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Advanced CFRP laminate modification techniques using thin-ply

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Introduction

The use of thin-ply CFRP laminates offers enhanced design flexibility and mechanical performance, particularly in adhesively bonded joints where peel stress is critical [1]. This study explores the effect of gradually distributed thin plies through the laminate thickness under transverse tensile loading. Both experimental testing and microscale numerical modelling were conducted, demonstrating improved joint strength and stress distribution, with the proposed configuration showing promising structural and cost advantages.

Experimental details

1. Materials

- CFRP: unidirectional , Thick thin-ply 70 gsm, Thin thin-150 gsm
- Cured process: in a hot press at 30 bar and 130° C for 2 h

2. Configurations

Reference laminates using three identified materials were first fabricated. Then, gradual laminates were produced by layering 50% conventional and 25% each of thin and intermediate plies symmetrically, as shown in Figure 1.

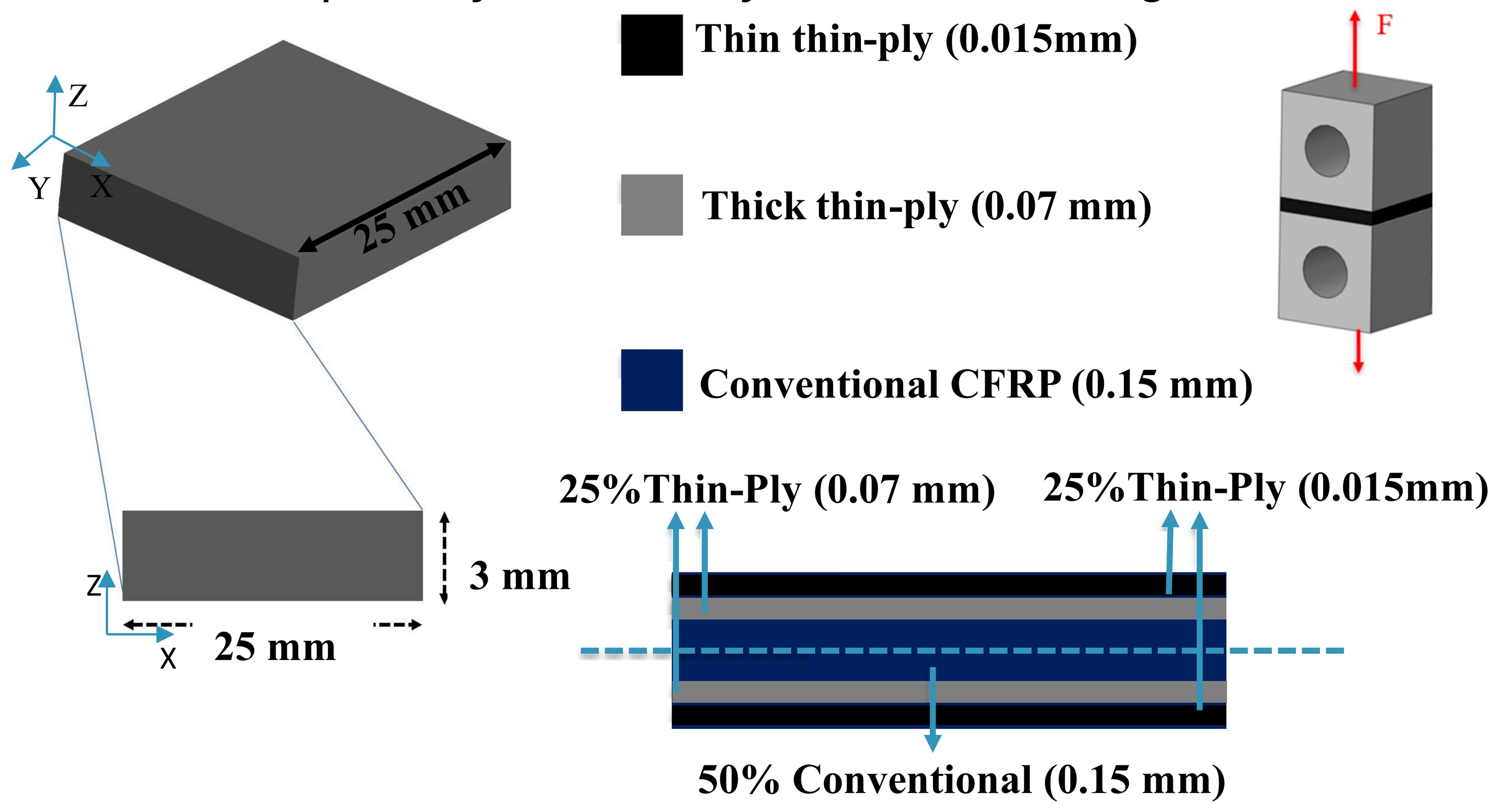


