A 3-scale computational homogenisation strategy for sheet moulded compounds using material network surrogates.

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Abstract: Sheet Moulding Compounds (SMC) are composite materials used in automotive components owing to their lightweight, versatility, and more economical manufacturing techniques relative to metallic components. SMCs with thermoset matrices in thick-walled composite applications are subjected to temperature variations that ought to be accounted for at the design stage. To perform a numerical analysis of thermoset SMCs, a high-fidelity thermomechanical multiscale model is required to adequately represent the distinct constitutive responses of the polymer and the dispersed fibre-polymer bundles. Consequently, adopting a 3-scale model attributed to the meso- and microscale complexities has been the norm [**1**].

In this work, a carbon fibre and vinyl ester SMC is first-order computationally homogenised using a 3-scale strategy, where the microscopic bundle is modelled in 2D as a combination of fibres impregnated by a thermosetting polymer, the mesoscale representation consists of the bundles dispersed in the polymer matrix, and the macroscale is the reference experimental sample. The mesoscale Representative Volume Element (RVE) is generated using Voronoi tessellation for the bundle placement, whose orientation is sampled directly from CT scans of compression molded SMC tensile test specimens. For fast homogenisation, the micro- and meso-scale problems are surrogated by Interaction-based Material Networks (IMNs), based on a thermomechanical extension of the methodology developed in [**2**]. IMNs have been shown to be thermomechanically consistent by preserving the form of the laws of conservation in their resolution of the finite element problem, achieved by assimilating similar regions or interactions in the microstructure into a network of nodes.

IMNs are capable of linear elastic and non-linear training. The former has been shown to be efficient for non-porous multiphase microstructures in terms of lower computational expenditure compared to Direct Numerical Simulations (DNS), especially for 3D cases [**2**]. In this work, this is extended to linear thermoelastic training for the 3-scale strategy and further non-linear training for plasticity-induced non-linearities at the sample level. The computational speed-up obtained in the 3-scale homogenisation due to the IMN surrogates is shown in comparison with full-field simulations.

Keywords: Sheet moulding compound, 3-scale computational homogenisation, Interaction-based material networks

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