Measurement of volume change in sheet elastomer testing using back-to-back stereo DIC

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Abstract. This paper presents a procedure to map the volume change in thin elastomeric sheets tested in tension. Finite element modelling and synthetic image deformation was used to verify the process, then experimental data were acquired. Some artefacts are present in the experimental data which are currently being investigated.

Possible Sessions

Novel Experimental Techniques, Optical and DIC Techniques, Testing of Polymers, Composite and Adhesives Materials

Introduction

Elastomers are generally considered incompressible meaning that their density remains constant during loading. However, depending on the material system, this assumption can be incorrect and there is a necessity to measure such volume change. In the past, this has mainly been done on dog-bone rubber-like material specimens by measuring the strain field over two or more of their faces to calculate the volume change [1-2]. A similar methodology was applied to plasticity in [3]. The main limitation of such approaches is that it can only be applied to uniaxial stress states while volume changes are likely to be dependent on stress multi-axiality.

An alternative is to use more complex test geometries in the spirit of Material Testing 2.0 [4-5] so that volume change could be measured as a function of stress multiaxiality. For this, it has been shown that two back-to-back stereo Digital Image Correlation (DIC) systems could lead to an average through-thickness deformation [6]. This is obtained as the difference of the out-of-plane displacements measured on the front and back faces. However, because of the large mismatch between the deformation in the longitudinal direction and that in the transverse ones, it is essential to have a very accurate registration of the two stereo-systems otherwise, some 'leakage' occurs from the vertical displacement to the out of plane one leading to spurious volume changes [7]. This also casts some doubts about the values obtained in [6] as this registration had not been performed accurately there.

Procedure and verification

The procedure consists of a tensile test on an elastomeric sheet with two back-to-back stereo-DIC systems recording the deformation of each face of the sheet. Since large deformations are in play, the Green-Lagrange strain metric is used. Since only surface displacements are measured, only the in-plane components of the deformation gradient tensor are measured. This study assumes that the out-of-plane shear components are negligible. As for the 33 component (through thickness normal strain), the idea is to evaluate it from the two out-of-plane displacement maps. Assuming that the in-plane displacements are constant through the thickness of the sample, the Green-Lagrange normal strain through the thickness is expressed as:

$$E_{zz} = \frac{\partial w}{\partial Z} + \frac{1}{2}\left(\frac{\partial w}{\partial Z}\right)^2, \qquad (1)$$

where w is the out-of plane displacement and Z the through-thickness coordinate.

The present study revisits this methodology by carefully looking at the registration procedure. The novelty lies in the availability of a tool that allows to simulate camera images from a stereo DIC calibration file and a finite element model [8-9] to verify the data processing procedure. A finite element model of a rectangular tensile specimen (150 x 50 mm, thickness 2.8 mm) was developed in Abaqus using a Neo-Hookean incompressible material model (C_1 = 50 MPa, D_1=0 MPa) with shell elements. Image deformation from [8-9] was performed using the FEDEF module of MatchID [10]. These images were then processed as if they were experimental which allowed to verify the complete data processing chain and to illustrate the sensitivity of the data processing to the local orientation of the material coordinate system. To realistically simulate the experiment, the specimen initial shape (not perfectly flat) was extracted from the experiment (see below) and exported to the FE preprocessor. The out-of-plane strain was calculated according to Eq. 1 and the results are shown in Fig. 1. The volume change is nearly zero everywhere, as expected, though some numerical noise is present on the right-hand side (about 1% of volume change), probably as a result of the numerical image deformation process. We are currently looking into this, including using a larger stereo angle to enhance the sensitivity to the out of plane displacement component.

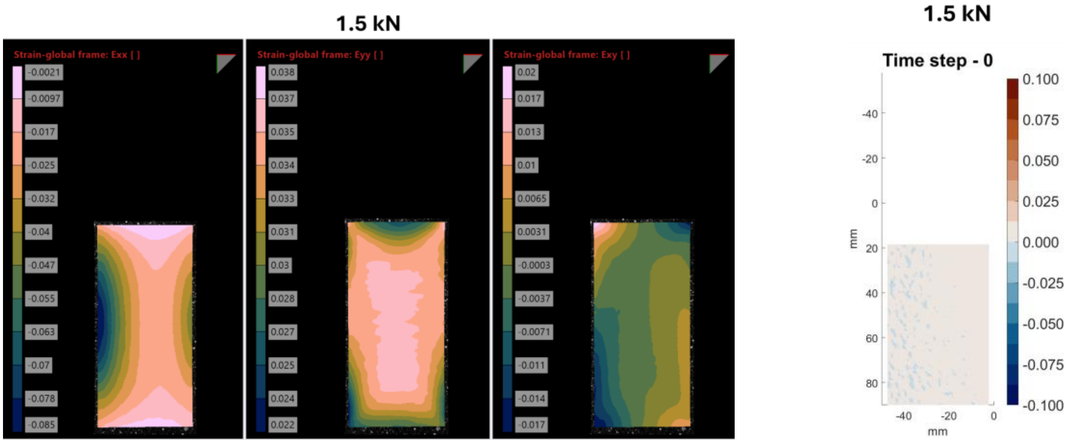

Fig. 1 – Three in-plane components of strain (left) and map of volume change (right)

Experimental data was acquired on a 150 x 50 x 2.8 mm natural rubber sheet specimen, loaded in tension at a crosshead speed of 0.1 mm/s. Speckle patterns were obtained by paint spraying both faces. Two back-to-back stereo DIC systems were used, employing four 5 Mpx cameras. The specimen was tested up to 60% of longitudinal strain and 80 loads steps were recorded at 0.28 Hz, generating 160 pairs of stereo images. The results show that some significant positive volume changes are detected at low loads, which is unlikely to happen in practice so there is still an artefact that we are trying to pin down. More will be provided on this during the presentation.

Conclusion

The procedure has been validated numerically but some artefacts are still being investigated on the experimental data. In the future, the procedure will be applied to a range of different elastomers tested on a biaxial machine to understand the compressibility of these materials as a function of stress multiaxiality and strain levels. The procedure will also be applied to the material system tested in [6] to verify their results. It would also be very interesting to study polymeric materials and also investigate the influence of strain rate on the compressibility of such materials.

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