# POSTER

## FATIGUE BEHAVIOR OF CONTINUOUS CARBON FIBER REINFORCED PEEK

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### INTRODUCTION

Although there is a substantial literature on reinforced thermosetting materials, studies of continuous carbon fiber reinforced thermoplastics have been relatively sparse until recently. The introduction of PEEK based composites in the early 80's gave rise to a rapid expansion in interest in this area(1). Initially, the simpler mechanical properties were reported, so that fatigue data have been relatively slow to emerge(2). However, there have now been several reports of both S-N data and fatigue crack propagation studies, although there is still some debate over the relative performance of thermoplastic and thermosetting based materials(2-4).

The development of damage in composites has also been studied by monitioring the stiffness changes that occur as the fatigue test progresses(5,6). Results from these tests suggest that there are three distinct stages in the fatigue life of central notched $[0/45/90/-45]_{4s}$ laminate layups of carbon fiber reinforced PEEK. The present paper compares results obtained from monitoring the deterioration in modulus that occurs during the fatigue testing of a range of different continuous carbon fiber layups in a PEEK matrix.

### EXPERIMENTAL

Three layups, namely $[\pm45]_{4s}$, $[-45/0/+45/90]_{2s}$ (= [QI]) and $[0/90]_{4s}$, of thermoplastic PEEK resin reinforced with AS4 carbon fibers were tested, as well as central notched samples of [QI] laminates. Compression moulded plaques were cut using a diamond impregnated slitting wheel, and gently waisted samples were produced with a polycrystalline diamond tipped fly cutter. This geometry defined the point of failure more reliably, without inducing excessive stress concentrations. For the central notched samples, the central hole was drilled in a parallel sided coupon with a diamond coated ultrasonically vibrating drill.

Fatigue testing was carried out on a servo-hydraulic machine at a frequency of 1Hz. The system was programmed to introduce a slower cycle at pre-set intervals, typically ~1000 cycles, so that load and extension data could be collected, using a specially designed extensometer and CIL interface. Load control, with an R-value ($\sigma_{min}/\sigma_{max}$) of -1, corresponding to fully reversed loading, was used, and specimens were surrounded with aluminium anti-buckling guides. Having established the number of cycles to failure, $N_f$, for a specific set of conditions, some tests were halted at 0.1, 0.5 and $0.9N_f$ and the samples sectioned and polished to examine, by optical and electron microscopy, the typical damage patterns.

### RESULTS AND DISCUSSION

For the first few cycles, all the layups gave rise to approximately linear stress-strain curves with little hysteresis. However, as cycling continued, modulus degradation, and thus damage accumulation, were found to vary significantly, depending on the layup.

The changes in modulus of the [±45] samples were found to follow three distinct stages as cycling progressed. Initially a relatively rapid decrease in modulus (corresponding to an increased maximum strain) occurred with tests up to, typically ~$0.1N_f$. As the tests progressed between $0.1N_f$ and $0.8N_f$ the modulus continued to decrease steadily, but more slowly, and this was accompanied by increased hysteresis. Finally, there was a significant, rapid deterioration in modulus as cycling exceeded $0.8N_f$ (Figure 1).

In contrast to these results, the [0,90] and [QI] layups displayed much less change in stress-strain behavior until the final failure cycle ($N_f$) was approached. This response may be seen from the modulus data shown in Figure 1. The normalised modulus (i.e. the modulus at N cycles divided by the initial modulus) is plotted against normalised fatigue life ($N/N_f$), to allow easier comparison of the behaviors of the various layups. It may also be seen from Figure 1 that the effect of having a central notch (CNC) in the [QI] coupon sample is to generate a more rapid fall off in modulus as fatigue cycling progresses.

These differences in fatigue response can be clearly related to the damage accumulation as fatigue testing progresses. For the [±45] layups the behavior is matrix dominated. Sectioned specimens of partly fatigued samples reveal that matrix cracking has clearly appeared at $0.1N_f$. By $0.5N_f$ this matrix cracking has extended significantly, with evidence of delamination (Figure 2). At $0.9N_f$, matrix cracking and delamination are extensive.

