MatchID

Metrology beyond colors

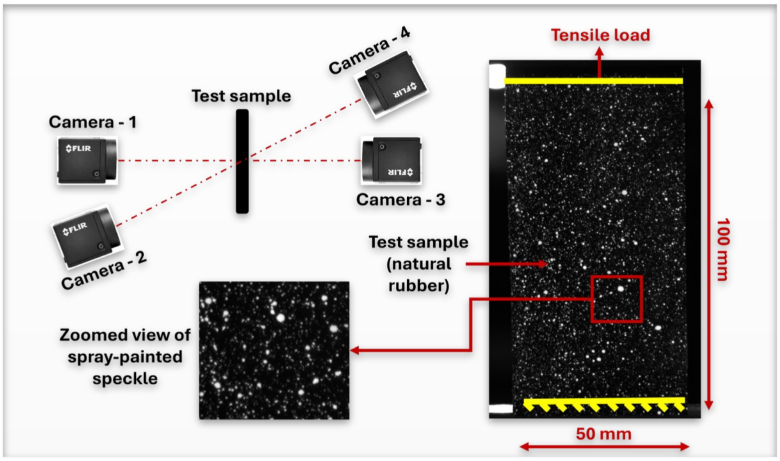
Application Note

Multi-camera DIC procedure for volume change measurement

Case description

Motivation: Measurement of volume change requires through-thickness deformation measurements, which a standard stereo-DIC system cannot provide. Multi-camera DIC systems, calibrated together, offer a solution by imaging the opposing faces of a thin object. This provides valuable insights to the material behaviour by enabling identification of its bulk properties.

Methods: Multi-camera DIC experiments were performed to measure volume change induced in a natural rubber test sample under uniaxial load. Numerical image deformation was used to create a digital twin of the DIC experiment to verify the approach and assess uncertainties.



Experimental setup

- ✓ **Cameras:** Four 5 MPx Flir Blackfly S BFS-U3-51S5M
- ✓ **Light source:** Two VARIO2 Lite w4 with polarization filters
- ✓ **Lenses:** Fujinon HF25XA-5M, focal length 25 mm
- ✓ **Acquisition speed:** 5 Hz
- ✓ **Field of view:** 50 mm x 200 mm

Analysis

- ✓ **Calibration:** Custom-made back-to-back calibration target
- ✓ **Type:** Multi-cam DIC
- ✓ **Digital twin:**
  - Neo-Hookean constitutive model to model natural rubber
  - Real-world conditions (e.g. non-flat shape, bending)

Results

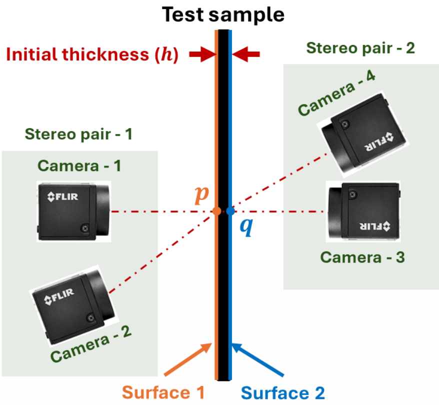
- ✓ DIC-measured **displacements** and **deformation gradient tensor** at each DIC subset center on both test sample faces
- ✓ **Volume change** at each DIC data point
- ✓ **Benchmark** for digital twin: volume change predicted by the FE model

Why MatchID

- ✓ Advanced **multi-camera** DIC module (more than two cameras)
- ✓ **Thickness calculation** when back-to-back multi-camera measurements are performed
- ✓ ***Full* deformation gradient tensor and volume change**
- ✓ **Multi-camera numerical image deformation** with seamless communication with most FE-packages

Calculation of volume change

Both faces of the test sample are imaged by two stereo-DIC systems calibrated in the *same world coordinate frame* using the MatchID multi-camera module. After performing DIC correlation, matching pairs of DIC subset centers (*p* and *q*) are obtained in the *reference configuration* by intersecting the normal to surface - 1 at subset center p with surface - 2.



