiré (WSM) [8].

The Moiré patterns as well as the ESPI patterns may be interpreted as contour maps of the changes in the topography induced by the deformation. According to Kreis [15], if the fringes in these patterns are labeled with consecutive numbers N, the out-of-plane displacement W undergone by each point (x,y) on the illuminated surface during the deformation is given by

$$W(x,y) = (\lambda/2)N(x,y), \quad (1)$$

where N is referred-to as the fringe order. Note that if both techniques use the same light source, they have identical sensitivity.

3. Experimental results

3.1. Qualitative observations

The specimens were cooper and aluminum sheets, in the "as-received" state, i.e. cold worked. Fig. 2 shows the dimensions of the samples. The thickness of the specimens was 0.6 mm. They were tested on a testing machine working in tension at a speed of 0.5 mm/min. The pulling direction was the y-axis.

We followed initially the changes in the sample topography induced on a cooper sample. We generated ESPI fringe patters by using the interferometer shown in Fig. 1. The illuminating source was a laser of $\lambda = 630\,nm$, therefore, according to Eq. (1), the contour interval was 315 nm. A CCD camera of 512×512 pixels was utilized. The illuminated area, close to center of the sample, was $20 \times 20\,mm^2$.

Fig. 3 shows the sequence of a cooper sheet tensile test; it was constructed from the values of force and specimen elongation indicated by the display device of the testing machine. The upper line of pictures in Fig. 4 shows ESPI patterns generated by the digital subtraction of speckle patterns recorded at two close load stages selected into the indicated regions of the test. By analyzing these patterns, we noted that during the elastic region of the test the changes in the shape of the illuminated surface were occurring in the area close to the borders of the sample. Near to the center of the field, changes occurred during the transition zone to the stage of plastic deformation. During this region the material began to be thinned along a relatively broad band. This band appeared clearer during

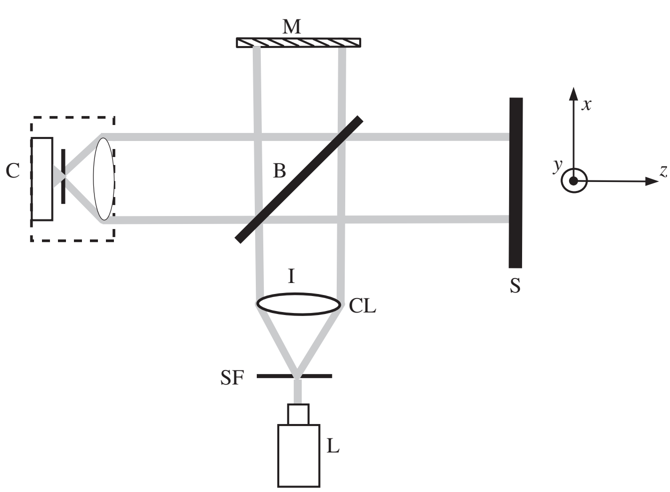

Fig. 1. Optical setup. I: incident plane beam in the x–z plane; S: specimen; C: CCD camera; M: mirror; B: beam splitter; SF: spatial filter; L: laser; CL : collimator lens.

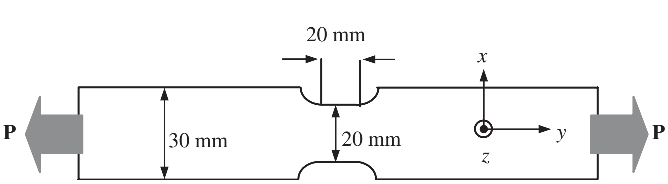

Fig. 2. Specimen dimensions. P: pulling direction.