# Experimental characterisation on open-hole compression of CFRP with hybridisation of carbon/glass fibres

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**Abstract.** This paper presents an experimental study which explores the effect of hybridisation of 0° layers in cross-ply laminates on the failure response of notched composites in compression. Open hole compression (OHC) tests are conducted in accordance with ASTM D6484. Three carbon/glass hybrid configurations are compared to a baseline carbon laminate, all with layup [902/05/902/0]s. The effect of varying the position of the 0° glass layers is explored. Failure mechanisms are investigated via Digital Image Correlation (DIC) and edgewise optical microscopy to detect damage on the surface and inner plies, respectively. Post-mortem CT imaging was also undertaken to compare the type of damage between configurations. Replacing the central 0° carbon layers with glass was found to match the OHC strength of an equivalent pure carbon laminate, whilst increasing the failure strain by 13.9%. Overall, the effect of hybridisation of 0° plies on the OHC strength and failure mechanisms was found to be heavily dependent upon the position of the glass within the laminates.

**Possible Sessions**

24. Testing of Composite Materials, 19. Optical and DIC Techniques, 2. Aerospace Applications

## Introduction

Carbon fibre reinforced polymers (CFRPs) have become increasingly more popular for advanced structural applications [1]. However, CFRPs typically suffer from significantly lower compressive strengths compared to tensile strengths [2]. To address these limitations, researchers are developing composite systems that promote progressive failure, so increasing damage tolerance and expanding application potential [3]. One promising approach involves hybridising CFRPs by incorporating fibres of differing mechanical properties [3]. Studies have shown that fibre hybridisation can influence compressive failure modes.

In real-world structures, notches, holes, and cut-outs are common due to assembly and access requirements. These discontinuities make notched composite performance critical, particularly under compressive loads [4]. OHC strength is a design limiting factor for three main reasons. As is previously mentioned, composites tend to have lower strengths in compression when compared to tension. Also, the presence of a notch itself will reduce the compressive strength of the material. An open hole, for example, can reduce the compressive strength of a multidirectional composite laminate by 45% [5].

Failure mechanisms under OHC loading are complex and influenced by stacking sequence, ply thickness, and off-axis plies [4]. The damage typically initiates in the 0° plies either through fibre microbuckling or matrix cracking, often propagating via delamination. Damage initiation during OHC tests of carbon/epoxy samples is reported in literature as either splitting in the 0° layer [6,7] or fibre microbuckling in the 0° layer [8]. Factors such as ply blocking, interfacial toughness, and fibre orientation all affect damage progression and final failure [6,7].

## Methodology

In this work, the experimental study is presented which explores the effect of hybridisation of 0° layers in cross-ply laminates on the failure response of notched composites loaded in compression. In particular, the effect of varying the position of the HE 0° layers on the OHC strength, failure strain and damage mechanisms, and potential to increase compressive performance have been explored. To the authors knowledge, OHC testing of hybrid composite laminates has yet to be explored in literature. Glass and carbon hybrids were used in this study since glass is a common hybridisation fibre for carbon. OHC tests were conducted in accordance with Procedure A of ASTM D6484. Three carbon/glass hybrid configurations are compared to a baseline carbon laminate, all with an identical stacking sequence (Table 1). During the experimentation, damage mechanisms were investigated via digital image correlation (DIC) and post-mortem microscopy. X-ray computed tomography (CT) was also conducted to compare the type of damage between configurations.

| *Abbreviation* | *Configuration* | *Carbon-glass ratio* |
| --- | --- | --- |
| C | $[90_2/0_5/90_2/0]_s$ | 100:0 |
| H1 | $[90_{2c}/0_{2g}/0_c/0_{2g}/90_{2c}/0_c]_s$ | 60:40 |
| H2 | $[90_{2c}/0_{2c}/0_g/0_{2c}/90_{2c}/0_c]_s$ | 90:10 |
| H3 | $[90_{2c}/0_{5c}/90_{2c}/0_g]_s$ | 90:10 |

