IMPACT OF THICK CFRP PANELS: NEAR EDGE IMPACT

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ABSTRACT

Carbon fibre reinforced plastic laminates of the order of 24mm thick are being considered for the wing panels of large civil aircraft. Further, the design of these wing panels will include access holes. In this paper, the effect of impact near a free edge is considered in detail. Finite element results show that the edge impact model predicts a much longer impact event duration and a larger maximum deflection, and hence a lower stiffness, due to the lack of support at the edge. A series of impact tests on 8.4mm thick multi-directional carbon fibre laminates found that the damage from an edge impact is significantly different compared to a central impact. In a central impact the damage is dominated by fibre breakage and back face splitting. In an edge impact there is much less surface visible damage, instead large delaminations that grow to the extent of the fixture, further verified using ultrasonic non-destructive testing. Subsequent residual strength tests have shown that centrally impacted laminate coupons have lower residual tensile strength compared to the equivalent edge impacted coupon due to the greater extent of fibre breakage. The edge impacted laminate coupons have lower residual compressive strength compared to the equivalent centrally impacted coupon due to the greater extent of delaminations.

1. INTRODUCTION

There is currently a desire to use composite laminates throughout the structure of large civil aircraft. In particular, use of composites for wing skins is being investigated, where thicknesses up to 24mm are being considered. In this paper laminates approximately 8.4mm thick are analysed and tested. Such wing skins are vulnerable to damage from dropped tools during maintenance, other such accidental impacts and Foreign Object Damage. The resulting damage can be invisible from the surface and also leads to conservative design.

Most research so far into impact has been on thin laminates, typically no thicker than 2 or 3mm. Only a few recent papers were found that analysed or experimented on what might be considered a thick laminate [1 - 3].

Impact of thin fibre reinforced laminates has been extensively studied and reported, for example [4, 5]. More recently there has been extensive research into modelling an impact event on a composite laminate, using a variety of approaches. Some researchers have developed closed form solutions [6], though these have limited applicability and are often not as accessible as approaches based on computational methods, such as the finite element (FE) method. Some researchers have chosen to use existing, commercially available, FE codes. When modelling panel impact, researchers have variously used 3D continuum solid [1, 7, 8, 10], 9-node modified Mindlin plate [9], 4-node layered shell [11, 12], and stacked 8-node 3D shell [13, 14] element FE models. Usually the lay-up is modelled either explicitly with a layer of elements for each ply, or by using a composite element that smears the ply properties across the thickness of the element sometimes with integration points at each ply interface.

Very little research has been found that looks specifically at the damage arising from an impact near a free edge, Green's research [8] perhaps being the most relevant. An edge impact on a wing skin is not unlikely as it presents a large target area and will have many access holes.

Multidirectional 8.4mm thick carbon fibre reinforced epoxy laminates have been impacted using an in-house designed instrumented drop weight impact tower. These panels have been impacted with three different energies, centrally and near a free edge. The damage has been evaluated non-destructively by ultrasonic C-scan and post impact strength tests, in compression and tension. These experiments and the consequent results are described and discussed in this paper with the aid of two finite element simulations. The simulations have been generated following an extensive FE based analysis of dynamic impact of composite panels with differing geometries which can be found in the literature [15, 16].

2. EXPERIMENTAL INVESTIGATION

2.1 Materials

The laminates were manufactured using non-crimped fabrics (NCF) and the resin film infusion (RFI) process to an Airbus specification. Three types of high strength carbon fibre NCF were used: one unidirectional (used for the 0^o plies) and two tri-axial ([45, 90, -45] and [-45, 90, 45]). Using a stacking sequence that produces an 8.4mm nominal thickness laminate, laminates with a fibre direction distribution of ($\%0^o$ / $\%\pm45^o$ / $\%90^o$) (42/48/10) were manufactured. A 180^oC cure epoxy resin film was used, and layers of resin were inserted between each layer of NCF.

