

Seeing and simulating: From imaging to prediction of mechanical properties

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The mechanical response of heterogeneous materials is governed to a large extent by their micro- and mesostructural architecture. Establishing robust structure-property relationships is therefore essential for reducing design safety factors, optimising material composition and morphology, and tailoring reinforcement orientations to achieve enhanced performance. A major challenge, however, is that manufacturing processes such as forming, compaction and draping introduce significant variability in the internal material structure, both between nominally identical components and within individual parts. Consequently, local mechanical properties may deviate substantially from those assumed on the basis of the nominal geometry and material specification, making characterisation of the as-manufactured structure a prerequisite for reliable mechanical prediction.

Image-based modelling offers a powerful framework for addressing this challenge. By utilising 3D X-ray computed tomography (XRCT) data, potentially complemented by high-resolution 2D optical or scanning electron microscopy, detailed representations of the internal material architecture can be generated and incorporated directly into computational models. When combined with accurately characterised constituent behaviour, such models provide a direct link between structure and performance, whilst also enabling quantification of how manufacturing-induced variations in the internal architecture contribute to variability in mechanical properties.

This plenary lecture presents recent developments in image-based mechanical modelling for two classes of heterogeneous materials: closed-cell polymer foams and three-dimensional textile-reinforced composites. For polymer foams, methods for extracting key morphological statistics from a combination of 2D and 3D image data will be discussed, together with their implementation in mesoscale mechanical models to assess the influence on the macroscopic mechanical behaviour. For 3D textile composites, an automated workflow will be presented in which XRCT-based reconstructions are transformed directly into numerical models capable of predicting engineering material properties. In both cases, the effective material response is obtained through computational homogenisation of the measured micro- and mesostructures. The lecture concludes with a discussion of the current state of the art in image-based mechanics and an outlook on the developments required to achieve the next generation of high-fidelity predictive models for heterogeneous materials.