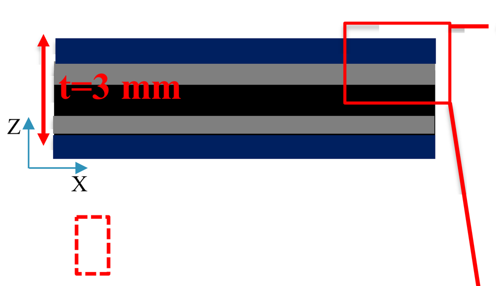
Figure 1 – reference and gradual manufactured CFRP laminates.

Numerical details

A Representative Volume Element (RVE) was employed to simulate the fiber distribution through the laminate thickness.

1. RVE generation

A micro-scale RVE model was developed in ABAQUS using fiber distribution data obtained from optical microscopy. A Python algorithm generated realistic fiber arrangements based on measured fiber diameter and volume fraction. Figures 2&3, shows real fiber distribution through the laminate thickness taken using optical microscope as well as the generated single RVEs. Afterward, Four RVE models were simulated—three as benchmarks and one gradual—by assembling smaller RVEs to match target dimensions.



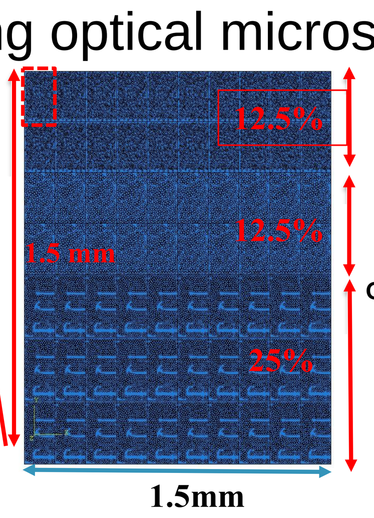


Figure 2–Gradual configuration RVE.

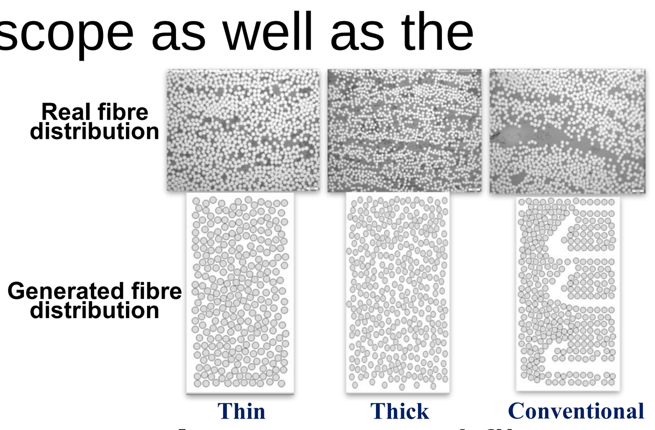


Figure 3– Real fiber distribution and generated RVEs.

2. BC, loading and failure criteria

To simulate the failure in matrix concrete damage plasticity and for fiber/matrix separation cohesive model were used (Figure 4). Embedded boundary condition was also used to avoid complexity of periodic one (See Figure 5).

