Through-Thickness Properties of Composite Thin Shell Booms

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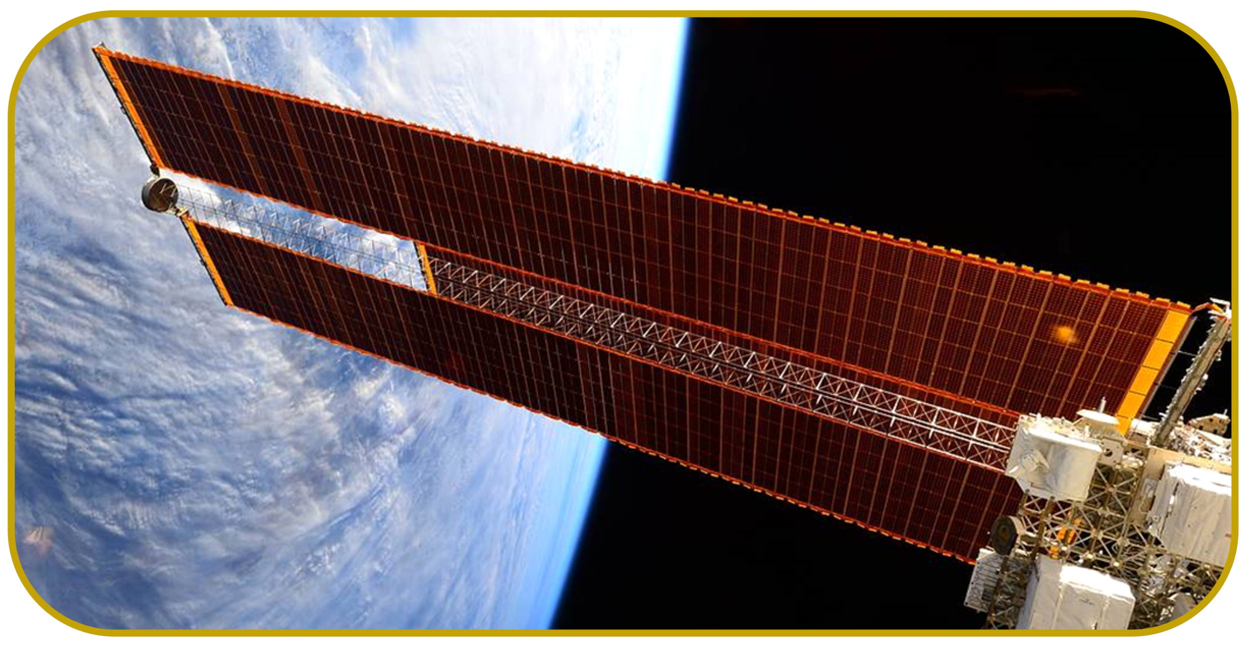
Aim

Evaluate the through-thickness properties of composite thin shell booms.

Background

The space industry demands reliable, lightweight, low-power spacecraft, which can require structures that change shape in space. These **deployable structures** aim to move something away from the spacecraft. Composite thin shell booms are a type of deployable structure and bistable composite slit tubes are a subset of these. The **through-thickness properties** of ultra-thin composites are not well understood particularly their **viscoelastic response**, which can be crucial to the success of deployable bistable composite slit tubes.