2.2 Impact Experiments

A falling weight impact machine that was designed at Bristol University was used for the impact tests. It features a maximum drop height of 4.3m, and multiple impactor masses. Guides clamped to the wall guide the impactor to the specimen and tests have shown that the losses in the system are small. The specimen is clamped to a 30mm thick steel plate with a 200mm diameter hole. The impactor has a spherical tup, and an accelerometer loaded inside the impactor records its acceleration. Another sensor records the velocity of the impactor just before and just after impact. Fig. 1 shows a schematic of the impact machine. The data acquisition allows detailed examination of the impact event.

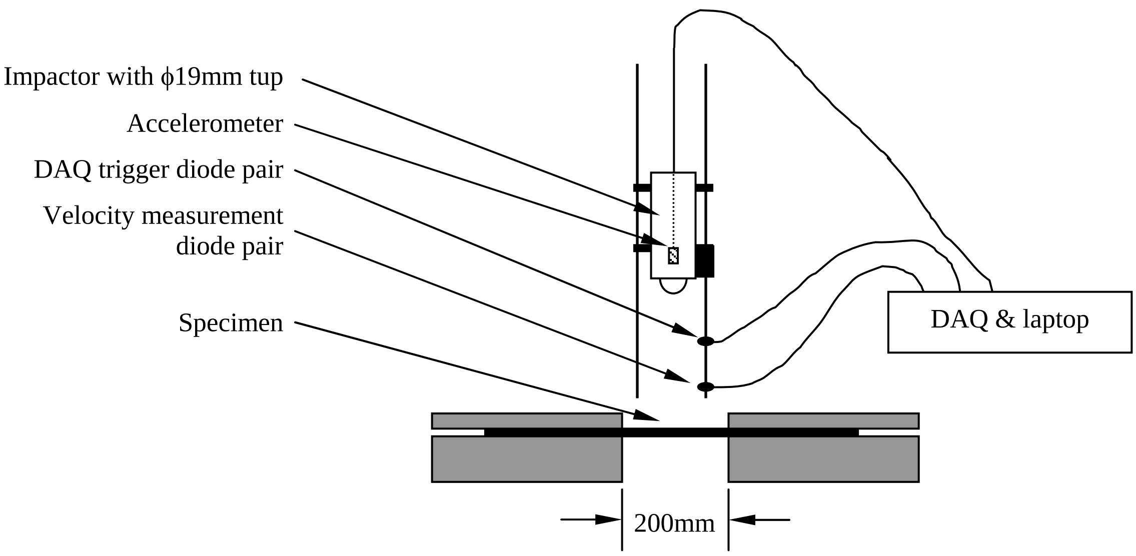

Fig. 1. Schematic of impact machine.

In the impact tests impactor masses of 2.47kg, 4.67kg and 8.37kg were used from the maximum height. This means the theoretical maximum impact energy is 350J. As the machine has such small losses, energies very close to this were achieved in practice, with typical impact velocities over 9m/s. The specimen was located on the support and clamped in place with a 10mm thick steel top plate. The top plate was held in place with four screws that were tightened with a torque wrench to provide a consistent clamping force. The edge impact specimens were positioned so that the impact was centred 20mm from the edge.

Two pairs of infrared diodes are positioned close to the specimen, the first pair triggers commencement of the data acquisition and the reading from the second pair is recorded along with the accelerometer signal. Post-processing of this data allows the maximum impact force to be ascertained, and the actual impact velocity and hence impact energy.

2.3 Ultrasonic C-scan

After impact the plates were examined using an ultra-sonic C-scan system with a 2.25MHz pulse-echo planar transducer. The scans were used to determine the size and location of delaminations. The data acquisition gates were set using the front face reflection as a trigger and a fixed delay to capture the amplitude and time of flight (TOF) of the signal reflected from the back face.

2.4 Post Impact Strength Tests

The final step was to cut 50mm wide coupons from each plate, with the impact site in the centre. They were then tested to destruction in tension and compression to evaluate the residual strength. This was performed with a 500kN servo-hydraulic test machine equipped with hydraulic grips.

