COLLAPSE MECHANISMS OF A BLAST-RESISTANT UHMWPE COMPOSITE BEAM

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Summary The collapse response of a built-in composite beam, comprising 0/90 layers of UHMwPE fibres in a PU matrix, has been measured and modelled. Collapse is by interlaminar shear at short spans and by plastic micro-buckling at long spans. The associated shear collapse load and plastic collapse moment are measured. Finite element simulations are able to capture the collapse modes provided the simulations include elastic anisotropy of the UHMwPE fibres and the plastic shear response of the PU matrix.

INTRODUCTION

Composite panels made from ultra high molecular weight polyethylene (UHMwPE) fibres and matrix have exceptionally high blast resistance. This is linked to the fact that the fibres have a low density, a high axial modulus and strength and a low value of shear modulus and strength; axial elastic waves travel quickly in-plane, and blast loading causes the plate to deform in a membrane manner with low induced shear stresses and bending stresses. In order to explore the potential of UHMwPE composite armour to carry structural loads in addition to the occasional ballistic loads, a combined experimental and theoretical study has been performed on the static response of an UHMwPE composite clamped beam to end loading.

EXPERIMENTS

Hot-pressed laminates, of volume fraction 83% UHMwPE fibres and 17% polyurethane (PU) matrix, were laid-up to the orientation $[0/90]_{48}$ from plies of thickness 60 μm. The laminates were cut into end-clamped cantilever beams of height h = 6mm, width w = 6mm and span L=6-300mm (Fig. 1a), and were subjected to a vertical load end-load, P, via a steel cylinder of diameter d=6.4mm using a screw-driven test machine of cross-head velocity 0.1 mm s^{-1}.

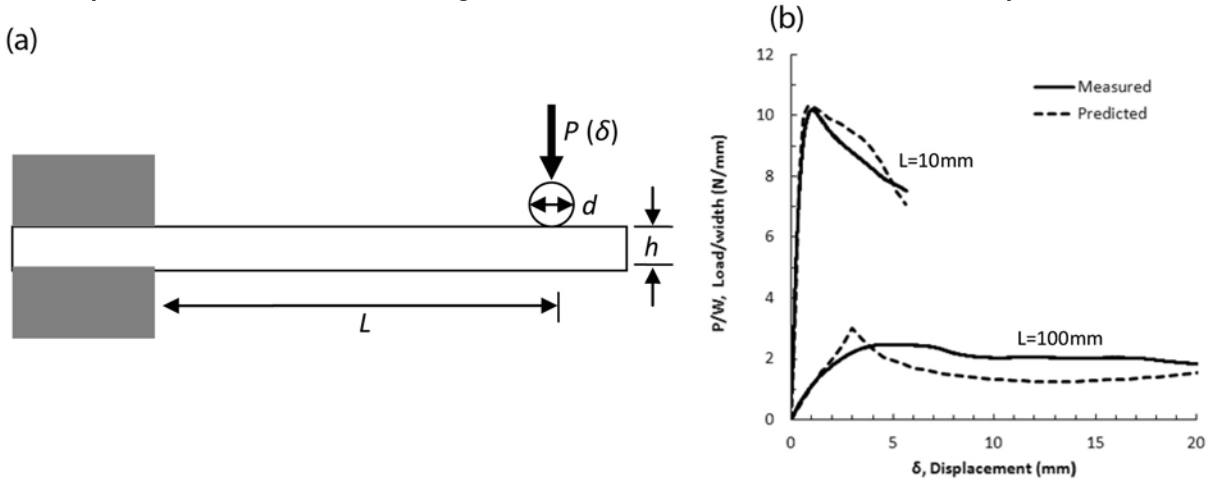

Fig. 1 (a) Sketch of the clamped composite beam. (b) Collapse response for beams of length L=10, 100 mm.

