

INTRODUCTION

Lightweight mirrors are critical for space optical systems, including telescopes and laser communication payloads [1,2]. Carbon fibre-reinforced polymer (CFRP) laminates offer:

- High specific stiffness
- Tailorable thermal expansion

However, performance is governed by:

- Thermoelastic deformation (in orbit)
- Moisture desorption (ground → orbit)
- Manufacturing-induced distortion

Rapid Tow Shearing (RTS) enables variable-stiffness laminates, but its impact on dimensional stability remains unclear [3].

RESEARCH OBJECTIVE

Evaluate RTS vs straight-fibre mirrors for mass–stability trade-off.

Assess:

- Thermoelastic deformation (in-orbit thermal loading)
- Hygroscopic deformation (moisture desorption during ground-to-orbit transition)
- Cure/process-induced distortion (cure and process effects)

METHODS

Approach

- FE modelling (Abaqus + CHILE process model)
- Multi-objective optimisation (mass vs RMS deformation)
- Manufacturing (IM7/8552 CFRP, RTS + baseline)

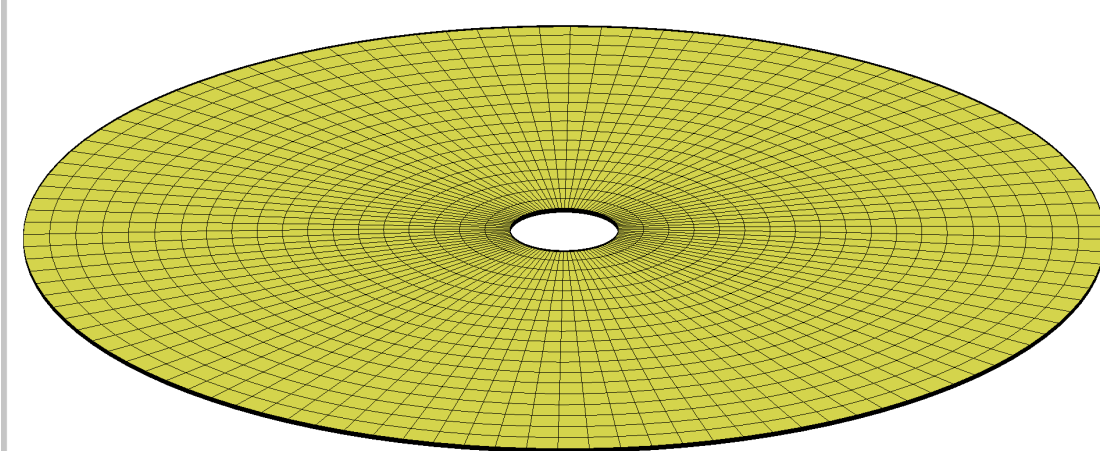


Fig 1: FE model

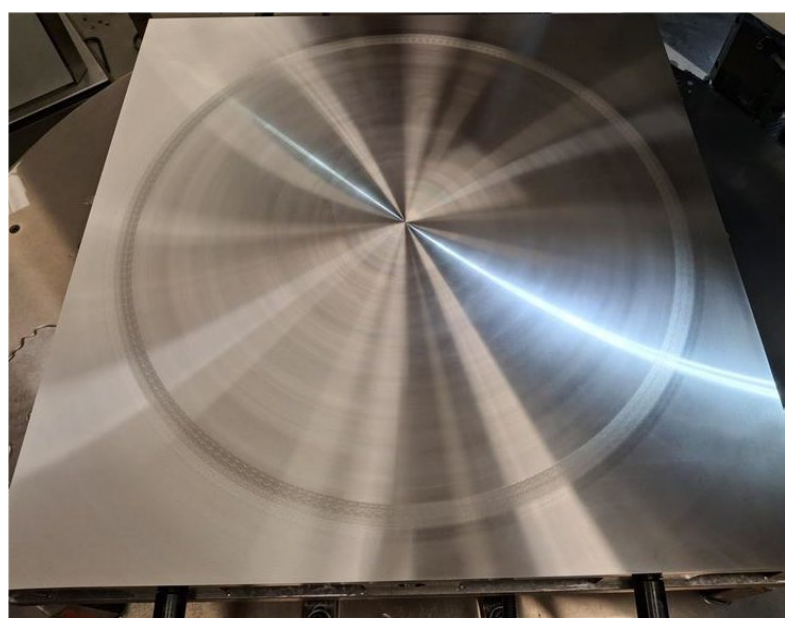


Fig 2: Invar tooling

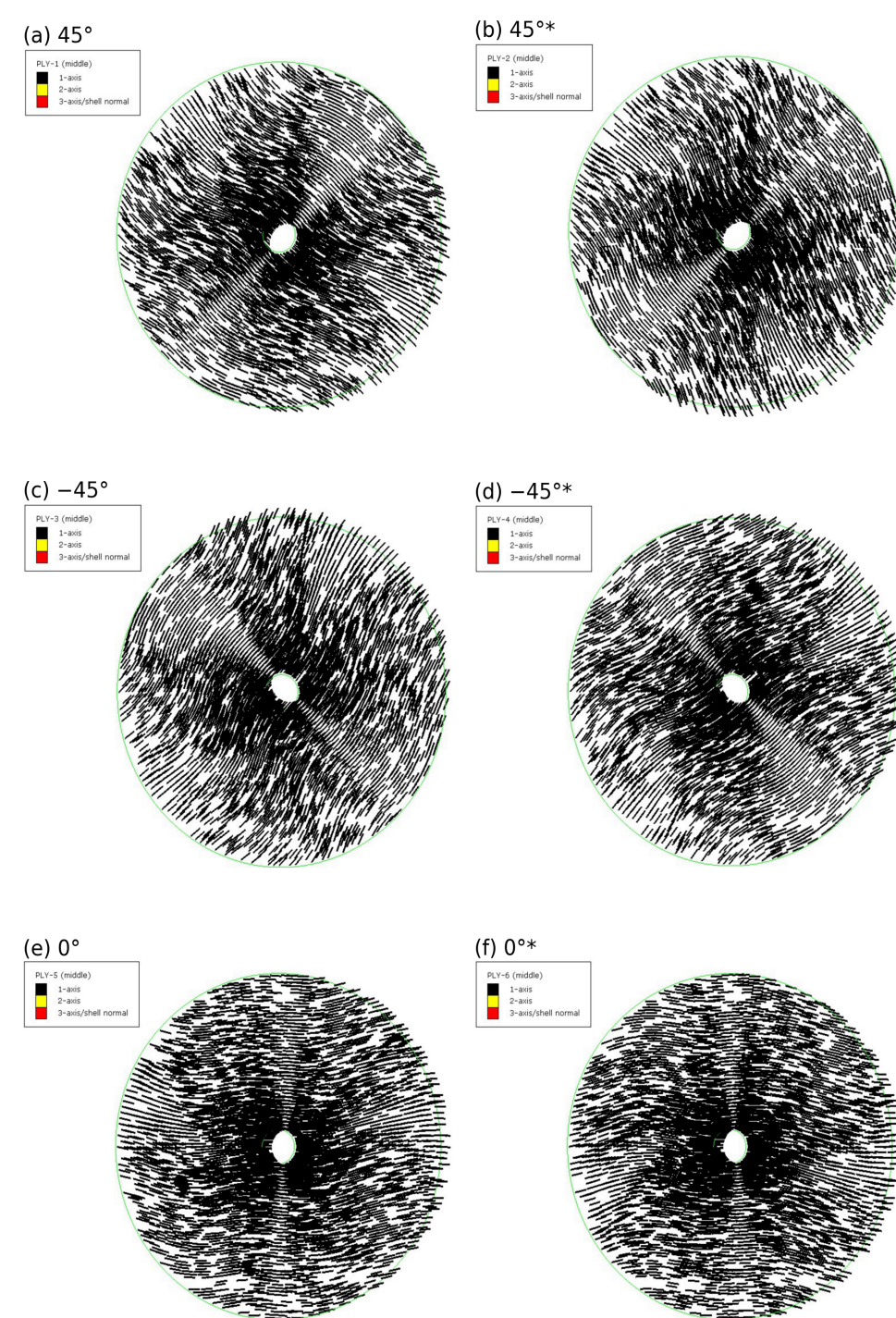


Fig 3: RTS fibre orientations

Validation

- Surface metrology (CMM + Zernike analysis)
- Thermomechanical testing (3D scanning)
- DSC (cure state)
- Flexural testing

