Dissipation at multiple length scales for improved delamination resistance

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Laminated composites can fail by delamination, that is the fast and possibly unstable propagation of cracks between the plies. Improving the delamination resistance of composite structures involves increasing the load levels associated to crack initiation and propagation, but also, and more importantly, making the crack propagation more progressive and stable to delay final failure of the structure.

The stability of crack propagation depends on the ratio between the energy stored in the structure and the energy dissipated by crack propagation. The first is a function of the material, geometry (including crack location) and loading conditions of the structure, while the second depends on the properties of the delaminating interface. As such, the first and main lever to ensure a progressive and stable crack propagation is the design at the structural scale, and in particular ensuring that the crack propagates towards zone of the structure where it can release little energy.

From the point of view of interface properties, two key parameters play a role in the delamination response, namely the maximum stress transferred by the interface, and the energy per unit surface required for complete interface failure, also known as the critical strain energy release rate. These two parameters contribute to define the characteristic process zone length, which increases linearly with increasing critical strain energy release rate, but decreases quadratically with increasing maximum stress [1]. If the process zone length is comparable to the characteristic problem dimensions, a gradual and stable crack propagation can be achieved.

The role of the maximum stress and critical strain energy release rate can be easily investigated through numerical simulations using Cohesive Zone Models (CZM), which describe the progressive failure of an interface via a traction/separation law involving both parameters. Typical values for delamination interfaces lead to process zone lengths of the order of a few millimeters [2], which is insufficient to provide gradual and stable crack propagation. For this reason, additional dissipation mechanisms, having small maximum stress and large critical strain energy release rate, should be designed to work in parallel with the initial energy dissipation mechanisms to provide crack stabilisation features. A typical example of such mechanisms consists in the creation of bridging ligaments across the cracked surfaces [3, 4].

In this work, the combined effect of dissipation mechanisms at different length scales on the response of composite structures with propagating cracks is simulated using CZM and a dissipation-driven algorithm [5] to ensure the correct representation of snap-back instabilities. Such simulation enable one to define the target CZM parameters for a desired structural response [6].

References

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