LONGITUDINAL SPLITTING OF NOTCHED FRP COMPOSITES

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The behaviour of notched carbon and glass reinforced plastics has been identified in terms of longitudinal splitting. Models are presented for determining the split length of CFRP under both static and fatigue loading conditions. Photoelastic studies on GRP indicate that longitudinal splitting can be related to the distribution of stress for both static and fatigue loading.

INTRODUCTION

The failure processes for FRP composites are complex and involve the accumulation and spread of damage and are more severe under fatigue loading than static loading for both uniaxial and biaxial stress conditions. In the laboratory damage and failure processes are often best studied using notched specimens of varying geometry since the damage will usually be localised by the concentration of stresses, which if sufficiently high will form a damage zone at the notch tip. For multi-directional laminates subjected to tensile loading in the principal fibre direction then the damage at the notch tip is in the form of transverse matrix cracking, splitting parallel to the fibre directions and delamination between the plies. The effect of damage is to cause a redistribution of the local stresses and to reduce the effect of the stress concentrator. Under fatigue loading the damage zone may increase leading to further notch blunting and reduction in stress concentration (1). A notch effect may also occur if FRP laminates are subjected to low velocity impact damage as produced by dropweight tests. Whilst the

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surface damage in the form of splitting may be barely visible the internal damage may be substantial and reduce the laminate strength by up to fifty percent to produce a similar effect to that of a hole the size of the impact tool (2).

Of importance to the designer is how to interpret the significance of damage in a structure and how it may effect the life and serviceability of the structure. A programme of work is being undertaken at Sheffield in order to formulate various models to describe damage states under static, impact and fatigue loading conditions with a view to being able to predict failure in FRP components and structures. The aim of this paper is to report on the progress being made in terms of understanding damage in the form of longitudinal splitting for carbon and glass reinforced plastics under static and fatigue loading conditions.

EXPERIMENTAL

The CFRP comprised of Grafil XAS fibres supplied by Fothergill and Harvey, impregnated with a Ciba-Geigy epoxy resin to form unidirectional $(0)_4$ and crossply $(0,90)_s$ laminates with 40% fibre volume fraction made by the hand lay-up technique. The GRP consisted of a plain weave unidirectional E-glass fibre supplied by Fothergill and Harvey and an isophthalic polyester resin supplied by Scott Bader. Three-ply laminates of 40% fibre volume fraction were produced by the hand lay-up technique to give configurations of $(0)_3$ and (0,90,0).

Specimens containing a slit, sharpened with a blade to form a centre crack of constant notch/width ratio, were subjected to static tensile tests and tensile fatigue tests at a stress ratio of 0.1. In addition for the GRP photoelastic studies were carried out using a portable transmission polariscope which was set up to produce circularly polarised light and a light-field photoelastic image consisting of isochromatic fringe patterns. Non-destructive and destructive techniques were employed to evaluate the location, extent and nature of damage resulting from the various tests.

ANALYSIS AND DISCUSSION OF RESULTS

For CFRP the split length D_s for static loading is related to the applied stress σ and the split initiation stress σ_s by

$$D_s = B_s\left(\sigma^2 - \sigma_s^2\right) \tag{1}$$

where B_s is the static split growth constant. Figure 1 shows that for the same stress difference the split length is greater for the crossply lay-up. The split length appears to be controlled by the split initiation stress which was higher for the unidirectional material. The crossply material offers less resistance to longitudinal splitting since the tensile load is mainly shared by only two 0° plies compared with four plies for the unidirectional material. A finite element analysis (3) suggests that split growth may be governed by the stress intensity factor at the split tip. A similar behaviour is observed (see Figure 2) for the fatigue loading of CFRP where the split length can be represented by

$$D_s = A + B\,\ell n(1+N) \tag{2}$$

where N is the number of cycles. The rate of split growth is governed by the constant B and is also related to an effective mode II stress intensity factor (3).

The static loading of GRP for unidirectional and crossply laminates is presented in Figure 3. The damage initiates at a slightly lower percentage of failure stress and has a greater split length for the unidirectional material, however at failure the splits propagated to the grips for both laminates. It is thought that the amount of stress in the fibres in the splitting direction plays a major part in driving the splits and that the transverse fibres inhibit their growth. The onset of longitudinal splitting has also been identified from photoelastic studies by monitoring the change in linear behaviour of the height of the first fringe with increasing stress (4). Furthermore the focus of the fringe loops only moved away from the notch tips when failure was imminent for both types of laminate. This suggests that the distribution of stress under static loading is controlled by the total split length D_s.

The reduction in damage stress σ_d and almost mirror image of increase in damage length with increasing fatigue cycles for a unidirectional GRP laminate are shown in Figure 4. σ_d is the damage stress across a damage zone ahead of, and parallel to, the notch tip and has been normalised to the static damage stress $\sigma_{d(st)}$. The reduction in the damage stress for the damage to propagate to the grips is given in Figure 5. Similar behaviour to that in Figures 4 and 5 was also observed for the crossply material. For the crossply material the split growth is similar for both static and fatigue loading. However split growth is faster under fatigue loading than static loading for the unidirectional material (6). A photoelastic study under fatigue loading showed that the movement of the focus of the fringe loops from the notch tip indicates the development of total local fracture, i.e. an inability to transmit load (5). The change in movement of the fringe loop focus and the propagation of damage is shown in Figure 6. D_E is the effective split length and is the distance across which there is no stress transfer and the parameter D_s-D_E is therefore the effective stress transfer length. Initially the total split length is higher in the crossply material however there is a larger effective split length in the unidirectional material and hence a greater redistribution of stress in this material.

