Thermo-Elastic Composite Helical Lattices – Analysis, Manufacture and Testing

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Abstract

The anisotropic nature of fibre-reinforced composites enables methods for stiffness tailoring that are not available to classical isotropic engineering materials. By carefully choosing constituent materials, fibre angles and tooling geometry, the internal stress states can be tailored to enable novel structural behaviour, particularly in thin shell structures. Pirrera et al. [1] developed a macroscopic helical lattice structure that utilises prestress, material anisotropy and geometry to enable multi-stable responses with large axial and radial deformations. Their analytical model highlighted a significant scope for other novel structural responses. The non-linear analytical model that describes the helical lattice was extended to include thermo-elastic effects by O'Donnell et al. [2], the behaviour of which is explored further in this study. Herein we present the results obtained from finite element (FE) modelling, manufacturing and testing of a thermo-elastic composite helical lattice structure that is tailored to exhibit a large negative coefficient of thermal expansion (CTE) along its cylindrical axis.

A modelling framework was developed to select fibre angles for the helical strips. By evaluating energy landscapes at different temperatures, the thermally induced lattice extension could be calculated. Fibre angles were selected to maximise the axial contraction as temperature is increased. Parameters such as the radius of the cylindrical mandrel and the helix width were chosen for ease of manufacturing.

The FE models were constructed in Abaqus 2016 Standard/Explicit. Individual left- and right-handed helices were combined into a cylindrical lattice configuration to calculate the axial extensions and contractions with changing temperatures. The models are comprised of individual helical strips (created on the tool geometry) meshed with shell elements, with hinge connectors between the strips to act as the bolt joints of the lattice. The contact forces between adjacent helices and the frictional forces in the joints are currently neglected. A thermal field was used to mimic the cure cycle and subsequent heating of the structure.

Prototypes were constructed by laying Hexcel IM7-8552 plies into flat strips, wrapping these at an angle around a cylindrical tool plate, and curing in an autoclave. Once cured, the individual helices were connected in a lattice using steel bolts separated by nylon washers to minimise joint rotational friction. As the variability of manufactured thicknesses might have an effect on the structural properties, an additional study was carried out to quantify and minimise the ply-level variation.

Two series of tests were conducted to experimentally verify the behaviour of the lattice. Firstly, the tailored thermal response of the lattice was determined by measuring the axial extension. Secondly, the force-displacement response of the lattice at ambient temperature was measured. The predicted behaviour was observed in the prototype, and good quantitative correlation was reached between experiments and the FE models.

This study shows that composite helical lattices designed to exhibit novel mechanical behaviour are physically realisable. One such novel thermal behaviour has been modelled and experimentally verified, and manufacturing considerations for such thin shell prestressed composites are explored.

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References

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