FATIGUE OF FIBRE REINFORCED INJECTION MOULDED POLYAMIDE

J.J. Horst*

To be able to predict the fatigue lifetime of products more accurately, the correlation of fatigue performance with Ultimate Tensile Strength was investigated. The strength in a product varies from place to place, due to the complicated structure of the material, making exact prediction of fatigue strength of a product difficult. For both Low Cycle Fatigue as well as Crack Growth Measurements, the fatigue strength for a specific location in flat plates can be related to the tensile strength at that location, provided that the specimens are all of the same thickness. Experiments at various frequencies showed that the difference in results for different thicknesses disappears when lower frequencies are used.

INTRODUCTION

A characteristic of Fibre Reinforced Plastics (FRP) is their high degree of anisotropy, caused by fibre orientation. An injection moulded FRP plate has a layered structure. Orientation in the layers as well as the thickness of the layers can vary from place to place in the plate, and therefore the strength of the material varies through the plate. Result of this is that the strength of specimens cut from a plate can vary between 100 and 160 MPa, depending on the location from where they were cut, and the direction of the axis of the specimen relative to the Mould Flow Direction.

To be able to relate the fatigue behaviour to the tensile strength, we used four different specimen-types, with Ultimate Tensile Strength varying between 108 and 152 MPa. The specimens were obtained by cutting them from injection moulded plates in two directions and at different locations (Figure 1), and with these specimens both tensile tests as well as Low Cycle Fatigue tests were executed. The injection moulded plates also were used for crack growth measurements, using a central notch to initiate the crack. The load was applied

* Delft University of Technology, the Netherlands

transverse or longitudinal to the Mould Flow Direction, giving two different specimen types with different average strength.

EXPERIMENTAL

The material used was Polyamide 6 containing 30%wt. of glassfibres; Akulon K224-G6 provided by Akzo, Holland. Square plates of 100x100 mm and of 2 and 5.75 mm thickness were injection moulded from this. For the fatigue experiments non-standard dog-bone type test specimens were milled from the plate, using a Roland PNC-3000 Computer Aided Modelling Machine. The width of the narrow part was 10mm. In Figure 1 the location of the different specimen types are shown. The crack growth experiments were executed on the plates, with a notch of 16 mm length machined in the centre of the plate, perpendicular to the load direction. Crack growth was automatically monitored using a video and image analyzing system, coupled to a PC. The fatigue experiments were executed in a servo-hydraulic MTS bench, generally at a frequency of 2Hz, thought to be low enough to prevent heat build-up in the material. The minimum to maximum load ratio was 0.1. Temperature during testing was 23°C and relative humidity 50%. Specimens were conditioned by exposing them to laboratory air for about 1 year.

RESULTS

Results of the lifetime tests for the 5.75 mm thick specimens are shown in Figure 2. The number of cycles to failure is plotted on a logarithmic scale, and shows that log(N) is linearly related to the maximum stress, if this stress is between 90 and 60% of UTS of the specimen. When these S - N curves are normalized to the UTS in a tensile test (Figure 3) the data points for the different specimens all fit the same curve, especially in the linear area.

For the 2 mm plates, specimens with different water content were available, because of different conditioning prior to experiments. Higher water content of the specimen leads to a lower UTS, and also to a lower fatigue strength (at a certain number of cycles). When the stress in the fatigue experiment is normalized to the ultimate strength, the curves for the differently conditioned specimens coincide, as for thick plates of different orientation.

Results for 2 and 5.75 mm plates are not, by normalizing to ultimate strength, comparable. Obviously the thickness of the specimen has an effect on the mechanism in fatigue. To investigate the reason for this difference, and also to investigate the effect of the frequency on lifetime, experiments were done at different loading frequencies, using only one specimen type. In Figure 4 the results are shown. For 5.75 mm specimens the curve changes dramatically with changing frequency, with longer lifetimes at lower frequency, in the case of low loads. For high loads the lifetime is shorter at lower frequency. For 1 Hz the curve for 5.75 and 2 mm thick specimens coincide. For 2 mm thick specimens the influence of frequency seems to be present only at high loads (80% of UTS), for lower loads the lifetime hardly changes with frequency (not shown in the figure).

