ANALYSIS OF CRACK PROPAGATION DURING FATIGUE TESTS IN INJECTION MOULDED NOTCHED SPECIMENS MADE OF SHORT GLASS FIBRE REINFORCED POLYAMIDE

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Abstract
In this work, we present the results of fatigue tests on injection moulded, notched specimens made of short glass fibre reinforced polyamide 66, containing 50%w of fibres. Specimens have three different notch radii (2 mm, 1 mm and 0.5 mm). The local fibre orientation was assessed by analysing the fibre orientation distribution using the optical method. Crack nucleation and propagation was monitored during fatigue tests by microscope observations in back light conditions. This technique allowed for observing and measuring the crack length. The role of propagation was quantified and discussed, by comparison with data previously obtained using a lower amount of reinforcing fibres and PA 6 matrix. It appears that with a higher content of fibres, most of the fatigue test is spent in nucleating the cracks, while propagation takes places over the last few cycles. In previous tests, with 30% glass fibres and PA6 matrix, crack propagation was dominant (more than 50% of total fatigue life), particularly for a small notch root radius.

1. Introduction

In the context of fatigue of short fibre reinforced polymers, understanding the effect of stress concentrations due to geometry variations in injection-moulded parts is of great importance for the correct assessment of mechanical components. Short glass fibre reinforced polyamides are often used as metal replacement solutions. The role of notches in the fatigue behaviour of short fibre reinforced polyamides was studied in [1-6], by the stress-life approach, i.e. by reporting the number of cycles to failure vs. the applied load.

In [5], injection moulded specimens with two symmetric V notches, with three different notch tip radii, were used to study the fatigue behaviour of a polyamide 6 reinforced with 30% by weight glass fibres. During those tests, cracks propagating from the notch roots were observed and monitored. Results highlighted early start of the propagation phase, beginning at 15% of total life for the sharpest notch (0.5 mm radius) and at 50% for the larger notch tip radii. In this paper, we present results obtained with a polyamide 66 containing 50% by weight glass fibres using the same three notch tip radii, 0.5, 1 and 2mm.

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2. Experimental

2.1. Material, specimens and fatigue tests

The material investigated was a short glass fibre reinforced polyamide 6, containing 50% by weight of glass fibres (PA66GF50). The specimen shape and dimensions are shown in Fig. 1. The specimens had two lateral V-shaped notches symmetric with respect to the longitudinal mid-section of the specimen. They were injection moulding through an edge gate located at one end. The mould had interchangeable inserts so that three different notch tip radii could be obtained, namely 0.5, 1 and 2 mm, with the same net cross-section width equal to 30 mm. The material was tested in a conditioned state (23°C at 50% r.h.). Load controlled, fatigue tests were performed in the range of cycles to failure from 10^3 to 10^6 with a load ratio R = 0.1 (i.e. the ratio of minimum to maximum applied load). Load frequency was 4 Hz.

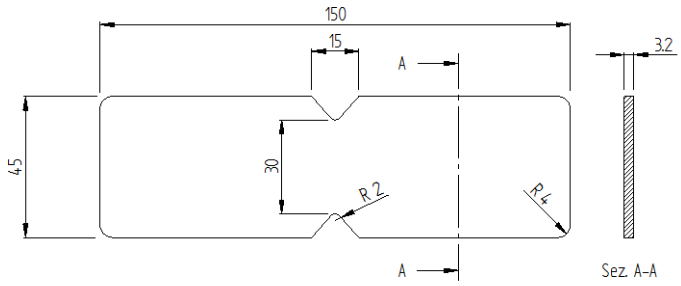

Figure 1. Specimen shape and dimension.

2.2. Analysis of fibre orientation distributions

Measurements of Fibre Orientation Distributions (FOD) were performed by means of the optical section method. 2D polished sections were taken from the gauge section area and then evaluated using an in-house image analysis facility developed at the University of Leeds [7, 8]. By measuring the ellipticity and the orientation of the major axis of the fibre footprints in the section plane, the two polar angles θ and ϕ that specify the orientation of each fibre.

Figure 2. Crack observation in back light configuration.

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2.3. Fatigue crack growth observations

During some of the fatigue tests, a travelling microscope was used with a back light configuration, as shown in Fig. 2, to identify cracks and monitor their propagation. Thanks to the partial transparency of the polyamide matrix, it was possible to highlight fatigue damage and locate its position. The fatigue damage appeared in the form of black areas, presumably due to plastic deformations of the matrix and fibre-matrix debonding, as shown in Fig. 3.

