Numerical modelling of through-thickness reinforced (TTR) composites

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A multi-scale framework for the numerical modelling of through-thickness reinforced (TTR) composites was developed. A micro-scale analytical model is capable of generating a library of bridging maps, each for a different combination of TTR length and asymmetry. A batch of experimental characterisation tests of individual TTR was conducted (meso-scale), which allowed to calibrate the micro-scale analytical model. The bridging maps are included into the macro-scale numerical model through an LS-DYNA compatible text file, where a user subroutine implements a tri-linear cohesive law built from the bridging maps. This approach has proven to be very stable and its predictions were validated against benchmark experimental tests under different mode-mixities. The capabilities of the user subroutine have been extended to include the interaction of multiple delamination planes. The subroutine identifies the position of the cohesive element and assigns proper geometrical parameters (TTR length and asymmetry). A link between cohesive elements is established which allows for the update of the geometrical parameters (and bridging map information) whenever a cohesive element fails and new crack faces appear.

Meso-scale experimental characterisation

Single TTR characterisation tests are performed to measure the individual bridging effect of a TTR as a function of mode-mixity (ø).

Energy Equivalent Bridging Map

The tri-linear cohesive law is built at the plane of mode-mixity, and the mode I and mode II responses are calculated from it.

Macro-scale FE analysis

A tri-linear cohesive law is defined from the micro-mechanical bridging model.

Mode I with multiple delamination

Mode II with multiple delamination

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