INDENTATION AND IMPACT BEHAVIOUR OF FRP COMPOSITES

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The response of plain GRP and CFRP panels subjected to static indentation and impact loading have been identified in terms of surface damage. There appear to be linear relationships between backface splitting in the principal fibre direction and frontface permanent indentation. For repeated impacts of CFRP the force-time response seems to be related to the threshold damage caused by a single impact.

INTRODUCTION

FRP composite structures may be subjected to impact damage during assembly, service or maintenance. Such damage may comprise of indentation, matrix cracking, debonding, delamination or fibre fractures. Visible damage usually occurs if an impact is above a threshold impact energy (which depends upon laminate stiffness) and causes strength degradation of the laminate. Whilst low energy impact below the threshold level may not create any visible damage, if the impact occurs repeatedly it may produce a reduction in laminate strength and damage may increase as the number of impacts is increased (1). Inspection of composite structures is often only possible from one surface and therefore expensive non-destructive evaluation is necessary in order to assess damage in terms of structural integrity. In order to reduce the high costs of inspection attempts have been made to relate structural integrity in terms of surface indentation (2). Thus an understanding of the relationship between permanent indentation of the frontface, internal delaminations and splitting of the backface is important.

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The overall aim of a programme of work at Sheffield on impact behaviour of FRP composites is to study the effect of static indentation and single and repeated impacts on plain and stiffened laminates and to assess their damage tolerance. This paper reports the findings on static indentation and single impacts on three plain GRP sections removed from pultruded beams and on static indentation, single and multiple impacts of two plain CFRP laminates.

EXPERIMENTAL

The three GRP pultruded sections comprised of random continuous mat and unidirectional rovings of E-glass fibres impregnated with an isophthalic polyester resin supplied via Fibreforce Composites Ltd, and are designated materials 1-3. Material 1 was removed from the web of an I-beam and had a thickness of 6.35 mm and a fibre volume fraction of 38%. Materials 2 and 3 were flat sheets with thicknesses of 6.35 and 4.75 mm respectively and fibre volume fractions of 34%. The two CFRP panels comprised of a five-harness satin weave preimpregnated with an epoxy resin supplied by Ciba-Geigy and autoclave moulded by Hurel-Dubois UK to produce a fibre volume fraction of 58%. Material 4 was laid up as eight-ply laminate of the form $(0/90, \pm45_2, 0/90)_s$ with a thickness of 2.4 mm and material 5 was a three-ply laminate (0/90, ±45, 0/90) and 0.8 mm thick. An instrumented dropweight impact rig was used for static indentation tests and single and multiple impact tests. The indentor, of 12 mm diameter with a hemispherical nose, was released by an electromagnetic switch for the impact tests. A hand-operated hydraulic jack provided the pressure for clamping the laminate between annular rings of 100 mm internal diameter. The test data is stored in a computer and then processed using compatible software. Static indentation tests were undertaken by mounting a mechanical loading system (using the same instrumented indentor) on a platform above the annular clamping rings (3). Indentation was determined by measuring the difference between the upper and lower surface displacements underneath the indentor during loading and unloading.

RESULTS

The force-deflection curves for all the materials were linear for small deflections. Initiation of damage in the form of matrix cracking occurred when the slopes became non-linear and audible cracking coincided with significant non-linear behaviour . The force-indentation behaviour for the three GRP materials and the two CFRP materials are presented in Figures 1 and 2 respectively. For most of the materials the response is almost linear for small indentations and then follows a modified contact law (4) given by

$$F = k\alpha^{3/2} \tag{1}$$

where F is the contact force, α is the indentation and k is the stiffness parameter which depends on the properties of the indentor and the laminate. Materials 2 and 3, which have similar properties, deviate from equation (1) at loads corresponding to initiation of damage identified from the load-deflection curve. However, for the slightly stiffer material 1 deviation from the contact law correlated with the onset of backface cracking. For CFRP the thicker material 4 also simulates the contact law until the onset of damage however because of significant bending with the very thin material 5 its behaviour cannot be modelled using equation (1).

For static indentation of the GRP materials there appears to be a common relationship between permanent indentation of the frontface and cracking along the backface parallel to the unidirectional rovings as shown in Figure 3. With increase in indentation force beyond initiation of damage the relationship between damage on the two surfaces is linear. The rate of increase slows down as the force is further increased towards a value to produce penetration by the indentor. At present no similar relationships have been observed for the CFRP materials.