Table 1 Laminate configurations

## Conclusion

This study investigated the effect of fibre hybrid composite materials on the OHC performance. Overall, failure was a shear driven compressive failure which initiated at the hole edge and propagated outwards towards the edges of specimens as loading progressed. The addition of glass fibres increased the failure strain, and the H3 configuration increases 13.9% failure strain while maintaining a comparable failure strength as the baseline model. The effect of fibre hybridisation on OHC strength depended greatly on the specimen configuration, since varying the position of the HE fibres within the laminates altered the failure mechanism. The addition of the lower stiffness glass fibres closes to the laminate surface reduced their stability, thus worsening their response in shear and therefore allowing earlier damage onset. This led to a failure which was dominated by the interaction between fibre fracture and delamination in the H1 samples (with the highest proportion of glass close to the laminate surface), resulting in a heavily reduced load carrying capability. As such, these samples had the lowest strengths of the configurations tested. The C and H3 configurations had the highest strengths and both had only carbon fibre present in the outer 0° ply block. The higher stiffness in this region caused a better shear response. The increased compressive strength of the carbon in these regions compared to the glass in H1 and H2 configurations also meant that matrix splitting propagated further before the onset of fibre damage. This occurred because the matrix splitting blunted the stress concentration and therefore delayed the onset of fibre damage and delamination, thus avoiding the buckling delamination failure which was observed in the weaker H1 samples. Failure in the C and H3 configurations was therefore compressive fibre failure dominated. Failure in the central 0° layers was found not to dictate catastrophic failure of the specimens. The inner glass layers in the H3 sample did not delaminate therefore the H3 with glass was found to match the OHC strength of an equivalent pure carbon laminate, whilst increasing the failure strain by 13.9%. Overall, a positive effect was not always achieved when using fibre hybrid composites for OHC. Maximising the quality of the material is also required to maximise the compressive performance of the specimens and solidify any conclusions which can be drawn from the data, since it is know that fibre alignment and volume fraction are critical to the compressive performance of a laminate. Finally, with the interaction of delamination and fibre fracture being critical to the strength in OHC, further investigation into the development of this would be valuable through a combination of SEM imaging and interrupted tests which can detect fibre level damage at various failure stages.

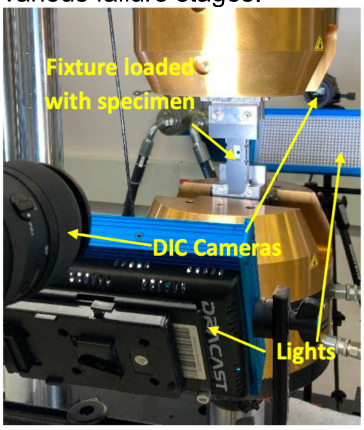


Fig 1. Test set-up

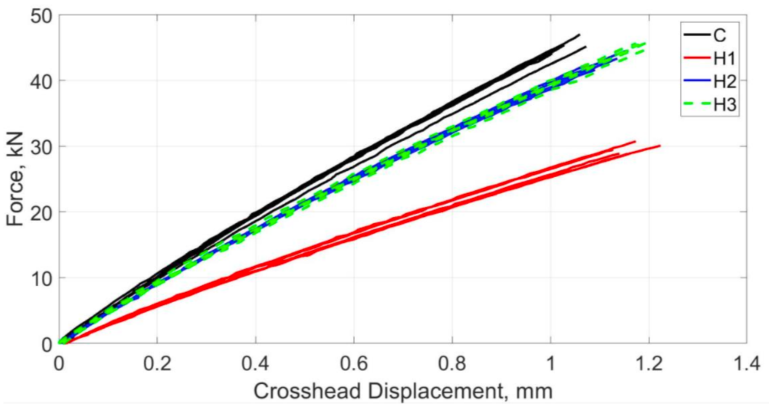


Fig 2. Load-crosshead displacement curves for all tested samples

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