Micromechanical modeling of thin ply effects on microdamage in Fiber-Reinforced Composite laminates

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Abstract

Introduced around 20 years ago, the so-called *spread tow technology* has allowed the production on industrial scale of extremely thin fiber-reinforced prepeg plies. The few manufacturers of this kind of composite material, such as North Thin Ply Technology [1] in Switzerland and Oxeon [2] in Sweden, are nowadays capable of providing prepegs with thicknesses up to 2/4 times the reinforcement's diameter for high performance carbon and glass E fibers.

The employment of thin plies in laminates for structural applications has been proven beneficial in terms of increased mechanical performance and improved tolerance to damage with concurrent savings in weights, particularly in cross- and angle-ply stacking configurations. The key factor underpinning the success of this technology is a phenomenon first experimentally observed around 40 years ago. This is known as the thin ply effect in the composite community, and made its appearance on the research stage thanks to a seminal paper by Parvizi and Bailey [3]. The main observation is that the transverse strength at failure measured for unidirectional composites (UD) is not applicable to a thin layer inside a laminate. Its real strength, known as the *in-situ strength*, is in fact much higher.

Damage propagation in thin and thick plies has been extensively studied experimentally and modeled by analytical and numerical techniques. Simulations with the Finite Elements Method has been proven to be a valuable tool to model transverse fracture processes at the micromechanical level, as in [4]. Many models of damage propagation recast the complexity of the phenomenon into a greater set of material parameters; unfortunately, several of them are inaccessible by means of mechanical tests and thus cannot be reliably measured. Indirect methods of estimation have been proposed, as for example in [5], but the applicability of such parameters outside the domain of training is still an open question.

On the other hand, crack initiation in thin plies has been mostly neglected and still represents a field ripe for investigation. Understanding is still lacking about the dependence of energy release rate with respect of debond size and position, the effect of adjacent plies, their thickness and relative orientation. Furthermore, the influence of fiber volume fraction, material selection, boundary conditions, load type and distribution should be considered to grasp the inner workings of this phenomenon. Detailed knowledge of the mechanisms underlying the initiation of fracture processes inside a single ply is useful in a twofold way: from the designer’s perspective, by providing guidelines on optimal laminate design; from the modeler perspective, by highlighting the best strategies to simulate crack initiation in terms of solver selection, mesh quality, boundary’s conditions, load type and distribution. To address these issues, several 2-dimensional models of Representative Volume Element (RVEs) have been developed by combining together different variations of the aforementioned elements. Energy release rates are computed for different debond position and size, as well as contact stresses and displacements at fiber/matrix interface and elastic strains and stresses along selected radial and circumferential sections.

References

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