# EFFECTS OF RESIN INTERLEAFING ON FATIGUE OF UNIDIRECTIONAL FIBRE/EPOXY COMPOSITES

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A beneficial effect of the inclusion of extra epoxy resin layers on the fatigue lifetime of UD glass fibre - epoxy tensile coupons is demonstrated. Reduction in fatigue crack growth rate, in Mode II delamination, is considered to be largely responsible for this effect. Supporting evidence is presented, from fatigue crack growth studies on other epoxy resin composite systems.

## BACKGROUND

The starting point for the present investigation was the somewhat unexpected finding that the tensile fatigue durability of Ciba-Geigy Fibredux 913 glass fibre/epoxy system can be improved by **lowering** the fibre volume fraction in the composite. As Fig.1 (after Partridge et al (1)) shows, at a given stress level, a UD laminate having fibre volume fraction $v_f$ of 47% can be expected to last 100 times longer than a corresponding laminate having $v_f$ of 69%. The implications of this finding should be considered in the light of current "design for stiffness" practices.

The fibre volume variation had been achieved by inserting additional layers of the 913 resin inbetween the prepreg plies during the lay-up, giving rise to resin-rich layers in the composite.

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In the preceeding publication (1) we attributed the improvement in tensile fatigue durability to the appearance of an interlaminar failure mode, in addition to the usual longitudinal splitting. The delaminations were favoured by the presence of the resin-rich layers.

## SCOPE OF PRESENT WORK

More detailed investigations of the above described phenomenon by tensile fatigue testing are unlikely to be fruitful because of the complex failure modes. We therefore decided to focus on delamination studies.

The cracked-lap-shear (CLS) specimen used in fracture mechanical studies of composites is a reasonably close approximation of the loading situation we observed in our tensile fatigue samples containing delaminations. Analysis of the CLS specimen indicates that about 70% Mode II contribution to crack-tip loading is to be expected (2).

Delamination growth rate measurement in Mode II fatigue was thus selected to investigate the effect of the resin-rich regions on the fatigue behaviour of UD laminates.

## MATERIALS AND METHODS

Resins and prepregs. Ciba-Geigy (UK) supplied commercial UD prepregs Fibredux 913 (E-glass fibre/913 epoxy) and Fibredux 920 (T300 CF/920 epoxy). Thin films of the 913 and 920 uncured resins were also supplied. Both resins are modified epoxy systems, of the "120°C cure" type.

Composite preparation. UD laminates were layed-up by hand at Cranfield and autoclave cured according to the manufacturers' instructions. The lay-ups are described in Table 1 which also gives the measured fibre volume fractions $v_f$ and the thicknesses of the resin-rich layers $t_m$ determined from polished cross-sections of samples.

Composite testing. Tension-tension fatigue tests were carried out, as in our previous work, at 30Hz, with sine wave loading at an R-ratio of 0.05. Straight sided 250 x 20 mm coupons were used, with bonded aluminium tabs.

Static Mode II fracture tests were carried out on 24-ply specimens, using the Edge-Notched-Flexure (ENF) configuration and following the EGF Task Group on Polymers and Composites protocol current at the time of writing.

Fatigue crack growth rate experiments were performed using the End-Loaded-Split (ELS) configuration, with specimens identical to those used for the static delamination tests. Fully reversible, constant amplitude displacement tests were carried out at 1 Hz, with continuous monitoring for load, displacement and crack length. The crack length was measured directly by a travelling microscope and the delamination growth rate, da/dN, determined from a third order polynomial fit to the experimental data. Maximum strain energy release rate values $G_{IImax}$ were calculated from an experimental compliance calibration.

## RESULTS AND DISCUSSION

Fig.2 shows a Paris plot comparing the delamination growth rates in Mode II for a 24-ply T300/920 laminate with $v_f$ of 60% with results for an similar lay-up containing an additional 50 μm thick layer of the 920 resin in the centre of the laminate, in the crack path. The equation is

$$da/dN = A \, ( G_{IImax} )^m \qquad (1).$$

The presence of the resin layer has the effect of lowering the A term in eq.1 by between 8 and 5 over the range studied. There is only a small effect on the value of the m parameter which increases from 3.4 to 3.5 when the resin layer is included. The conlusion is that the delamination growth rate is reduced significantly when the crack propagates through resin-rich regions.

Static $G_{IIc}$ values are 800 J/m$^2$ for the standard laminate and rise to over 1500 J/m$^2$ in the laminate containing the resin layer. In accordance with Russell's observations (3) we therefore find that the ratio of the A parameters in eq.1 is the same as the ratio of the corresponding static $G_{IIc}$ values **raised to the power m.** The implication is that the static toughness improvement achieved by the interleafing technique is transferred efficiently to the dynamic loading condition.

The toughness improvement in this system may be attributed to the reduced restriction on the crack tip region as the fibre plies are separated by the resin layer. The 50 μm resin layer thickness is to be compared to the estimated Irwin plastic zone size in this resin, in Mode I, which is 175 μm (Jaussaud and Partridge (4)). It should be noted that the toughness improvement has been obtained without any significant reduction in the stiffness of the laminate.