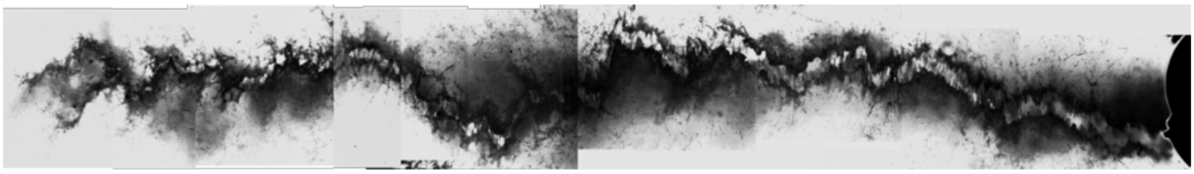

Figure 3. Image of a propagating crack.

3. Results and discussion

3.1 Results of FOD analysis

Results of FOD analysis can be displayed as a spatial grey scale map of the average value of a chosen second order tensor average (for instance $\langle\cos^2\theta_X\rangle$ as shown in Fig. 4). For this visualization, a white pixel indicates a high level of orientation with respect to the X-axis (which here is the flow direction) in that region. Average values of the three second order tensor averages over the scanned area through the thickness are then plotted as a function of the distance across the sample width (between the notches along the Y-axis). For this scan, one notch root is located at the left hand edge and the opposite notch at the right hand edge.

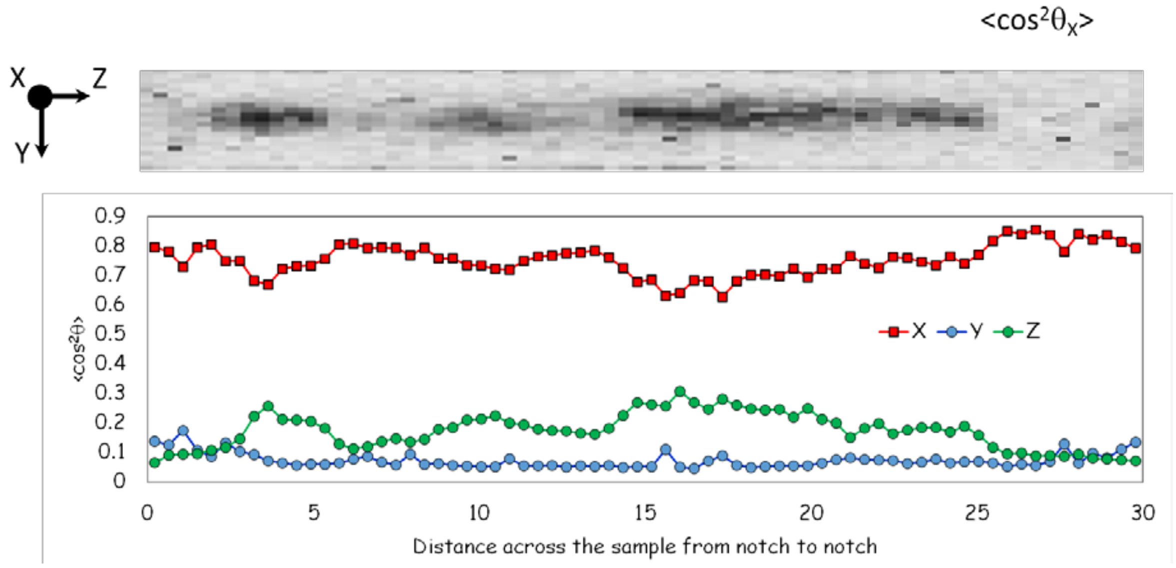

Figure 4. FOD in the gauge section (between the notches) of the sample with a 1 mm notch radius.

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In the specimen with a 1 mm notch tip radius, the FOD is characterized by a high degree of alignment of fibres along the X direction (perpendicular to the section plane, i.e. parallel to the specimen's axis) and by the absence of a core layer in proximity of the notch tips.
The other two specimens with different notch tip radii displayed practically the same FOD, as shown in Fig. 5 and 6, for the 2 mm and 0.5 mm case, respectively. It must be noted that in the specimens made of PA6GF30 used in [5], the specimen with 0.5 notch tip radius was characterized by a lower degree of alignment of fibres in proximity of the notches.

