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# THE EFFECT OF CIRCULAR DELAMINATIONS ON THE BUCKLING AND POSTBUCKLING BEHAVIOUR OF GLARE LAMINATES UNDER COMPRESSION

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**Abstract** A series of Glare 4B specimens with and without artificial circular delaminations to represent manufacturing defects or damage after impact (bird strike, tool drop) were tested under compression to examine their buckling and postbuckling behaviour and hence the effect of such defects on performance. Tests were monitored using Digital Image Correlation (DIC) for visualisation of full-field displacements whilst Acoustic Emission (AE) monitoring enabled the detection and location of damage propagation. Results for specimens incorporating delaminations inserted in the first Aluminium/GFRP interface and pristine specimens are presented here. Tests have been modelled using a bi-linear cohesive zone model (CZM) implemented in ABAQUS/Explicit to perform dynamic nonlinear analyses incorporating load eccentricity and geometrical initial imperfection. Good correlation is observed between test results and model predictions.

**Introduction** FML's including Glare are manufactured from alternating metallic sheets and fibre reinforced composite layers. Glare offers a 10% reduction in specific weight compared with aluminium and has advantages over CFRP's including improved impact, fire and corrosion resistance; and increased damage tolerance leading to its increased commercial use, with applications including the A380 fuselage, the ECOS3 blast-resistant Unit Load Device (a freight container designed to contain explosion and fire), the Learjet 45, the cargo floors of the Boeing 737, and the cargo doors of the latest models of the C-17 Globemaster III [1, 2]. Despite its advantages however, the use of Glare brings additional challenges in terms of understanding damage mechanisms. This paper examines the effects of potential damage arising from the manufacturing process or impact, specifically from artificial circular delaminations.

**Experimental work** A series of specimens were tested in a Zwick / Roell servo-hydraulic testing machine (maximum force 500 KN) using a specially designed test rig as shown in Figure 1. Specimens measured 140 × 80 mm (unsupported area during testing 100 x 80mm) and incorporated artificial circular delaminations of diameter 50mm created by inserting a circle of PTFE film 10 µm thick into the interface between the first aluminium layer and the first GFRP ply by (Figure 2). They were manufactured by Airbus Germany GmbH from Glare 4B which consists of 3 layers of aluminium alloy 2024-T3 0.4 mm thick and two layers of UD-S2 glass fibre reinforced epoxy (GFRP) prepreg (3 plies with the layup [90$^o$/0$^o$/90$^o$] and a cured ply thickness of 0.133mm) according to the standard for commercial Glare [1]. Each test was monitored using the Limess™ Q-400 stereoscopic Digital Image Correlation (DIC) system with 2 Megapixel cameras with a spatial resolution of (1600x1200) [3] to gain full field displacement data. Four nano 30 Mistras Group™AE sensors with a frequency response range of 125 – 750 kHz and diameter of 8 mm, positioned as shown in Figure 4 were used to monitor damage. Event locations were calculated using a bespoke location algorithm developed at Cardiff University called 'Delta-T Mapping' [4] which has shown improved source location capability compared to time of arrival (TOA) techniques, especially for anisotropic materials like laminated composites [5].

**FE model** A 3D cohesive zone model (CZM) was implemented to simulate damage in the interfaces. The geometry and thickness of each layer were extracted from detailed scans of real specimens with each layer meshed using linear continuum (C3D8R) elements with one element through the thickness. The interfaces between each layer were meshed using cohesive (COH3D8) elements. The laminates were then assembled and material properties were assigned accordingly based on a comprehensive literature review of the mechanical properties for the Glare material constituents. Geometric imperfections and load eccentricity were included [6]. Artificial delaminations were introduced via a reduction in cohesive properties along the interfaces covered by the PTFE strip.

**Results and conclusions** Figure 3 which plots the experimental load versus displacement of specimens both with and without the shows that its introduction and particularly its location at the point of maximum out of plane displacement during

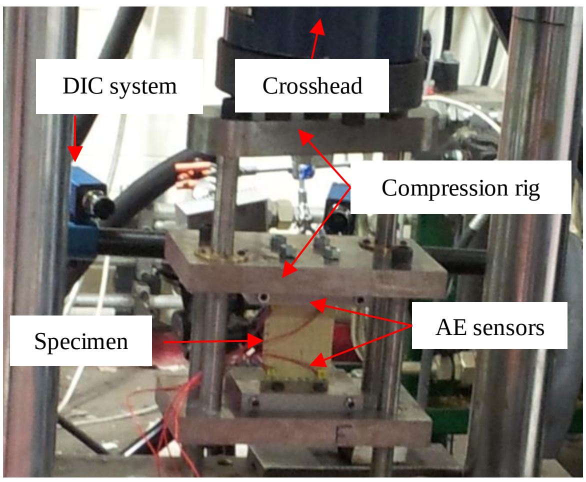


Figure1. Experimental setup

buckling and size (covering 62.5% of the width) has a significant effect on the buckling and postbuckling behaviour of the specimen. This reduction in properties can be seen to correlate well with the propagation of the delamination as detected by the AE. Figure 4 illustrates the progressive increase in AE events located around the periphery of the delamination as it grows, and in particular around the area where we see the most out of plane displacement (Figure 5). Excellent correlation with the FE model is also demonstrated in Figure 6, which predicts the growth of the delamination around it periphery as well as matrix cracking along the horizontal centreline where the highest curvature is seen. Comparison of the load versus displacement behaviour predicted by the model also shows very good correlation with experimental results showing its suitability in assessing the effects of this type of delamination damage.