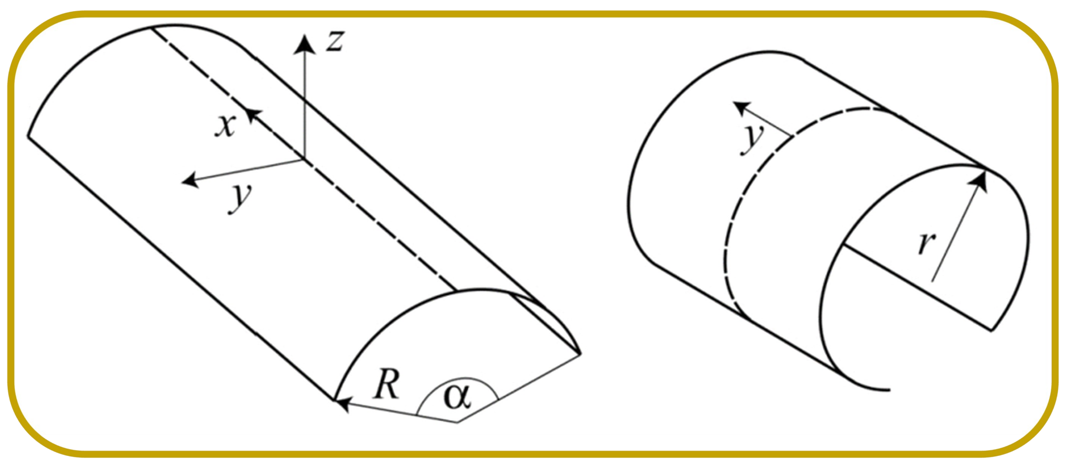
Deployable structure: International Space Station deployed 32 m solar-array [NASA]

Through-Thickness Properties

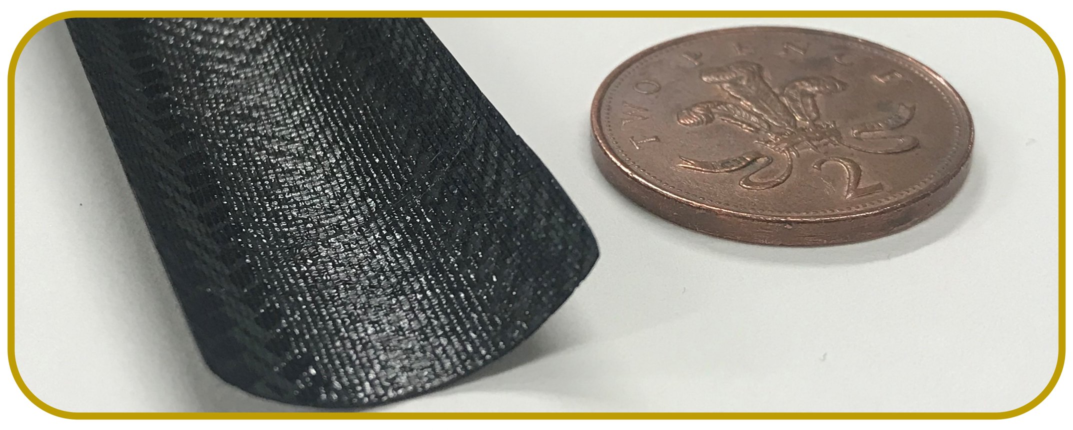
The through-thickness direction for mechanical properties is denoted by subscript 3 (i.e. the third axis direction). The through-thickness properties under investigation in this work relate to the composites' out-of-plane response to compressive loading. The out-of-plane compressive modulus (E_{3comp}) describes how an elastic material deforms under a load. The out-of-plane compressive loss modulus (E''_{3comp}) describes how the material creeps over time under a constant load and how it relaxes once the load is removed.

Bistable Composite Slit Tubes

Bistable composite slit tubes are ultra-thin carbon fibre composite materials; approximately ⅓ mm thick. They will remain at rest in either their deployed or stowed configuration.