3. RESULTS

3.1 Impact Damage

The edge impact specimens showed significantly less surface evidence of the impact. The central impact specimens had more back face blistering and a deeper dent. However the free edge of the edge impact specimens show significant cracking between the plies, hence extensive delaminations, in some cases beyond the fixture.

Fig. 2 shows photographs of front and back face damage to centrally impacted specimen following a 190J impact. Fig. 3 shows the same for an edge impacted specimen following a 190J impact.

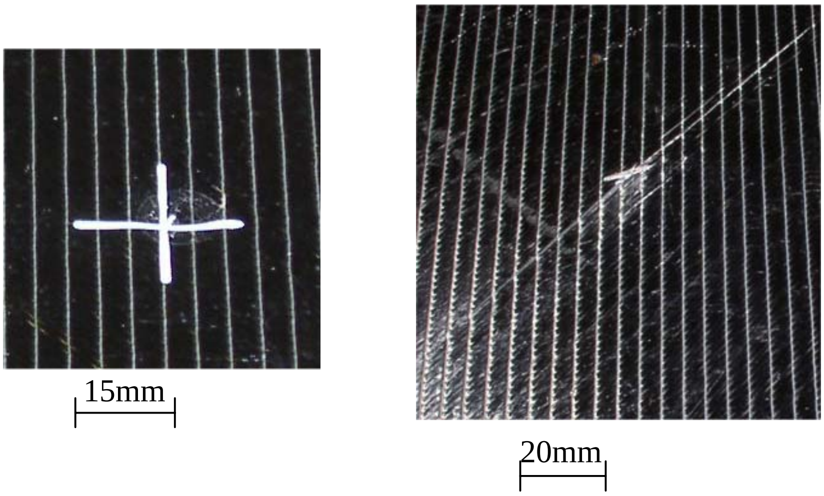

Fig. 2. Post impact damage from a centrally impacted specimen showing the (left) front face and (right) back face.

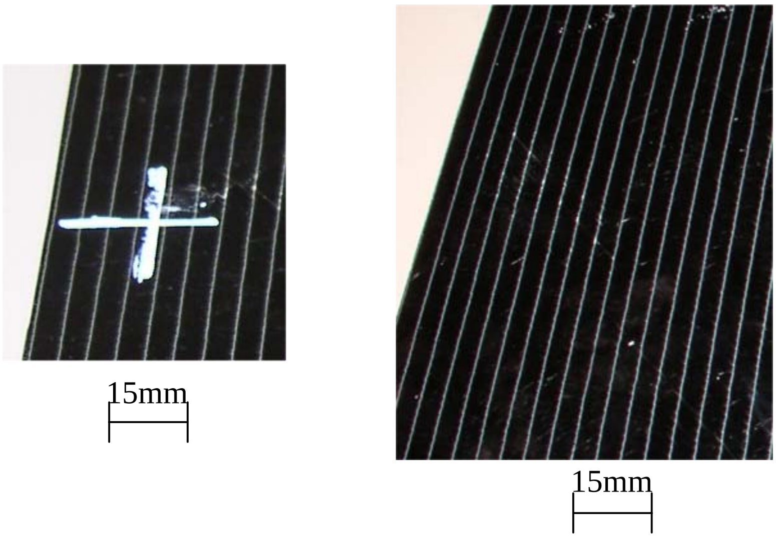

Fig. 3. Post impact damage from an edge impacted specimen showing the (left) front face and (right) back face.

Fig. 4 shows a photograph of the free edge of a 190J edge impacted specimen, with the cracks highlighted by hand.

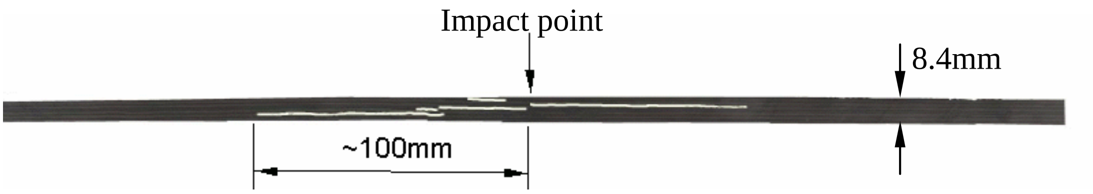

Fig. 4. Post impact edge cracking from an edge impacted specimen.

