FATIGUE BEHAVIOUR OF A GLASS FIBRE REINFORCED POLYPROPYLENE COMPOSITE

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This paper presents fatigue results obtained on a comminged E-glass fibre reinforced woven into a bi-directional cloth of polypropylene. This composite was manufactured with fibre volume 33.8%. The effect of test conditions on the fatigue behaviour has been investigated. The effect of loading conditions, frequency, stress ratio and temperature were considered. The S-N curves, the rise in the temperature of the specimens during the tests and the loss of stifness through the fatigue tests were obtained and discussed accordingly.

INTRODUCTION

Advanced fibre reinforced thermoplastic composites fabrics which consist of thermoplastic filaments such as polypropylene, nylon, etc, interwoven with reinforced fibres based on glass, Kevlar, carbon or hybrid mixtures have been developed over the last years as one promising alternative to thermosetting resin systems. When heated and compressed the systems become filered reinforced thermoplastic composites.

This paper presents results associated with glass fibre reinforced polypropylene composite. The influence of the fatigue test conditions has been investigated. The parameters studied were the load mode, frequency, stress ratio and temperature. The fatigue strength in terms of the number of cycles to failure versus the stress range was obtained. During the fatigue tests a rise in temperature of the specimens was observed. This rise in temperature is reported by Sims and Gladman (1) and increases with the fatigue life specially close to the final failure.

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Some theoretical and experimental approaches are reported in literature to model the fatigue damage such as: the number of debonded fibres, fracture mechanics parameters, the strain energy density and the loss of stiffness. The loss of stiffness through the fatigue tests was used as a damage criteria by Spearing and Beaumont (2) in composite laminates. Also Joseph and Perreux (3) has used this damage criteria in glass/epoxy composites and Echtermeyer et al (4) in glass/phenolic and glass/polyester composites. Czigny and Karger-Kocsis (5) quantify the fatigue damage by the size of the damage zone in textile fabric reinforced polypropylene composites using modified compact tension specimens. The damage zone size was obtained by acoustic emission. The paper presents results of the loss of stiffness observed during the fatigue tests for several tests conditions.

The stress ratio and frequency effect were also investigated. Generally when the stress ratio increases the fatigue strength decreases. This effect can be predicted by means failure criterions. El Kadi and Ellyin (6) presents a fatigue failure criterion based on the input strain energy for fibre reinforced materials. As is reported in (1), when the frequency decreases the fatigue strength also decreases.

MATERIAL AND EXPERIMENTAL PROCEDURE

Composite sheets multi-layers of "Twintex T PP" wich were processed in a mould pressure (5 bar for 10 minutes) after heating above the PP matrix at 190° C (above melting temperature of the polypropylene). The overall dimensions of the plates were 250x250x2.5 mm and fibre volume fraction 33.8%.

The specimens used in the tensile and fatigue tests were prepared from these thin plates. The geometry and dimensions of the specimens are shown in Fig.1. The fatigue tests were carried out in a electromechanical machine where frequency and stress ratio can be changed and the load controlled by a load cell. The load wave was sinusoidal constant amplitude.

One set of tests was carried out in three point bending (3PB) with frequency of 10 Hz and stress ratio R=0 at room temperature (RT). The remaining tests were performed in tension. Changes in fatigue parameters were investigated. Stress ratio of R=0 and R=0.25, frequencies of 2 and 10 Hz and the temperature of ambient and 60 °C were used.

The tensile mechanical properties were obtained using an electromechanical Instron Universal Test machine. For each conditions four specimens were tested. The average values obtained for the tensile strength are presented in Table 1. This Table presents results for three different temperatures. The increase in temperature produces a decrease in σ_{UTS}, especially for temperature above 60 °C. σ_{UTS} obtained at 100 °C is lesser about 25 % the σ_{UTS} obtained at 25 °C.

TABLE 1 - Tensile strength in MPa

Rate of strain loading(RSL) (s^{-1})	Temperature (°C)	Static strength (σ_{UTS}) (MPa)
0.008	25	310
0.008	60	261
0.008	100	233

RESULTS AND DISCUSSION

Fatigue results for glass fiber reinforced polypropylene composite are presented in 3PB and in tension for different frequencies, temperatures and stress ratio.

Fig. 2 presents the S-N curves obtained at 25 °C in tension and in 3PB at R=0 and frequency of 10 Hz. Also the S-N curve obtained in tension for 25 °C at R=0.25 and 10 Hz is plotted. The S-N curves show the stress range against the number of cycles to failure. Experimental points and the medium curve were plotted. As was expected the increase in R decreases the fatigue strength. For R=0.25 the fatigue strength is less (by about 18 %) than for R=0. A comparison between the S-N curves for bending and tensile shows that the fatigue strength in tension is nearly half that for 3PB.