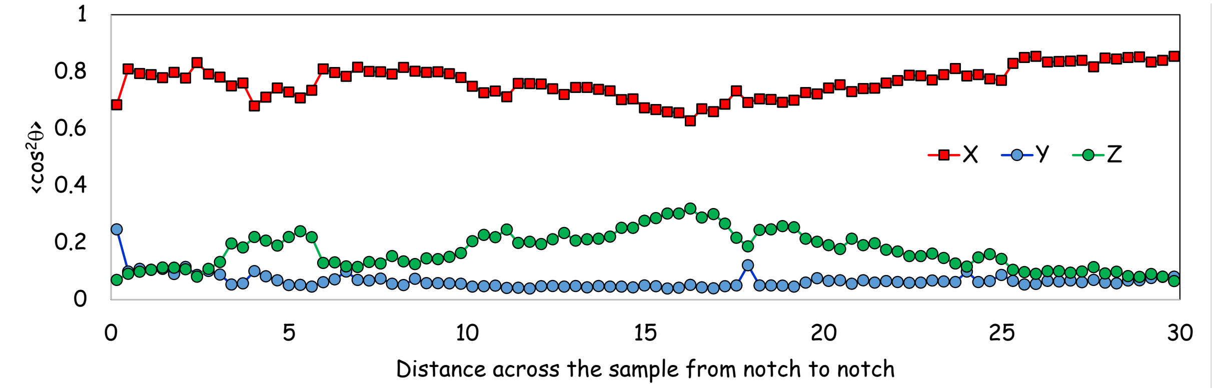

Figure 5. FOD in the gauge section of the sample with 2 mm notch radius.

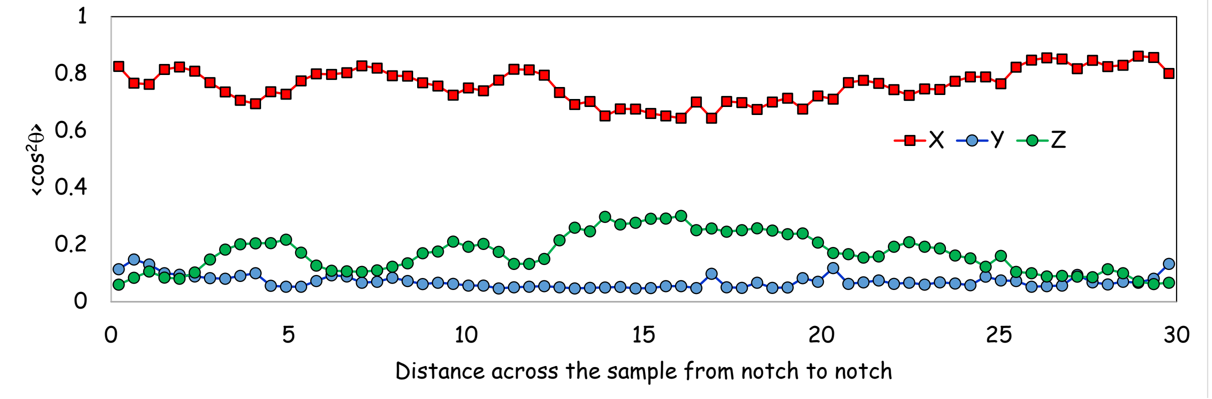

Figure 6. FOD in the gauge section of the sample with 0.5 mm notch radius.

3.1 Results of fatigue tests

Fatigue test results are reported in diagrams on log-log scales in Fig. 7, where values of the maximum applied nominal fatigue stress σ_{max}, i.e. the ratio of maximum applied load to the initial net area of the specimen cross-section, is plotted against the cycles to failure N_f. Values of σ_{max} are normalized, by dividing by the ultimate tensile strength of the material, obtained using un-notched ISO 527-2 type A specimens.

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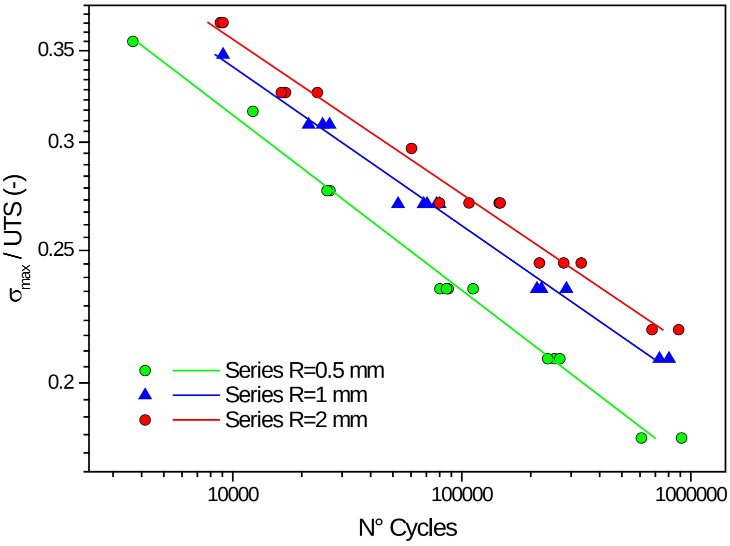

