ESIS 2008

5th International conference on the Fracture of Polymers, Composites and Adhesives

September 2008, les Diablerets, Switzerland

Kingston University London

Imperial College London

Crashworthiness of Composite Thin-walled GFRP and CFRP Boxes

H. Ghasemnejad[a], B.R.K. Blackman[b], H. Hadavinia[a]

[a] *Faculty of Engineering, Kingston University, Roehampton Vale, London SW15 3DW*

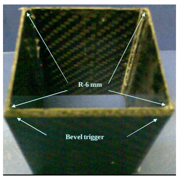
[b] *Department of Mechanical Engineering, Imperial College London, Exhibition Road, London SW7 2BX, UK*

1. INTRODUCTION

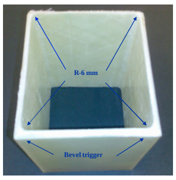
Frond bending due to delamination between plies makes a considerable contribution to the specific energy absorption (SEA) of composite box in crushing process. The crack propagation at the middle of the side walls of composite box are in Mode-I interlaminar fracture. In this regard the effect of fibre orientation and stacking sequence on the composite crash box design is sought by studying the effect of these on the interlaminar fracture toughness. In order to achieve this, glass fibre/epoxy orientations of $[\pm 60]_{10}$, $[0_2,\pm 45]_{5}$, $[0,90]_{10}$ and $[0,90]_{5S}$ and carbon/epoxy twill-weave fabrics of $[0]_4$, $[45]_4$ and $[0,45]_2$ were studied experimentally.

2. EXPERIMENTAL STUDIES

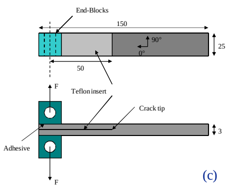
The fabrication of each DCB sample and composite box was laid-up with the same fibre orientation. The mid-plane interfaces of GFRP DCB samples were 0/90, 90/90, 0/45 and +60/-60 and CFRP DCB samples were 0/0, 45/45 and 0/45 to determine the Mode-I interlaminar fracture toughness. The configuration of these tests are shown below.



(a)



(b)



(c)

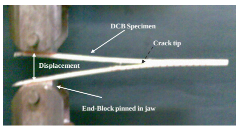
(a) CFRP Composite Box

(b) GFRP Composite Box

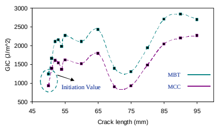
(c) DCB Sample

3. MODE-I INTERLAMINAR FRACTURE TOUGHNESS

All samples were tested in quasi-static condition at a crosshead displacement rate of 2 mm/min. The Mode-I interlaminar fracture toughness G_{IC}, for each fibre orientation was calculated using Modified Beam Theory (MBT) method and Modified Compliance Calibration (MCC) method (as shown below).



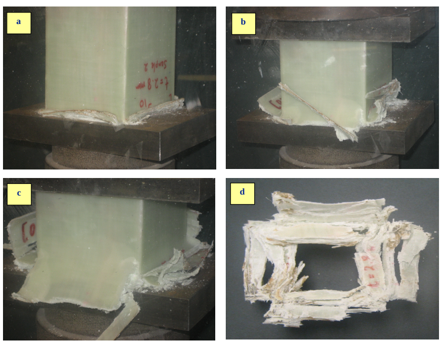
DCB test sample in universal tensile machine



R-curve in DCB sample with 0/90 fracture plane interface

4. CRUSHING PROCESS OF COMPOSITE BOX

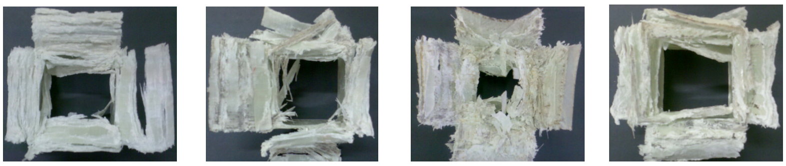
The crush box specimens were made of GFRP and CFRP by hand lay-up with various fibre orientations which are following the same lay ups as DCB samples. Each specimen was crushed between two parallel plates for 50 mm stroke using Universal Testing Machine with 500 kN load cell. The crush speed was set at 2 mm/min the same as the one used in DCB tests. (as shown below).



Various crushing process of GFRP composite box between two plates.