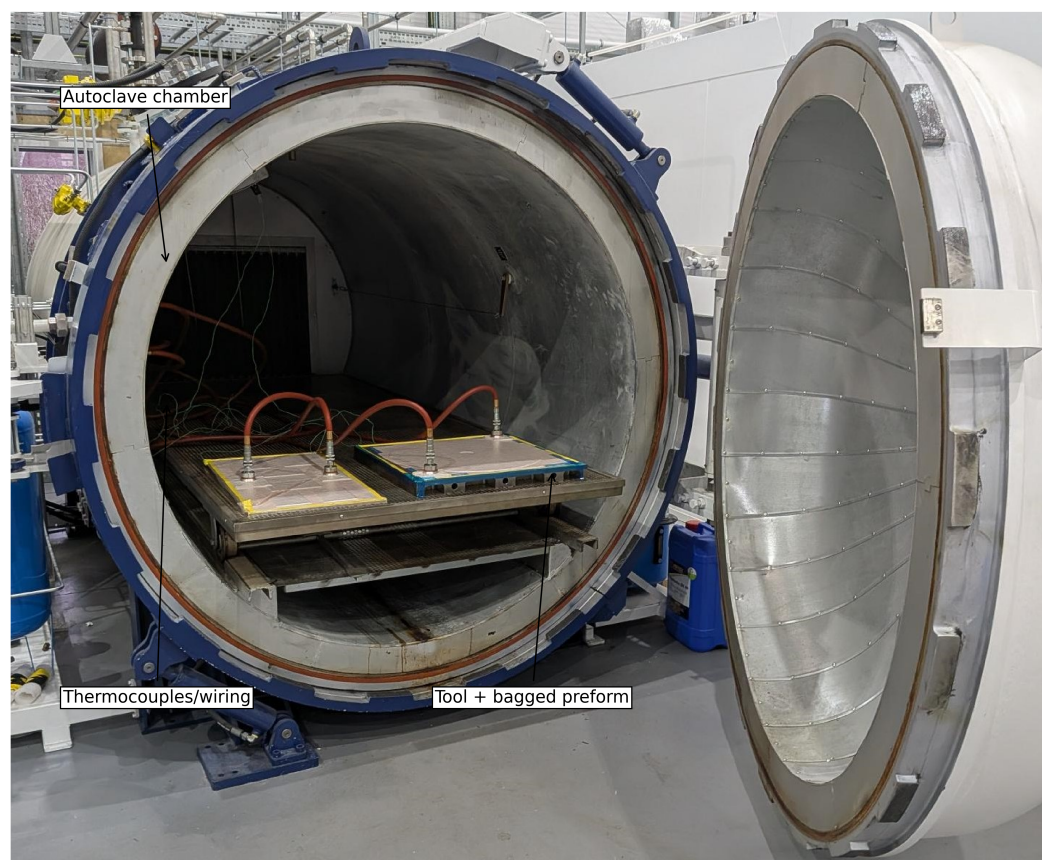


Fig 4: Autoclave curing

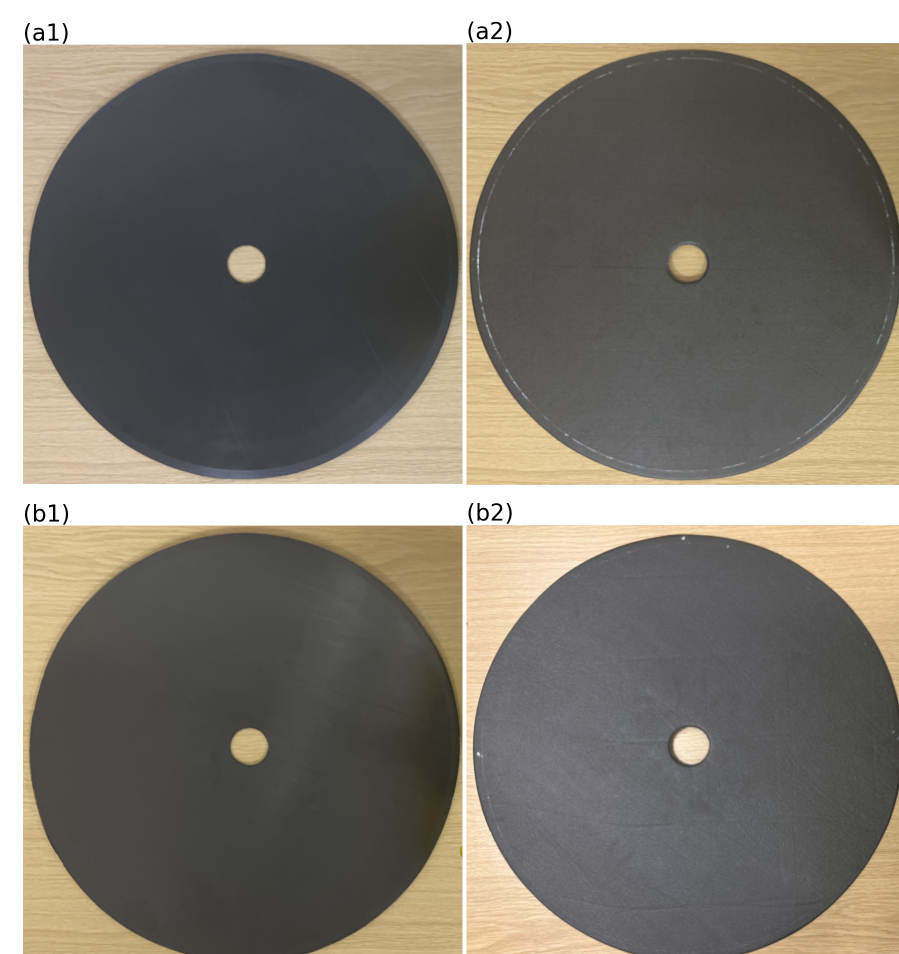


Fig 5: Manufactured mirrors

RESULTS

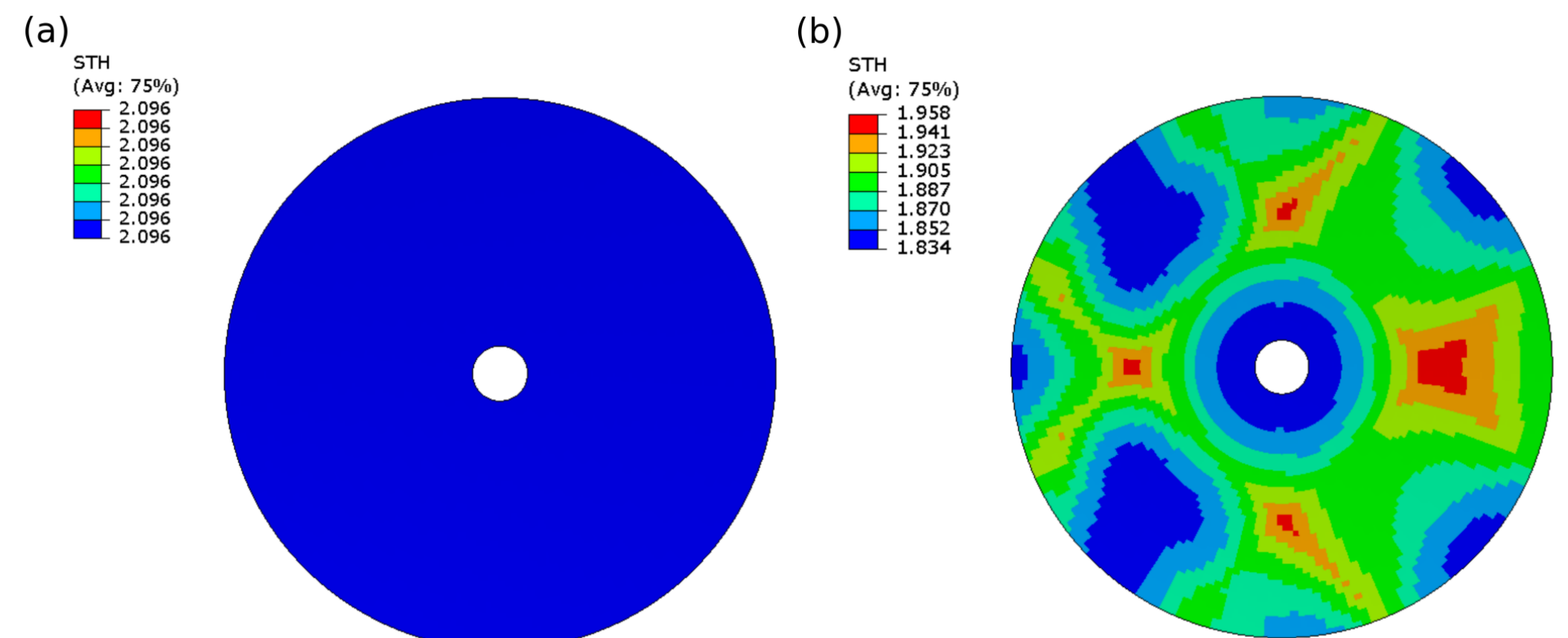


Fig 6: Thickness distribution

