THE ROAD MAP FROM FRACTURE TOUGHNESS TO RESIDUAL STRENGTH OF AIRCRAFT HIGH GRADE CFRPS

S. Psarras[1], L. Iannucci[2] and M. Fouinneteau [3]

[1]Dept. Aeronautics, Imperial Colege London, SW7 2AZ, London, UK
Email: s.psarras@imperial.ac.uk
[2] Dept. Aeronautics, Imperial Colege London, SW7 2AZ, London, UK
Email: lo.iannucci@imperial.ac.uk
[3]Airbus Operation S.A.S, 31060 Toulouse, Cedex 09, D46 0A2 – 135, France
Email: michel.fouinneteau@airbus.com

Keywords: composites, fracture toughness, impact, compression, finite elements

Abstract
This study presents the road map from obtaining the fracture toughness to predicting the residual strength of aircraft high grade CFRPs. Starting with results of translaminar fracture testing in order to obtain fracture toughness values that needed to fully feed damage material models. These models were used on a second stage to predict the damage size after low velocity impacts (LVI) and the residual strength in compression (CAI). Finally, the predictions are compared with experimental results.

1. Introduction

Due to RNT framework, vulnerability analyses have increasingly investigated composites structures submitted to various loadings (bird-strike, tire impact, crash, …). Standards of composite modelling technique have significantly evolved allowing to predict various ply failure modes but also delamination. Such complex failure mechanisms are highly dependent of material input used as input to the damage material model. However, fracture toughness values needed to fully feed the model are not always well defined. Fracture toughness values enable the model to predict crack propagation in fibre and matrix directions under tensile and compressive loadings. Calibrated properties are currently conservative leading to additional weight which could be avoided using correctly measured energies.

2. Fracture toughness determination

In order to measure the fracture toughness, compact tension specimens were modelled and tested. Cross-ply compact tension (CT), compact compression (CC) and double end notch (DEN) specimens were tested; two different stacking sequences were investigated:

1. Lay-up A
    - DEN :[0/902/0]s
    - CT/CC: [(90/0)5]s
2. Lay-up B:
    - DEN : [0/902/0/90]s
    - CT/CC: [(902/0)3/90]s

Excerpt from ISBN 978-3-00-053387-7

The stacking sequences were designed such that the specimens were approximately equal in terms of proportion of 0° and 90° plies and thickness.

All the specimens were cut from plates using a water-jet cutter to the dimensions that each test procedure required. Cutting the notch tips by hand resulted in a non-uniform sharpening of the crack over the plies of the laminate causing substantial scatter. To avoid this problem, a diamond disc saw with a v-shaped edge was used. This way, the shaped notches had a constant radius between different specimens less than 250μm.

All tests were performed using an Instron 1052 with a 50 kN load cell. All specimens were measured before being loaded under displacement control of 0.5 mm/minute. Measurements of load and displacement were recorded using a data logger, Figure 1(a). Video recording, photography and Digital Image Correlation (DIC) were used in order to reecord the crack lengths and check for invalide tests, as in Figure 1(b).

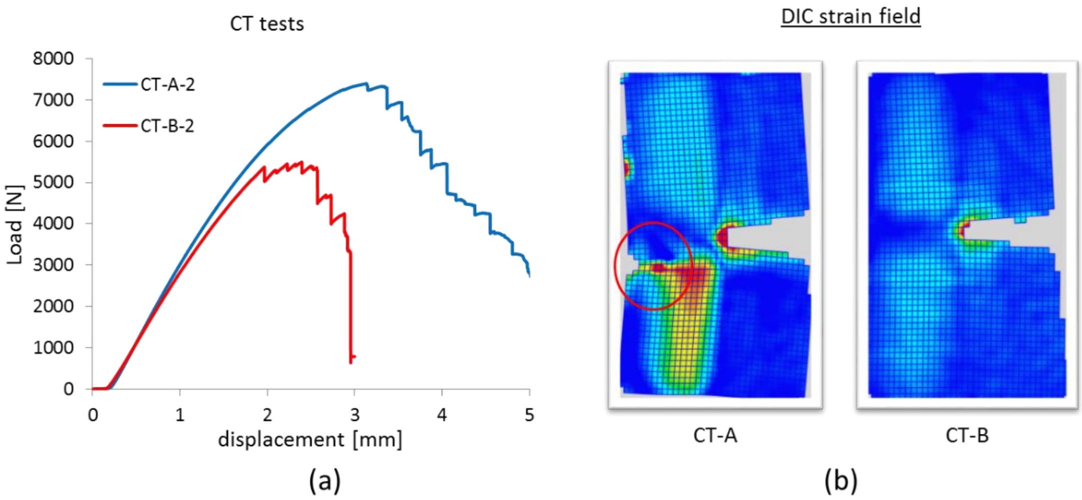

Figure 1

In order to calculate the fracture toughness the critical energy release rate has to be calculated. Once the critical energy release rate for the laminate is obtained, the critical energy release rate corresponding to fibre tensile failure is obtained by accounting for the toughness corresponding to matrix cracking in the 90° layers. The results of this study are presented in Table 1 where the values are normalized against a given fracture toughness.

Table 1 Normalized fracture toughnesses

Lay-up	Fracture toughness for initiation		
	DEN	CT	CC
A	1.92	1.23	0.51
B	1.97	1.83	1

3. Compression after low velocity impact

Low velocity impacts were performed on composite plates with the same lay-ups as in the CC/CT tests and their performance was investigated in compression after impact. During

Excerpt from ISBN 978-3-00-053387-7

experiments, the impact load history was recorded and after each test, the extent of damage was visualised with ultrasound-scan method. An impact example of the A and B lay-ups can be seen in Figure 2.