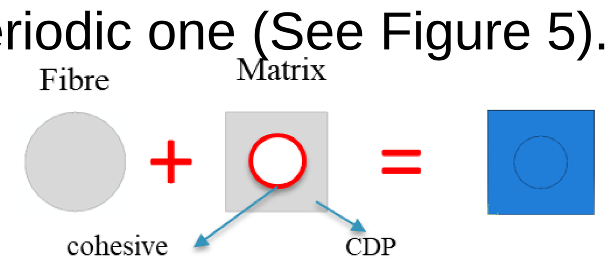


Figure 4– Applied concrete damage plasticity and cohesive.

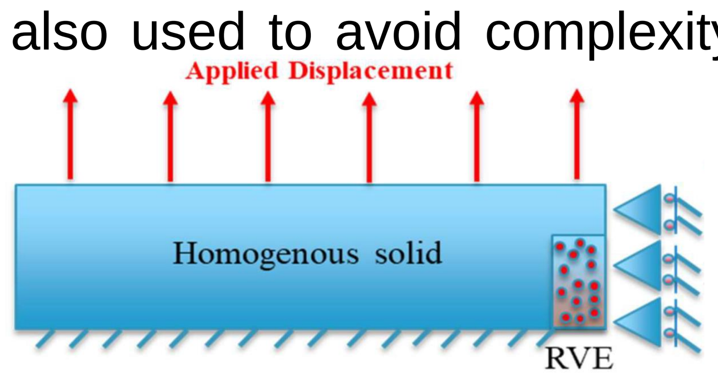


Figure 5– Applied load and BC.

The load applied at the macro scale induces traction at each corner node and side of the RVE. Computational homogenization is employed to establish the connection between the macroscopic and microscopic fields (Figure 6), aiming to determine the strength in the macro scale domain

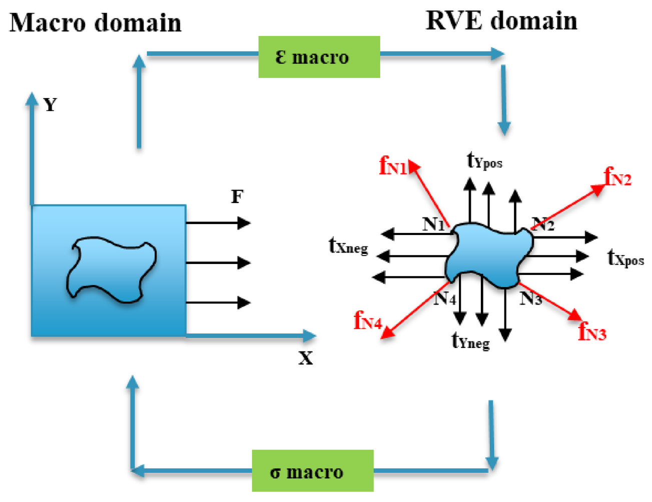


Figure 6– Macro-to-micro scale transitions.

Results and discussion

Gradual and thin-ply configurations show less interface damage under displacement (see Figure 7), indicating potentially higher strength compared to other configurations. Figure 8 shows that the gradual configuration has a higher failure load compared to the conventional and thick thin-ply. This improvement is attributed to enhanced ductility and well-distributed fibers, leading to a complex crack path.