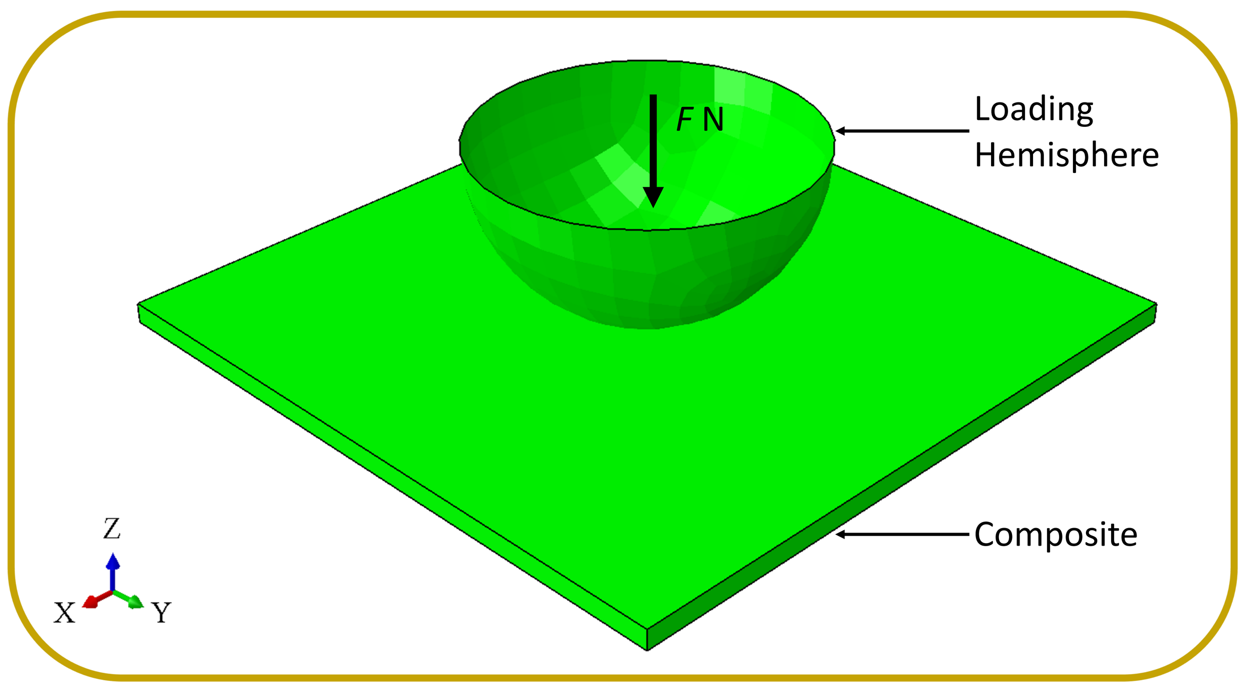


Bistable Composite Slit Tube stable sections



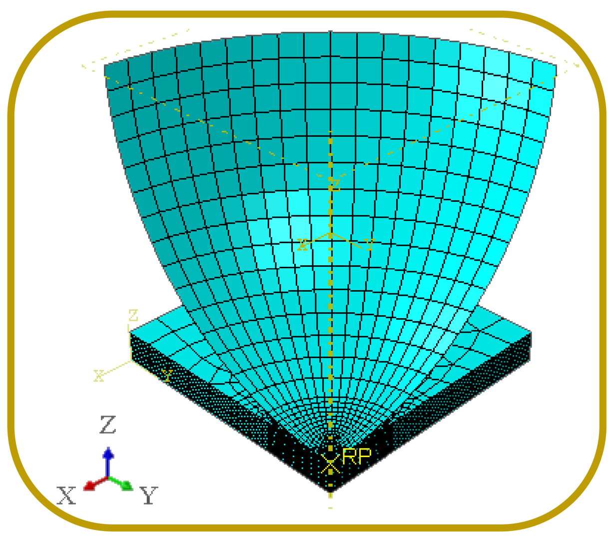
Bistable Composite Slit Tube

Finite Element Analysis (FEA)