1. Structural Performance

- Straight-fibre: 3.31 kg/m², 153 Hz
- RTS: 2.97 kg/m² (~11%), 145 Hz
- Both satisfy launch requirements
- Large strength margins (Tsai–Wu < 0.02)

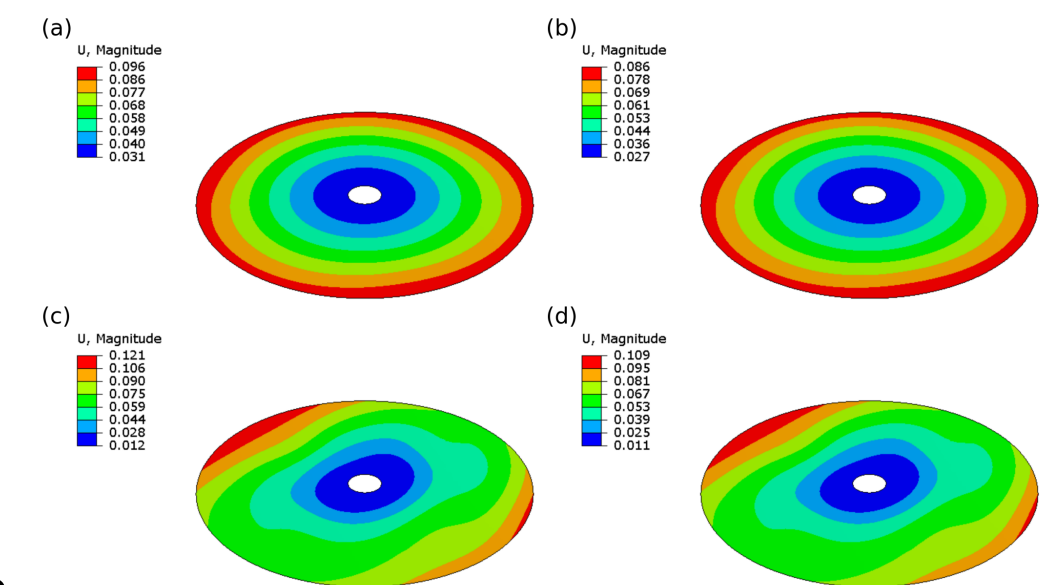


Fig 7: Thermal deformation

2. Thermoelastic Behaviour (Dominant)

- Straight-fibre: ~69 μm RMS
- RTS: ~68 μm RMS
- No significant improvement with RTS
- Governed by laminate CTE + global stiffness