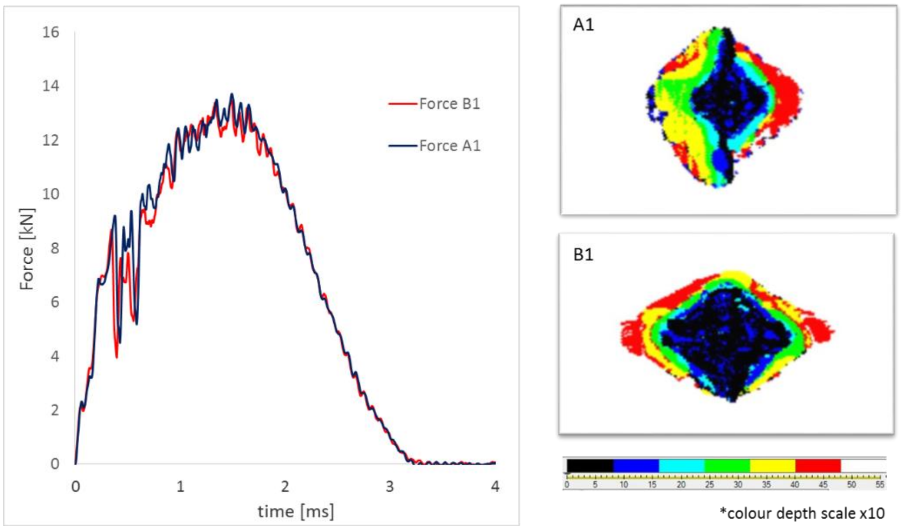

Figure 2 Left: Example of impact histories, Right: Ultrasound time of flight scans

Monotonic compression-after-impact tests were conducted in an Instron testing machine with a 250 kN load cell at a rate of 1 mm/min under displacement control by using a AITM 1-0010 CAI fixture [1]. A Linear Variable Differential Transducer (LVDT) was attached onto the lower loading plate to record the machine displacement. The average failure loads were 115kN for lay-up A and 65kN for lay-up B.

4. Comparison of the FE models with the experimental results

An existing damage model developed by Imperial College, which has been implemented into the Abaqus Finite Element system, was used to simulate the LVI and CAI performance of the composite specimens. A Finite Element (FE) model of the laminate was developed using continuum shell elements. Layers of cohesive elements were inserted between sublaminates in order to model delamination initiation and growth during impacts. An energy-based damage model was employed to represent translaminar damage.

By using five subliminates with cohesive elements between them and a mesh size of 2mm the prediction of the force-time curve of coupons is quite good compared with the experimental results,as can be seen from Figure 3

With compressive failure loads of 152kN for lay-up A and 75kN for lay-up B , the FE model slightly overestimates the failure load. Force-time curves can be better predicted when the number of cohesive layers increases. However, the use of multiple cohesive layers significantly increases the computational cost of the FE model.

Excerpt from ISBN 978-3-00-053387-7

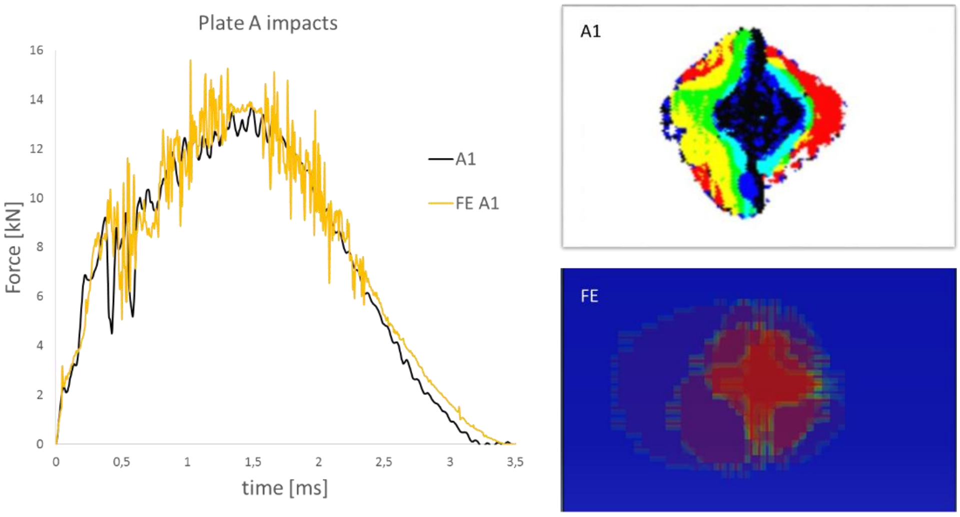

Figure 3. Comparisson of force/time histories between test results and FE predictions as well as the damaged areas

5. Conclusions

The complex procedure was modelled as a multi-step analysis for CAI after LVI which accounts for both intraply and interply damage. The damage predictions based on the damage model were correlated well with the test data and s showed a good correlation in terms of damage size, failure modes and failure load. A more detailed study will follow in near future.

References

[1] ASTM, Standard Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates (ASTM-D7137/D7137M-12). 2014.
[2] G. Davies and R. Olsson, "Impact on composite structures," Aeronautical Journal, vol. 108, 2004.
[3] J. Prichard and P. Hogg, "The role of impact damage in post-impact compression testing," Composites, vol. 21, pp. 503-511, 1990.
[4] L. Iannucci and M. Willows, "An energy based damage mechanics approach to modelling impact onto woven composite materials—Part I: Numerical models," Composites Part A: Applied Science and Manufacturing, vol. 37, pp. 2041-2056, 2006.
[5] C. G. Dávila and P. P. Camanho, "Failure criteria for FRP laminates in plane stress," 2003, pp. 2003-1991.

Excerpt from ISBN 978-3-00-053387-7