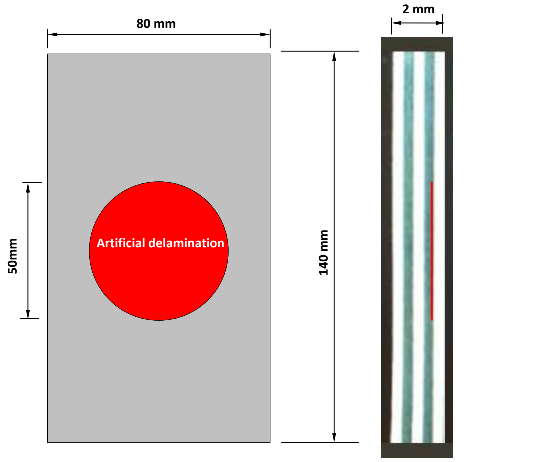


Figure2. Layout of coupon specimen for Glare 4B-3/2 with a circular delamination

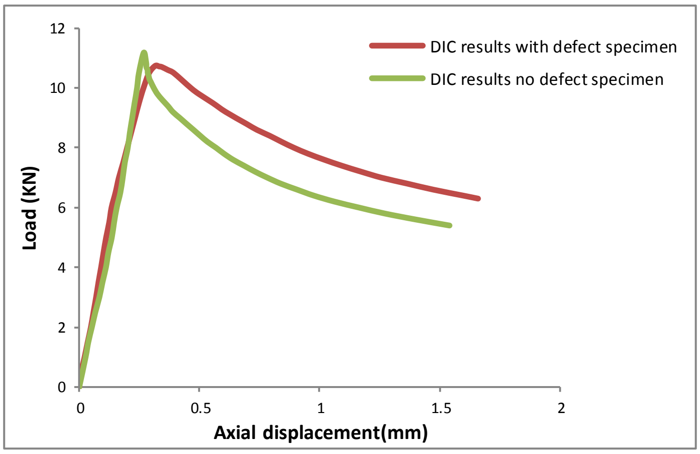


Figure 3. Load-versus displacement for Glare4B-3/2 specimens with and without delamination

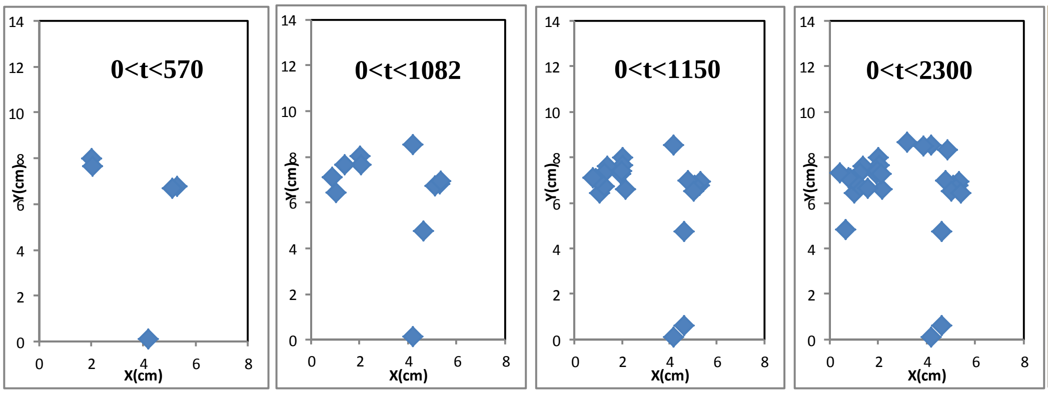


Figure 5. Location of AE events (cumulative)

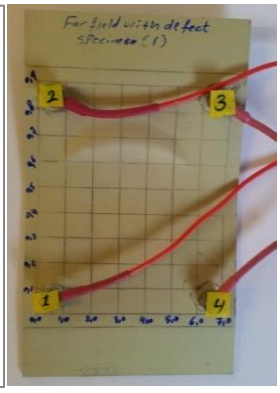

Figure4. Damage in Glare 4B -3/2 specimen with defect

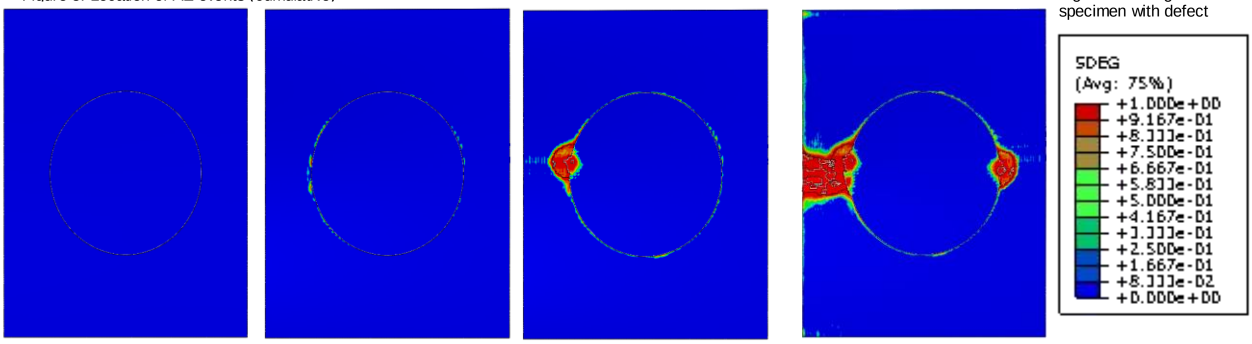


Figure 6. FE model interface damage

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