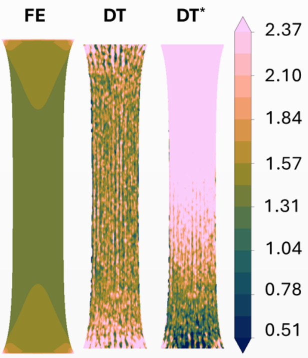
$$F^p = \begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} & \frac{u^p - u^q}{h} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} & \frac{v^p - v^q}{h} \\ \frac{\partial w}{\partial x} & \frac{\partial w}{\partial y} & \frac{w^p - w^q}{h} \end{bmatrix}$$

$$\Delta V^p = 1 - \det(F^p)$$

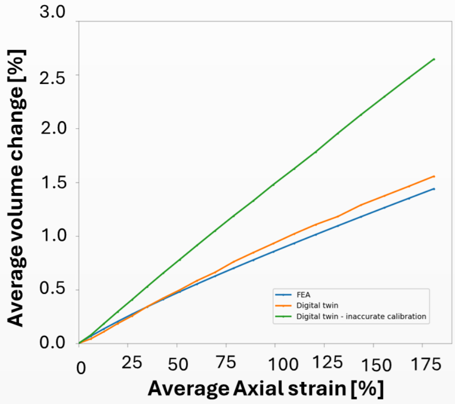
Displacement time history at these pairs was then used to calculate the through-thickness terms of the deformation gradient tensor (F^p_{i3} shown in three colors) which are otherwise inaccessible. Terms of F^p shown solely in orange are calculated using the standard strain window smoothing. As shown, the determinant of F^p, which corresponds to volumetric strain can then be used to calculated volume change at subset center p.

Creation of digital twin

Numerical displacements were obtained from a finite element (FE) model. Neo-Hookean constitutive behavior was assumed. Based on FE displacements, a digital twin (DT) of the DIC experiment was created using the MatchID multi-camera numerical image deformation tool. To demonstrate the essentiality of calibrating the two stereo-DIC systems together, a small calibration error of 0.01° was introduced pertaining to the rotation between the two stereo systems.

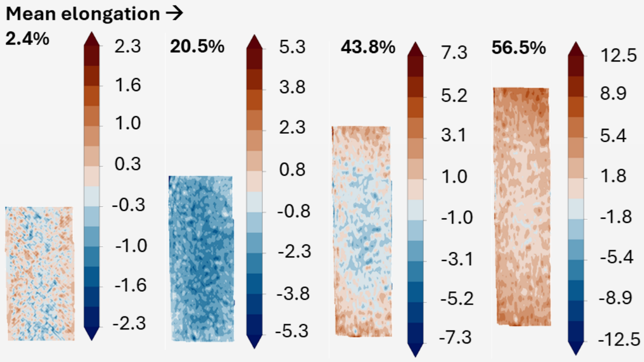


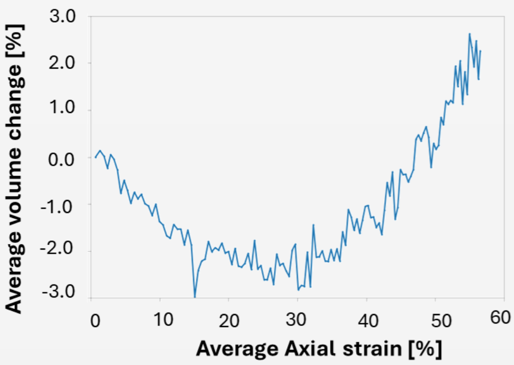
*Wrong calibration



Key conclusions: It is evident that the DT can predict the average volume change well. DIC bias errors simulated by the DT introduce primarily high spatial-frequency errors. Small calibration errors can deteriorate the results significantly.

Experimental volume change





The average experimental volume change shows an interesting trend - an initial decrease followed by subsequent increase. The initial volume decrease is relatively homogeneous with no significant spatial trends. Volume increase is driven by the areas near the test machine grips.

Conclusion: This approach for measuring volume change of thin specimens is promising.