The sectioned samples of the [QI] and [0/90] layups show that very little damage occurs until the failure point is approached (Figure 2). This results from the fatigue response of these layups being dominated by the fibers, particularly those parallel to the applied stress. These fibers ensure that the strains remain small, typically well below 0.5%, so that the relatively ductile PEEK matrix is able to deform without cracking. This behavior means that fracture occurs without any obvious warning signs, making prediction of imminent failure relatively difficult. On the other hand, when stress concentrations are introduced into such [QI] samples, by for example central notching, then damage accumulation is more gradual and can be monitored by modulus deterioration and this correlates well with direct observation of damage that occurs in the stress concentration regions.

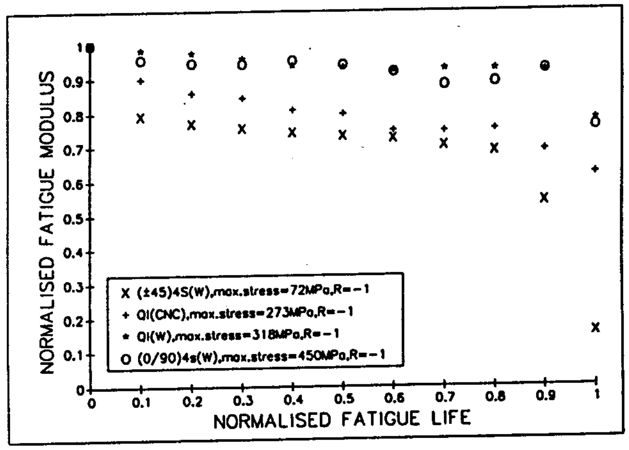


Figure 1 Normalised Fatigue Modulus as a function of Normalised Fatigue Life for the Various Laminate Layups and Geometries.

(a)

(b)

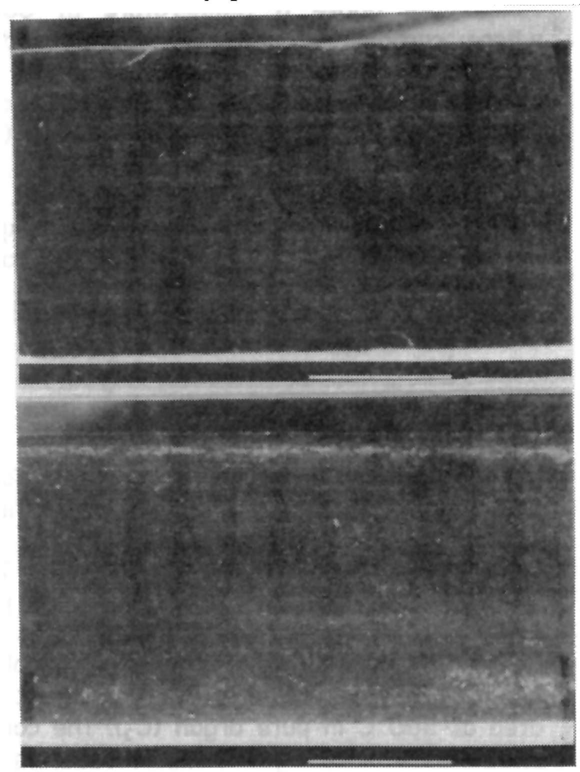

Figure 2. SEM micrographs of samples taken at $0.5N_f$, (a) [±45] layup and (b) [QI] layup. Note in (a) the matrix cracks at both edges and the clearly defined lines between the layers where delamination has occurred. In contrast, the [QI] sample in (b) exhibits very little evidence of damage. (Bar=1mm)

## CONCLUSIONS

Measurement of modulus deterioration during fatigue testing may be closely related to the observation of damage accumulation. There is significant variation in the fatigue behavior depending on the laminate layup and specimen geometry. The matrix dominated [±45] layup, and the notched [QI] geometry with a high stress concentration, display more progressive deterioration in modulus than the $0^{o}$ fiber dominated [0/90] and [QI] layups.

## REFERENCES


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