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CAI FATIGUE TESTING IN CFRP: IS THE TEST REPRESENTING WHAT HAPPENS IN REAL STRUCTURES?

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ABSTRACT

Impacts on carbon fiber reinforced composites (CFRP) can produce internal damage comprising of matrix cracks, multiple delaminations and fiber fracture, which are hard to detect by visual surface inspection. This situation is known as barely visible impact damage (BVID). There is evidence that BVID can propagate in compression fatigue in the form of delamination growth causing failure [1,2]. In the past decades, great attention has been paid to this scenario by the aerospace research community, since low velocity impacts are frequent in aviation and BVID can potentially grow unnoticed during an aircraft's operational life, exposing structures to the risk of unexpected failure.
The study of fatigue after impact propagation has been conducted usually by tracking the growth of projected delaminated area using periodic ultrasound inspections. To compare results of different experimental campaigns, the ASTM D7137 static compressive test fixture has often been used also in case of fatigue tests. Results of the previously described class of experiments [1,2], showed first a phase of almost no growth in the projected delamination area, followed by a fast propagation of delamination in the perpendicular to loading direction. However, the reason why this no-growth phase is observed is still unknown. It is also not clear how dependent the observed growth pattern is on the adopted test fixture. In the present work, we use the results of a series of CAI fatigue tests to critically discuss and redefine these two knowledge gaps.

Toray M30SC – Deltapreg DT120-200-36 UD was manually laid-up in $[-45,0,45,90]4,s$ laminate. Impact testing was conducted using a drop-weight tower according to ASTM D7136, while the following fatigue test was conducted adopting ASTM D7137 fixture. The damage propagation was monitored combining acoustic emission, C-Scan and digital image correlation. The results of echo pulse C-Scan and through thickness attenuation scan, clearly showed that the projected delaminated aera is not sufficient to capture two scenarios of delamination growth:

1. Impact tests often creates a non-delaminated cone below the impact contact point caused by the out of plane compressive stress. In our fatigue test, through thickness attenuation scan revealed that fatigue growth happened first inwards, in the non-delaminated cone area and only after, a transverse growth outside of this area was observed (Fig.1).
2. Using echo pulse scan it was possible to observe that, before the transverse direction growth outside of projected area took place, smaller impact delamination growth was going on inside the projected area (Fig.1). This growth would not be visible if only a through thickness attenuation scan would be used.

The two reported observations clearly show that the current practice of only studying growth of the projected delamination area is not sufficient. More importantly, they show that delamination growth might in fact occur during the phase identified as the no-growth plateau phase in previous works.

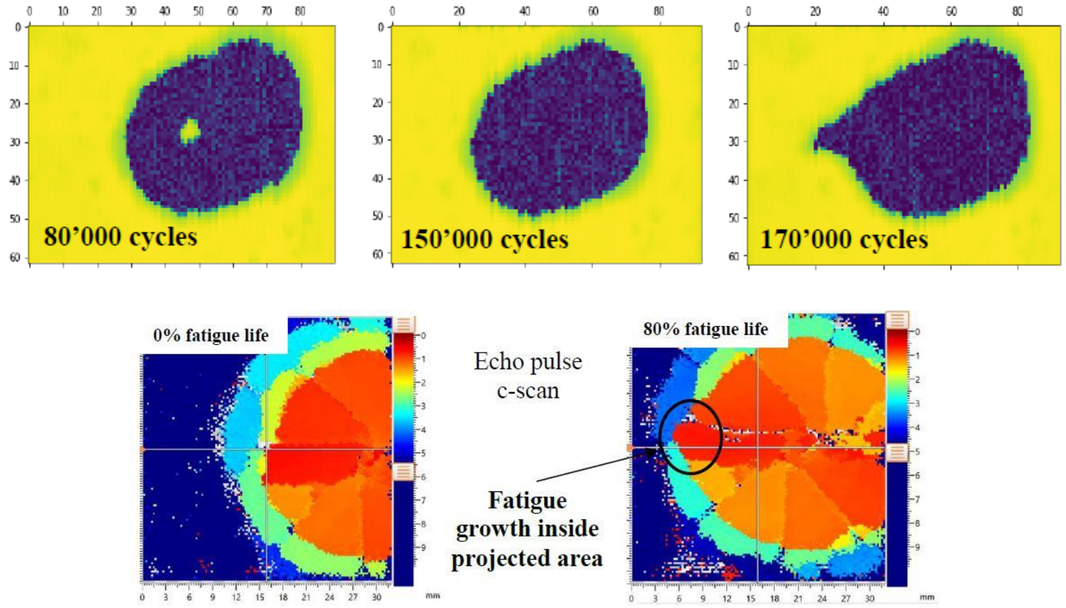

Fig.1: Results of attenuation scan monitoring (top) and echo pulse c-scan monitoring (bottom) in different moments of fatigue life to track delamination growth (colours represent different interfaces)

The delamination propagation study shows a typical growth pattern: first, inward growth in the non-delaminated impact cone and outward growth of a smaller delamination took place. Then there was a fast delamination growth in the transverse direction. The final delamination growth leading to failure was always located in the first few interfaces close to the impacted surface. Interestingly, the described phenomenon was observed in all specimens regardless of the fatigue life. However, the following two characteristics of the observed delamination growth pattern, suggest that it may be highly dependent the adopted test fixture:

1. In the ASTM D7137 standard, lateral guides are present on the sides of the specimens to prevent global buckling, but in real applications global buckling is likely to appear under compressive loading. The buckling mode of sublaminates primarily determines the strain energy release rate of the multiple delamination fronts. Therefore, we cannot exclude that the final growth of a single delamination located in interfaces close to the impacted face is a consequence of the buckling constrains we impose by adopting the ASTM D7137 fixture.
2. The ASTM D7137 test fixture is asymmetrical in terms of specimen dimensions (100x150mm) and load application (unidirectional compression only on the 100mm edge). Also, the observed growth was asymmetrical and happened always in the perpendicular to load direction. It is then possible that, if specimen aspect ratio and loading are changed, different growth could be observed.

Before generalizing the test observations about fatigue after impact delamination growth, it is important to further investigated these two critical points. This because, in contrast to standard tests, real structures can have different shapes and experience a variety of loading cases.

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