Some Fatigue and Fracture Parameters of Fibre-Reinforced Composite Materials

A. K. Green and P. L. Pratt
Metallurgy Department, Imperial College, London S. W. 7, England.

INTRODUCTION

The fatigue and fracture behaviour of carbon-fibre reinforced epoxy resin composites have been studied, to assess the applicability of current testing techniques to these new materials. Some experimental development was found necessary as a consequence of the highly anisotropic character of the materials. The composites were found to have properties similar to those observed by other workers, with some features not previously reported.

EXPERIMENTAL TECHNIQUES

(1) Fatigue Studies

The fatigue properties of a 60% volume fraction Morganite Type IIIS (surface treated) Carbon Fibre/Ciba LY 558:HT 973 epoxy resin system in a uniaxial lay-up were determined. Both wet and dry lay-up preparation techniques were employed using the "leaky mould" system, the dry lay-up technique being found to yield a superior product. Material prepared by the dry lay-up technique was found to have a lower void content and a higher degree of fibre orientation than that prepared by the wet technique. The fatigue specimens were similar to those of Owen and Morris (1970). Aluminium plates were attached to the ends of the specimens, following the surface preparation techniques of Sturgeon (1971).

Tensile-going, zero-tensile fatigue loading with a sinusoidal waveform was applied with an Instron 1250 servo-hydraulic testing machine. The tests were carried out at 60 Hz, at which frequency the machine performed satisfactorily. The pressure in the hydraulic grips of the Instron machine was reduced from 21.1 $MN.m^{-2}$ to 11.3 $MN.m^{-2}$, to avoid crushing the composite material in the grips.

(2) Fracture Toughness Studies

The material used for fracture toughness studies was a 60% volume fraction Morganite Type IS (surface treated) carbon fibre/LY 558:HT 973 epoxy resin, in uniaxial lay-up, prepared by the dry technique. Aluminium plates were attached to each end of the specimen, as before. Specimens were loaded in a 100 kN capacity Instron machine using the grips shown in Figs. 2& 3. The grips were designed to provide virtual pin-loading on the composite, without drilling holes in the material and were used at loads up to 60 kN without evidence of slipping in the grip faces.

The specimen configuration was designed to provide a long, predictable fracture path, so that its progress could be followed by ultra-high speed photography. By analysis of the photelastic patterns produced around the crack tip, a measure of the variation of fracture toughness of the material with crack speed can be obtained. The fully synchronised system is shown in Fig. 1, and is described in greater detail in Green (1971) and Green and Pratt (1973), except that in the previous cases, a transmitted light system, as shown in Fig. 1, was used, whereas, in this work,a reflected light system was necessary since the composite material studied is opaque.

EXPERIMENTAL RESULTS

(1) Static Properties

The static tensile properties of the composites were as follows:

Fibre Type	Batch	Preparation Technique	U.T.S.	Tensile Modulus	Failure Strain
IIIS	H516	Wet lay-up	540 $MN.m^{-2}$	150 $GN.m^{-2}$	0.3%
IIIS	H516	Dry lay-up	640 $MN.m^{-2}$	140 $GN.m^{-2}$	0.5%
IIIS	H649	Dry lay-up	740 $MN.m^{-2}$	160 $GN.m^{-2}$	0.5%
IS	G44	Dry lay-up	600 $MN.m^{-2}$	230 $GN.m^{-2}$	0.27%

(2) Fatigue Studies

The fatigue results are shown in Fig. 4. Only specimens that broke in a well-defined manner across the minimum section of the specimen, as shown in Figs. 5 & 6 were considered to give a valid result. Results in Fig. 4 are those obtained on batch H516, and show no significant difference in fatigue behaviour of the materials prepared by the dry and wet lay-up techniques, in spite of the superior static properties of the dry lay-up composite.

The large initial drop from the static UTS value, in contrast to the results of Owen and Morris (1970) is evident. Preliminary results on the stronger batch H649 material indicate long fatigue lives ($>$5 x 10^6 cycles) at stress amplitudes of greater than 500 $MN.m^{-2}$.

