MatchID
Metrology beyond colors

Application Note

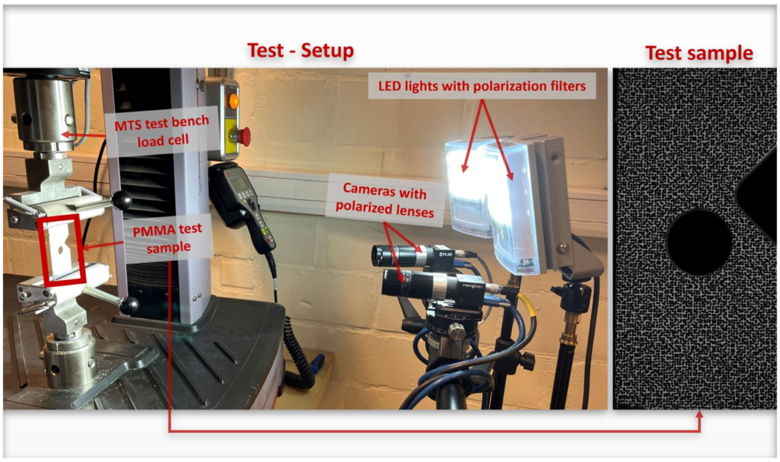
Force reconstruction to troubleshoot constitutive model problems

Case Description

Background: The Force Reconstruction Error (FRE) can be used to evaluate constitutive model validity. The resultant force acting at a cross section of a test sample is calculated by integrating full-field stresses and comparing it to the measured resultant force.

Description of the test case: Deformations of a uniaxially loaded PMMA test sample were measured using Digital Image Correlation (DIC). The Virtual Fields Method (VFM) was used to identify the elastic constants. A Digital Twin (DT) of the DIC experiment involving synthetic images was used to investigate FRE deviations due to DIC smoothing and transverse bending.

Conclusions: DIC-DT FRE comparison yields quantitative conclusions about constitutive model validity by disentangling constitutive model errors from other errors.



Experimental Setup

- ✓ Cameras: 2X 5 MPx Flir BFS-U3-51S5M-C
- ✓ Lens: Fujinon 50 mm
- ✓ Acquisition Speed: 5 Hz
- ✓ FOV: 30 mm x 60 mm
- ✓ Stereo Angle: 17°
- ✓ Subset, Step: 21, 3 Pixels
- ✓ VSG: 63 pixel
- ✓ Displacement noise: 0.2 µm

Analysis

- ✓ **Type:** Stereo-DIC
- ✓ **Material identification:** noise-optimized piecewise virtual fields
- ✓ **FRE:** To judge the validity of the constitutive model
- ✓ **DT of DIC experiment:** To judge impact of DIC smoothing and transverse bending on FRE

Results

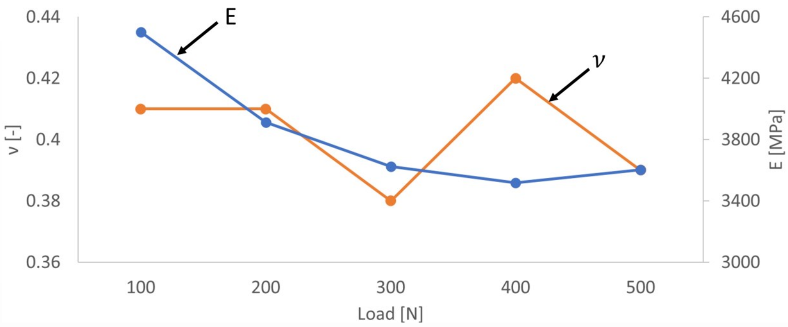
- ✓ **VFM-identified** elastic constants
- ✓ **FRE plots calculated using axial stress fields from**
  - DT of the DIC experiment
  - DIC experiment

Why MatchID

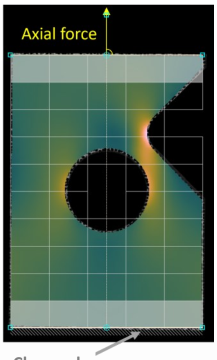
- ✓ Powerful **material identification platform** based on the virtual fields method (VFM).
- ✓ **Digital twin** of the DIC experiment using **FEDEF module** for investigating DIC bias errors.
- ✓ A generic **force reconstruction tool** embedded in the MatchID Results Viewer.

VFM identification

Young's Modulus (E) and the Poisson's ratio (ν) of PMMA were identified using VFM at five different loads. The identified E modulus decreases with increasing tensile load, which is an artefact of the transverse bending of the test sample due to small misalignment in test bench grips. From loads ≥ 300 N, Young's modulus is mostly stable indicating that the contribution of transverse bending to the total strains is gradually decreasing.



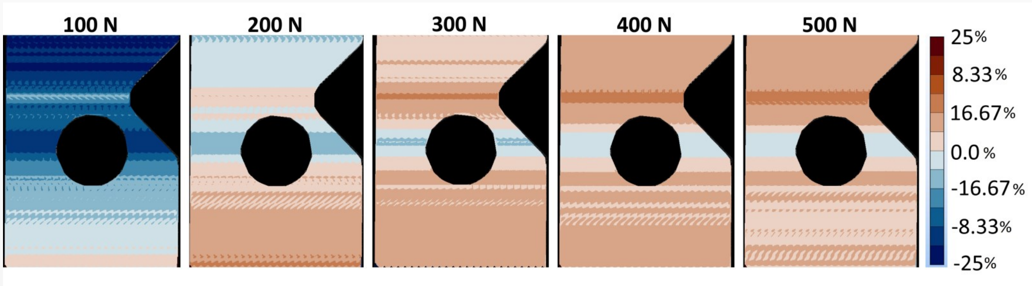
VFM boundary conditions



Clamped

FRE (Digital Twin)

A Finite Element (FE) model of the test sample subject to DIC-measured displacement boundary conditions and involving linear elastic constitutive behavior (E and ν at 300 N) was performed. FE displacements and the DIC calibration model were used to synthetically deform the experimental speckle pattern creating FE-based virtual images using the MatchID FEDEF module. Next, identical spatial smoothening as for the experimental deformation fields was enforced on the FE quantities by correlating the virtual images using the experimental DIC processing parameters. Below, the FRE full-field plots (%) are displayed from 100 to 500 N, whereby a fully compliant FRE plot corresponds to 0%. At 100 N, the presence of transverse bending is responsible for deviations up to ±25% at the top of test sample. Although at higher loads the impact of transverse bending is reduced, DIC smoothing introduces small deviations within ±3% near the stress concentrations at the notch and the hole.



FRE (experimental)

FRE was calculated using the experimental stress fields. Any deviations in these maps w.r.t. the DT counterparts can be attributed to DIC noise and constitutive model errors. Similar trends as for the DT are observed at loads ≤ 200 N, where the impact of transverse bending is evident except for spatially random deviations attributed to DIC noise. An overall overestimation of the FRE is seen at loads ≥ 300 N, which is attributed to the slight overestimation of E modulus identified by VFM, originating from small but impactful contribution of transverse bending of the test sample. Toconclude, FRE is a valuable tool for checking the compliance of constitutive models and the usage of DT is essential for disentangling constitutive model errors from DIC bias errors.