Damage scenario of CFRP composite laminates under Quasi-Static Indentation loading

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Motivation and objectives

- Any attempt to achieve composite laminates with improved damage tolerance to low velocity impacts must depart from the understanding of the sequence of damage mechanisms taking place. Low velocity impacts caused by large masses can be treated as a static indentation problem because the impact duration is much longer than the time required by the propagating waves to travel from the impact site to the supports or free edges [1]. Therefore, quasi-static indentation (QSI) tests can provide meaningful evidence of the damage events occurring during a low velocity impact as well as its sequence and interactions.
- The main objective of this work is to present a detailed experimental study of damage associated to QSI tests on carbon laminated composites.

Experimental set up

- The material used in this study was a UD tape prepreg AS4D/TC350 carbon/epoxy from which a laminate with stacking sequence [45/0/ -45/90]3s was manufactured following standard aeronautical procedures.
- The unidirectional material properties were measured in **AMADE lab** according to ASTM standards.
- The specimen dimensions for the QSI tests were 80 x 80 x 4.46 mm. The QSI tests consisted of step-loading bending indentation tests, which were performed using a 100 kN MTS universal testing machine.
- Figure 1 illustrates the experimental setup with the sample location, indenter, and the fixture (centrally-hollow support). The indenter was a stainless steel hemisphere of 12.7 mm in diameter according to ASTM standard [2].

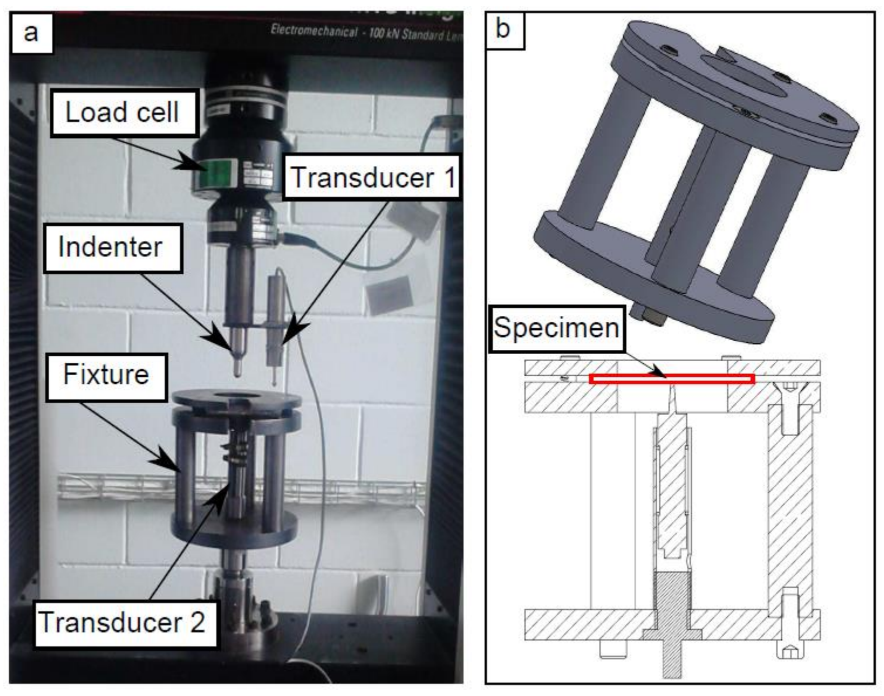

Figure 1. Experimental set up of the QSI test.

Results and discussion

Figure 2 shows a load-displacement curve representative of each batch; with each batch corresponding to a predetermined displacement (d = 0.8, 1.0, 2.0, 3.2 and 3.9 mm). As each curve overlaps the curves with smaller displacement, this figure illustrates the excellent repeatability of the QSI tests. In view of the results, QSI load-displacement curves can be divided into four different stages, termed here as I, II, III and IV.

The first stage (I), here referred to as the elastic stage, spans a displacement of 0 to 0.85 mm and is associated with the Hertzian contact response. There is no evidence of any form of damage in the SEM or C-scan.

The second stage (II), corresponds to a sudden load drop at 0.85 mm. In view of extensive matrix cracking being observed immediately after this load drop, Figure 3(a), we termed it the matrix cracking stage. Matrix cracks grow in an almost 45 direction from the end of contact area in the transverse plies. There is no delaminations observed, Figure 4(a).

The third stage (III), within 1 mm < d < 3.3 mm, is termed delamination propagation. Figure 3(b) shows the SEM inspection at d =2 mm. Towards the end of stage III, d = 3.2 mm, a higher crack density and a larger extent of delaminations is easily observable both by SEM (Figure 3(c)) and C-scan (Figure 4 (b), (c)).

