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Can tailored non-linearity of hierarchical structures inform future material development?

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Abstract

Structures that present non-linear elastic responses to applied loading have the potential to offer predictable, repeatable, load-displacement behaviour that has favourable characteristics. We describe how a hierarchical structure composed of a helical lattice and elastic medium can be successfully tuned to achieve a set of desired characteristics. In general, the resulting behaviour may be tuned to a variety of responses, however, to highlight one such possibility, we focus on the introduction of pseudo-ductile qualities in the resulting system's elastic stress-strain response. As there is no universally accepted definition of pseudo-ductility, we describe pseudo-ductile systems as those that possess characteristics that mimic the key features of a traditional ductile material via non-linear elasticity, e.g. a decrease of the effective modulus following an initially positive region.

An energy based model for the helical lattice developed by Pirrera et al. (2013) is extended to include the effects of the elastic medium. The additional components are included in the energy formulation as effective axial and circumferential springs. The simplifying assumption in the analytical model, i.e. the investigation of an equivalent "three-spring" system, allows for a straightforward representation of the underlying physics that could, in future works, be applied to micro-braided lattice structures. Using this modelling approach insight into the required stiffness, geometry and form factors of such systems can be obtained. In identifying how the hierarchical properties of the system must be tuned to achieve desired pseudo-ductile behaviour we are able to inform the development of future pseudo-ductile composites materials. In general, through exploiting composite hierarchy in this manner it is possible to produce systems that offer bespoke material characteristics providing significant opportunities for improved design.

We present the development of the underlying analytical framework. Key non-dimensional parameters governing the nature of the response are identified and examples of the predicted behaviour presented. Regions of pseudo-ductile feasibility are identified in terms of these non-dimensional parameters. Through exploring the behaviour of the hierarchical system we are able to predict material behaviour at multiple length scales.

By forming composite systems that exploit structural hierarchy it can be seen that non-linear responses may be tuned to produce desirable material characteristics. It follows that more complex systems, incorporating helical bundles and differing materials, pre-curvatures and geometries, would allow even greater scope to tailor the response.