The extent of the cracking was indicating was elucidated by ultrasonic examinations. The C-scan results can reveal several things about the internal damage to a panel, particularly the extent and approximate depth of the delamination. The results clearly showed that the edge impacted specimens were delaminated extensively along the free edge. At the higher impact energies this delamination became bounded by the fixture. For simplicity, only the back face reflection amplitude plots will be shown. These show the extent of the damage clearly. Figures 5 – 7 show the plots for specimens having been subjected to the three different impact energies. The panels have been impacted with both an edge and central impact, except for the highest energy where the delaminations from each can interact. Hence in Figure 7 two panels are shown. The lighter the colour in the plot means the higher the value of the reflected signal. A low amplitude signal means that there is a strong likelihood of an internal defect as the reflected ultrasonic signal is attenuated.

The figures show clearly that the edge impacted sites have a much larger delamination area compared to the equivalent central impacts, and this area increases with larger impact energies. The larger impact energies, as mentioned earlier, give rise to delaminations that extend beyond the diameter of the fixture which is indicated with a white dashed circle.

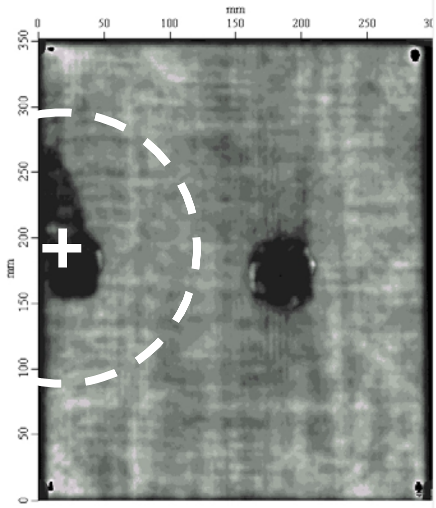

Fig. 5. Back face amplitude reflection C-scan plot for a single panel with 100J edge and central impacts.

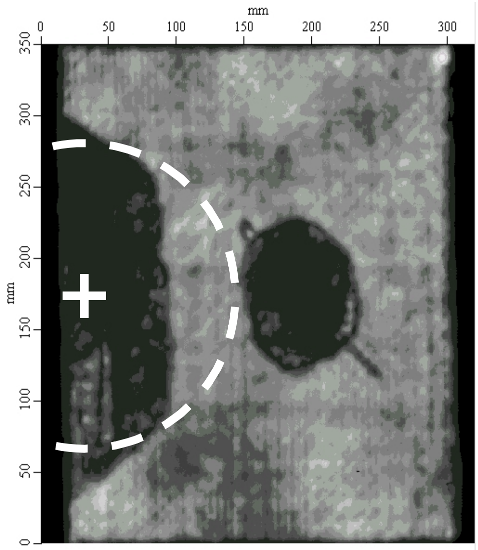

Fig. 6. Back face amplitude reflection C-scan plot for a single panel with 190J edge and central impacts.