The normalization procedure was also executed for the beforementioned crack growth measurements, Figure 5. Crack growth is normally plotted as crack growth speed da/dN to stress intensity ΔK on a double logarithmic scale, where $\Delta K = (\sigma_{max}-\sigma_{min})\sqrt{\pi a} \cdot Y$, (with a = crack length and Y = geometry factor that compensates for the geometry of the specimen). The original curves show that the Paris Law is obeyed: $da/dN = A \cdot \Delta K^m$ with different values of A and m for the different directions. The curves shown in Figures 5 and 6 are averages of various measurements. Normalization was done by dividing the maximum and minimum stress by the UTS (measured on dog-bone specimens), valid for the material where the crack tip is located. The result of this is that the crack growth curves for cracks in Longitudinal and Transverse directions coincide, Figure 6. For different thicknesses a difference remains. Wyzgoski and Novak (1) used the Strain Energy Release Rate to obtain a similar normalization for cracks parallel and perpendicular to Mould Flow Direction. The difference is that normalization is done using the Elastic modulus to convert ΔK to ΔG, by $G = K^2/E$, instead of using UTS.

DISCUSSION

Fatigue lifetime at a certain stress level is directly related to the ultimate strength of specimens cut from different locations in a square plate, indicating that the variation in fibre orientation between different specimens does not lead to a change in failure mechanism. The same holds for specimens with different water content. This leads to the belief that this might be a more generally applicable concept in which fatigue for any specimen can be related, just by measuring its ultimate strength, to a "master curve" for fatigue. Further research should concentrate on investigating the conditions (temperature range, humidity, thickness, fibre fraction, fibre length) for which the "master curve" is valid.

The influence of frequency is very high, even at relatively low frequencies. The lifetime at 50% of UTS is 5 to 10 times higher at 1 Hz, as compared to 2 Hz. This is entirely different from other materials, where experiments can be executed at upto 10 Hz without the problem of hysteretic heating. This effect can be explained by the glass transition temperature of the amorphous phase of the semi-crystalline material. This is about 50 °C, in dry condition. The glass transition temperature is lowered when the material absorbs water, to 25-30 °C at equilibrium (ca. 2.5% water), so very close to the testing temperature. At the glass transition temperature a peak in damping exists, so the hysteretic heating in glass fibre reinforced Polyamide is relatively high. The consequence of this is that in testing (reinforced) polyamide, great care must be taken in assuring that conditions (temperature, water content of the specimen) are constant. Also the high damping, caused by the fact that the material is used very near to the glass transition temperature, causes the fatigue process to be very sensible to the frequency of loading.

The increasing fatigue lifetime with higher frequencies, that has been observed at high loads can be explained by a creep effect, as shown by Wyzgoski at al. (2) for unreinforced Polyamide 66. The creep effect is a time dominated effect that increases with increasing experiment time, so with decreasing frequency (at an equal number of cycles). With decreasing load this creep effect diminishes, and the heating effect increases relatively.

The reason for the difference in crack growth speed for thin and thick plates is not entirely known, the difference in stress state (more plain strain for the thick plate) as well as the higher ability for a thin plate to transport the dissipated heat to the environment will influence this. The crack growth speed for thin plates is higher as compared to thick plates. Lang and Manson (3), investigated crack tip heating in short-fibre reinforced composites and found that due to the temperature rise at the crack tip the material weakens, giving a crack blunting effect. This effect lowers the crack growth speed, and can in this way be responsable for the difference between thin and thick plates: the thin plates do not heat up to the same extent as the thick ones, because the heat is more rapidly transferred to the environment. Thus less crack tip blunting occurs in thin plates, and the crack growth speed is higher. By using lower loading frequencies, the difference between thick and thin plates should diminish.

REFERENCES

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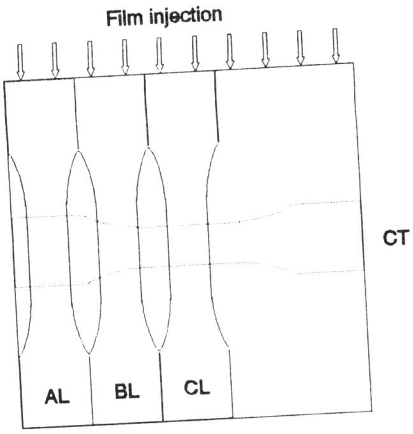

Figure 1 Location of the specimens in the original square plate.

