Isotropic and orthotropic material parameter identification from full-field bulge inflation tests on PVC-coated polyester

Special attention to the objective function

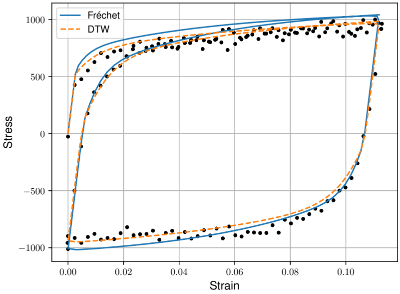
C.F. Jekel, R.T. Haftka, M.P. Venter, G. Venter

September 2, 2019

University of Florida, Gainesville, USA
SEMC 2019

Different fields use different discrepancy measures

- Discrete Fréchet distance
  - L_∞ norm
  - hand writing analysis
- Dynamic Time Warping (DTW)
  - L_1 norm
  - voice recognition
- [1] showed that these method produce different kinematic hardening parameters
- **Different objective functions produce different parameters**



Optimum results for Discrete Fréchet distance and DTW on tension-compression-tension curve.

Obtaining material model parameters: emphasis on objective

Objective function

How we quantify the discrepancy between models and experiments

- Finite Element (FE) material model parameters for Isotropic and orthotropic models
- Bulge inflation test match full displacement field data to FE model
- Demonstrate how **two different objective functions** the choice in objective function influences material parameters

PVC-coated Polyester

- Complex non-linear behavior
- In-plane weave of polyester yarns
- Coating makes material impermeable
- Non-continuous material
- Commonly modeled as continuous orthotropic in FE models

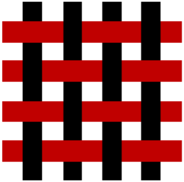
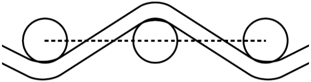
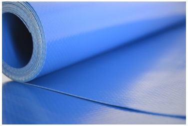


Illustration of woven yarns from Ellis [2].



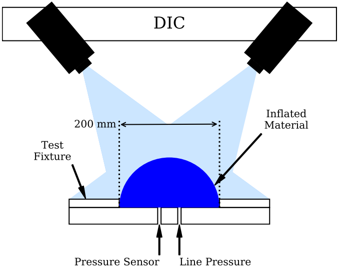
Through thickness effect of the weave from Ellis [2].



A roll of PVC-coated polyester.

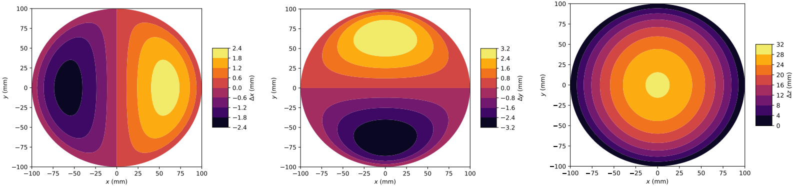
Bulge inflation tests

- Circularly clamped material
- Record inflation pressure (up to ≈ 3.0 bar)
- Digital Image Correlation (DIC) measures the full-field displacements
- Displacement components $\Delta x, \Delta y, \Delta z$
- Experiments performed at Stellenbosch University, South Africa



Overview of bulge inflation test setup.

Typical FE model displacement fields



Displacement fields of FE model at 2.0 bar and orthotropic properties. Left Δx, Center Δy, Right Δz. Note field data is symmetric.

- Displacement field data as function of inflation pressure
- Order of magnitude issue: Δz is about 10x larger than Δx or Δy

Isotropic and orthotropic material models

Identifying representative material models.

Material stiffness is dependent upon direction, thus anticipate orthotropic model will represent material behavior better.

Isotropic

- Single unknown parameter E
- Fixed $\nu = 0.24$

Simplified orthotropic

- Three unknown parameters E_1, E_2, G_{12}
- Fixed $\nu_{12} = 0.24$

Discrepancies between FE model and Experiments

Considering the residual displacement components equally:

$$e = r_{\Delta x}(\boldsymbol{\beta}) + r_{\Delta y}(\boldsymbol{\beta}) + r_{\Delta z}(\boldsymbol{\beta}) \tag{1}$$

Relative weighted residual displacements:

$$e_w = r_{\Delta x}(\boldsymbol{\beta}) + r_{\Delta y}(\boldsymbol{\beta}) + \frac{1}{10} r_{\Delta z}(\boldsymbol{\beta}) \tag{2}$$

Compare these two objective functions

Show that minimizing e or e_w will result in different material parameters.

Optimization process for material parameter identification

$$\text{minimize:} \quad e(\boldsymbol{\beta}) \tag{3}$$

$$\text{subject to:} \quad \beta_l \leq \beta_k \leq \beta_u, \quad k = 1, 2, \cdots, n_p. \tag{4}$$

Process to compute single objective function:

Step	Description
1	Write the material model parameters to the ABAQUS input file
2	Run ABAQUS solver on the input file
3	Export displacement field of FE model
4	Load the FE displacement field into memory
5	Compute the discrepancy between FE model and DIC data
6	Compute the final objective function of e or e_w

Multi-start gradient based optimization algorithm to minimize the objective function

Differences of using e or e_w as objective function

- Four experimental tests
- Isotropic and orthotropic material parameters
- Differences with minimizing e or e_w

Isotropic results

Table 1: One parameter isotropic material results from each inverse analysis. Note ν was fixed to 0.24.

