Damage and Failure in Natural Fibre Composites: A Multiscale Perspective

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Abstract

Natural fibre composites (NFCs) display several positive traits, including low density, renewability of sources, and full biodegradability when combined with polymers such as poly(lactic acid). Among natural fibres, flax is widely cultivated, has desirable mechanical properties, and is readily available in forms suitable for composite production. Structural application of NFCs requires more accurate failure prediction than what is currently available, and such predictions can be achieved through computational multiscale modelling.

In composites, processes at several length scales contribute to the overall damage and ultimately failure. The primary aim of this paper is to predict NFC failures using multiscale computational techniques, including quantification of damage in NFCs within a continuum damage framework.

Four composite systems have been studied, two involving flax and polypropylene and two combining flax and epoxy. The flax used in this work was obtained in the form of a unidirectional fabric.

At the microscale, the properties of flax fibre and of the fibre-matrix interface were studied through tests on fibres and fibre-matrix interface specimens. Analytical modelling was used to model the fibre properties, while numerical models were constructed to model the interface properties, and compared to predictions using shear-lag models.

The mesoscale considered flax yarns impregnated by polymer. Impregnated yarns were tested in tension, and their failure modelled numerically, incorporating yarn geometry and properties of the fibre and interface. Finally, at the structural or macroscale, the tensile, compressive and flexural properties of the composite systems were studied using standardized tests.

Material damage evolution laws for the mesoscale impregnated yarns were estimated from microscale finite element (FE) models once the fibre and interface properties were established. Material damage was also quantified experimentally via image analysis of specimens damaged by tensile loading.

A FE-based two-scale coupled multiscale homogenization technique was implemented to simulate the failure behaviour of flax composite specimens subjected to bending. The damage evolution laws obtained from the microscale FE models were utilized to assign material damage. The multiscale models predicted the bending behaviour reasonably accurately, with predicted bending failure values being within 12% of the test values. Validation studies using a glass/epoxy composite system yielded a failure value 12.6% lower than the test average. The framework implemented can be extended further to assist in the prediction of NFC properties in structural applications.

Keywords: Multiscale modelling, Natural fibre composites, Damage, Failure, Microscale, Mesoscale.