IMPACT DAMAGE AND RESIDUAL INTERLAMINAR FRACTURE RESISTANCE IN CARBON-EPOXY COMPOSITES.

A.Pavan°, T.Ricco°°

Understanding of the damaging effect of impacts and their consequences for the residual mechanical properties of carbon-epoxy composites is of paramount importance for the employments of these materials in stuctural applications. The present work is aimed at characterizing the residual impact strength and the interlaminar fracture resistance of carbon-epoxy laminates damaged by low energy impacts.

INTRODUCTION

The increasing use of polymer-based composites in primary structures for aeronautic applications raises questions as to the vulnerability of these parts to low-energy impacts that may occur during manufacture, assembly, or in-service life. In fact, low-energy or low-velocity impacts are potentially dangerous mainly because the damage caused to the material may remain undetected; the level of impact energy at which damage becomes visible may be higher than the level at which substantial loss of mechanical properties occurs.

To relate damage to residual properties in the area of low-energy impacts poses a twofold problem: the damage assessment and the evaluation of the residual mechanical

°Politecnico di Milano. Dip.Chimica Industriale e Ingegneria Chimica G.Natta. P.zza L. da Vinci 32. 20133 Milano (I)
°°Università degli Studi di Trento. Dip.Ingegneria dei Materiali. 38050 Mesiano di Povo. Trento (I)

strength of the damaged structures.
The present work addresses both problems in carbon-epoxy laminates. Residual impact strength and residual interlaminar fracture resistance in Mode I are considered.

EXPERIMENTAL DETAILS

Quasi-isotropic (QI) and orthotropic (OT) carbon-epoxy laminates with stacking sequences of ((+45/-45/0/90)n)s and ((+45/-45/0/0)n)s, with n=1,2,3, respectively, were kindly supplied by Costruzioni Aeronautiche G.Agusta Spa, Gallarate (Italy). QI materials from two different batches supplied by the American Cyanamid Co. were used, and will be designated A and B hereafter. The difference is unimportant for the present study.
60X60 mm plaques of each sample were impacted normally to their surface with an instrumented drop-weight Fractovis, mod.6789/000, by CEAST Spa, Torino (Italy). Different impact energy levels, obtained by varying the mass of the drop-weight (from 1 to 30 Kg), while keeping the impact speed at a constant value of 1 m/s, were used to damage the specimens to different degrees. The area of the damaged zone was determined by ultrasonic C-scanning. The residual impact strength was subsequently measured at an impact speed of 5 m/s.
240-mm-longX60-mm-wide double cantilever beam (DCB) specimens of the((+45/-45/0/90)3)s type, containing a fracture starter, placed at the 0/90 degree interface between the eleventh and the twelfth ply, were damaged by impact in the same way. Mode I interlaminar fracture testing was carried out by means of an Instron machine at a cross-head speed of 1 mm/min.
All tests were performed at room temperature.

RESIDUAL IMPACT STRENGTH

The impact energy, W, lost from the impactor during the first impact carried out at low speed is assumed to determine the extent of damage. The residual impact strength, Rres, measured in the subsequent impact test at higher speed, is plotted in Fig.1 as a function of W for 16- and 24- ply QI laminates (matrix A). These results, displaying a linear dependence of Rres on W with slope -1, indicate that Rres+W=R, in which R denotes the impact strength of the undamaged material.
Fig.2 shows the results obtained on QI and OT laminates (matrix

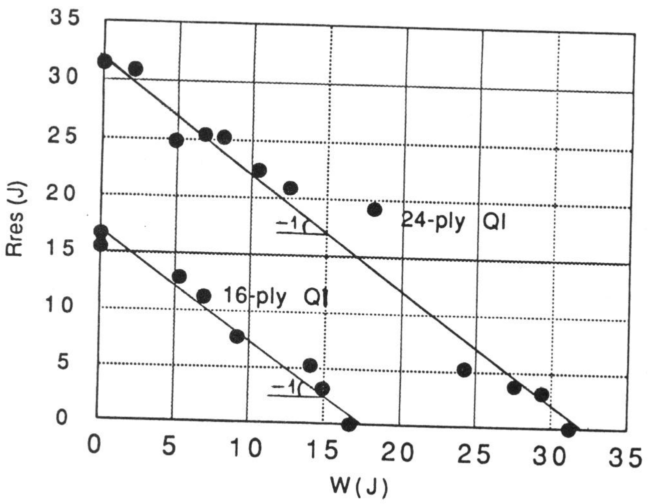

Figure 1. Residual impact strength vs. impact energy,W, for QI laminates (matrix A). (Straight lines with slope -1 indicated).

