THE INFLUENCE OF MATRIX ON THE S-N FATIGUE BEHAVIOUR OF CONTINUOUS CARBON FIBRE COMPOSITES.

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The fatigue strength of a range of continuous carbon fibre reinforced composites has been examined in terms of their S-N curves. The composites vary in terms of their fibre type (3 different CF systems) and the matrix type (4 different thermoplastic materials and two different thermosetting materials). The influence of temperature rise during fatigue is explored as too are the S-N curves for a quasi-isotropic and cross-ply laminates.

INTRODUCTION

Continuous carbon fibre composites for aerospace applications are available with a range of different matrix materials as well as different carbon fibre types. The fibre types will vary in stiffness and in strength where composites based on intermediate and high strength fibres are now available. There is also a range of matrix materials that can be used in the preparation of the pre-preg materials. Historically, this has been divided between thermoplastic and thermosetting materials, eg Poly Ether-Ether-Ketone (PEEK) and simple Epoxy formulations (eg Fiberite's 934 resin) respectively. More recently, there have been developments in the design of the matrix materials themselves. For example, thermoplastic toughening of Epoxy resins (1) has lead to composites with improved toughness. In the thermoplastic composites development there have been a range of different matrix materials used for impregnating the carbon fibres, where the resins have been selected often on a desire to achieve higher temperature performance (2).

The availability of these composites enables a study to be made of their fatigue behaviour. The principal purpose of this paper is to measure and compare a simple stress-log number of

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cycles (S-N curves) expression of this fatigue strength. A number of the materials in this study are experimental materials. Moreover, it is not likely that the materials are designed for the same type of applications. Therefore, the intention of the work is not to attempt a comparison of the composites materials, particularly because a wide balance of properties are required in the selection of a material for a given application. However, three different carbon fibre types and the selection of up to seven different matrices provides a medium for considering the influence of both fibre and matrix on the S-N curves.

The fatigue strength will be measured in the form of S-N curves on unnotched specimens in zero-tension fatigue at 23 °C using load controlled square waveforms. Two lay-ups will be used for the 16 ply laminates prepared from the various pre-preg materials. First, a quasi isotropic lay-up, namely $(+45,0,-45,90)_{2s}$ where strength will be dominated by the fibre. Second, a cross-ply laminate, namely $(\pm 45)_{4s}$ where strength will be more strongly influenced by the matrix and the matrix/fibre adhesion. The selection of a square waveform is made for practical convenience allowing us to use a selection of both servo-hydraulic and pneumatic fatigue machines for the testing. The pneumatic machines will provide only a load controlled square waveform. Previous work has shown a similarity of results from either type of machine (3). The use of a square waveform at a particular frequency introduces a higher frequency harmonic. Previous work with thermoplastic matrix composites has shown that fatigue at higher frequencies can introduce an autogeneous heating effect, which in turn can influence fatigue strength (3). Consequently, this possible influence was also incorporated in our study.

MATERIALS.

A range of thermoplastic and thermosetting continuous carbon fibre composites have been used in this study. In each case, there is 62% by volume carbon fibres in the pre-preg material which is then laid up into two types of laminate, namely:-

$(+45,0,-45,90)_{2s}$

$(\pm 45)_{4s}$

The thermoplastic laminates were consolidated by a compression moulding method using standard cooling rates from the melt, whilst the thermosetting composites were consolidated by an autoclave method. Ultrasonic C scanning was used to confirm adequate consolidation. The various fibre and matrix combinations are listed in Table 1 where it should be noted that a number of the samples are experimental materials. All materials originate from ICI Fiberite.

TABLE 1 CONTINUOUS FIBRE COMPOSITES USED IN THE FATIGUE STUDY.

FIBRE TYPE	MATRIX	DESCRIPTION OF THE COMPOSITE
IM7	934	Epoxy compound
IM7	977-2	Thermoplastic toughened Epoxy
AS4	PEEK	Intermediate strength fibre
IM8	PEEK	Tg=143°C,high strength fibre
IM8	ITX	Tg=175°C, semi-crystalline
IM8	ITA	Tg=233°C, amorphous
IM8	HTA	Tg=260°C, amorphous

DISCUSSION OF RESULTS

Autogeneous Heating.