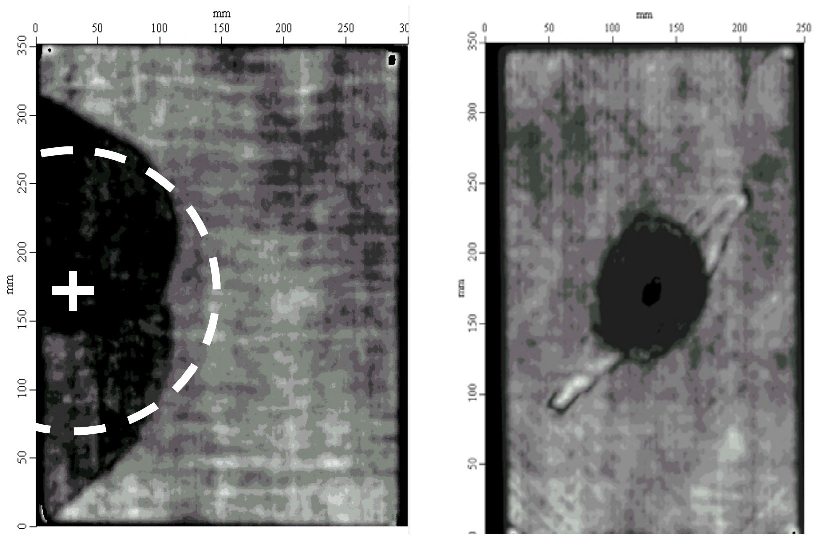

Fig. 7. Back face amplitude reflection C-scan plots for two panels with 350J edge and central impacts.

3.2 Residual Strength Measurement

As is well understood, the compressive residual strength of a given laminate will depend largely on the number and size of sub-laminates created by delaminations. Conversely, the residual tensile strength depends largely on the amount of fibre breakage. Thus the edge impacted specimens should have a reduced compressive strength compared to their equivalent central impacted specimens, but a higher tensile strength

Fig. 8 shows the residual tensile strength for all impacted specimens. Fig. 9 shows the residual compressive strength for all impacted specimens. Where the impact energy is marked as 0, this is for an undamaged laminate.

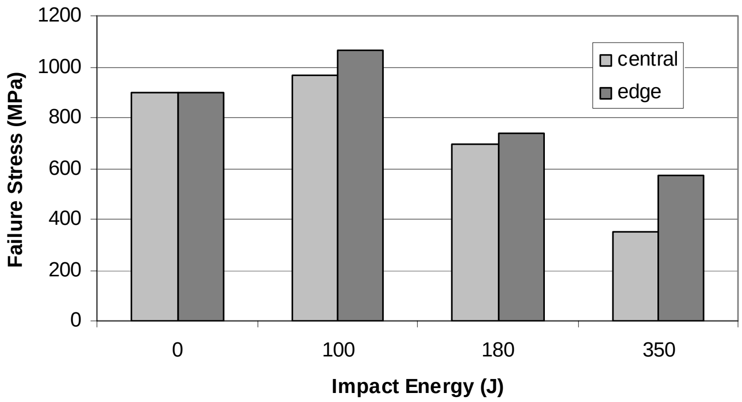

Fig. 8. Residual tensile strength for all impacted specimens.

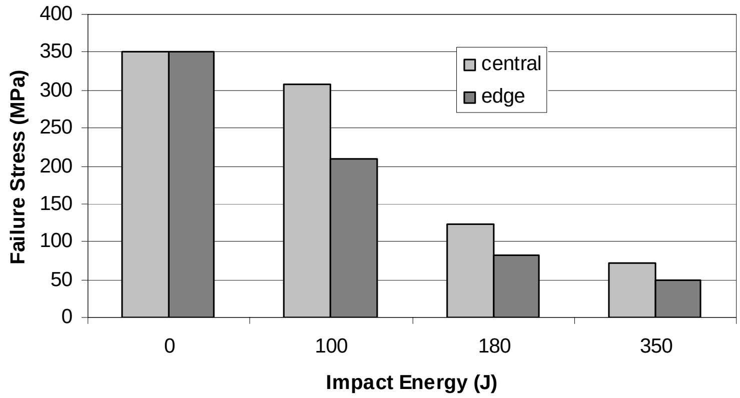

Fig. 9. Residual compressive strength for all impacted specimens.

Each data point in the Figure 8 and 9 are from only one coupon. Hence the reason, in Figure 8, why the 100J impacted coupons have higher tensile strengths that an undamaged laminate is due to reasonable scatter. The strengths are significantly lower in compression compared to tension because effectively a maximum load due buckling is being measured with a free length of 150mm in each case. The strength decreases with each energy level because more delaminations are introduced and hence the buckling load will decrease.

4. DISCUSSION

The edge impacted specimens show a lower compressive strength and higher tensile strength compared to equivalent central impacts. The reason for this is how the panel deforms and the manner in which the energy dissipates itself.

