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Enhancing the exploitation and efficiency of fibre-reinforced composite structures by improvement of interlaminar fracture toughness

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Abstract

Fibre-reinforced composite materials are used extensively in stiffness critical, weight sensitive structures such as those found in aerospace and motor racing. They are characterized by high in-plane strength, stiffness and toughness and low density. The most widely used family of these materials is essentially two-dimensional, characterized by relatively poor out of plane properties. As a consequence of low interlaminar toughness in particular, many possible applications are precluded and others severely compromised in performance per unit weight efficiency. Formula 1 racing represents the most advanced exploitation of composite materials both in terms of the percentage usage and complexity of application [Savage GM, J STA 2000;140:18]. In order to develop their products leading F1 teams work very closely with the major raw materials suppliers to expand the horizons of composites usage. The problems of interlaminar performance are discussed along with the techniques used to measure them and the fracture mechanics principles applied to improve them. A number of Formula 1 applications and developments are used to illustrate the effectiveness of the improved understanding of the interlaminar fracture behaviour of composites.

Keywords: Composites; Design; Fracture toughness; Failure mechanism

1. Interlaminar response of composite materials

It is generally accepted that the interlaminar fracture mode is potentially the major life-limiting failure process in fibre-reinforced composite materials subject to severe service loading [2]. The test most often

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referred to in the literature for evaluating the interlaminar performance of composites is the "short beam shear test" [3]. A shortened span is used on a three-point flexure test fixture in order to maximise the shear stress at the specimen's neutral axis. The shear testing of fibre-reinforced composites is dominated by the matrix phase. In the short beam shear test it is difficult to establish a state of pure shear. The relatively low strength of the matrix and interface renders the composite vulnerable to any extraneous local normal stress. A further complication is the existence of areas and planes of weakness, along which a specimen may fail preferentially, irrespective of the principal axes of the stress field. In multiphase (toughened) composites it is extremely likely that cracks will propagate in a non-self consistent manner, i.e., they will deviate from the path of the initial crack direction. In most test configurations this will result in the measured property being notional rather than genuine.

It has been shown that the interlaminar fracture toughness test is a useful method of characterising the interlaminar failure of carbon fibre fabric reinforced composites [4]. The energy per unit area required to propagate an existing flaw between the plies of the material is evaluated as a measure of the ability of the material to resist interlaminar fracture.

The energy absorbing capability of composite materials is a consequence of the "work of fracture" arising from the mechanisms occurring during catastrophic fracture. The inherent brittleness of composites ensures that they do not undergo the yield processes characteristic of ductile metals but on the application of load, deform elastically up to the point of fracture. A number of modes of deformation are available to complex multiphase composite materials. The primary energy absorbing mechanisms in fibre-reinforced plastics are:

- cracking and fracture of the fibres;
- matrix fracture;
- de-bonding (pull-out) of fibres from the matrix;
- delamination of the layers making up the structure.

A composite body thus disintegrates both structurally and microscopically during impact. A typical load/deflection response for a composite tube is shown in Fig. 1. After the initial peak load the curve is much flatter than a plastically deforming metal tube. The area under the curve, i.e., the amount of energy absorbed, is therefore much greater. This combined with the lower density of the composite makes it far more efficient.

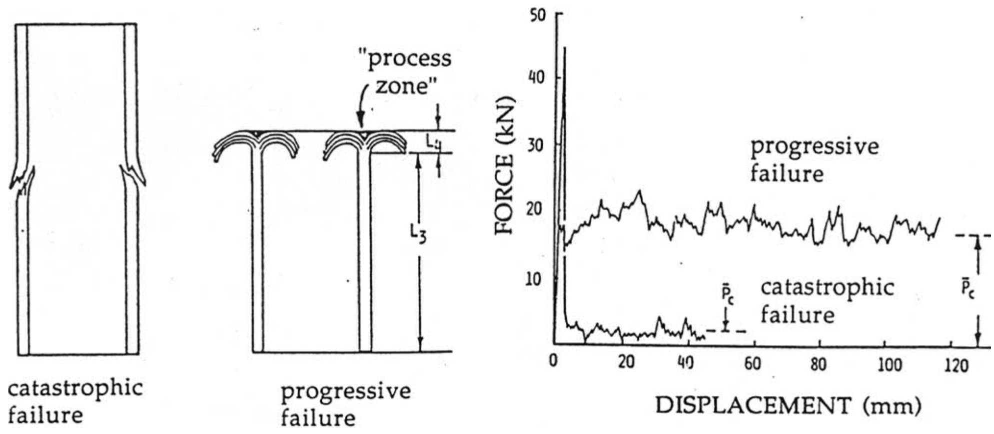

Fig. 1. Axial crushing of composite tubes.