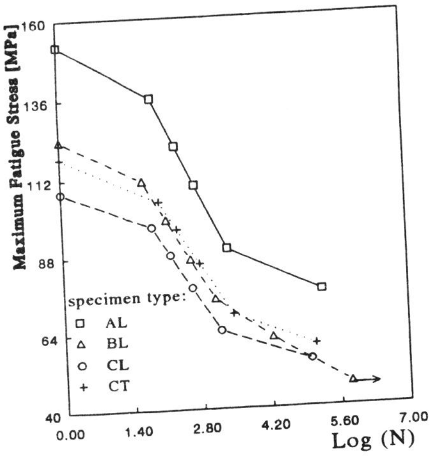

Figure 2 S-N curves for 4 different specimen types.

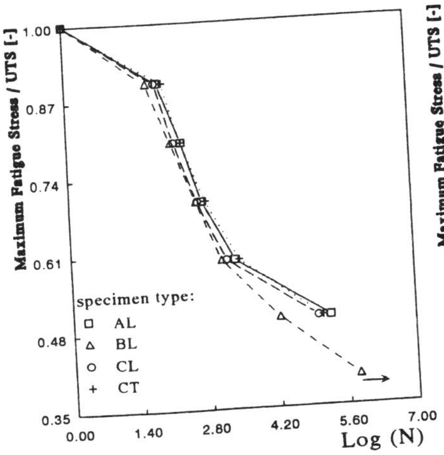

Figure 3 Normalized S-N curves for the same specimens as in Figure 3.

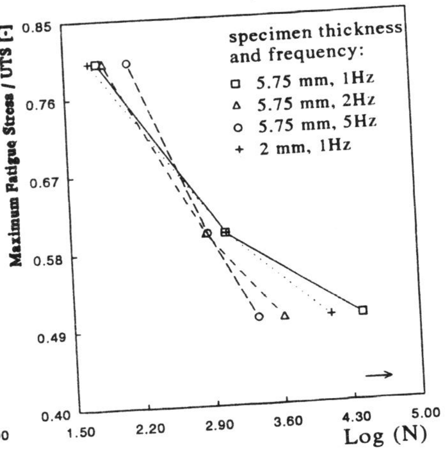

Figure 4 Influence of frequency on fatigue of the thick specimens.

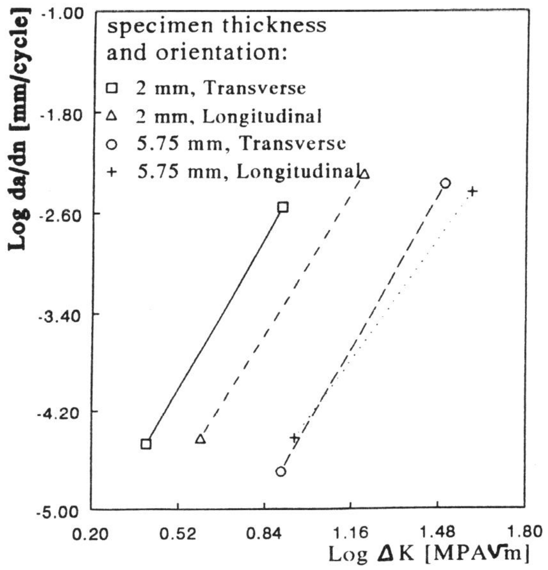

Figure 5 Crack growth curves for both thick and thin specimens.

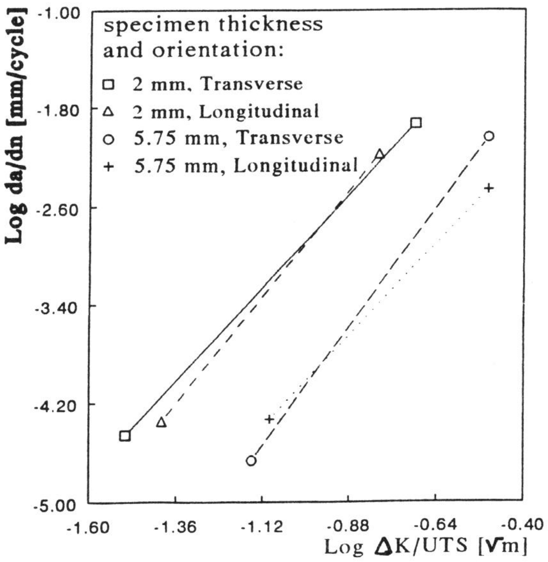

Figure 6 Normalized Crack growth curves for the same experiments. ΔK was normalized using the UTS at the crack tip.