Hyperelastic Material Characterisation of Rubber by means of Novel Experimentation and Reverse Engineering

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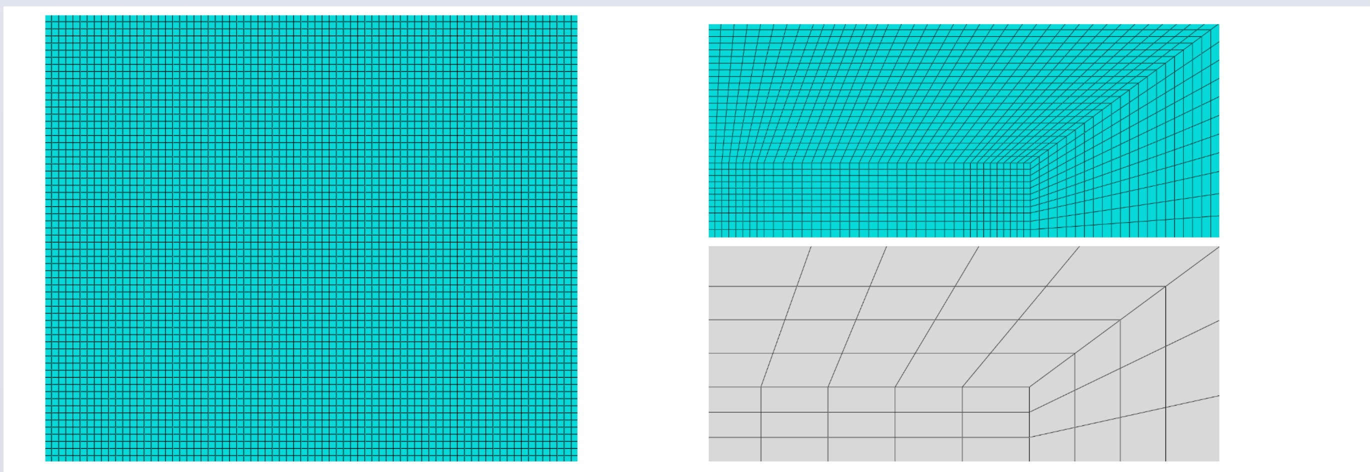
ABSTRACT

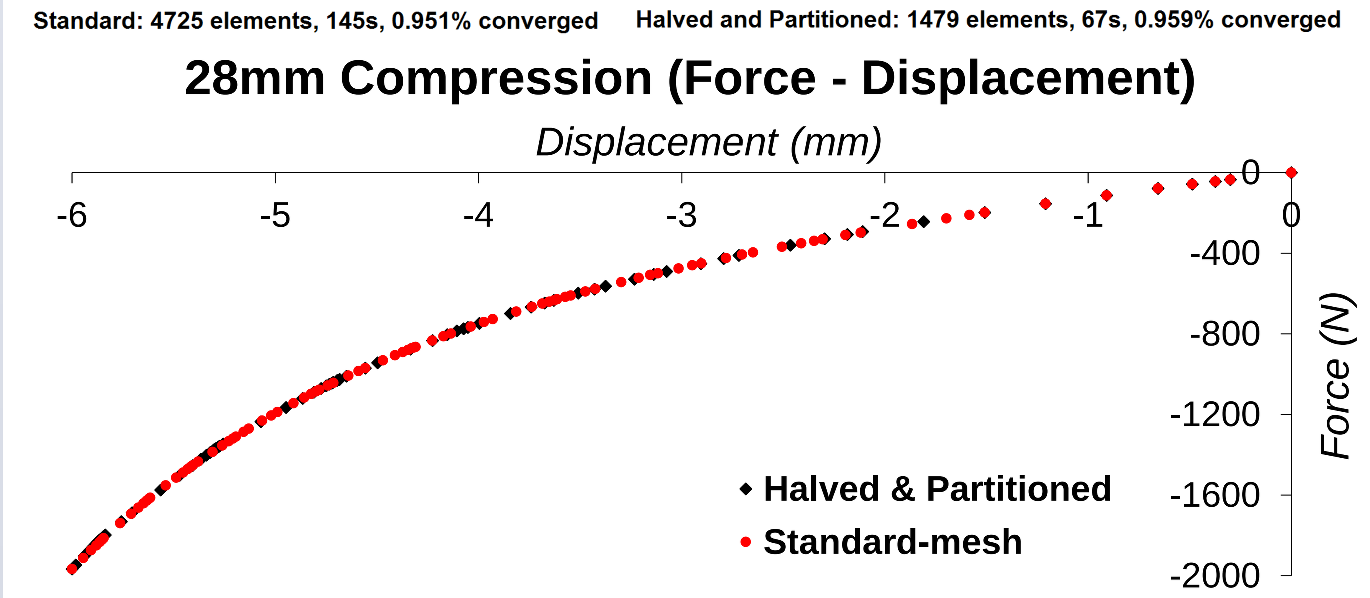
- Hyperelastic characterisation requires multiaxial test data – uniaxial tension, pure shear and equibiaxial tension
- To increase the efficiency of material characterisation, a novel, inhomogeneous experiment is introduced utilising finite element optimisation
- No-slip compression test data is compared to an equivalent finite element model to optimise the coefficients of several material models
- Autonomous investigation of method through Finite Element Analysis (FEA)
- 8-chain, Yeoh and Ogden-3 models were investigated
  - 8-chain and Yeoh are suitable for this method but Ogden-3 is not
- Combining with uniaxial test data enables an improved fit to test data