	Minimizing e E (GPa)	Minimizing e_w E (GPa)
Test 1	0.279	0.283
Test 2	0.222	0.292
Test 3	0.242	0.282
Test 4	0.218	0.253

- Highlighted big differences in Test 2 and 3!
- e_w resulted in more consistent moudli across the 4 tests

Orthotropic results

Table 2: Resulting orthotropic material parameters from minimizing tests independently with each inverse analysis. Note that ν_{12} was fixed to 0.24.

	Minimizing e (GPa)			Minimizing e_w (GPa)		
	E_1	E_2	G_{12}	E_1	E_2	G_{12}
Test 1	0.34	0.25	0.005	0.30	0.23	0.005
Test 2	0.21	0.24	0.004	0.31	0.23	0.005
Test 3	0.22	0.26	0.004	0.31	0.23	0.005
Test 4	0.24	0.22	0.004	0.28	0.22	0.005

- Highlighted most drastic changes
- Minimizing e_w resulted in more consistent parameters
- Minimizing e was unable to identify $E_1 > E_2$ or vice versa

Conclusions - carefully consider objective function

Previous work [1] showed that **different objective functions** (L_1, L_2, L_∞) lead to substantially different material parameters.

This work shows that different normalization schemes also do.

On the difference in e and e_w objective functions

e_w more consistent parameters

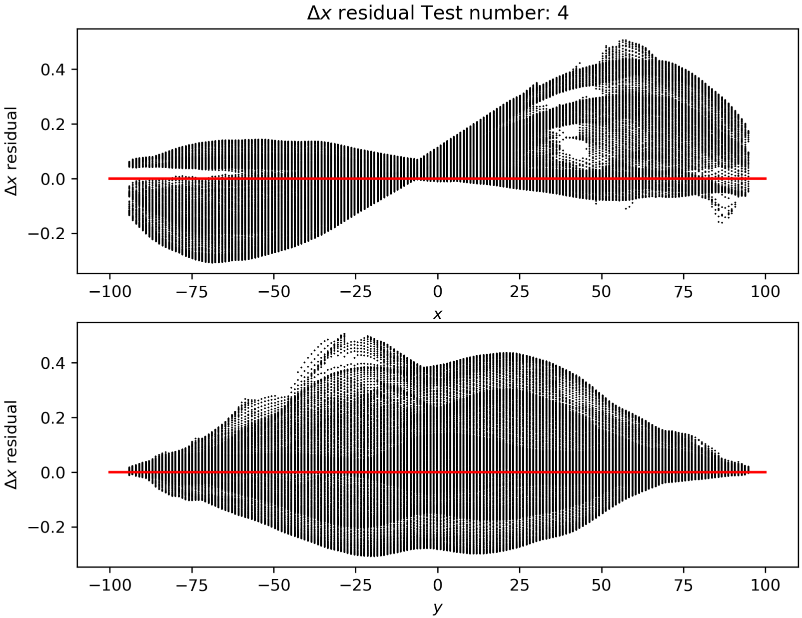
e_w better identified E_1 and E_2

References i

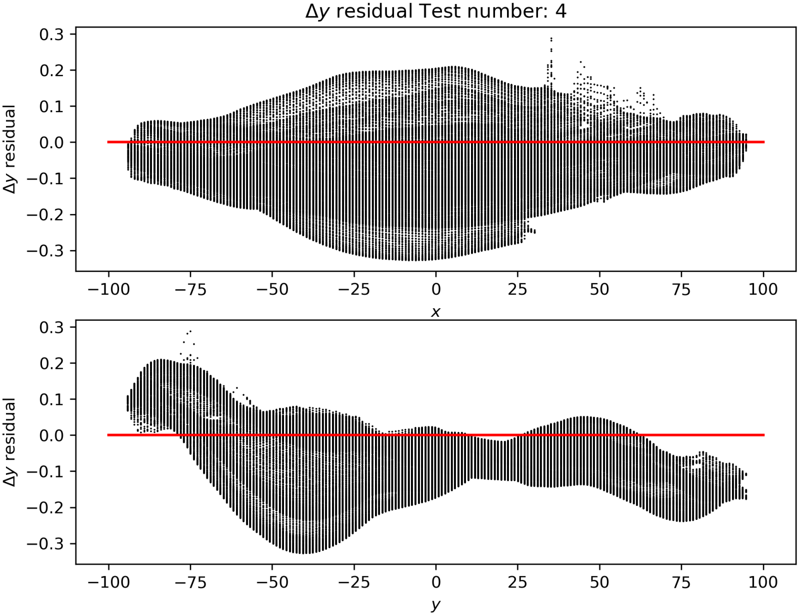
[1] Jekel, C.F., Venter, G., Venter, M.P. et al., Similarity measures for identifying material parameters from hysteresis loops using inverse analysis, Int J Mater Form (2019) 12: 355. https://doi.org/10.1007/s12289-018-1421-8

[2] Ellis, D.R., 2017. Mechanical characterisation for simplified response modelling of woven polypropylene (Masters Thesis, Stellenbosch University).

Residual plot Δx test 4



Residual plot Δy test 4



Residual plot Δz test 4