Effect of uniform distributions of bonded and debonded fibers on the growth of the fiber/matrix interface crack in cross-ply $[0^\circ_n, 90^\circ]_S$ laminates with different fiber contents under transverse loading

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Abstract

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1. Introduction

The structure is designed to very similar to the paper about UD, i.e. the line of thought is the same but applied to cross-plies. Maybe we could consider the two as part of one big work and call the two articles *Part 1* and *Part 2*. Thoughts?

1. We start with a few lines devoted to the spread tow technology and thin plies: what they are, what can be done, what are the possible applications.
2. By quoting the relevant references, we report on the observation that one of the main beneficial mechanisms in thin ply is the retardation of transverse crack propagation. We then enlarge by reporting the microscopical

observations by Saito, in which debonds where also observed. We observe that available microscopic observations are just a few and mainly in 2D.

3. Propagation of transverse cracks has been widely investigated both analytically and numerically
4. Initiation at the level of fiber/matrix interface is instead a less researched subject.
5. cohesive elements are a possible choice, but have some drawbacks, which makes a LEFM approach valuable
6. With regard to LEFM studies of laminates under transverse loading, models can be found in the literature about: the single fiber in infinite matrix under different mode of loading, the effect of adjacent fibers on a fiber in infinite matrix under different mode of loading, the single fiber in an equivalent composite in transverse tension, the effect of adjacent fibers on a fiber in an equivalent composite in transverse tension. We mention these works more briefly.
7. We concentrate a little more on works with cohesive elements, as there is more of them on fiber/matrix interface crack in cross-ply
8. Initiation of transverse cracking at the fiber/matrix interface in cross-ply laminates under transverse tension hasn't been directly addressed with LEFM in the literature. We address this gap with this paper and we focus on (in analogy with the work on UDs): the effect of fiber volume fraction; the interaction of debonded and bonded fibers in micro-structured assemblies, i.e. no homogenization.
9. We conclude the introduction with a summary of the article's structure.

2. RVE models & FE discretization

2.1. Models of Representative Volume Element(RVE)

We start by describing the different idealized micro-structures considered and the corresponding repeating element or RVE used to model them. Fig. 1, Fig. 2 and Fig. 3

(a) A debonded fiber every 2 fully bonded ones.

(b) Central debonded fiber with 1 fiber each side.

(c) A debonded fiber every 4 fully bonded ones.

(d) Central debonded fiber with 2 fibers each side.

(e) A debonded fiber every 6 fully bonded ones.

(f) Central debonded fiber with 3 fibers each side.

Figure 1: Models of $[0^\circ_n, 90^\circ]_S$ laminates in which the central 90° ply possesses a single layer of fibers and debonds repeating at different distances (left column), and corresponding Representative Volume Elements (right column) with symmetry applied on the lower boundary line. The interface crack is represented in red.

(a) 3 layers with a central line of debonded fibers.

(b) Central debonded fiber with 1 fiber above.

(c) 5 layers with a central line of debonded fibers.

(d) Central debonded fiber with 2 fibers above.

(e) 7 layers with a central line of debonded fibers.

(f) Central debonded fiber with 3 fibers above.

Figure 2: Models of $[0^\circ_n, 90^\circ]_S$ laminates in which the central 90° ply possesses a central line of debonded fibers (left column), and corresponding Representative Volume Elements (right column) with symmetry applied on the lower boundary line. The interface crack is represented in red.

(a) 3 layers with a debonded fiber every 2 fully bonded ones in the central line of fibers.

(b) Central debonded fiber with 1 fiber on each side and 1 above.

(c) 3 layers with a debonded fiber every 4 fully bonded ones in the central line of fibers.

(d) Central debonded fiber with 2 fibers on each side and 1 above.

(e) 5 layers with a debonded fiber every 4 fully bonded ones in the central line of fibers.

(f) Central debonded fiber with 2 fibers on each side and 2 above.

(g) 3 layers with a debonded fiber every 6 fully bonded ones in the central line of fibers.

(h) Central debonded fiber with 3 fibers on each side and 1 above.

Figure 3: Models of$[0^{\circ}_{n}, 90^{\circ}]_{S}$ laminates in which the central 90° ply possesses multiple layers of fibers with debonds repeating at different distances in the central line of fibers (left column), and corresponding Representative Volume Elements (right column) with symmetry applied on the lower boundary line.

(a) Single layer of debonded fibers.

(b) Element with a single debonded fiber and free boundary on top.

Figure 4: Models of$[0^{\circ}_{n}, 90^{\circ}]_{S}$ laminates in which fibers belonging to the central 90° ply are all debonded (left column), and corresponding Representative Volume Elements (right column) with symmetry applied on the lower boundary line.

2.2. Finite Element (FE) discretization

3. Results & Discussion

3.1. Effect of 0° *ply thickness on the interaction between debonds in a* 90° *ply with a single layer of fibers*

3.2. Effect of 0° *ply thickness on the interaction between layers of fully bonded fibers and a centrally located line of debonded fibers in a* 90° *ply*

3.3. Effect of 0° *ply thickness on the interaction of debonds in a* 90° *ply with multiple layers of fibers*

subsectionComparison with the single fiber model with equivalent boundary conditions

4. Conclusions & Outlook