Design and analysis of graded FRP laminates plates varying fiber volume fraction through the thickness

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Introduction

Thin-ply laminates are typically characterized as composites with ply thicknesses below 100 µm and ply areal weights lower than 100 g/m2 [1]. Reinforced hybrid FRP laminates with thin-plies exhibit higher failure loads than commercial laminates [1]. However, the load transfer throughout the thickness is non-monotonous due to abrupt stiffness changes. Consequently, this study investigates the potential of presenting a novel graded FRP laminate by applying thin-ply materials with varying properties through the thickness. In order to accomplish this objective, the FRP laminates are modified by incorporating various conventionally available prepreg thin-plies and also conventional CFRP. The investigation is carried out using Abaqus software, utilizing a representative volume element (RVE).

Experimental details

In order to verify the accuracy of the numerical study, transverse tensile tests were performed on two distinct thin-plies and conventional CFRP with varying thicknesses, as illustrated in Figure 1.

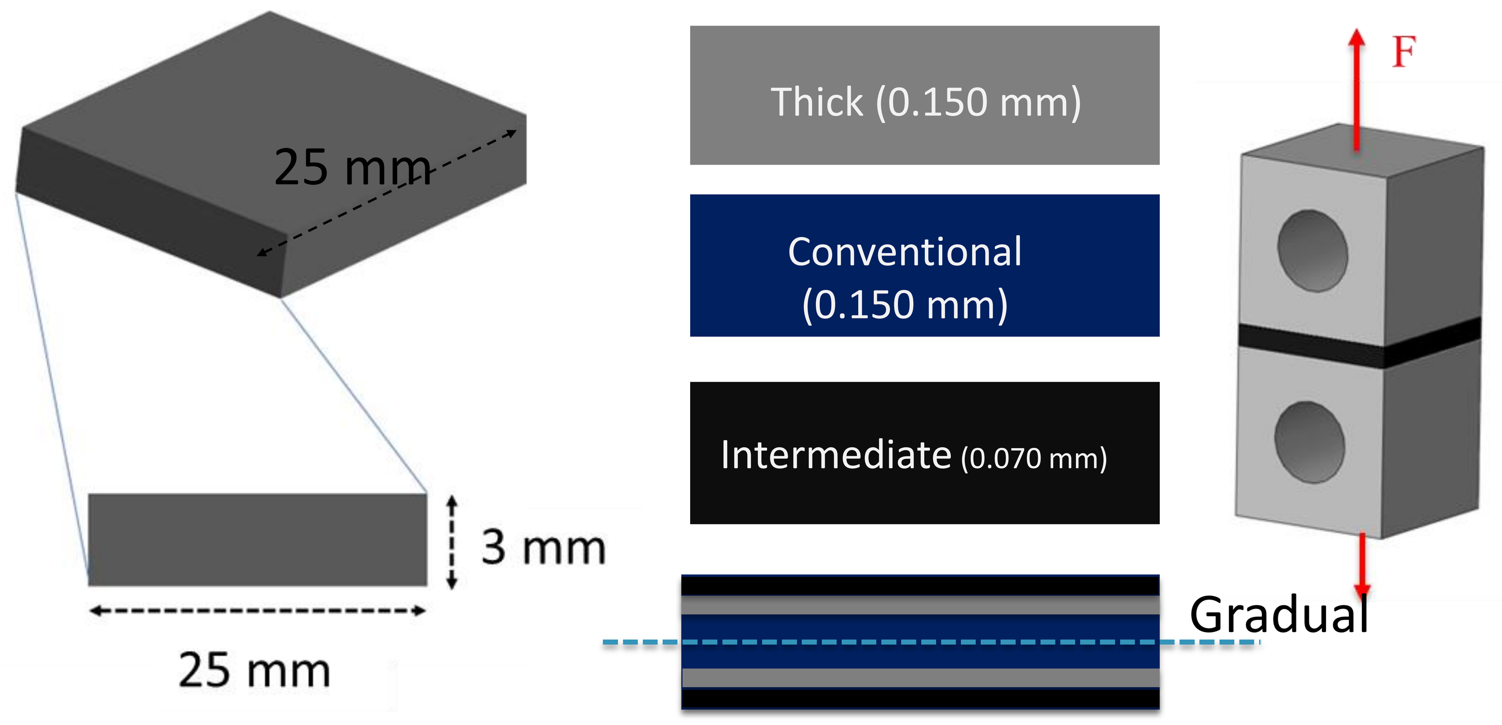

Figure 1– manufactured laminate