The viscoelastic nature of some of the matrix materials implies that they may give rise to temperature rise during fatigue and that test frequency may also influence this process. It is our intention to present S-N curves that are not influenced by such events and therefore some simple and limited measurements were made of the temperature rise during fatigue by contact probe thermometry on [±45] laminates from a selection of these materials at two test frequencies. It is apparent from our observations that all of the materials exhibit temperature rise during fatigue since our measurements spanned the various different types of materials (ie from simple thermoset, to full thermoplastic via thermoplastic toughened thermoset). It can be seen from our data that higher temperature rises occur at higher test frequency, and therefore the experimental programme to collect the S-N curves was conducted at 0.5 Hz in order to minimise the influence of temperature rise on the measured fatigue strength. Subsequent to these measurements we examined the loss factors for these materials by DMA measurements and found that at 23°C that the materials exhibited similar values of tan δ.

Fatigue of $(+45,0,-45,90)_{2s}$ laminates.

The thermoplastic matrix composites were used in order to examine the fatigue strength for this quasi-isotropic lay-up. Results are shown in Figure 1 where it can be observed that the S-N curves up to 0.1 million cycles for four of the materials are very similar (namely IM8/PEEK, IM8/ITX, IM8/ITA and IM8/HTA). In turn all of these materials for the same number of cycles show a higher fatigue strength than AS4/PEEK. It is expected that the strength of this laminate in tension will be strongly influenced by the strength of the fibre despite the likelihood of three different mechanisms that will be responsible for the failure in fatigue (4). The ratio of fibre strength for IM8 to AS4 carbon fibres is 1.3 which supports the expectation of fibre dominance in this test and by implication shows that the matrix has little influence, at least upto 0.1 million cycles at 23°C, for this quasi-isotropic lay-up. Beyond 0.1 million cycles, there is a suggestion that the composites based on amorphous matrices exhibit a relatively lower fatigue strength to those based on semi-crystalline matrices, although a lack of data makes this a tentative trend at present.

Fatigue of $(\pm 45)_{4s}$ laminates.

Four thermoplastic composites (AS4/PEEK, IM8/PEEK, IM8/ITX and IM8/ITA) and two thermosetting composites (IM7/934 and IM7/977-2) have been used in this part of the study. It is known that the failure mechanisms resposible for tensile fatigue in [±45] laminates include matrix cracking between the fibres (for which a complex combination of matrix toughness and interfacial adhesion will influence the process) and delamination between the plies (for which matrix toughness will be an important contributor). The fatigue measurements order the strengths of the materials in the following manner:-

AS4/PEEK > IM8/PEEK > IM8/ITX > IM8/ITA = IM7/977-2 > IM7/934

The static strengths of these laminates are similar except for the laminates based on PEEK which show higher static strengths. Therefore the dynamic loading is having an influence on the mechanisms leading to the measurement of strength.
The difference in fatigue strength for the two composites based on PEEK indicates that matrix toughness alone is not responsible for the dynamic behaviour. However, the higher fatigue toughness of the the semi-crystallne thermoplastic matrices over the amorphous thermoplastic matrices does indicate that resin toughness is an influencing parameter, in addition to other factors.

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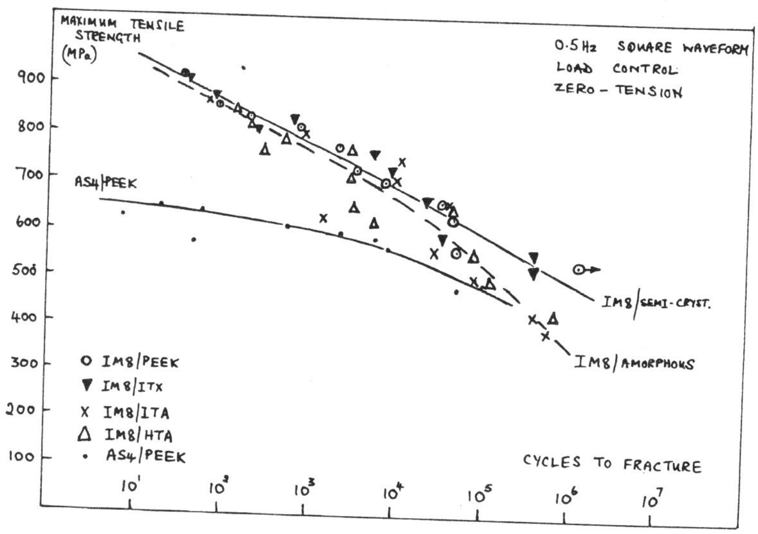

FIG.1 Fatigue strength at 23°C for thermoplastic composites