5. PROGRESSIVE CRUSHING OF *GFRP* COMPOSITE BOX

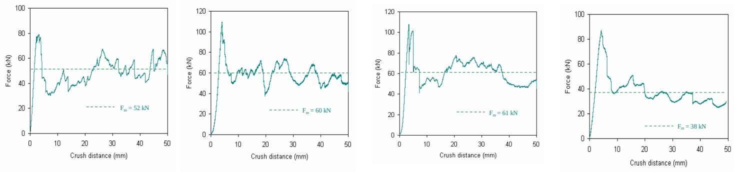
The combination of two distinct crushing modes of transverse shearing, and lamina bending which is called brittle fracture was observed for all laminate designs of GFRP composite boxes.



(a) $[0,90]_{10}$ (b) $[0,90]_{5S}$ (c) $[0_2,\pm 45]_5$ (d) $[\pm 60]_{10}$

Plane view of crushed GFRP composite box, a) $[0,90]_{10}$, b) $[0,90]_{5S}$, c) $[0_2,\pm 45]_5$, d) $[\pm 60]_{10}$.

The experimental results of force-crush distance and mean force for all lay ups are shown below.



(a) $[0,90]_{10}$ (b) $[0,90]_{5S}$ (c) $[0_2,\pm 45]_5$ (d) $[\pm 60]_{10}$

The force-crush distance diagrams for GFRP composite box. a) $[0,90]_{10}$, b) $[0,90]_{5S}$, c) $[0_2,\pm 45]_5$, d) $[\pm 60]_{10}$

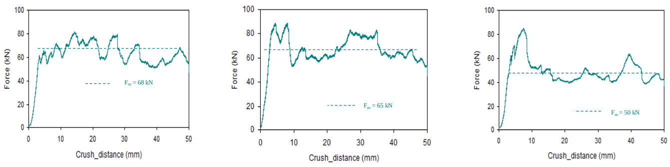
6. PROGRESSIVE CRUSHING OF *CFRP* COMPOSITE BOX

The progressive failure with three distinct crushing modes of transverse shearing, lamina bending and brittle fracture was observed for all laminate designs of CFRP composite boxes.

(a) Lamina bending (b) Brittle fracture (c) Transverse shearing

Plane view of crushed CFRP composite boxes, a) $[0]_4$, b) $[0,45]_2$ and c) $[45]_4$.

The experimental results of force-crush distance and mean force for all lay ups are shown below.



(a) $[0]_4$ (b) $[0,45]_2$ (c) $[45]_4$

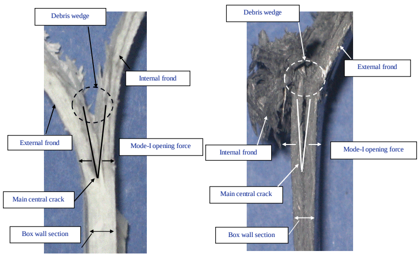
The force-crush distance diagrams for CFRP composite box. a) $[0]_4$, b) $[0,45]_2$ and c) $[45]_4$

7. RESULTS

The energy absorption and the force stability of composite boxes are related to fracture behaviour of the main central interwall crack . The main central crack which causes to shape lamina bundles has an important role on resistance against crushing energy. The propagation of this crack is similar to crack propagation in Mode-I delamination in composite laminates. It means that the SEA varies with fibre orientation and fracture behaviour of the main interlaminar cracks (As shown below).

Lay up	F_{max} (kN)	F_m (kN)	CFE %	SEA (kJ/kg)	G_{IC} (kJ/m^2) MCC
$[0,90]_{10}$	78	52	67	15.8	0.923
$[0,90]_{5S}$	110	60	55	17.5	0.778
$[0_2,\pm 45]_5$	105	61	58	17.7	0.884
$[\pm 60]_{10}$	87	38	43	10.8	0.449

Lay up	F_{max} (kN)	F_m (kN)	CFE %	SEA (kJ/kg)	G_{IC} (kJ/m^2) MCC
$[0]_4$	65	68	104	26.1	
$[0,45]_2$	85	65	76	25	
$[45]_4$	85	50	58	19.2	



GFRP CFRP

8. CONCLUSIONS

- Fibre orientation at interface fracture plane affects the interlaminar fracture toughness of GFRP and CFRP composite materials.
- Interlaminar fracture toughness for GFRP interface fracture planes of 0/90, 90/90 and 0/45 are close together while +60/–60 behave differently.
- SEA in axial crush of composite box depends on the interlaminar fracture toughness between laminates. The higher the Mode-I fracture toughness, the higher SEA. However this relationship is not linear.
- The specific energy absorption (SEA) of those fibre orientations which have a combination of 0/Θ angles are close together because of the similar interlaminar fracture toughness at interface fracture plane.