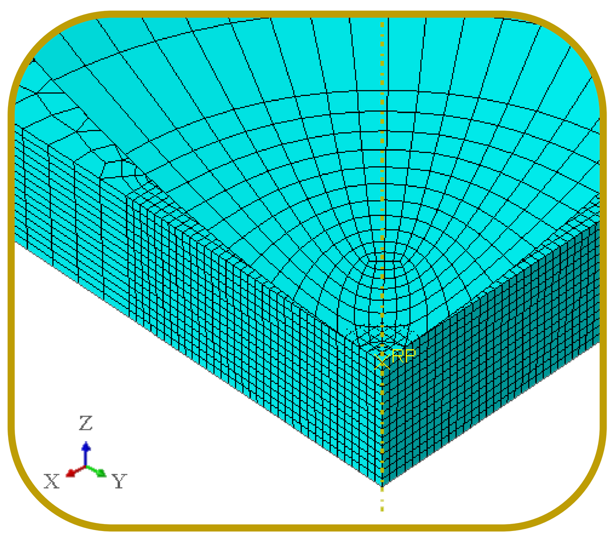


ABAQUS full geometry model definition

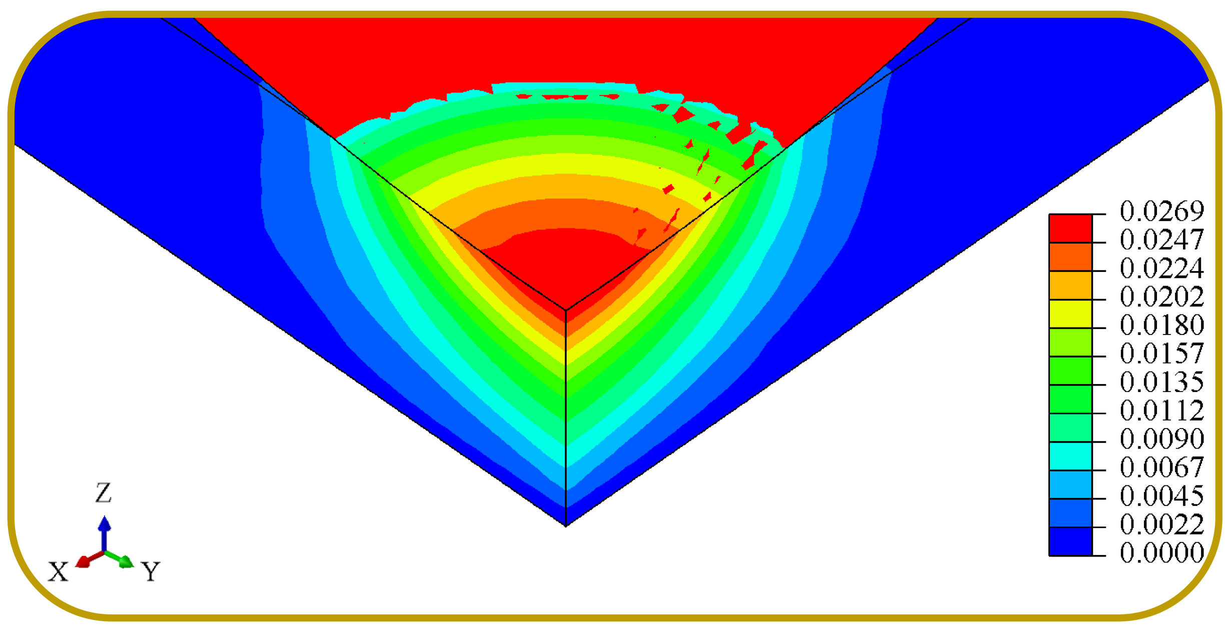
A finite element model was built in ABAQUS/CAE to model the out-of-plane deformation of an ultra-thin composite under compressive loading by a hemisphere. The full geometry was simplified to a quarter section model using symmetric boundary conditions and a load was applied through a rigid hemisphere. The ultra-thin composite has a thickness of 0.3 mm and is modelled with five equal thickness ply layers ([+45/-45/0/+45/-45] from top to bottom surface). The hemisphere was meshed with 504 R3D4 elements, and the composite with 28,200 C3D8R elements. Both had increased mesh density in the contact area. The model was interrogated for the maximum displacement for loads from 0 N to 50 N.