With an edge impact the panel is not as well supported and has nearly half as much material as a central impact specimen. The consequence of this is that will deflect more than if impacted in the centre. Thus for edge impact the panel deflects more and in a more global manner. This in turn means that there is a greater likelihood of delamination being the greater energy absorption mechanism due to shear bending stresses. The opposite is true for the centrally impacted specimens where the response is likely to be more localised due to the higher stiffness and the greater energy absorption mechanism fibre breakage. This can be seen in the C-scan results where delamination is significantly greater in the edge impacts, and the residual strengths where they follow the expected pattern.

This hypothesis was further tested by a simple elastic finite element analysis comparing two similar impacts, where one is near a free edge. Both are conducted with a 3D model using ABAQUS/Explicit. Fig. 10 shows the meshes and Fig. 11 the displacement time history results. Both models simulate a 200J impact onto an 8mm thick CFRP laminate with a 200mm diameter.

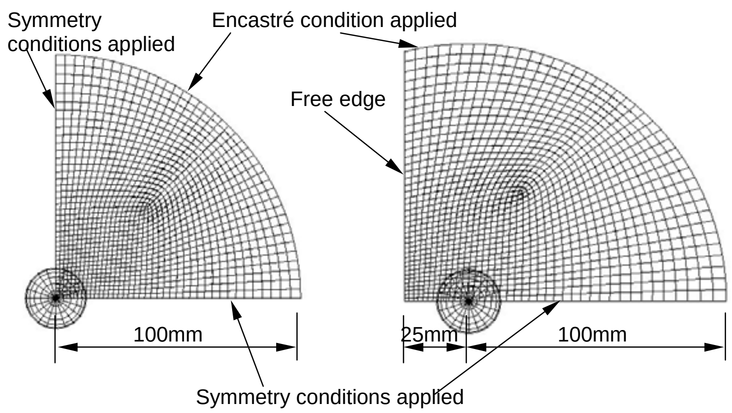

Fig. 10. Finite element meshes used.

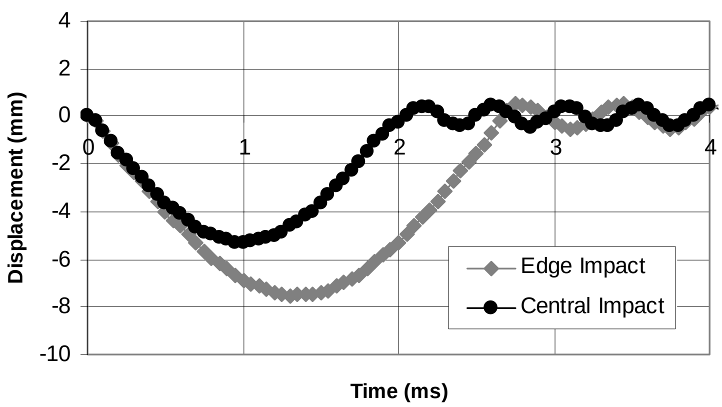

Fig. 11. Displacement history comparison between edge and central impacts.

Fig. 11 shows that the edge impact has a significantly longer impact event duration and a larger maximum deflection. This gives credence to the hypothesis that the edge impacted specimen absorbs impact energy through a large deflection. This will create larger bending shear stresses and give rise to delaminations. The centrally impacted deflects less and so delaminations will be smaller.

5. CONCLUSIONS

Several CFRP laminates 8.4mm thick have been manufactured and impacted with three different energies, near a free edge and centrally.

Following ultrasonic C-scanning, the edge impacts show consistently bigger delaminations areas compared to the centrally impacted specimens, as shown in Fig. 5 - 7. The residual strengths of 50mm wide coupons cut from the impacted panels show that the edge impacted specimens all have lower compressive strength and higher tensile strength, as shown in Fig. 8 - 9.

Finite element analysis has shown that the manner in which a panel deforms in an edge impact means that the panel will absorb the impact energy with delamination rather than fibre breakage.

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