FATIGUE PROPERTIES OF COMACO COMPOSITES

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ABSTRACT

COMACO composites are fibre reinforced plastics in which the plastic matrix shrinkage is controlled in order to enhance the toughness. The fatigue properties are also improved by the control of the shrinkage, and there is a correlation between composite toughness and the slope of the S-N curve.

KEYWORDS

Fibre reinforced plastics; fatigue; shrinkage pressure.

INTRODUCTION

Carbon fibre reinforced plastics have excellent strength and stiffness in addition to being very light. Thus, they are ideally suited for use in aircraft, helicopters, and other situations where light weight is very important, and these composites are rapidly replacing aluminum in structures used in aerospace.

A problem preventing complete acceptance of these materials is their lack of toughness. Toughness can be improved by controlling the shrinkage of the polymer matrix (Piggott, 1981) and this technique has been patented (Piggott, 1984).

This study was carried out in order to ensure that this method of controlling toughness did not result in a decrease in the excellent fatigue properties of carbon fibre reinforced plastics.

EXPERIMENTAL METHOD

Aligned carbon fibre pultrusions were made using Hercules AS1 fibres and a number of different epoxy resins, with special additives used to control the shrinkage of the resin during cure. To make the pultrusions, the fibres were soaked in the resin and then pulled inside a die, with internal dimensions 20 mm wide, 3.0 mm deep and a length of 30 cm.

Mechanical properties were measured using an MTS machine. The specimens were end tabbed for tension, and fatigue testing. Izod toughness was measured using a Tinius Olsen Impact Tester.

Fatigue tests were carried out at a frequency of 10 Hz, except for the low cycle tests, for which a frequency of 2 Hz was used. Tension-tension (R = 0.1) and tension-compression (R = -0.3) conditions were used.

Resin cure shrinkage stresses were measured using a square polymer bar, to which strain gauges were attached. This was inserted in a small vessel containing the resin, and the resin was allowed to cure at room temperature.

EXPERIMENTAL RESULTS

Figure 1 shows a typical S-N curve for tension-tension fatigue, and fig. 2 shows the pooled fatigue life curve. Using the pooled life, failure probabilities were calculated, and the highest and lowest lines in fig. 1 indicate 0.98 and 0.02 failure probabilities respectively.

The slope of the S-N curve, β% per decade, was used as an indicator of fatigue resistance. This correlated with the fatigue power law parameter b:

$$\beta = 2 + \frac{100}{b}$$

and is normally used, rather than b.

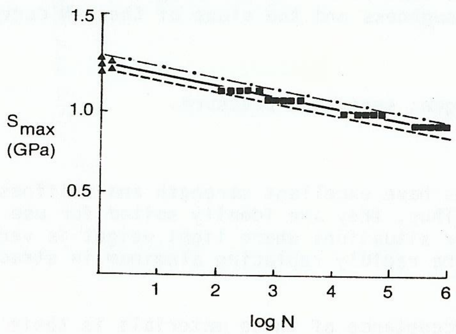

Fig. 1. S-N curve for aligned carbon fibre-epoxy pultrusion. The dashed and dotted lines indicate 0.02 and 0.98 failure probability respectively.

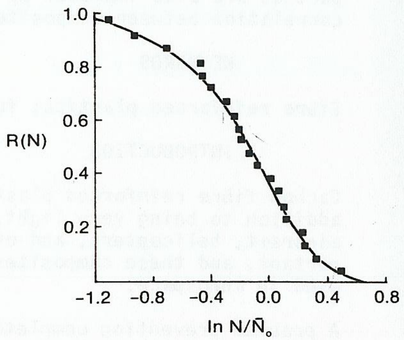

Fig. 2. Pooled life curve for specimens giving S-N curves shown in Fig. 1.

Improved fatigue resistance was associated with control of shrinkage pressure, as shown in fig. 3. The results for tension-tension fatigue (R = 0.1) and tension-compression fatigue (R = -0.3) fall into different regions on this diagram. In addition, Izod impact strength correlated well with fatigue resistance. Fig. 4 shows a plot of toughness of composites made with the modified resins, G_r as a fraction of toughness of the composites made using the neat resin, G vs β. Different straight lines are observed for tension-tension (R = 0.1) and tension-compression (R = -0.3) fatigue.