B) over the low W range, where the damage on the specimen face opposite to the impacted face cannot be visibly detected. It is found that the Rres vs. W behaviour, as well as the minimum impact energy necessary to produce visible damage (i.e. the right-hand limit of that range), depend on the number of plies in the same way for quasi-isotropic (QI) and orthotropic (OT) laminates. However, if the residual impact strength is represented as a function of the damaged area, A, as measured by ultrasonic C-scanning, 8-ply QI and 8-ply OT laminates show different behaviour. This implies that the dependence of A on W is different for these laminates, as can be seen in Fig.3. A same level of W produces in the QI laminates a larger damaged area than in the OT laminates, even if their residual impact strengths do not differ.

In conclusion, ultrasonic C-scan inspection appears a sensitive mean to characterize the extent of damage in these types of laminates, far and above the sensitivity of the residual impact strength.

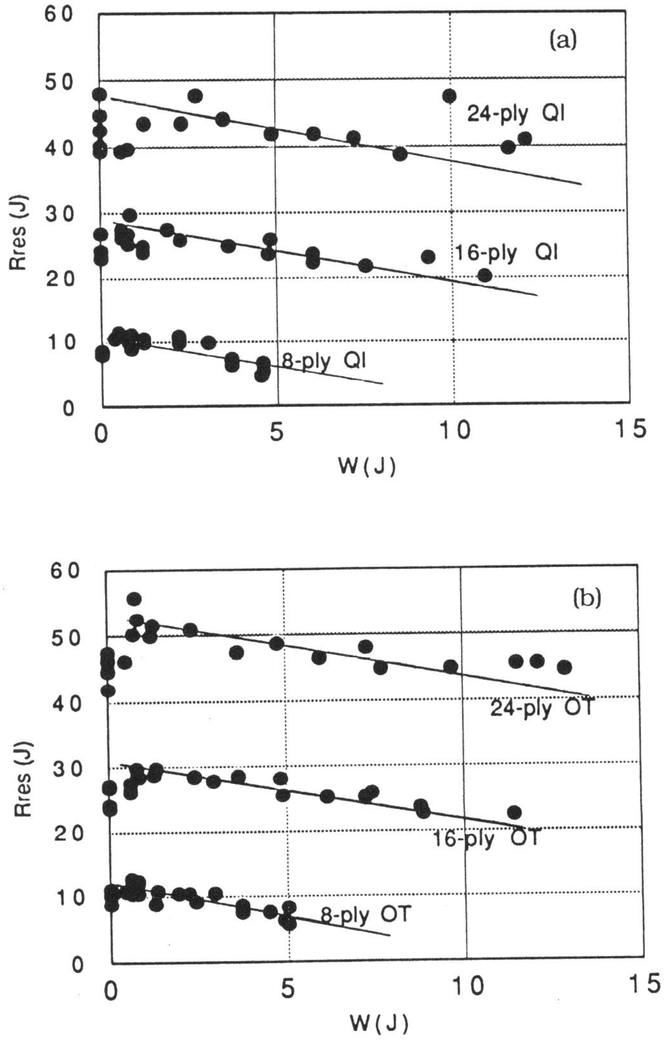

Figure 2. Residual impact strength vs. impact energy,W, for non visible damages: a) QI laminates (matrix B) and b) OT laminates (matrix B). (Straight lines with slope -1 indicated).

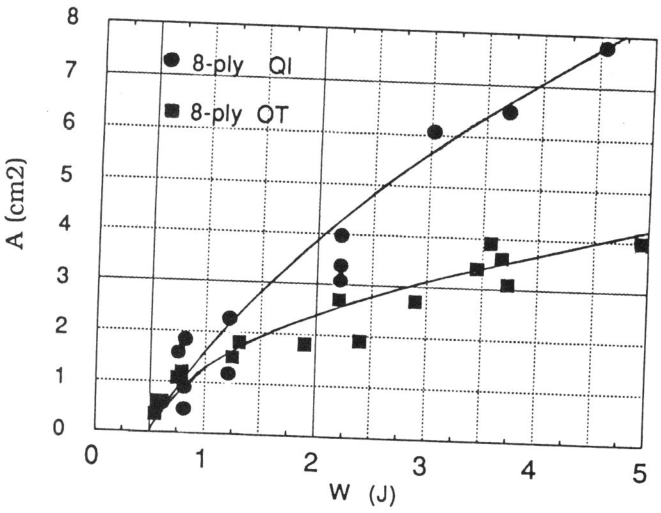

Figure 3. Extension of the damaged zone vs. the impact energy W.

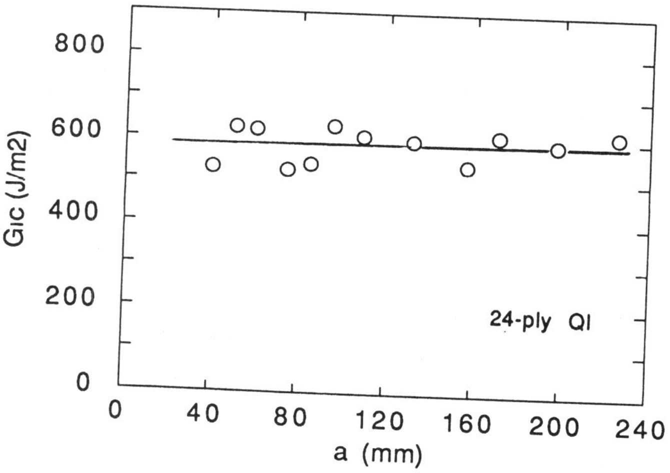

Figure 4. Mode I interlaminar fracture resistance for undamaged 24-ply QI laminates (matrixA).