The above findings suggest that it is the **spatial distribution** of resin layers and prepreg plies, rather than an effect of the fibre volume fraction, which is responsible for the previous observations of improved fatigue lifetimes in our GF/913 tensile specimens. To test this hypothesis, we repeated the tensile fatigue experiments described in (1) but included a laminate in which the prepreg plies are separated by two resin films (see Table 1). The results obtained were in complete agreement with the data depicted in Fig.1, with the [2 plies/2 resin films] lay-up showing a marginal improvement over the [1 ply /1 resin film] lay-up, at **identical $v_f$**. The delamination damage mode is observed very clearly in the [2 plies/ 2 resin films] laminate.

Temperature changes were monitored with several of the GF/913 samples, using an infra-red camera. In localised hot-spots, where fibre failure has occurred, the temperature can rise up to 100°C above ambient; however, the overall temperature rise of the sample was never more than 15°C above ambient. In this respect there was no difference between laminates containing different thickness resin layers. The resin layer thickness is more likely to influence any residual stresses in the laminates and this effect should be investigated in any further analysis of our findings.

## CONCLUSIONS

1. Beneficial effect of inclusion of additional epoxy resin layers upon the tensile fatigue durability of GF/913 epoxy UD laminates has been confirmed.

2. This effect is attributed to preferential delamination damage mechanism in laminates containing resin-rich layers. Increasing the thickness of the resin rich layer further improves the fatigue lifetime by reducing the shear delamination crack propagation rate in the tensile sample.

3. Mode II static toughness is doubled and fatigue crack propagation rate reduced more than five times when a 50μm thick resin layer is placed along the crack path in a CF/ 920 epoxy laminate. This toughness improvement is achieved with only a 5% reduction in the laminate stiffness.

## ACKNOWLEDGEMENTS

The authors acknowledge financial support by Kobe Steel Ltd for JAMJ and an EEC grant for TN. Materials were kindly donated by CIBA-GEIGY (UK). Technical assistance and helpful discussions with staff at RAE Farnborough are also gratefully acknowledged.

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TABLE 1 - Details of laminates tested

| **Material** | **Stacking Sequence** | $V_f$ % | **tm (µm)** | **Test** |
|---|---|---|---|---|
| GF/913 | $[0°]_8$ | 66 | ≈0 | TF |
| GF/913 | [0°/RF/0°/RF/0°/RF/0°/RF/0°] | 48 | 12 | TF |
| GF/913 | $[0°_2/RF_2/0°/RF°_2/0°_2]$ | 48 | 24 | TF |
| T300/920 | $[0°]_{24}$ | 60 | 5 | FCP |
| T300/920 | $[0°_{12}/4RF/0°_{12}]$ | 57 | 50 | FCP |

| Key: | | |
|---|---|---|
| | TF | tensile-tensile fatigue |
| | FCP | fatigue crack propagation in Mode II |
| | RF | resin film |

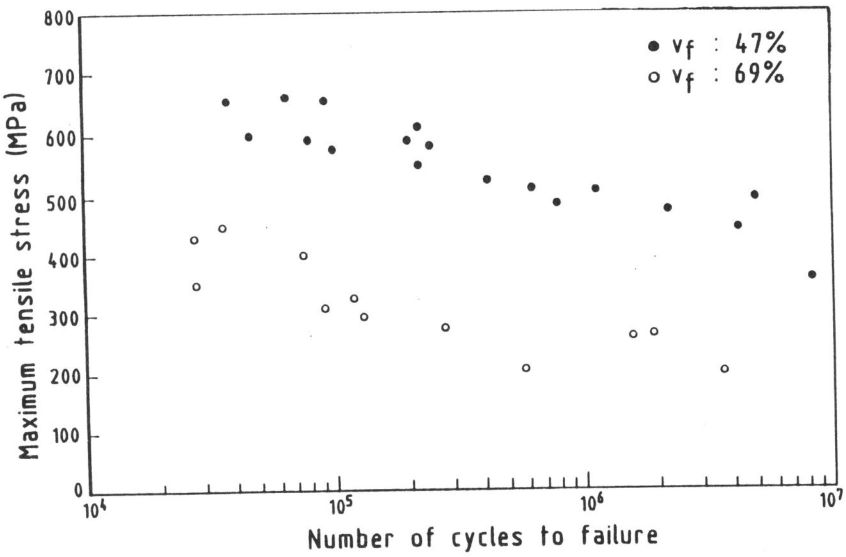

Figure 1 Tensile fatigue s-n curves (after ref.1)

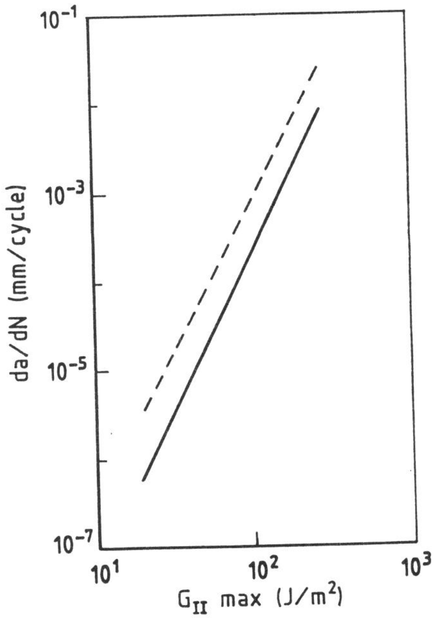

Figure 2 Paris plots

Key: - - - - 24-ply;
——— 24-ply with 50 μm resin film.