Fig. 3 shows the influence of frequency on S-N curves at a temperature of 25 °C and R=0 in tension. Results for 2 and 10 Hz are plotted. As these results are very close the fatigue life seems to be unaffected by the frequency.in the range 2-10 Hz

The S-N curves at temperatures of 25 °C and 60 °C obtained in tension for the frequency of 10 Hz and at R=0 are plotted in Fig. 4a). This figure shows a decrease on fatigue strength (about 17 %) when the testing temperature increases from 25 °C to 60 °C. This fact is also reported in literature for other composite materials. Fig. 4b) plots the fatigue ratio against the number of cycles to failure referring to Fig. 4a). The fatigue ratio is defined by the ratio between the stress range and the value of σ_{UTS} obtained for the same temperature. In terms of the fatigue ratio the fatigue strength appears to be independent of the temperature (Fig. 4b).

The rise in temperature at the surface of the specimens was obtained for the fatigue tests carried out at room temperature. The value obtained was negligible for the specimens tested at 2 Hz. For the specimens tested at 10 Hz, the temperatures increases slowly both in bending and tension. The maximum value for both cases was obtained at failure. The range of values obtained for the rise in temperature at 10 Hz, was between 10 and 30 °C both in tension and bending. This value seems to increase with the stress range of the test. Fig. 5 summarizes some of the results obtained in tension at R=0.

For the majority of the tests, the variation of the Young's modulus during testing, was measured. Young's modulus was obtained plotting load against displacement. Fig. 6 gives the variations of the normalised modulus E/E_0 with the normalised number of cycles N/N_f for tests carried out at room temperature, for frequency of 10 Hz, tension mode and R=0.25. E_0 is the Young modulus at the start of the fatigue test and N_f the number of cycles to failure. The results obtained present a wide range both in bending and tension. The variations are smaller in bending where a stable decrease of E/E_0 was observed until nearly the failure. In tension (Fig. 6) an important decrease was observed in E/E_0 at the begin of the fatigue process. After this stage E/E_0 remained nearly constant until failure.

CONCLUSIONS

1- The fatigue strength of glass fiber reinforced polypropylene composites at room temperature in tension was nearly half that in bending.

2- Within the range 2-10 Hz the influence of the frequency on fatigue strength was negligible in tension at room temperature and R=0.

3- In tension and at 10 Hz important influences related to stress ratio and temperature were observed. At room temperature a significant decrease (18 %) of fatigue strength was observed when the stress ratio increased from 0 to 0.25. For R=0 a significant decreases in fatigue strength (17 %) occured when the test temperature increased from 25 to 60 °C.

4- At ambient temperature the damage defined in terms of loss of stiffness (E/E_0) started early in fatigue life. In bending the damage grew slowly until near the failure. In tension a sudden drop of E/E_0 (about 10 %) was observed during the first 10-20 % of the fatigue life and there after, remains nearly constant until failure.

5- Temperature rise on the surface specimens was negligible at 2 Hz. At 10 Hz the temperatures reached maximum values at failure and were in the range of 10-30 °C.

REFERENCES

(1) Sims, G., and Gladman, D., Plast. and Rubber: Mat and Appl.,1978, pp. 41-48.

(2) Spearing, M., Beaumont, P.W., Comp. Sci. Tech., Vol. 44, 1992, pp. 159-168.

(3) Joseph, E. and Perreux, D., Comp. Sci. Tech., Vol. 52, 1994, pp. 469-480.

(4) Echtermeyer, A.,T., Engh, B., and Buene, L., Composites, Vol. 26, No. 1, 1995, pp. 10-16.

(5) Czigany, T., and Karger-Kocsis, J., Pol. and Pol. Comp., Vol. 1, No. 5, 1993, pp. 329-339.

(6) Kadi, H., and Ellyin, F., Comp., Vol. 25, No. 10, 1994, pp. 917-924.