SIMULATED EXPERIMENT

- No-slip uniaxial compression (NsC) test
  - Standard ASTM D575 specimen: 28.6mm diameter, 12mm thickness
  - Compressed with full friction – sticking once in contact
  - Strain field is inhomogeneous – simultaneous tensile, compression and shear modes
- Finite Element (FE) modelling in Abaqus
  - Investigate test & optimisation parameters using axisymmetric FE model
  - Ogden N=3 constants fitted to Treloar's data [1] (uniaxial, planar and equibiaxial tension)
  - Generate pseudo-test data for use in Isight optimisation
  - Requires accurate and converged solution before simplification
- FE optimised model requirements:
  - Minimise solution time while maintaining accuracy
  - Symmetry applied and mesh partitioned – significant element reduction
  - "Rough" friction formulation further reduces solution time to 26 seconds
  - Free from volumetric locking and hourglassing



Standard: 4725 elements, 145s, 0.951% converged — Halved and Partitioned: 1479 elements, 67s, 0.959% converged

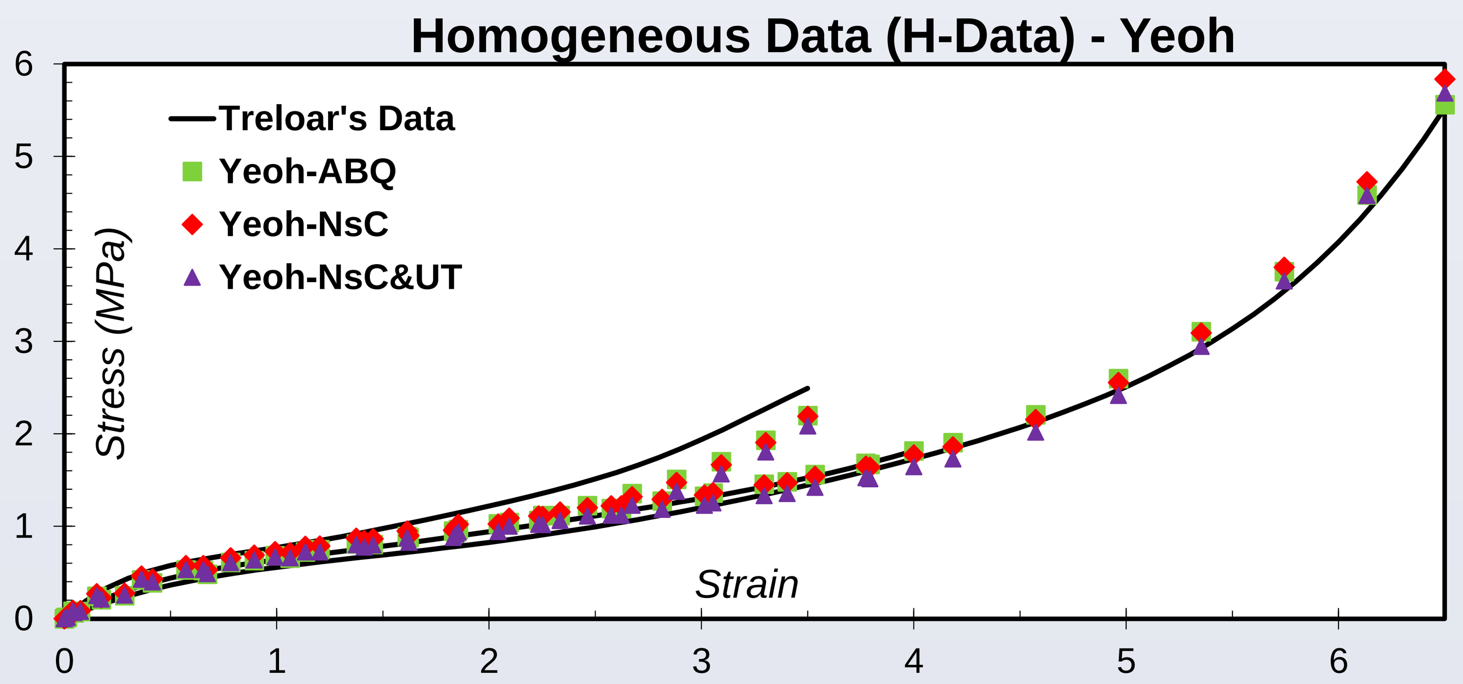


OPTIMISATION METHOD

- Isight Optimisation
  - Abaqus with Isight used for optimisation
  - Hyperelastic constants adjusted to minimise error between experimental and simulated force-displacement measurements
  - Relative error function used throughout study
- Optimisation of hyperelastic constants
  - 8-chain, Ogden & Yeoh models start with arbitrary constants
  - Optimised to NsC test only and NsC with Uniaxial Tension (UT) tests
  - Different amounts of compression investigated: 33%, 50% & 66%

RESULTS

- Observations
  - Higher compression reveals more accurate multiaxial constants but results in more convergence failures
  - Ogden-3 model is by far the least efficient method and fails most often
- Assessment criteria
  - Homogeneous test data plotted using fitted constants