CONCLUSIONS

For notched carbon and glass reinforced plastics subjected to static and fatigue loading a similar behaviour is observed in terms of longitudinal splitting. Splitting initiates earlier and propagates faster in crossply materials than in unidirectional materials for the same applied stress, However if the applied stress is normalised to its respective failure stress then the unidirectional material exhibits a longer split length, i.e. transverse plies inhibit split growth. Photoelastic studies on GRP indicate that the effects of stress distribution under static loading are related to the total longitudinal split length and to the effective split length for fatigue loading.

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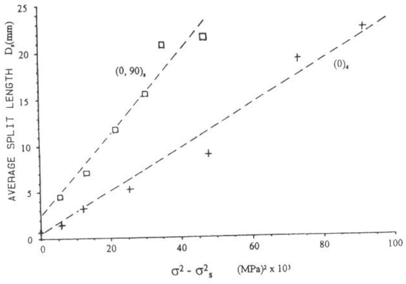

Figure 1 Static split growth of CFRP

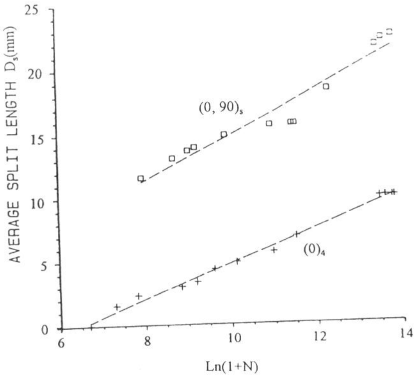

Figure 2 Fatigue split growth of CFRP

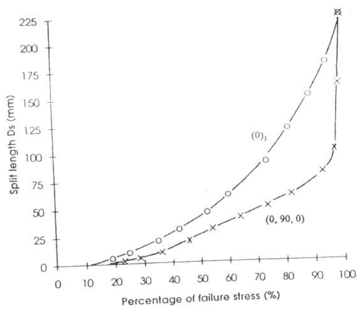

Figure 3 Static split growth of GRP

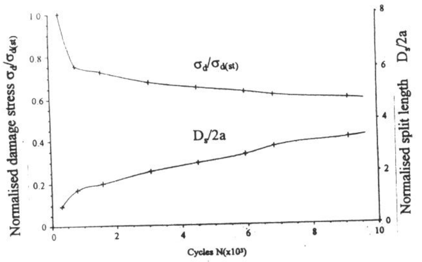

Figure 4 Damage stress and split length for U/D GRP

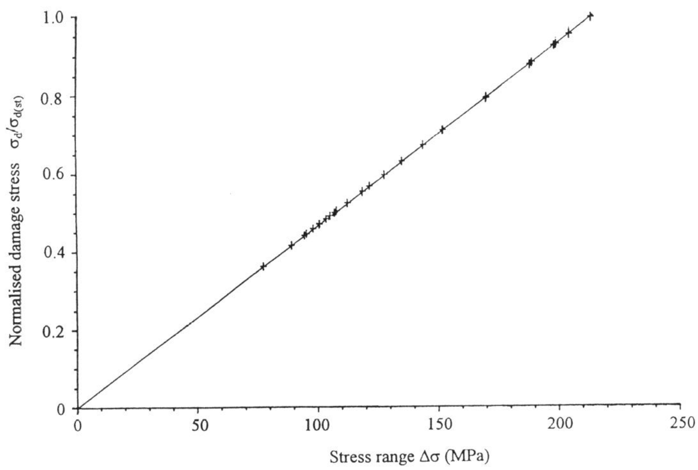

Figure 5 **Damage stress for grip failure of U/D GRP**

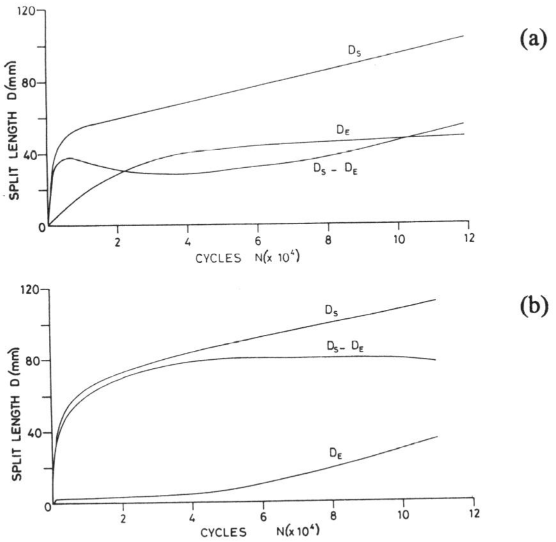

Figure 6 **Split growth curves for (a) unidirectional and (b) crossply GRP**