ABAQUS quarter model meshing

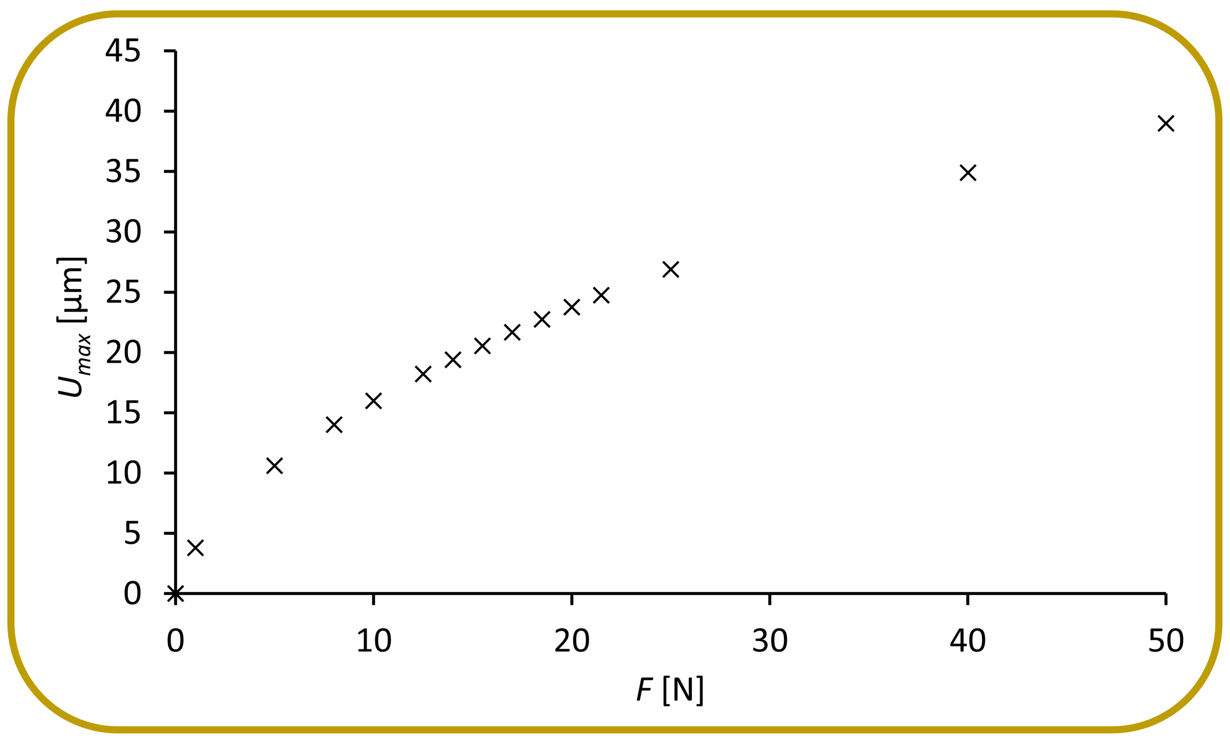


ABAQUS though-thickness mesh zoom-in



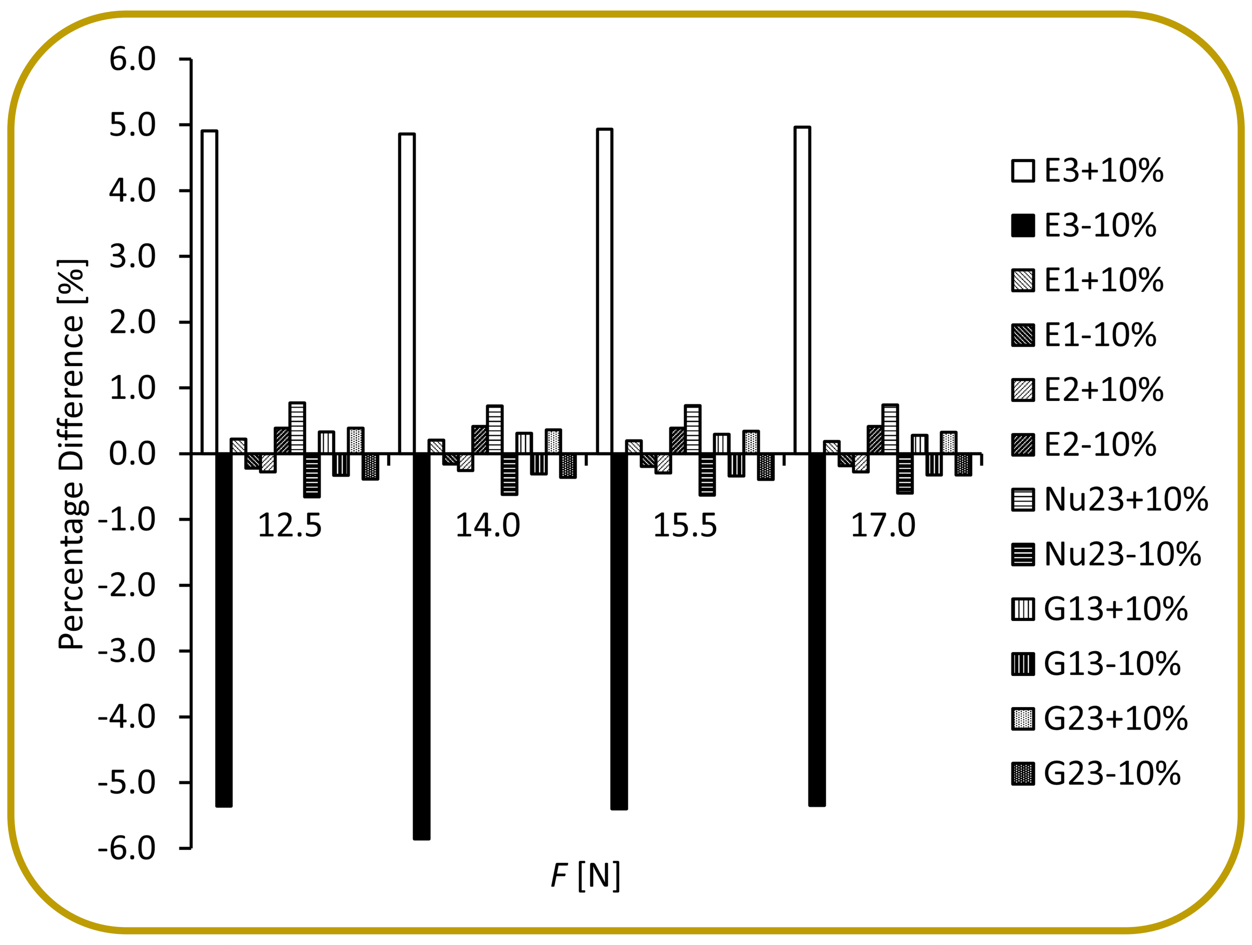
ABAQUS deformation result for F = 25 N, U_{max} = 0.0269 mm

- $E_3 = E_2$ assumed for the composite material model,
- Results show a logarithmic trendline due to the hemisphere loading shape as the contact area increases with deformation,
- Mechanical property sensitivity analysis required to validate the behaviour of the ABAQUS model by assessing the impact of each mechanical property values on the deformation result.