  - Relative error calculated for each and compared to optimal fit from Abaqus
- Optimisation with NsC test only
  - All models fit the NsC test accurately
  - 8-chain and Ogden models do not reveal multiaxial parameters
- Optimisation with NsC and Uniaxial Tension tests
  - 8-chain and Ogden are significantly improved
  - Yeoh model gives a better average fit



	8-chain			Yeoh			Ogden		
	ABQ	NsC	NsC + UT	ABQ	NsC	NsC + UT	ABQ	NsC	NsC + UT
NsC Error	0.140	0.105	0.601	0.469	0.001	0.137	0.000	0.001	0.056
ET Error	2.247	1.908	2.686	2.541	2.260	3.320	1.437	2.780	3.617
PT Error	1.649	2.681	1.381	1.236	1.943	1.320	1.369	2.023	1.599
UT Error	3.014	4.398	2.737	2.147	2.546	1.964	1.362	4.905	1.553
Average (H-data)	2.303	2.996	2.268	1.975	2.250	2.201	1.389	3.236	2.256
Average (all-data)	1.410	1.819	1.481	1.279	1.350	1.348	0.833	1.942	1.365

CONCLUSIONS & FUTURE WORK

- Novel characterisation method can reduce required testing
  - Yeoh and 8-chain may use one and two tests, respectively
  - The Ogden model is too inefficient to be considered as viable
- Further investigation: parametric study of specimen geometry
- Improvements to method
  - Previous study by Le Saux [2] revealed that indentation may be used to reveal the constants of the Edwards-Vilgis model – requires UMAT implementation
  - The extended-tube model [3] is similar to the Edwards-Vilgis and will also be implemented for comparison
- Experimental validation: assess method for unfilled and filled rubbers

REFERENCES

[1] L. R. G. Treloar, "Stress-strain data for vulcanised rubber under various types of deformation," T. Faraday. Soc., vol. 40, pp. 59-70, 1944.

[2] V. Le Saux and et al, "Identification of constitutive model for rubber elasticity from micro-indentation tests on natural rubber and validation by macroscopic tests," Mech. Mater., vol. 43, no. 12, pp. 775-786, 2011.

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