CFAI TESTS

Manufacturing:

Toray M30SC Deltapreg DT120-200-36 UD, a commercial carbon fiber/epoxy prepreg, was laid up in [−45, 0, 45, 90]4,S orientation.

The plies of prepreg were laid up manually in a clean room. Debulking was conducted after the positioning of every four plies to minimize air inclusions at interfaces. The obtained laminate was laid on an aluminium plate, with Marbocote 220 releasing agent, and sealed with a vacuum bag. The curing process was conducted in an autoclave with a maximum pressure of 6 bar and a curing temperature of 120°C. The bag was kept in vacuum conditions during the entire curing cycle. The curing cycle in the autoclave was applied to large plates (400 × 600 mm) which then were cut into smaller rectangles using a circular diamond blade. The final specimens had nominal dimensions of 150 × 100 × 5.15 mm, as specified in the ASTM D7136 standard.

Impact:

Impact testing was carried out in accordance with ASTM D7136 [1] using a drop-weight tower. The support fixture had a cut-out with dimensions of 125 ± 1 mm in the length direction and 75 ± 1 mm in the width direction. To ensure single impacts, the impact tower was equipped with a catcher activated by optical sensors. A hemispherical impactor with a diameter of 16 mm and a mass of 4.8 kg was utilized. Following ASTM D7136's recommendation of 6.7 J per mm of laminate thickness, a target impact energy of 34 J was employed in the impacts.

Fatigue after impact:

As there is no standardized method for fatigue CAI testing, the same setup as that normally used for static CAI testing ASTM D7137 [2] was employed in the fatigue tests.

In contrast with the standard fixture, the lateral anti-buckling guides had a flat contact instead of a knife edge. Different specimens were tested at various compression load levels to obtain short-life fatigue and long-life fatigue tests. Load levels between 70% and 80% of the residual CAI strength were applied in the test. A constant R ratio (R = 10) was kept and frequency of 3 Hz was adopted.

DIC:

The system adopted consisted of two nine MP "Point Grey" cameras with 'Tamron' 25 mm lenses. The speckle pattern images were captured by ViC-Gauge 3D software with an acquisition rate of 1 fps. To obtain a steady picture of the buckled sub laminate, fatigue tests were periodically interrupted and a displacement of 80% of maximum compression. Afterward, the images were processed using 'ViC-3D 8' software to perform a strain analysis.

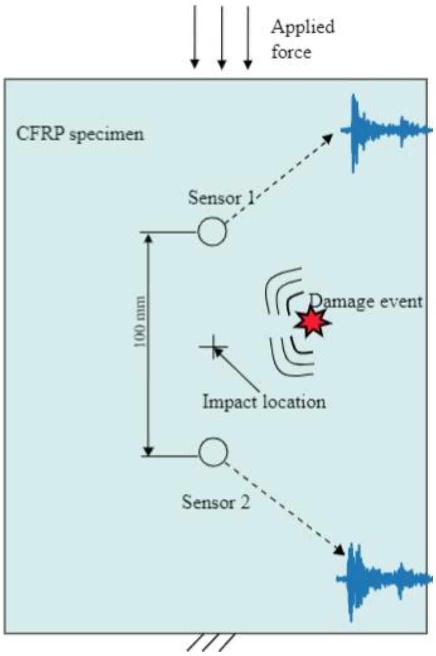
Ultrasound:

To assess the size of delaminations, two ultrasound systems were utilized. The first system was a water-tank immersion system operating in through-transmission attenuation mode.

This system uses a 5 MHz ultrasound frequency, with a distance of 100 mm between the emitter and receiver. The scanning speed was set at 100 mm/s, resulting in a resolution of 1 mm. The second system adopted was the pulse-echo Dolphicam 2 system, equipped with a scanning probe operating at 8 MHz. The obtained scans were analyzed in the time of flight mode.