The fourth stage (IV), we termed it the fiber breakage stage. It is characterized by a sudden load drop at 3.3 mm. The SEM micrograph taken at d = 3.9 mm (Figure 3(d)) shows two damage mechanisms: a shear cone formation, in which plies are broken in the upper part of the laminate (the upper 2/3 of the laminate) and the tensile failure of plies at the bottom of the laminate (bottom 1/3 of the laminate). Figure 5 the relation between the projected delamination area and the maximum displacement of the indenter.

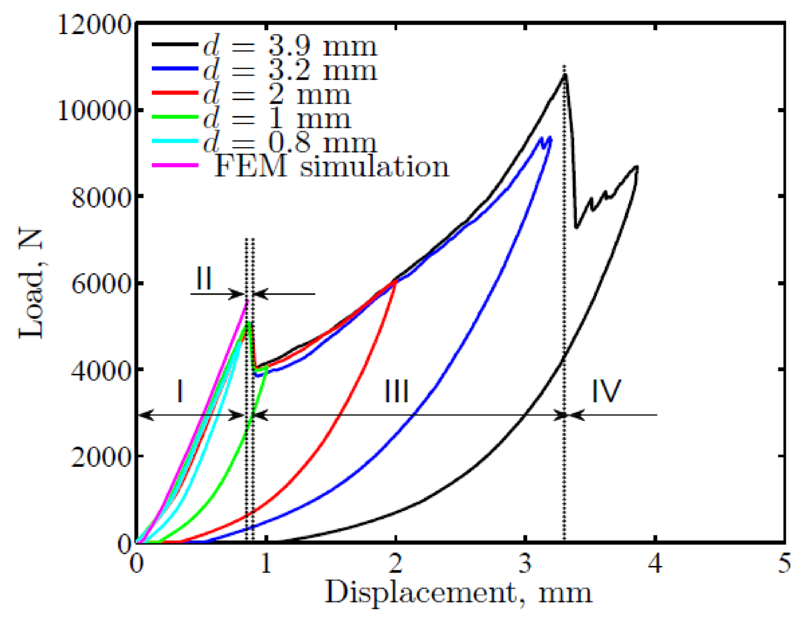

Figure 2. Load-displacement curve for QSI tests.

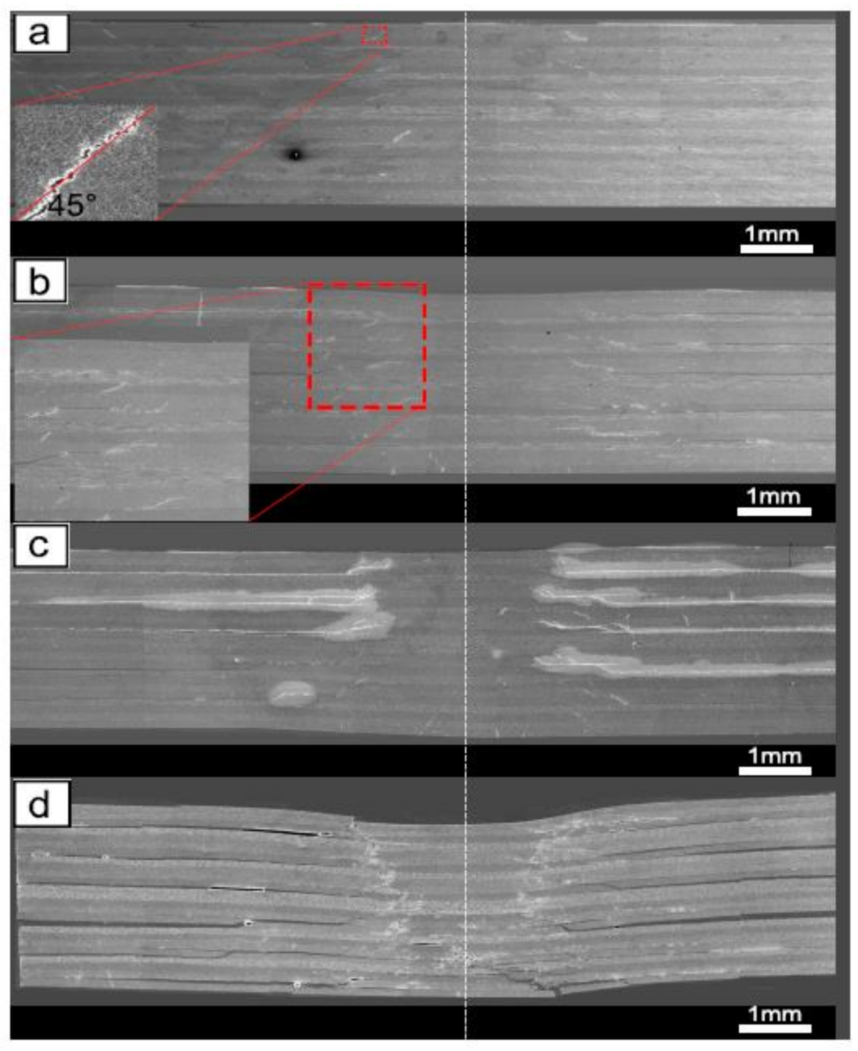

Figure 3 SEM of the specimens' cross sections.