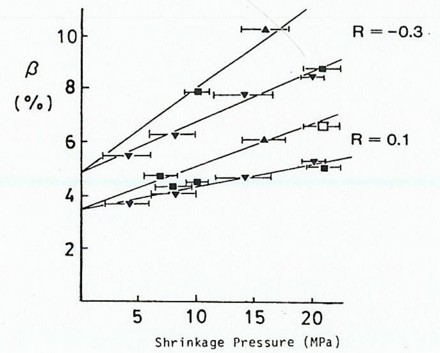

Fig. 3. Effect of shrinkage pressure on slope of S-N curve.

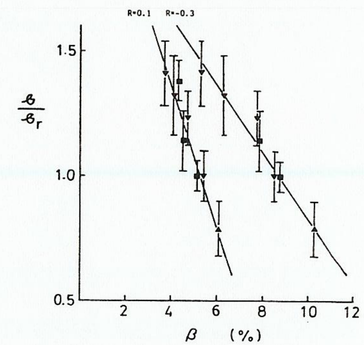

Fig. 4. Izod impact strength of aligned carbon fibre pultrusions with various matrices versus slope of S-N curve.

The improved fatigue resistance appeared to be associated with the matrix or fibre-matrix interface, since there was no loss of tensile modulus during fatigue, except just before failure, fig. 5, while flexural modulus declined continuously, fig. 6. In fig. 6, the different lines, associated with different matrices, which gave lines with different slopes (or rates of loss of flexural modulus, m_E) also had S-N curves with different slopes, β. The loss of modulus correlated well with β, fig. 7, and if a teflon patch was inserted in the centre of the composite, β was increased while m_E changed very little, as is also shown in fig. 7.

Visual observation of the specimens indicated that the composites were splitting during the fatigue tests.

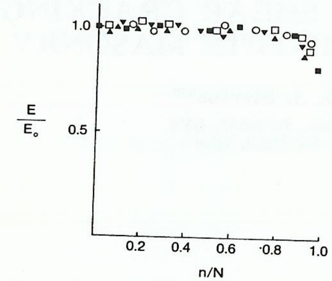

Fig. 5. Loss in tensile modulus during fatigue, measured with extensometer, R = 0.1.

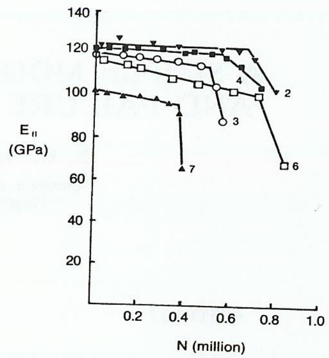

Fig. 6. Loss in flexural modulus of aligned graphite fibre pultrusions during fatigue R = 0.1.

DISCUSSION

COMACO composites have improved fatigue resistance, both in tension-tension and tension-compression fatigue. They permit a new variable to be introduced into the composite, i.e. the shrinkage pressure, and this facilitates the identification of processes contributing to fatigue failure.

In these experiments the fatigue process involves the splitting of the matrix, or progressive failure of fibre-matrix interfaces. This results in gradual loss of flexural modulus. Fibre failure is not involved to any significant extent, since tensile modulus does not decline until the fatigue life is almost exhausted.

It seems very likely that the lower shrinkage stresses in the matrices of COMACO composites reduce the rate at which matrix or interface damage takes place, as indicated by loss in flexural modulus. This reduces the slope of the S-N curve.

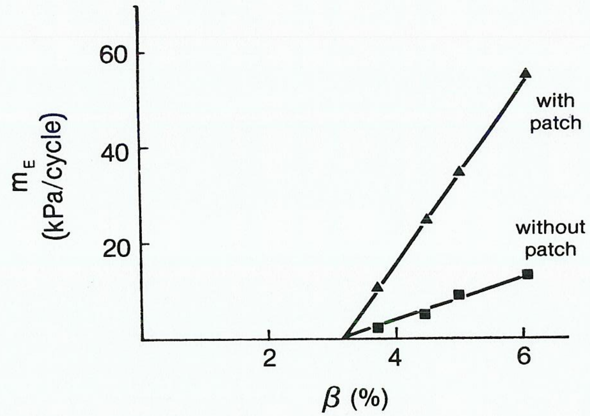

Fig. 7. Rate of loss in flexural modulus versus slope of S-N curve. R = 0.1.

CONCLUSIONS

The COMACO concept can be used to improve the fatigue resistance of aligned carbon fibre-epoxy pultrusions. Matrix or interface damage during fatigue appears to be much reduced by the lower stresses in the matrix, and this leads to S-N curves with lower slopes, and a reduced rate of degradation of flexural modulus.

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