Acoustic emissions:

The used AE sensor was the AE1045SVS900 M, a broadband single-crystal piezoelectric transducer with an operational frequency range of 100–900 kHz supplied by Vallen Systeme GmbH. In addition, an external 34 dB pre-amplifier was used to amplify the recorded signals. To reduce noise, an acquisition threshold was set to 45 dB. The AE data was collected with a sampling frequency of 2 MHz by the AMSY-6 Vallen, 4-channel AE system. Ultrasound gel was applied to improve the coupling between the AE sensor and the specimen's surface. The two sensors were kept in position using plastic sensor holders glued to the non-impacted surface of the specimen.

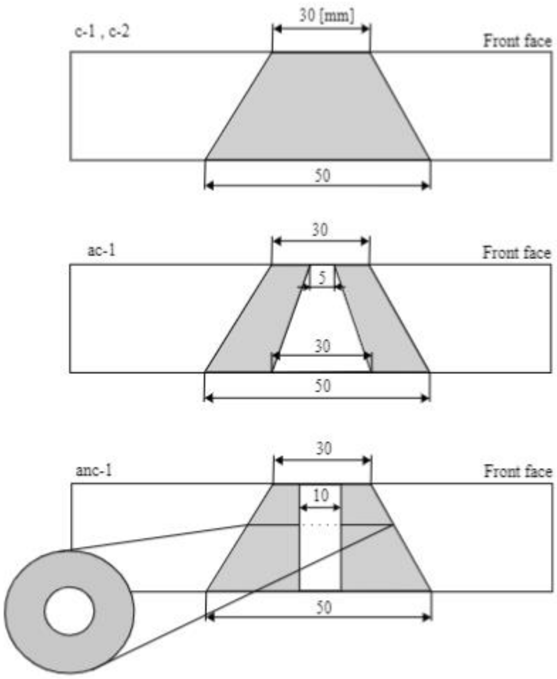


PTFE TESTS

The PTFE fatigue tests utilized the same Toray M30SC Deltapreg DT120-200-36 UD prepreg as employed in the Compression After Impact (CAI). The
laminate was laid up in a [−45, 0, 45, 90]2,S orientation, resulting in a thickness of 2.6 mm. During the layup process, PTFE inserts were positioned at
all interfaces where a mismatch angle between the upper and lower plies existed. This is because in impact damage delamination forms only in the presence of the mismatch angle. Considering this, no PTFE insert was placed in the central interface between two plies of 90-degree orientation. All PTFE inserts were manually aligned and positioned during the layup process thanks to the use of a reference alignment scheme on non-stick paper.
To generate distinct delamination envelopes and replicate impact dam-
age structures, diverse shapes of PTFE inserts were employed. Circular PTFE
inserts were used in two specimens of class **C,** with the radius gradually increasing from one surface to the other of the laminate. This methodology aimed to emulate the damage cone typically observed in impacted specimens. Additionally, specimens of classes **Ac** and **Anc** were fabricated with annular inserts to mimic the presence of a non-delaminated central area. In the case of **Ac** specimens, the internal area also exhibited a conical envelope
The curing cycle in the autoclave was applied to one large plate of dimensions

400 × 600 mm which then was cut into six smaller rectangles using a circular diamond blade. The final specimens had nominal dimensions of 150 × 100 × 2.6 mm.

(a) PTFE rings (in figure placed on a sheet of paper) before being located in the prepreg, one per each interface



(b) Schematic of the section of the specimens. The grey areas indicate where the PTFE circular or annular inclusions are situated

Fatigue test:

The test was conducted using the fixture of CAI fatigue tests [2].

An MTS 100 kN uni-axial hydraulic testing machine was used in the force control option. To decide which load to apply, a slow compressive displacement ramp (1 mm/min) was applied to specimen C-1 until the PTFE inserts detached and a buckling snap was observed. The obtained load was then used as maximum compression stress in the following fatigue test. The fatigue load applied was a compressive load of max compression 10.3 MPa, R = 10, and frequency of 3 Hz. In all specimens before starting the fatigue test, a slow ramp until the maximum compressive load was applied before starting the fatigue test.

[1] Compass ASTM D7136 D7136M-15. Standard test method for measuring the damage resistance of a fiber-reinforced polymer matrix composite to a drop-weight impact event.

[2] Compass ASTM D7137 D7137M-17. Standard test method for compressive residual strength properties of damaged polymer matrix composite plates.