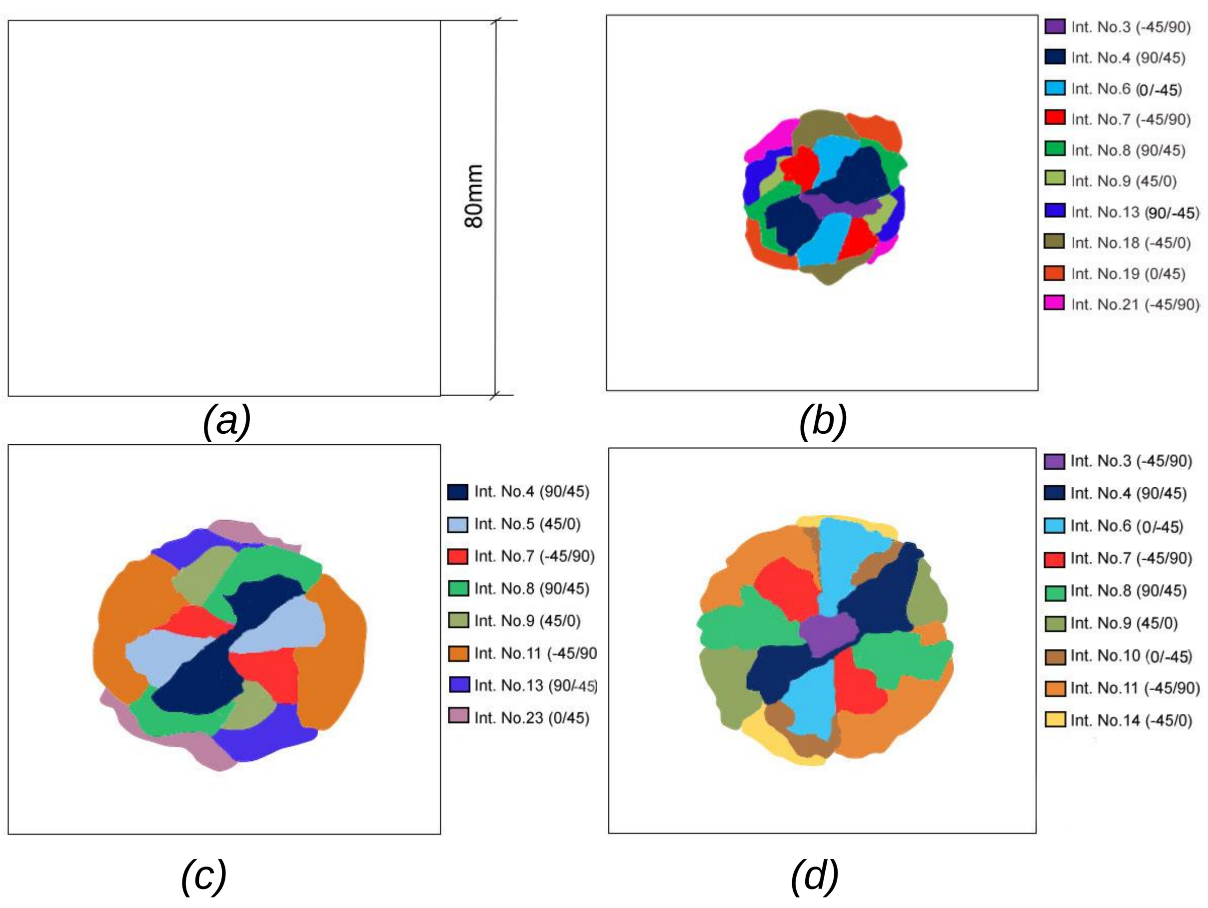

Figure 4. Through-the-thickness position and extension of individual delaminations at different displacement: (a) d = 1 mm, (b) d = 2 mm, (c) d =3,2 mm, and (d) d = 3,9 mm .