Materials

- CFRP: unidirectional 0°carbon-epoxy
- Intermediate thin-ply: unidirectional 0°, TP415/70 gsm by NTPT
- Thick thin-ply unidirectional 0°, TP402/HR40/150 gsm by NTPT

Cured process: in a hot press at 30 bar and 130° C for 2 h

Methodology

An Abaqus numerical RVE model was created to forecast the strength of laminates featuring graded through thickness using conventional CFRP and thin-plies with different thickness (see Figure 2). To predict the failure in matrix, concrete damage plasticity (CDP) was used and cohesive element as contact was modeled to simulate the fiber/matrix debonding (see Table 1 and 2).

Table 1– Parameters of the damaged plasticity model that characterize the matrix and fiber [2]

Materials	E Resin (GPa)	E Fiber (GPa)	Fiber diameter (µm)
Conventional	3.3	294	7
Thin thin-ply			5
Intermediate thin-ply	3.6	230	7
Thick thin-ply			6

σ_{yt} (Pa)	ε_t	d_t	σ_{yc} (Pa)
121e6	0	0	176e6
1.21e6	1.6	0.9	176e6
			17.6e6
			1.76e6

Table 2– Fiber/matrix interface properties

Conventional composite: Property	Value	Thin-plies: Property	Value
Tensile strength (MPa)	25	Tensile strength (MPa)	35
Shear strength (MPa)	13.5	Shear strength (MPa)	32
G_{IC} (N/mm)	0.33	G_{IC} (N/mm)	0.76
G_{IIC} (N/mm)	0.79	G_{IIC} (N/mm)	0.83