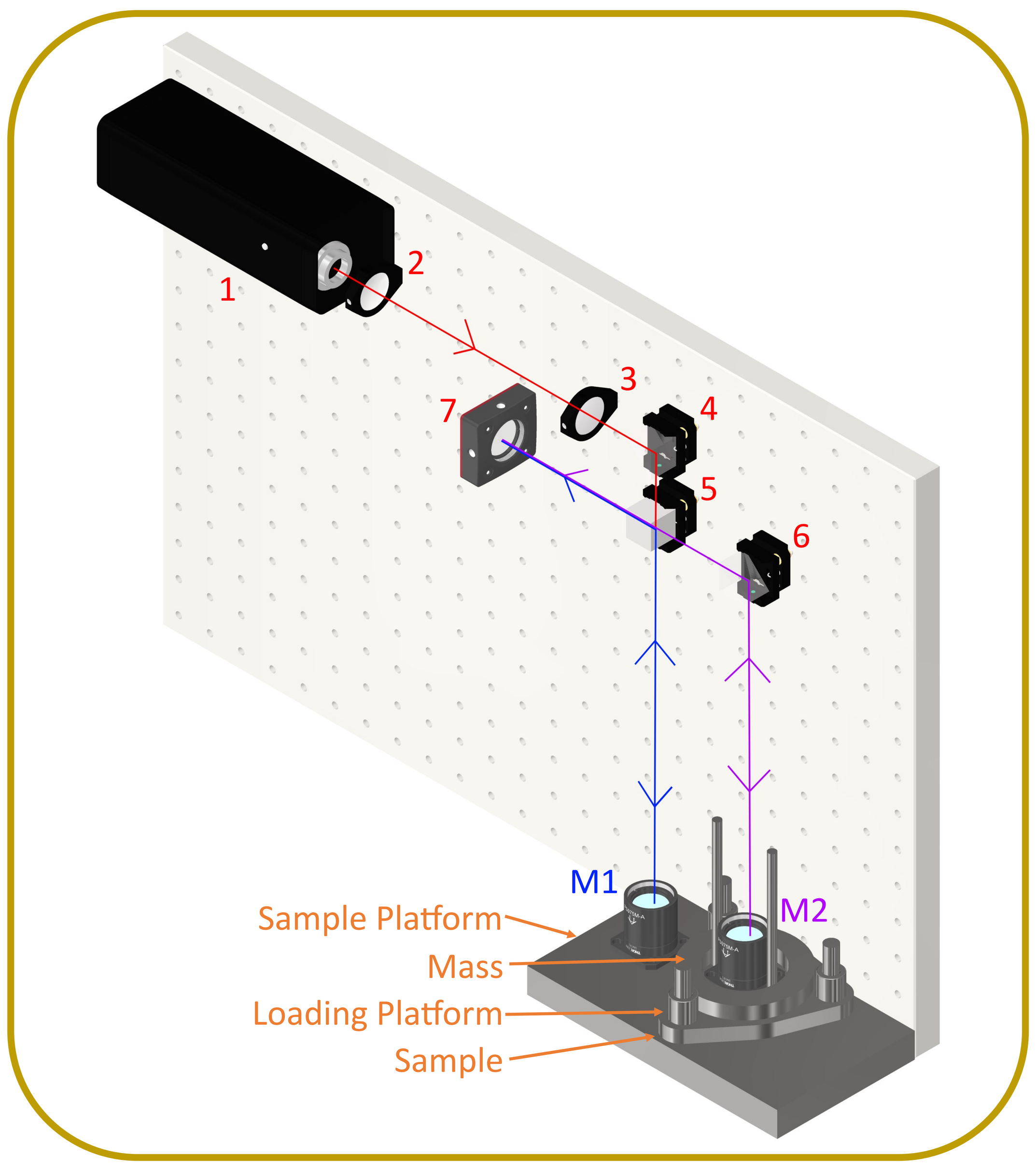
ABAQUS composite maximum deformation response to hemisphere loading

Mechanical Properties Sensitivity Analysis



Effect of changing the input mechanical properties by ±10% on the deformation result

Experimental Setup



Interferometric setup based on a classical Michelson architecture with a designed resolution of 1 x 10^{-8} m.

1) 0.8 mW Helium-Neon Laser λ = 632.8 nm
1) Bi-Concave Lens
2) Plano-Convex Lens
3) Right-Angle Prism
4) 50/50 Beamsplitter
5) Right-Angle Prism
6) CMOS Sensor
M1) Primary (reference) Mirror
M2) Secondary (measurement) Mirror

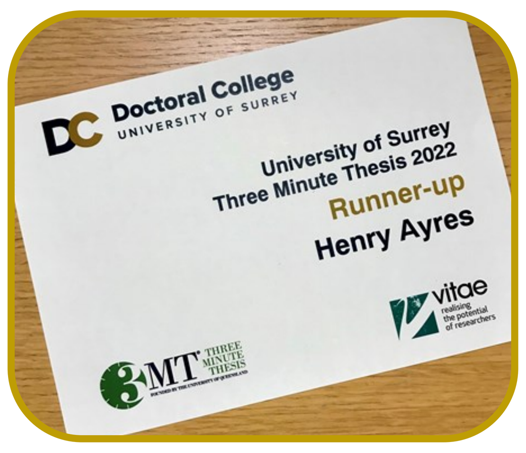
Conclusions

- Validation of FEA model behaviour,
- E_3 has the largest impact on the deformation result (as expected),
- Uncertainty of the impact of the $E_3 = E_2$ assumption used in the ABAQUS model on the deformation result.

Further Work

- Experimentally evaluate E_{3comp} from interferometric measurements to validate the model mechanical properties,
- Experimentally evaluate E''_{3comp},
- Model the composite time-dependent response to out-of-plane compressive loading.

Awards



Get in Touch

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