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Mechanical Characterization and FEA Simulation of SLA-Printed 50A Materials using Hyperelastic Models

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OPTIMAL MODEL	MASTER-CURVE FIT	SLA ISOTROPY	HIGH-ORDER RISK
Ogden N=3	**R^2 = 0.996**	**< 2 %**	**N5–N6 ✗**
Accuracy & stability in balance	Tension + compression unified	Across 4 print orientations	Violate Drucker → divergence

01 The challenge

Flexible architected materials — lattices, dampers, energy-energy-absorbing midsoles — need a route that gives gives geometric precision *without* FDM's layer anisotropy, anisotropy, plus a law that predicts large-strain response response reliably.
Hyperelastic calibration hides a **stability–accuracy dilemma** : high-order fits look perfect yet diverge in 3D in 3D solvers. We resolve it for a Shore 50A SLA photopolymer using combined tension + compression compression data.

02 Materials & methods

1. **Specimen fabrication**
   Formlabs Form 3, Elastic 50A · 0.05 mm layers · IPA wash wash + 20 min UV cure @ 60 °C
2. **Mechanical characterisation**
   Tension (ISO 37, 12 dumbbells × 4 angles) + cyclic compression (ISO 7743, Type A)
3. **Constitutive modelling**
   Poly-6 master curve → calibrate Ogden, Polynomial & Van Polynomial & Van der Waals models
4. **FE simulation & validation**
   Abaqus, C3D8RH hybrid elements (~15k) — experiment vs experiment vs FEA against Drucker stability

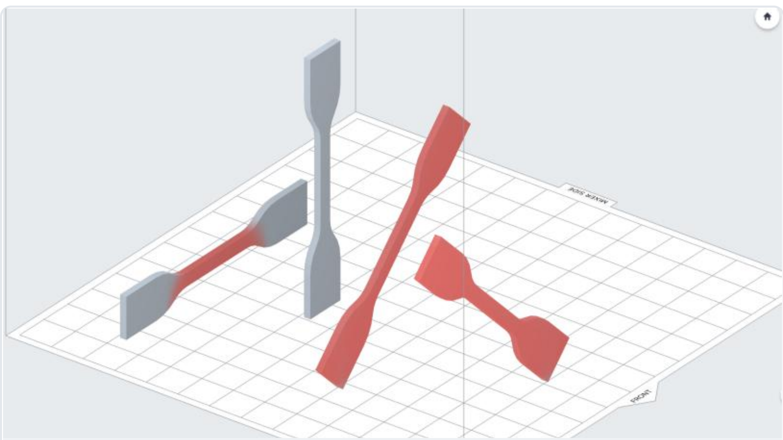

Fig. 1 Dumbbells printed at 0/45/90/135° to probe in-plane plane isotropy.

03 Experimental response

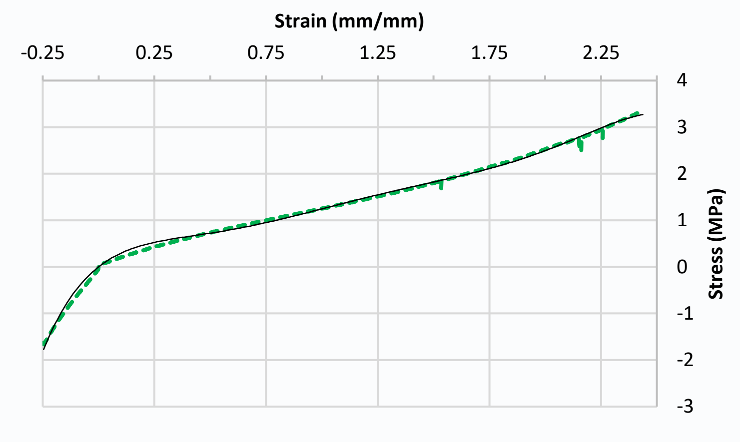

Fig. 2 Unified stress–strain master curve: a tensile toe + strain-hardening S-shape, and a convex compression branch.

- **Near-isotropic:** peak tensile stress 2.7–3.4 MPa, elongation >2.1 elongation >2.1 mm/mm across all four angles.
- **Stable damping:** cyclic compression settles by cycle 4 at 1.68 MPa peak with ~20% energy loss.