At short spans (L=10mm), the beam undergoes shear collapse at peak load; the magnitude of the peak load is independent of span and implies an interlaminar shear strength of 2MPa. In contrast, at long lengths (L=100mm), the beam fails benignly at a limit moment $M_L = PL$ by the formation of a hinge at the root of the beam, and experiments reveal that the collapse moment is independent of span. The hinge mechanism is dominated by fibre microbuckling on the compressive side. The measured plastic collapse moment $M_L = \sigma_b h^2 w / 2$ implies a microbuckling stress level on the order of $\sigma_b = 12$ MPa. X-ray tomography images of the collapsed beams are shown in Fig. 3, contrasting the two types of collapse mechanism.

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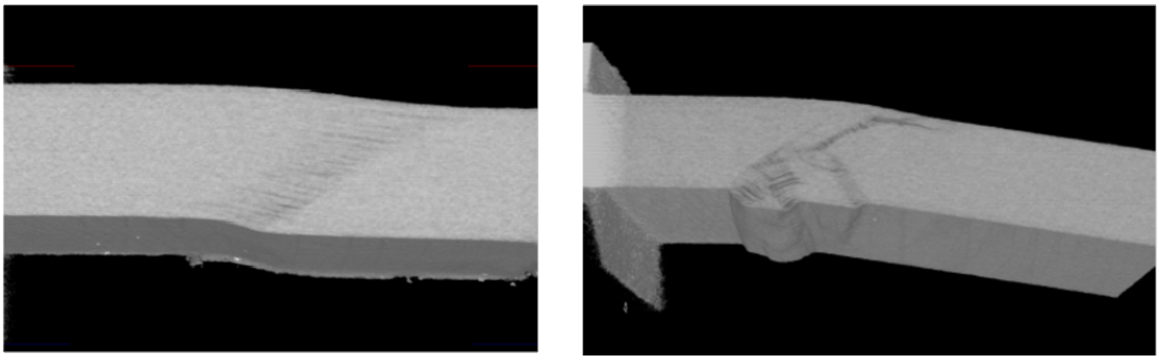

(a) L=10mm (b) L=100mm

Fig. 2. X-ray tomography sections of beams that have plastically collapsed by (a) plastic shear or (b) plastic microbuckling.

FINITE ELEMENT SIMULATIONS

Two dimensional finite element analyses were carried out using the explicit version of the commercial finite element software ABAQUS. In order to obtain accurate predictions of collapse response, as exemplified by Fig. 1(b), the following features were needed:

(i) anisotropic elastic plies with the correct values of low shear modulus and high axial modulus

(ii) the measured non-linear inter-laminar shear response

(iii) each ply and inter-ply interface is treated explicitly.

Each ply was modelled by four-noded plane strain elements with reduced integration (CPE4R in the ABAQUS notation).

A typical prediction of the bending hinge is shown in Fig. 3, showing the microbuckled plies. It is clear from Fig. 1b that the model captures the broad features of the observed collapse behaviour.

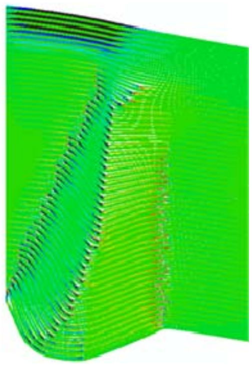

Fig. 3 FE prediction of bending hinge

CONCLUSIONS

A combined experimental and numerical study has been performed in order to elucidate the collapse mechanisms of a built-in composite beam, comprising 0/90 layers of UHMwPE fibres in a PU matrix. The collapse mechanism switches from a shear-dominated mode to that of a bending hinge with increasing beam span. The nature of the hinge is explored, and it is found that it has a characteristic structure associated with fibre microbuckling. The finite element simulations reveal that the axial stress across the hinge is almost constant at approximately 12 MPa, and this has been confirmed by independent measurements of the compressive microbuckling strength of this composite. However, the microbuckling mechanism for a hinge is different from that of composites in direct compression: the collapse mode in bending resembles that of a centred-fan, whereas in direct compression a parallel kink band is observed.