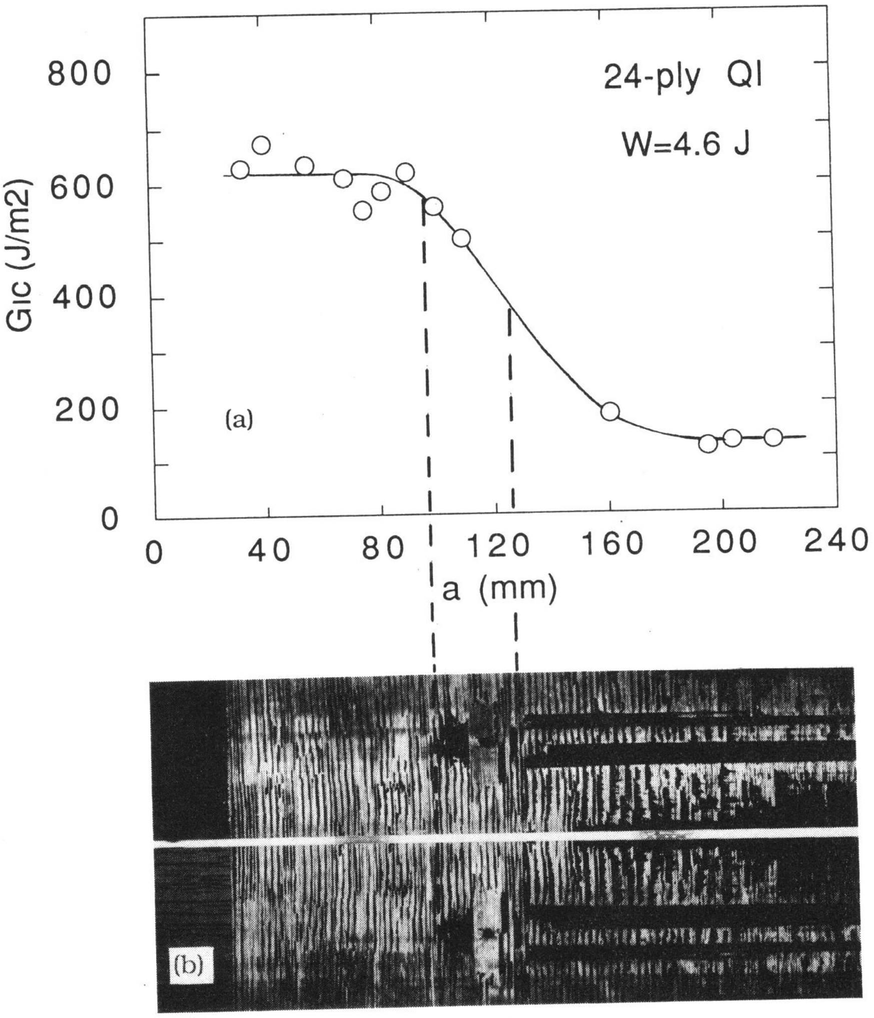

Figure 5. a) Mode I interlaminar fracture resistance for a 24-ply QI laminate (matrix A) previously damaged with impact energy W=4.6 J. b) Relative fracture surfaces.

INTERLAMINAR FRACTURE RESISTANCE

The interlaminar fracture resistance in Mode I, G_{Ic}, in respect of the 0/90 interface was measured for the undamaged 24-ply QI laminate (matrix A) by different methods, namely the area method (1), the elastic beam theory method (2), and the compliance method(3), producing results in good agreement with each other. The resistance curve, $G_{Ic}(a)$, in Fig.4, remains flat over the entire range of the crack length,a. The crack growth was found to occur stably along a wormlike path through the two median (twelfth and thirteenth) 90 degree plies, remaining confined between the two adjacent (eleventh and fourteenth) zero degree layers, as shown by optical microscopy analysis.
Fig. 5a gives an example of the corresponding curve, $G_{Ic}(a)$, for a specimen previously damaged with an impact energy of 4.6 J, while Fig. 5b shows the fracture surfaces of the two specimen halves. As can be observed, when the growing crack encounters the damaged zone, quite low energy is required to propagate the crack further, and its path changes dramatically, tending to become intralaminar inside one of the two confining zero degree layers. Furthermore, crack stability appears to be impaired.
Comparison of the behaviour of specimens damaged to different extents (impact energy W ranging from 4 to 13 J) indicates that the interlaminar resistance of these materials is equally impaired by low and high energy impacts.

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