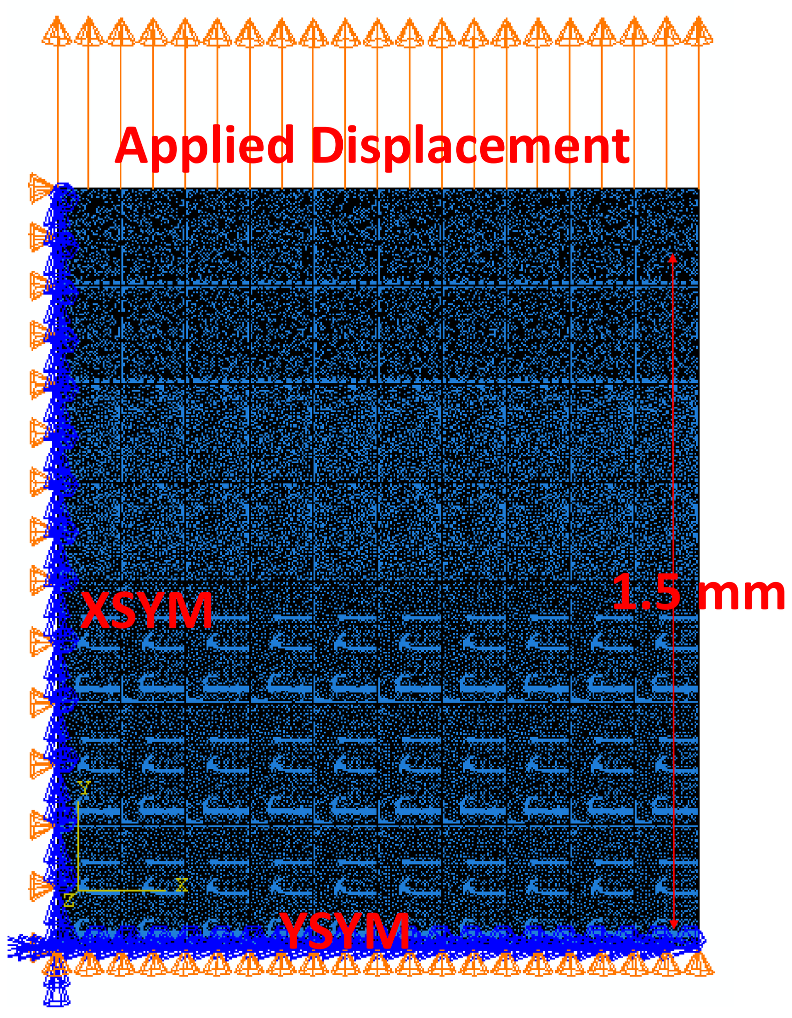

Figure 2- Boundary condition and loading

RVE generation

Electro Optical microscopy analyzed resin and fiber distribution in thin-plies and conventional composites. A custom Python algorithm generated random RVE with desired fiber configurations (Figure 3).

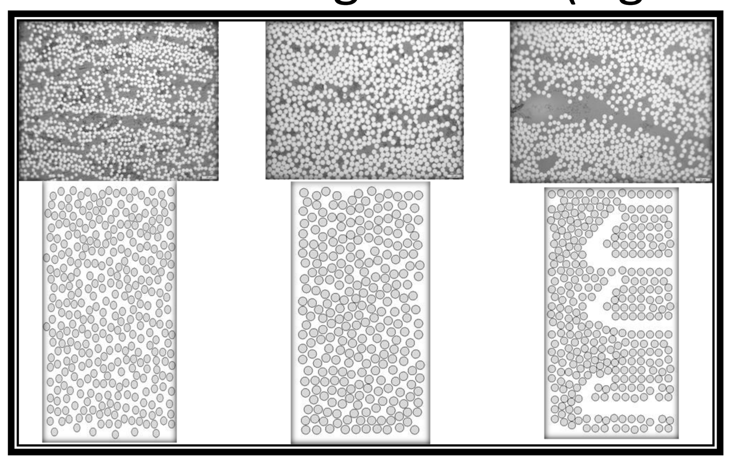

Figure 3- Generated RVE

Results

Numerical findings from Figure 4 indicate that the gradual configuration, incorporating 25% thin-plies and 25% intermediate thin-plies, exhibits higher failure load than the conventional configuration. This is attributed to enhanced ductility and well-distributed fibers, resulting in a complex crack path. The laminate structure's weakest component is the fiber/matrix interface, as shown in Figure 5, where interface debonding occurs.