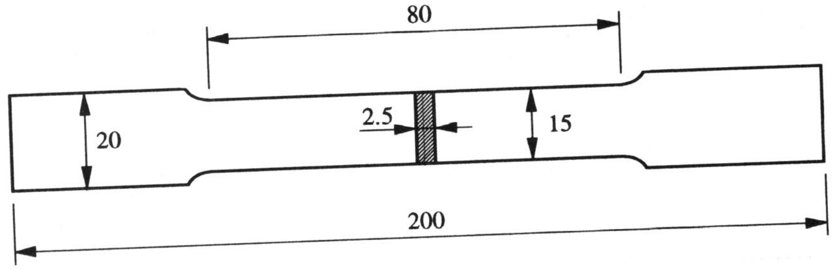

Figure1 Specimen for the tensile and fatigue tests (dimensions in mm)

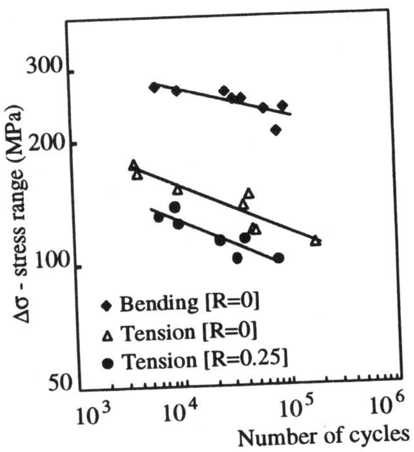

Figure 2 S-N curves for 3PB and tensile. T=25 °C. Frequency 10 Hz.

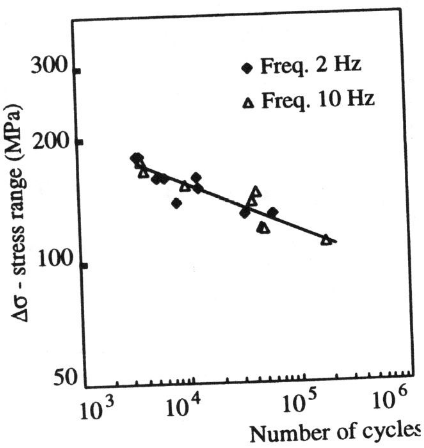

Figure 3 S-N curves for tension. R=0. T=25 °C. Frequencies 2 and 10 Hz.

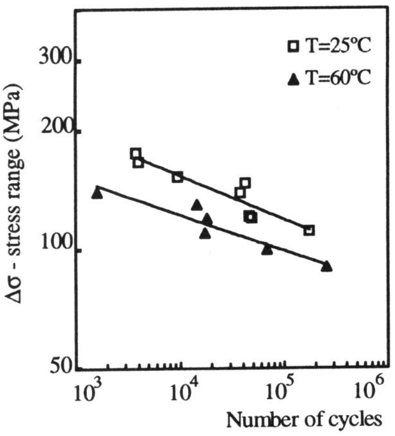

Figure 4a S-N curves for three point bending. R=0. Frequency 10 Hz.

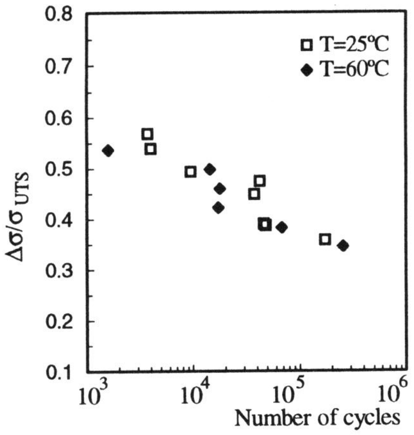

Figure 4b Fatigue ratio against life. R=0. Frequency 10 Hz.

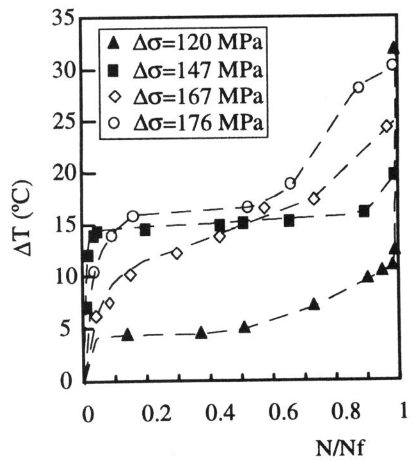

Figure 5 ΔT against the number of cycles. Tension. R=0. f=10 Hz.

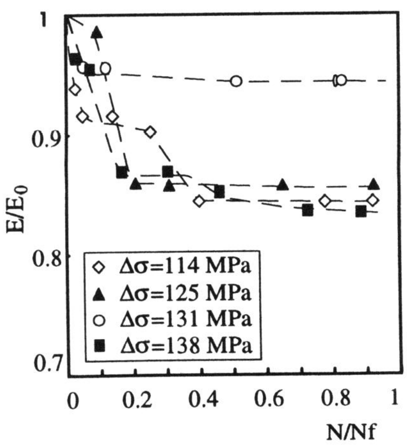

Figure 6 E/E_0 against N/N_f in tension. R=0.25. T=25 °C. f=10 Hz