Quantification of the compressibility of elastomers using DIC

F. Davis, J. L'hommel, Jean-Benoit Le Cam, F. Pierron

▶ To cite this version:

F. Davis, J. L'hommel, Jean-Benoit Le Cam, F. Pierron. Quantification of the compressibility of elastomers using DIC. 1st Annual International Digital Imaging Correlation Society, 2016, Nov 2016, Philadelphia, United States. pp.199-201, 10.1007/978-3-319-51439-0_47 . hal-01638854

HAL Id: hal-01638854

https://hal-univ-rennes1.archives-ouvertes.fr/hal-01638854

Submitted on 16 May 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Distributed under a Creative Commons Attribution| 4.0 International License

Quantification of the Compressibility of Elastomers Using DIC

Frances Davis, Jason L'Hommel, Jean-Benoît Le Cam, and Fabrice Pierron

Abstract Both filled and unfilled elastomers are generally modeled as incompressible solids. However studies on the compressibility of elastomers have indicated that volume expansion is observed at large stretches coinciding with the onset of cavitation. Varying methods such as dilatometry and hydrostatic weighting have been used to calculate volume changes that elastomers undergo during stretching. However, these techniques cannot map volume variations for a heterogeneous state of stress, motivating the present work. In this study, carbon black filled elastomer samples were subjected to a uniaxial stretch and the deformation was recorded using two back-to-back stereo-correlation systems. The back-to-back stereo-correlation systems allow the in-plane strains on the front and back face of the specimen to be calculated along with the normal strain through the thickness. Using the assumption of plane stress, the volume variation of the elastomer as a function of the applied longitudinal strain was determined.

Keywords High strain rate • Inertial impact • PMMA • Grid method • Virtual fields method

47.1 Introduction

Elastomers are soft rubbers that can undergo very large reversible deformations (up to 300%). They are routinely used for wide variety of engineering applications due to their damping qualities and high elongation at failure. The mechanical response of rubbers is generally modeled by assuming that they are incompressible solids. Early studies examining the volume variation in rubbers used dilatometry and observed volume changes when large stretches were applied [1]. Recently, digital image correlation has been used to examine the volume change in natural rubbers [2]. A uniaxial stretch was applied to the rubber and a single camera was used to record the deformation. The stretch through the thickness was calculated assuming that the rubber was transversely isotropic. While this approach can be used to study uniaxial tension it would not be appropriate to examine heterogeneous states of stress. In this paper, two back-to-back stereo-correlation systems were used to examine the volume variation in a filled elastomer.

47.2 Experimental Protocol

As proof of concept, a carbon black filled elastomer was subjected to a uniaxial stretch and the volume variation was measured using two back-to-back stereo-correlation systems. The uniaxial tensile test was performed on an Instron 5569 equipped with a 2 kN load cell. Samples were cut from rubber sheets with a gauge length and width of 50 mm. The initial thickness was 2 mm. A white speckle pattern was applied to both sides of the elastomer using transfer paper before installing the sample in the grips (Fig. 47.1). The imaging setup consisted of four cameras (Manta, Allied Vision, 2452 × 2056 px) with 50 mm AF Nikkor lenses. The cameras were positioned as shown in Fig. 47.1a. Nila LED lights were used to illuminate the field of view. To eliminate specular reflections, polarized light filters were used on each of the lights and lenses. The samples were loaded at a rate of 10 mm/min up to a displacement of 175 mm. Images of the elastomer were collected at a rate of 0.3 Hz.

F. Davis (✉) • J. L'Hommel • F. Pierron
Faculty of Engineering and the Environment, University of Southampton, Highfield SO17 1BJ, UK
e-mail: frances.davis@soton.ac.uk

J.-B. Le Cam
Université de Rennes, Institut de Physique de Rennes, 35042 Rennes, France