04 Constitutive model

The Ogden potential works in principal stretches λ_i, capturing the resin's non-linearity better than invariant-based models. For the near-incompressible resin the volumetric term vanishes (J = 1):

$$W = \sum_{i=1}^{3} \frac{\mu_i}{\alpha_i}\left(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3\right) + \sum_{i=1}^{3} \frac{1}{D_i}(J-1)^2$$

CALIBRATED OGDEN N=3 PARAMETERS

μ_1 / α_1	μ_2 / α_2	μ_3 / α_3
−8.51 / −3.08 −3.08	**3e−7 / 13.84**	**9.57 / −3.48**

CYCLIC CONDITIONING MECHANISM

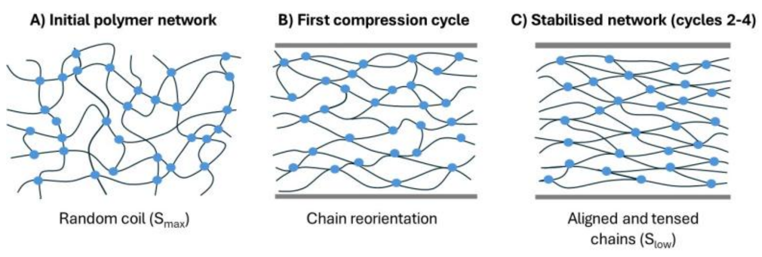

Fig. 5 Instead of Mullins softening, the network reorients and tenses over cycle 1, giving slight cyclic hardening to a stable steady state.

05 Stability–accuracy trade-off

On the unified master curve the dilemma is explicit: low-order order models are too stiff, and the lowest-RMSE high-order fits are order fits are physically unstable.

Model	RMSE	R^2	FEA
Polynomial N1	0.427	0.846	too stiff
Ogden N1	0.222	0.958	too stiff
Ogden N3 ★	**0.068**	**0.996**	**stable √**
Ogden N6	0.048	0.998	unstable ✗

Lowest RMSE (N6) ≠ best model. Mooney–Rivlin was discarded — — unstable in all regimes.

06 FEA validation

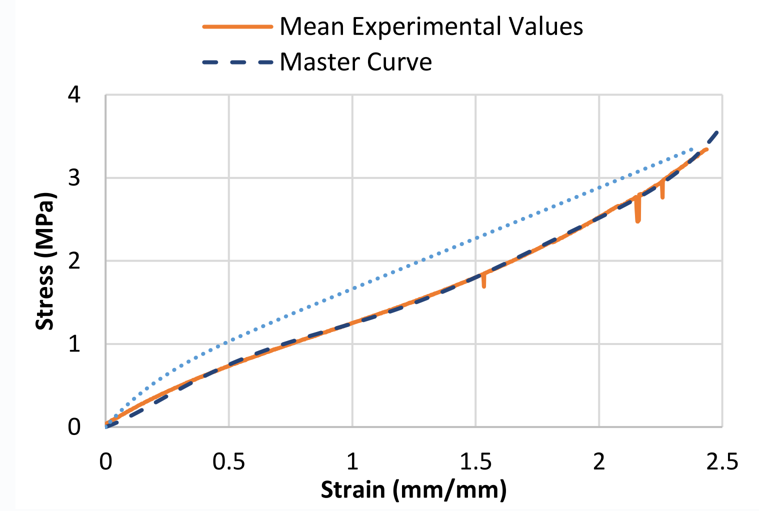

Fig. 3 N6 develops a non-physical oscillation near ε≈−0.25; N3 stays N3 stays monotonic and slightly conservative.

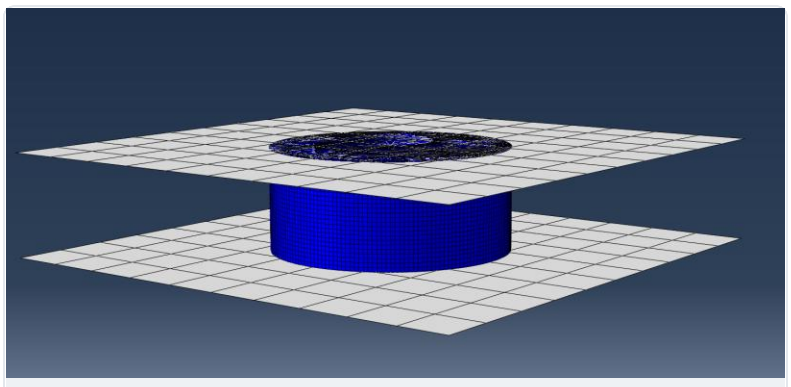

Fig. 4 Abaqus digital twin: cylinder (C3D8RH) between rigid platens, platens, reproducing barrelling.

07 Conclusion

SLA delivers a **near-isotropic** Shore 50A elastomer modellable with classical hyperelastic potentials. Among them **Ogden N=3** is definitive: it reproduces the low-stiffness toe region and stiffness toe region and ultimate strain-hardening S-curve *and* satisfies Drucker stability — the accuracy of high-order fits without their divergence. This makes it the reliable basis for large-reliable basis for large-deformation FEA of energy-absorbing lattices and auxetic structures.

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