2D mapping of volume change in sheet elastomer testing using back-to-back stereo DIC systems

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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 were used to verify the process. Then, experimental data were acquired on an SBR elastomeric sheet sample. The results show good agreement with expectations.

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. Because surface displacements are measured, only the in-plane components of the deformation gradient tensor are directly measured. The idea here is to evaluate the components that include the through-thickness derivatives, E_{xz}, E_{yz} and E_{zz} by the difference between the displacement quantities measured on each face by each stereo-DIC system. This implicitly assumes constant strains through the thickness.

First, the procedure was verified using synthetic image deformation. 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. It was confirmed that the process is very sensitive to the vertical alignment of the back-to-back systems.

Then, experiments were conducted on SBR elastomeric samples cut from a 2.8 mm sheet as tested in [11], kindly supplied by Dr Julie Diani from the LMS laboratory at Ecole Polytechnique, Paris. First, a 50 x 50 mm^2 specimen was tested in rigid body motion to evaluate the resolution in volume change. This was estimated at about 1% of volumetric strain. Then, a 100 x 50 specimen was tested in tension up to a stretch of about 80%. Two back-to-back stereo DIC systems were used, employing four 5 Mpx cameras. The calibration was performed using a target with dots printed on both faces and a well-controlled thickness. A bundled optimization was then run allowing to simultaneously identify both intrinsic and extrinsic parameters for each stereo pair, but also the extrinsic parameters describing the position of the back stereo pair with respect to the front one. An automated gimbal system was used to hold and move the calibration target, ensuring that no motion blur occurred during image acquisition. Fig. 1 shows the experimental set-up.

The results evidence that there is no significant volume change (Fig. 2), as expected from [11]. There is however a low spatial frequency pattern showing that some systematic errors are still present and that there is potential to improve the performances. This may be due to a small uncertainty remaining in the registration angle between the two stereo systems, or some lens distortion not entirely compensated for. This will be studied in more depth in the future.

Fig. 1 – Experimental set-up

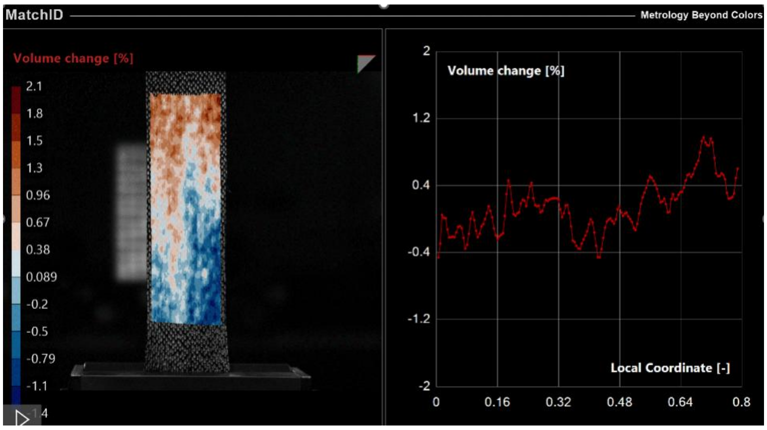

Fig. 2 – Volume change at maximum elongation (80%)

Conclusion

The paper shows a successful implementation of the use of two back-to-back stereo-DIC systems to map the volume change of thin samples. It relies on their accurate simultaneous calibration using a dedicated double-faced calibration target. This is essential to obtain accurate results as volume change is highly sensitive to any vertical misalignment of one stereo pair with respect to the other [7]. Rigid body tests showed that a resolution of about 1% volumetric strain could be reached, and a tensile test on a 2.8 mm SBR sheet showed no significant volume change, as expected from the results in [11]. Future work will look at even more accurate calibration (lens distortion, camera angles), use of more complex tests (biaxial, more complex geometries) and high strain rate deformation. The effect of such volume change on hyperelastic model identification will also be investigated.

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