3. Hygroscopic Effects

- Straight-fibre: ~16.7 μm RMS
- RTS: ~22.7 μm RMS
- RTS shows higher sensitivity
- Caused by stiffness/thickness non-uniformity

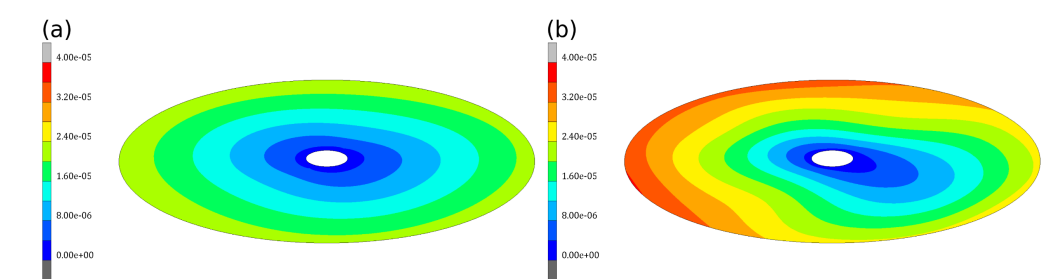


Fig 8: Hygroscopic deformation

4. Manufacturing-Induced Distortion

- Straight-fibre: ~90 μm RMS
- RTS: ~98 μm RMS
- Similar magnitude
- RTS shows more non-axisymmetric deformation

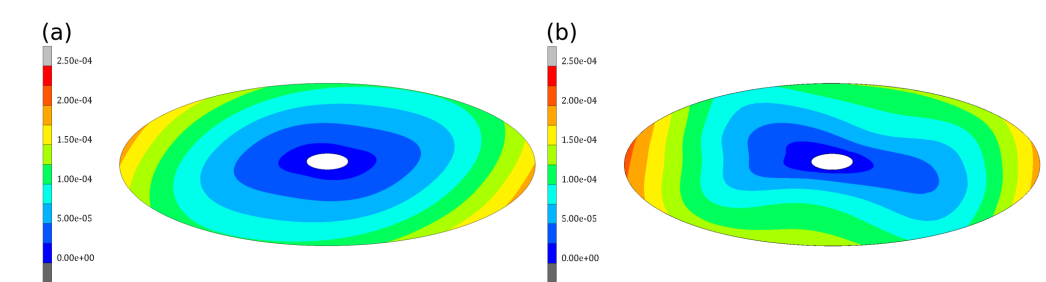


Fig 9: Cure distortion

5. Surface Quality (Profilometry)

- All roughness values < 1 μm
- Surface roughness << figure error → not performance-limiting

6. Experimental Validation

- Residual RMS (Zernike, N ≤ 6):
 - Straight-fibre: 49.1 μm RMS
 - RTS: 58.5 μm RMS
- Thermomechanical testing:
 - RTS shows smaller variation with temperature.
- Cure (DSC):
 - Uniform cure (~93–95%)
- Flexural testing:
 - RTS retains ~85–90% strength
 - Reduced stiffness (expected)