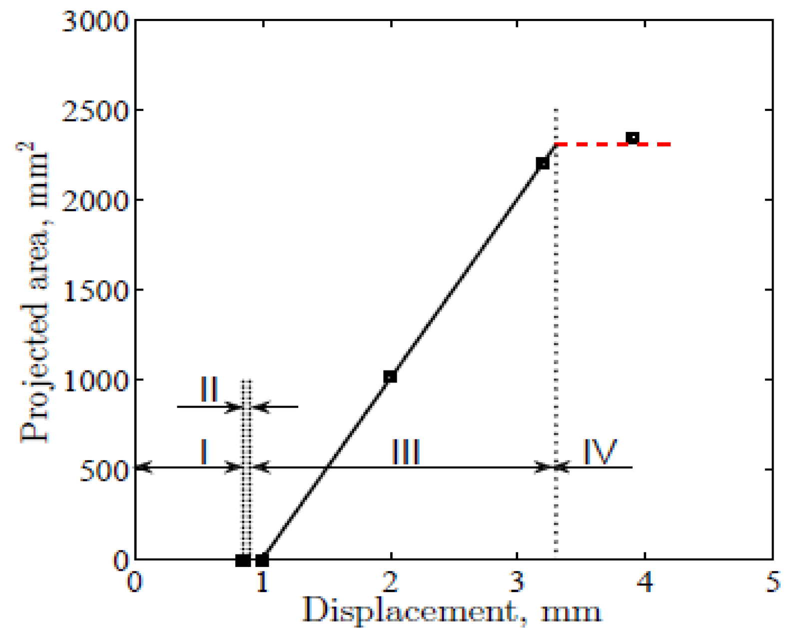

Figure 5.Projected delamination area as a function of Maximum displacement.

Conclusions

The sequence of damage events observed in the QSI tests along with its correlation with the load-displacement curve is summarized in Figure 6.The load displacement curve is plotted using four different colors each color corresponding to the damage mechanism represented in Figure 6(a) of the same color.

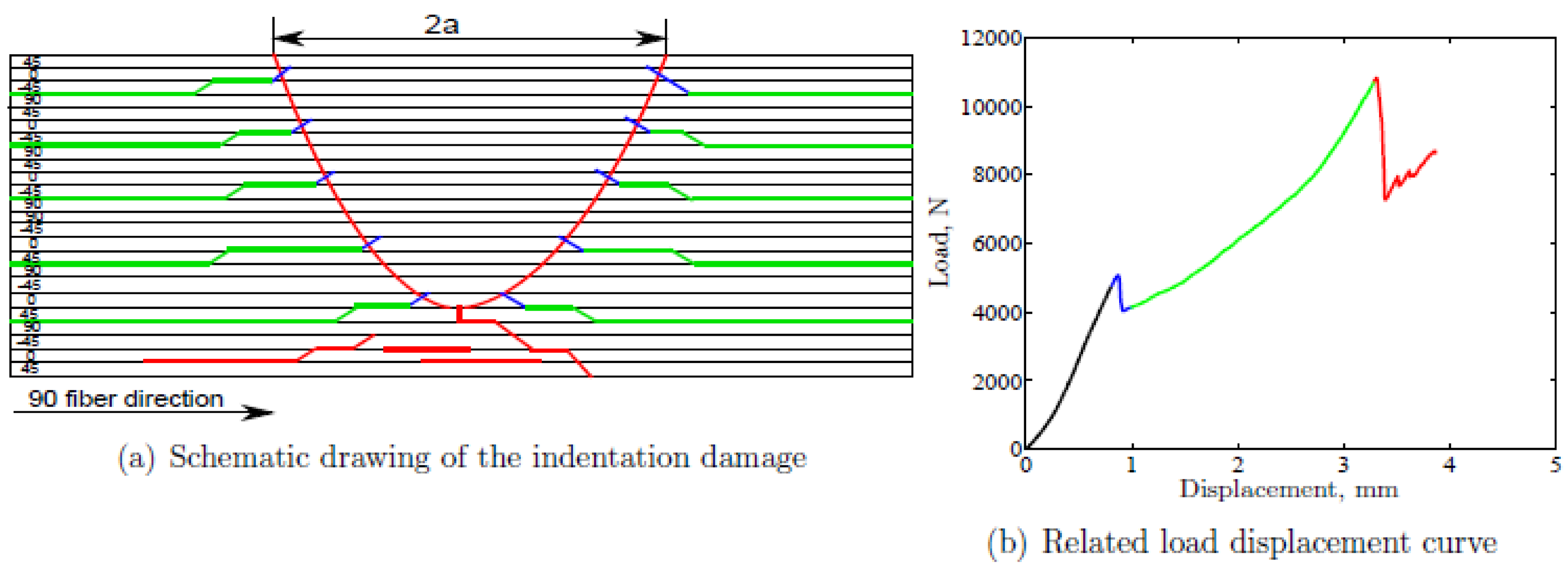

Figure 6. Summary of the damage sequence during QSI tests.

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[2] ASTM D 6264 - 98 (Reapproved 2004). Standard Test Method for Measuring Damage Resistance of Fiber-Reinforced Polymer-Matrix Composite to Concentrated Quasi-Static Indentation. 2004.

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