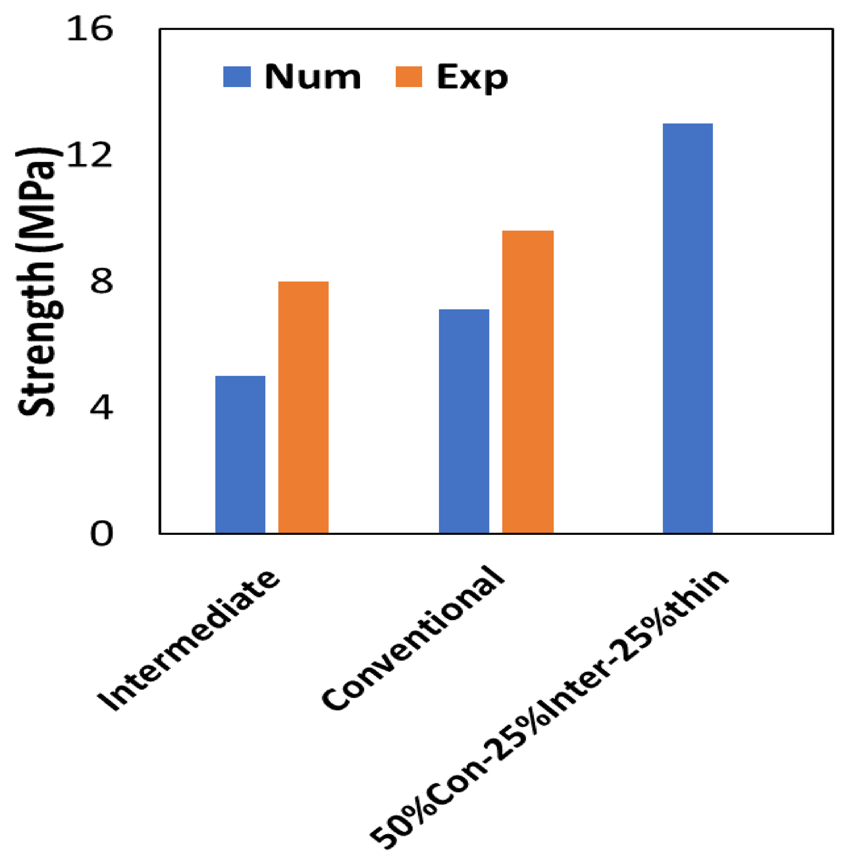

Figure 4 – manufactured laminate

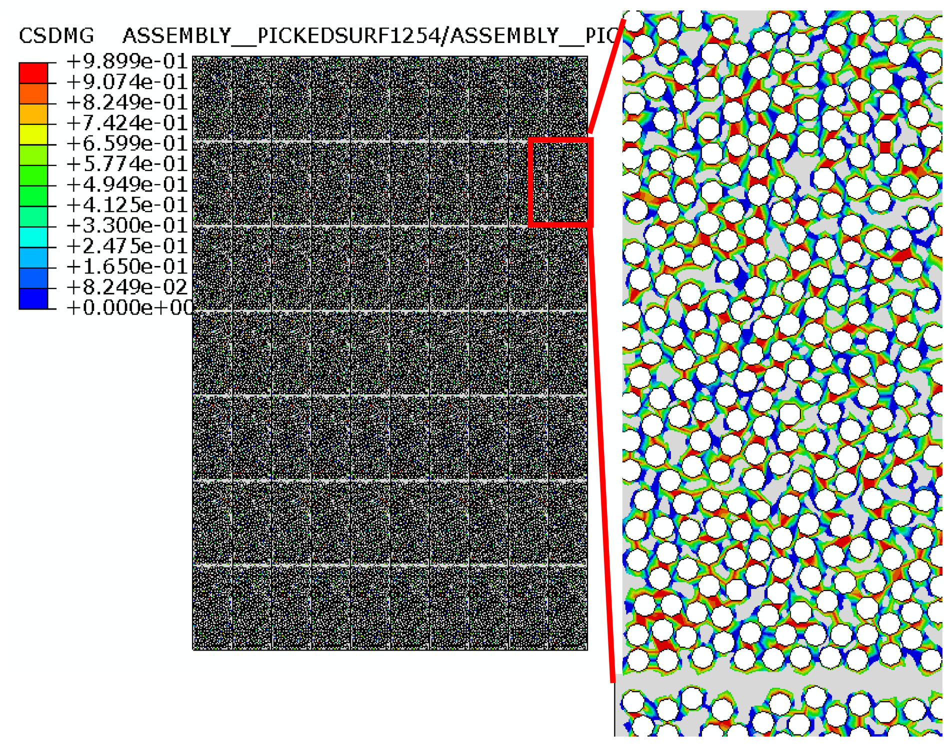

Figure 5 – fiber/matrix interface failure

Conclusions

A numerical 2D model was used to compare the strength of a reference CFRP configuration with gradually modified configurations. Elastoplastic simulations revealed that the gradual modification exhibited higher strength, indicating a positive impact on the CFRP's strength characteristics. The study employed concrete damage plasticity and cohesive zone models for accurate analysis. These findings highlight the potential benefits of gradually modifying CFRP configurations.

References

[1] F. Ramezani, R. Carbas, E. A. S. Marques, A. M. Ferreira, and L. F. M. da Silva, “Study on out-of-plane tensile strength of angle-plied reinforced hybrid CFRP laminates using thin-ply,” Mech. Adv. Mater. Struct, 2023.

[2] Naya, “Prediction of mechanical properties of unidirectional FRP plies at different environmental conditions by means of computational micromechanics,” Madrid, 2017 .

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