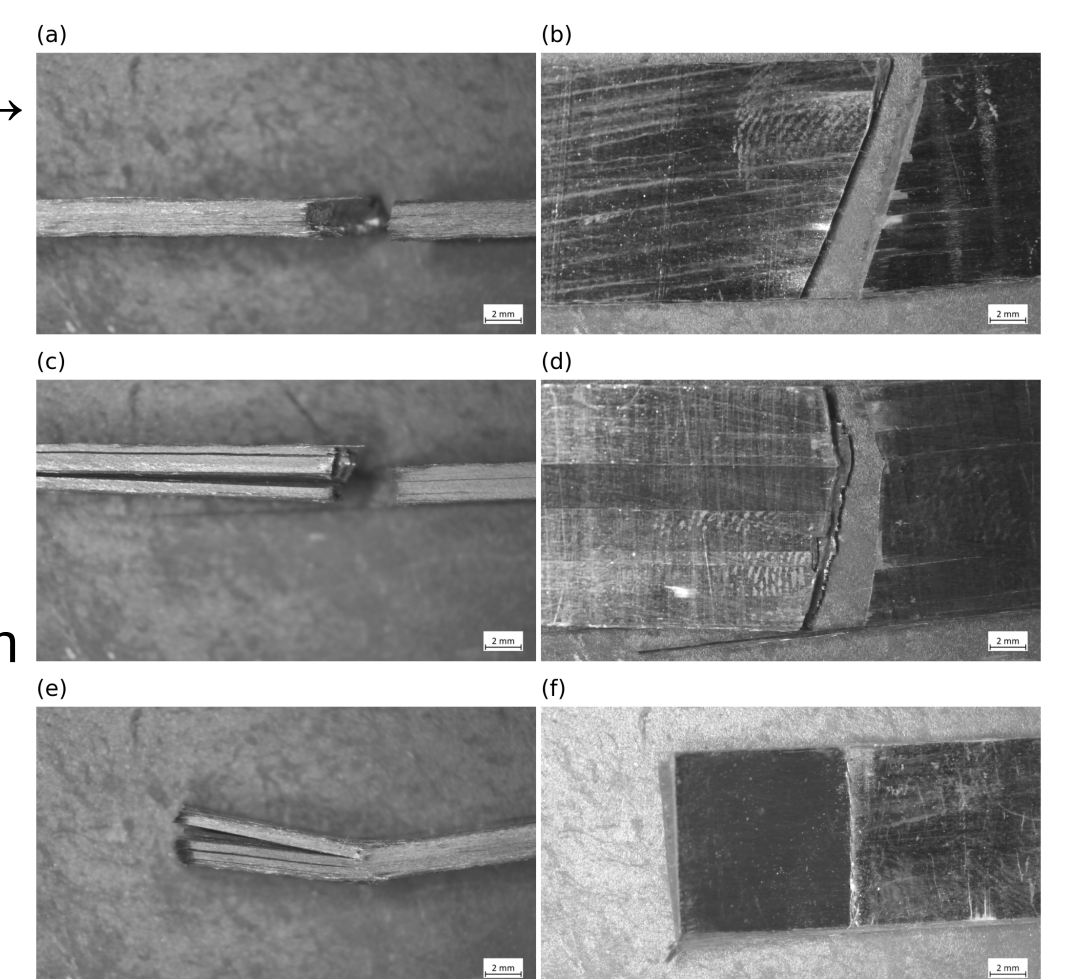


Fig 10: Microscopy of failure modes (flexural + ILSS)

KEY FINDING: RTS reduces mass by ~11% without degrading global thermoelastic stability — but increases sensitivity to manufacturing and hygroscopic effects.

CONCLUSIONS

- RTS enables mass-efficient stiffness tailoring
- Thermoelastic performance remains unchanged
- RTS increases:
 - Non-axisymmetric deformation
 - Sensitivity to moisture & manufacturing effects
- Key implication: Mirror stability is dominated by material system and processing, not fibre steering

ACKNOWLEDGEMENTS

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REFERENCES

- [1] Trumper, I. et al. Optics technology for large-aperture space telescopes: from fabrication to final acceptance tests. *Adv. Opt. Photon.* 10(3), 644–702 (2018).
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- [3] Kim, B.C., Weaver, P.M., Potter, K. Manufacturing characteristics of continuous tow shearing for variable angle tow composites. *Compos. Part A* 61, 141–151 (2014).