(3) Fracture Toughness Studies

The specimen design as described enabled straight fracture paths to be obtained perpendicular to the fibre direction as shown in Fig. 7. Considerable variation was observed in the pre-load necessary to produce fracture propagation after wedge impaction. This was thought to be a consequence of the difficulty in reproducing a groove of precise depth, and variations between batches of resin. The stress-intensity factor on the specimen before the wedge was driven into the notch root, was typically in the range 30-34 $MN.m^{-3/2}$. At the time of writing, crack speeds up to 1500 $m.sec.^{-1}$ have been observed, and analysis of the available photoelastic data have indicated values for dynamic stress intensity factor of the order of 40 $MN.m^{-3/2}$ at a crack speed of 650 ± 50 $m.sec.^{-1}$.

4. Fractography

Specimens were examined in the S.E.M. and the results are shown in Figs. 8-11. Figs. 8 and 9 show respectively the fracture surfaces of a Type IIIS composite after tensile testing and fatigue testing. Figs. 10 and 11 show the fracture surfaces of the Type IS composite after tensile and fracture toughness testing.

DISCUSSION OF RESULTS AND CONCLUSIONS

The significant feature of the fatigue data is the large initial drop from the static UTS value of the material, in contrast to the behaviour observed by Owen and Morris (1970) who worked on Type I (untreated) material at 6 HZ. No explanation of this behaviour is apparent, but it is possible that the surface treatment of the fibres used in this work may have increased their susceptibility to fatigue breakdown, as a result of an increase in number of surface defects on the treated fibres. The fracture toughness data indicate that the fracture toughness of CFRP increases with crack velocity. The nature of the energy absorption processes contributing to this increase are not yet clear.

REFERENCES

Owen, M.J. and Morris, S., (1970), Modern Plastics, 47, 158.
Sturgeon, J.B., (1971), R.A.E. Tech. Note TR 71026.
Green, A.K. (1971), Ph.D. Thesis, Imperial College, London.
Green, A.K. and Pratt, P.L., (1973) to be published.
Sturgeon, J.B., (1971), Composites, 2, 104.

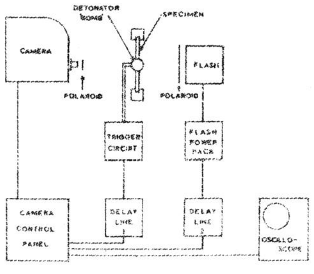


FIG. 1 SCHEMATIC EXPERIMENTAL SET-UP

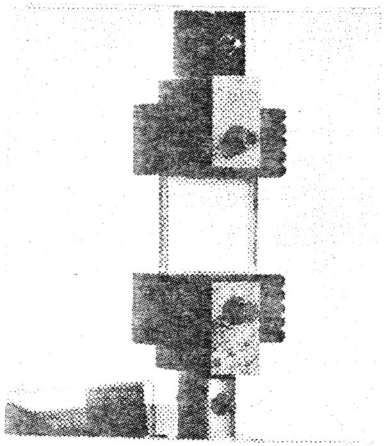
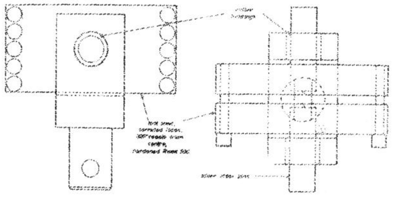


Fig.2



[illegible] Pin-Loading Grips used for Fracture Toughness Tests on CFRP

Fig.3

Fatigue Data for Morganite IIS Carbon Fibre/CIBA LY558 Epoxy Resin Composite (50%)