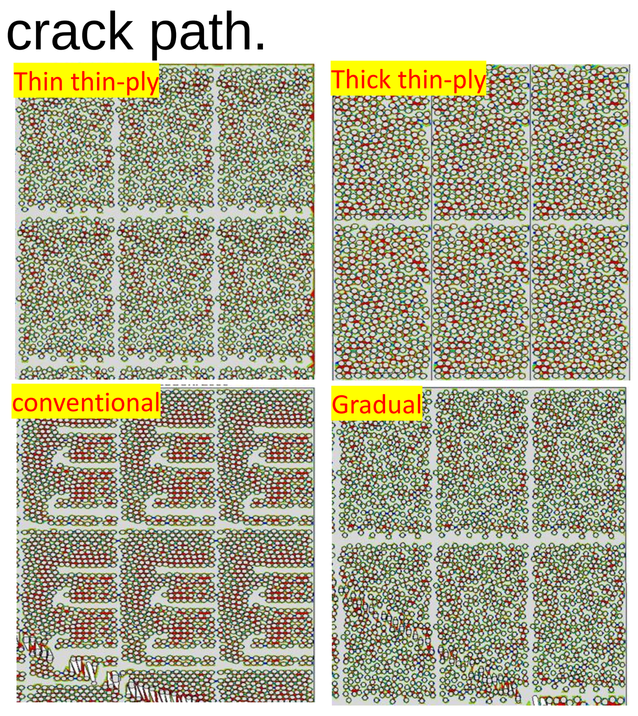


Figure 7 – Fiber/matrix interface failure.

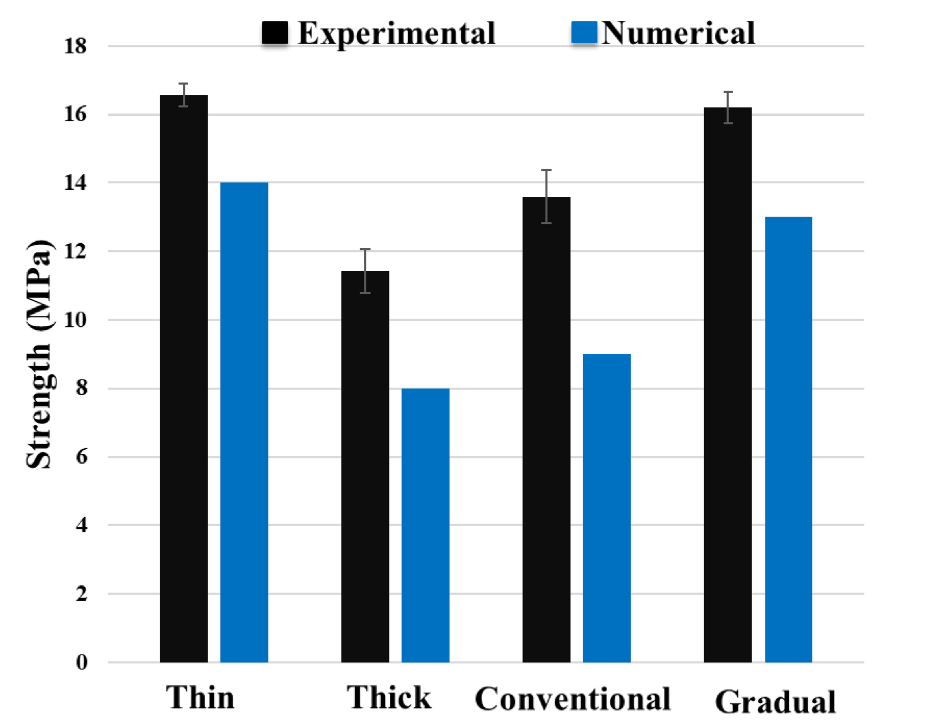


Figure 8 – Obtained experimental and numerical strength.

CONCLUSION

- Gradual modification using thin plies improves transverse tensile strength
- Gradual configurations achieve similar strength to full thin thin-ply laminates but require significantly fewer layers to reach the same thickness, reducing material usage and manufacturing complexity.
- Numerical modelling using 2D RVEs, concrete damage plasticity, and cohesive zone models effectively captured experimental results

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[1] Malekinejad, H.; Ramezani, F.; Carbas, R.J.C.; Akhavan-Safar, A.; Marques, E.A.S.; Ferreira, M.; da Silva, L.F.M. Study of CFRP Laminate Gradually Modified throughout the Thickness Using Thin Ply under Transvers Tensile Loading. Materials.. 2024, 17(10), 2388.