The damage behaviour resulting from single impact loading of GRP and CFRP laminates at increasing incident kinetic energies is given in Figures 4 and 5 respectively. For all materials there is an initial linear relationship between permanent indentation of the frontface and cracking or splitting along the backface. For the CFRP material 4 the energy has been increased towards that to cause penetration by the impactor which produces a non-linear relationship. In addition internal damage, mainly delaminations, also follows a similar trend to that of backface cracking. No delaminations were identified by non-destructive or sectioning techniques in any of the GRP materials under either impact loading or static indentation for the range of tests undertaken.

The response of CFRP laminates to multiple impacts is shown in Figure 6. For material 4 the impacts were at an incident energy of 1.9 J and for material 5 at 1.15 J which corresponds to approximately 70% of the energies to produce barely visible impact damage (BVID) by a single impact in the respective materials. For the thicker material which was impacted at an energy near to its damage threshold there is a gradual reducing impact force for up to ten impacts with an increasing impact duration with a further ten impacts. For the thin material which was impacted significantly above its damage threshold there is a sudden and proportionately greater reduction in impact force for the second impact compared with that for the thicker material.

DISCUSSION

Static indentation may be predicted using a modified contact law (4) until the onset of damage for all of the materials evaluated except the thin CFRP (material 5) which suffers significant bending. The law is dependent on the through-thickness laminate properties and assuming the transverse stiffnesses are similar (i.e. $E_2 = E_3$) tends to underestimate the indentation of the thicker GRP materials. For moderate amounts of damage sustained during static indentation or impact loading there appears to be a linear relationship between backface crack length and frontface permanent indentation. Panels with increasing stiffness offer the greater resistance to both static indentation and impact loading. For the GRP pultruded sections the damage relationship is independent of flexural stiffness for static loading but dependent upon it for impact loading which suggests that the type of loading governs the damage behaviour. The force-time response of CFRP laminates to repeated impacts may be related to the damage caused by a single impact. It appears that the damage threshold rather than the onset of BVID is important. If repeated impacts are undertaken at energies above the damage threshold produced by a single impact then critical damage will occur with few impacts. A significant increase in damage for repeated impacts produces a reduction in peak force and an increase in impact duration.

Whilst some progress has been made in trying to understand the behaviour of FRP materials subjected to both static indentation and impact loading the prospect of reliable prediction of their response based on inspection of permanent indentation of an outer surface seems distant. For example, the same size of permanent indentation may be produced by static indentation and single or repeated impacts but the resulting backface or internal damage may be quite different for each case.

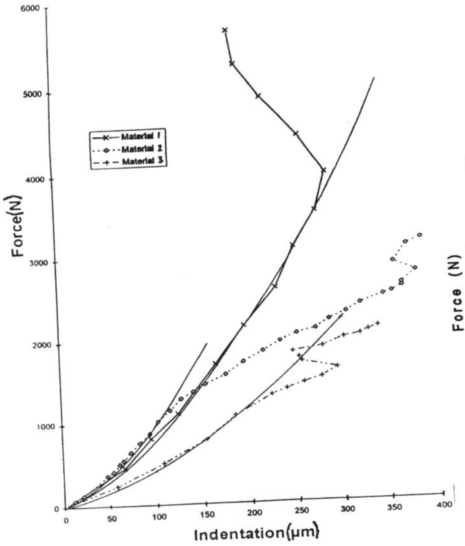
REFERENCES

1. Wyrick, D. A. and Adams, D. F., Composites, Vol. 19, 1988, pp. 19-27.

2. Tropis, A., Thomas, M., Bounie, J. L. and Lafon, P., Proc. I.Mech.E., Vol. 209,. Part G, No. 4., 1995, pp. 327-339.

3. Kumar, M., Found, M. S. and Howard, I. C., "Drop-weight Instrumented Impact Test to Compare the Effect of Single and Multiple Impacts", Proceedings 2nd International Seminar on Experimental Techniques and Design in Composite Materials, Sheffield, UK., edited by M. S. Found, Sheffield Academic Press, Sheffield, UK, 1995.

