Creating Composites that Fail More Gradually

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Composite materials have excellent specific strength and stiffness, but a major drawback is their lack of ductility. This presentation considers ways of addressing the challenge of creating new materials and architectures that give a more gradual failure, drawing on the work of the High Performance Ductile Composite Technology programme (HiPerDuCT) between the University of Bristol and Imperial College.

Fibre reinforced composite materials normally exhibit sudden brittle failure, with linear elastic response to failure. Although some analyses have suggested the possibility of gradual degradation as a result of successive ply failures, such behavior is rarely observed experimentally, and failure is normally catastrophic, with little warning.

Ideally, ductile failure is desirable, with no loss of modulus on reloading. A more achievable target using currently available materials is pseudo-ductility, where non-linearity or "pseudo-yielding" is achieved via damage. Although this results in a loss of modulus on reloading, it still allows load redistribution around stress concentrations, potentially making the material less notch sensitive and more damage tolerant.

A number of different mechanisms are presented which enable pseudo-ductility. Thin plies can be used to suppress matrix cracking and delamination and prevent premature failure. Fibre reorientation in thin angle plies allows additional strain to be created by rotation of fibres towards the loading axis combined with shear in the matrix, creating a non-linear response. Thin ply hybrid composites can produce stable fibre fracture in the low strain to failure material without delamination occurring. This creates a plateau on the stress-strain curve as progressive fragmentation occurs with load transfer onto the higher strain material. These two mechanisms can be combined by using ductile thin angle plies as the high strain material whilst low strain 0° plies allow fragmentation to occur as well.

Discontinuous fibre composites can also create additional strain and non-linear response via interfacial slip and matrix plasticity. This can be achieved at either the level of individual fibres, or at ply level with composite platelets. The approach can also be combined with hybridization and fragmentation to further increase strains.

Progress on ductile fibres which yield and create truly ductile composites is also discussed briefly.

Michael Wisnom is Director of the recently established Bristol Composites Institute at the University of Bristol, which builds on ACCIS, the Advanced Composites Collaboration for Innovation and Science. He is Professor of Aerospace Structures, Director of the Rolls-Royce Composites University Technology Centre, Queens School Research Director and a member of the steering board for the UK National Composites Centre.

Prof. Wisnom is a leading international authority on the mechanics and failure of fibre reinforced composites, and Principal Investigator on the Programme Grant on High Performance Ductile Composites Technology in collaboration with Imperial College funded by the UK Engineering and Physical Sciences Research Council. He is the author of over 400 refereed journal and conference publications, and is Editor in Chief and European Editor for Applied Science and Manufacturing of Composites Part A. He is a fellow of the Royal Academy of Engineering, the Institution of Mechanical Engineers and the American Society for Composites, recipient of a Royal Society Wolfson Research Merit Award, and past president of the International Committee on Composite Materials.