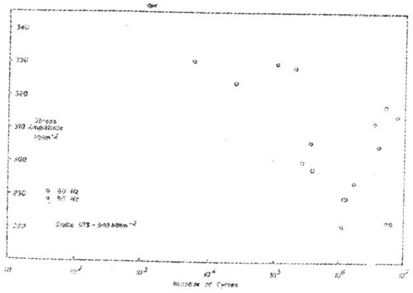


Fig.4

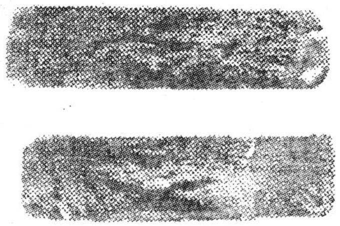


Fig.5

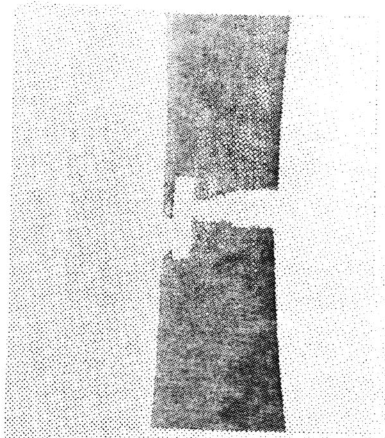


Fig.6

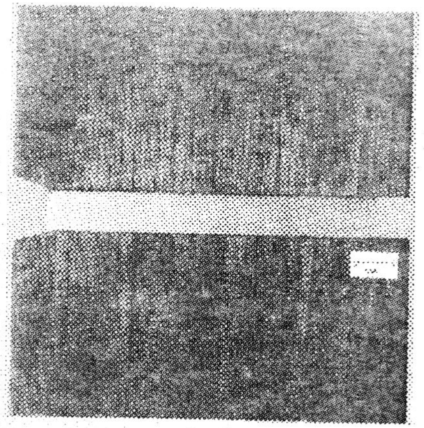


Fig.7

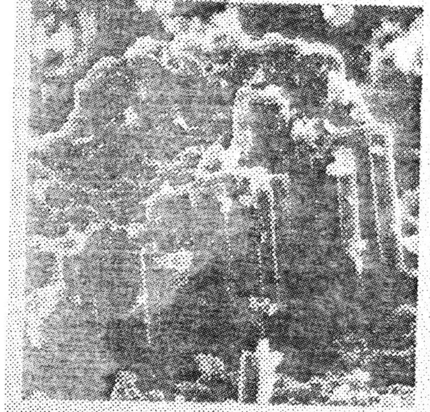


Fig.8

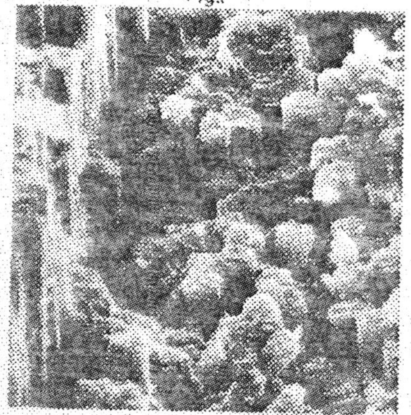


Fig.9

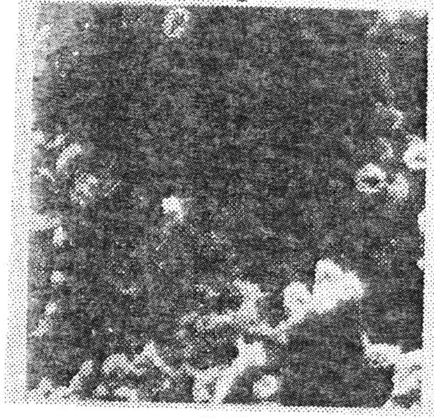


Fig.10

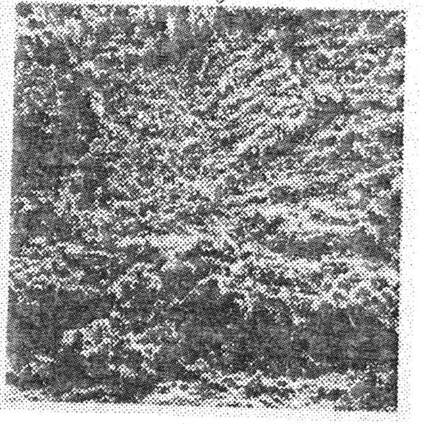


Fig.11