4. Sun, C. T., ASTM STP 617, 1977, pp. 427-440.



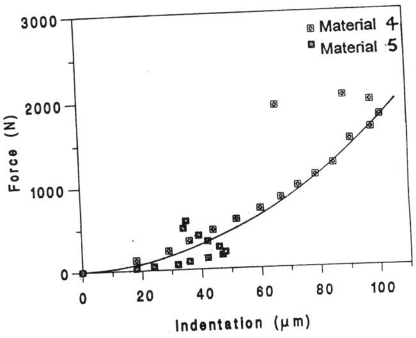


Figure 1 Force-indentation behaviour of GRP Figure 2 Force-indentation behaviour of CFRP

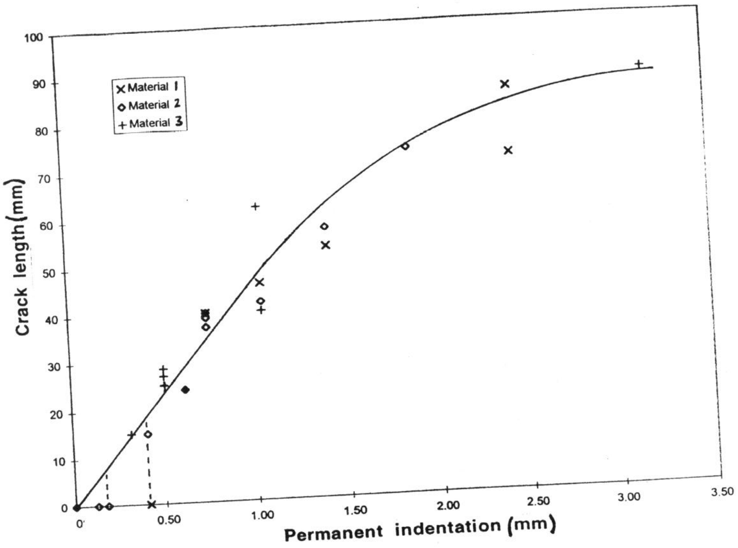


Figure 3 Relationship between frontface and backface damage for static indentation of GRP

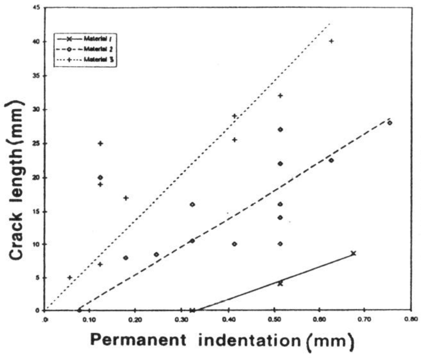


Figure 4 Relationship between frontface and backface damage for impact of GRP

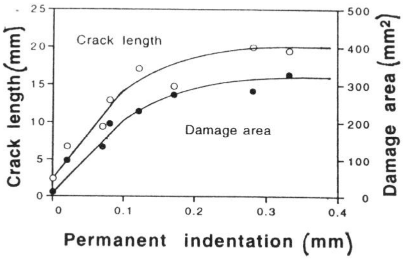


Figure 5 Relationship between frontface and backface damage for impact of CFRP

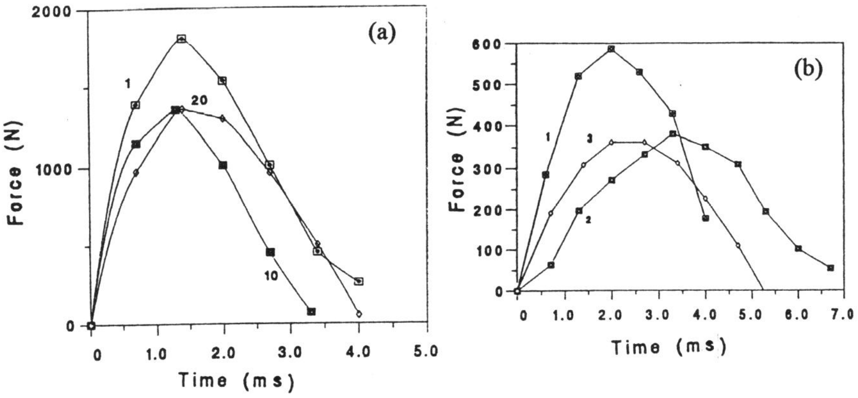


Figure 6 Force-time response of (a) material 4 and (b) material 5 for repeated impacts at 70% BVID for single impact