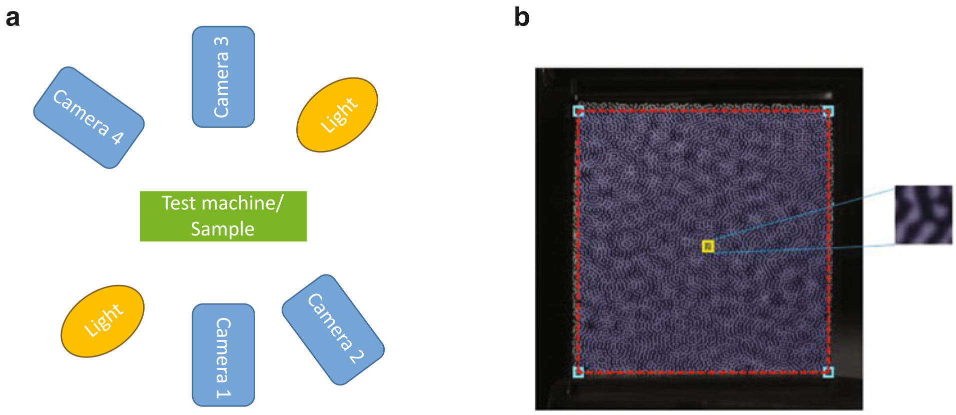

Fig. 47.1 Schematic of the back-to-back camera test configuration showing (**a**) the position of the cameras and lights relative to the test machine and (**b**) a sample image of the elastomer with the speckle pattern applied. The *small block* shows a representative subset

The commercial code MatchID (v. 2.1) was used to capture images, calibrate the stereo systems, and analyze the images. To calculate the change in volume the displacement data from the front and back camera systems must be obtained in a single coordinate system. To achieve this first, the front and back stereo systems were calibrated individually. Then a secondary calibration was performed between cameras 1 and 3. A black speckle pattern was transferred onto a thin sheet of PMMA and several images of speckle pattern were captured using both camera systems. A custom code was built to determine the coordinate transformation between cameras 1 and 3. The images collected during the tension test from the front and back stereo systems were analyzed individually both using a subset size of 33×33 px and a step size of 15 px. Due to the large deformation that occurred during the test the reference image was updated after every image. The resulting displacements were exported from MatchID in the coordinate systems of cameras 1 and 3 for the front and back camera systems, respectively. The coordinate transformation obtained from the secondary calibration was then used to bring all of the displacement data into a single coordinate system (Camera 1).

Using the transformed displacement data, the deformation gradient, $\mathbf{F} = \mathbf{1} + \nabla\mathbf{u}$, was calculated assuming a state of plane stress. The volume variation is then given by

$$\frac{dv}{dV_0} = \det\mathbf{F}\,. \tag{47.1}$$

In addition, the Green-Lagrange strain was calculated, $\mathbf{E} = 1/2\,(\mathbf{F}^{\mathrm{T}}\mathbf{F} - \mathbf{1})$.

47.3 Results and Discussion

The sample was first stretched to a displacement of 200 mm and then unloaded and allowed to recover. This initial stretch was applied to avoid observing the Mullins effect during the test which has been shown to have no impact on the volume variation [2]. The carbon black filled elastomer was then subjected to the experimental protocol described. The strain maps collected during the test revealed slight misalignment in the grips. This led to a small twist being applied to the sample in addition to the uniaxial stretch. The carbon filled elastomer was found to be incompressible at low strains ($<15\%$). As the strain increased small increases volume ($<5\%$) were observed. These findings agree well with the observed behavior reported for the uniaxial stretch of elastomers [2, 3]. In the future, the goal is to use this back-to-back camera technique to study more complex stress states and determine if the incompressibility assumption is valid. In addition, since this technique can produce maps the volume variation it will be possible to study the volume variation locally.

Acknowledgements Dr. Frances Davis and Prof. Fabrice Pierron acknowledge support from EPSRC through grant EP/L026910/1. Prof. Fabrice Pierron also expresses gratitude to the Wolfson Foundation for support through a Royal Society Wolfson Research Merit Award.

References

1. Cam, J.-B.L.: A review of volume changes in rubber: the effect of stretching. Rubber Chem. Technol. **83**(3), 247–269 (2010)
2. Le Cam, J.B., Toussaint, E.: Volume variation in stretched natural rubber: competition between cavitation and stress-induced crystallization. Macromolecules **41**(20), 7579–7583 (2008)
3. De Crevoisier, J., et al.: Volume changes in a filled elastomer studied via digital image correlation. Polym. Test. **31**(5), 663–670 (2012)