Figure 7. S-N curves of the specimens with three different notch tip radii

3.2 Results of fatigue crack propagation analyses

One specimen from each series with 0.5, 1 and 2 mm notch tip radii, respectively, was used for crack propagation analysis. Based on the S-N curves previously obtained, the applied load was chosen such that the expected number of cycle to failure was 100,000. The tests were interrupted every 1000 cycles up to 10,000 cycles, then every 5,000 cycles, to allow for crack observation. During crack observation, a load equal to the mean load was applied to open the crack faces and enhance visibility. The results of the observation of the fatigue crack propagation are reported in the graphs of Fig. 8, Fig. 9 and Fig.10 for the 0.5 mm, 1 mm and 2 mm specimen, respectively.

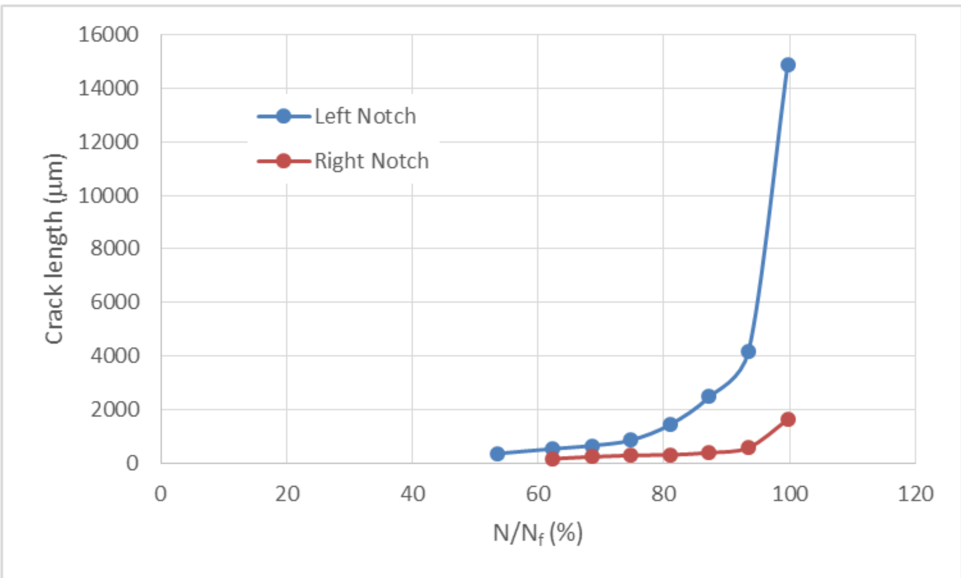

Figure 8. Crack propagation in the 0.5 mm specimen

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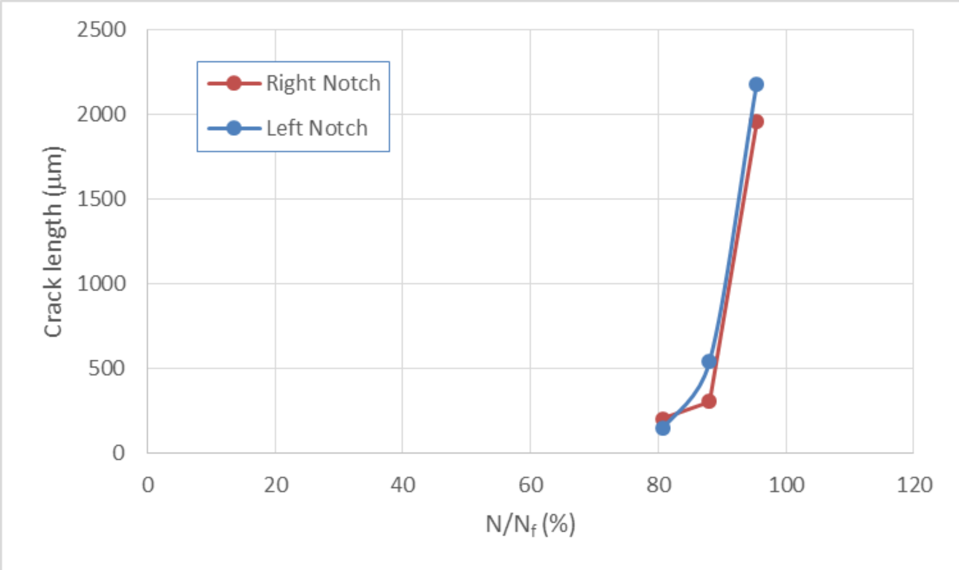

Figure 8. Crack propagation in the 1 mm specimen

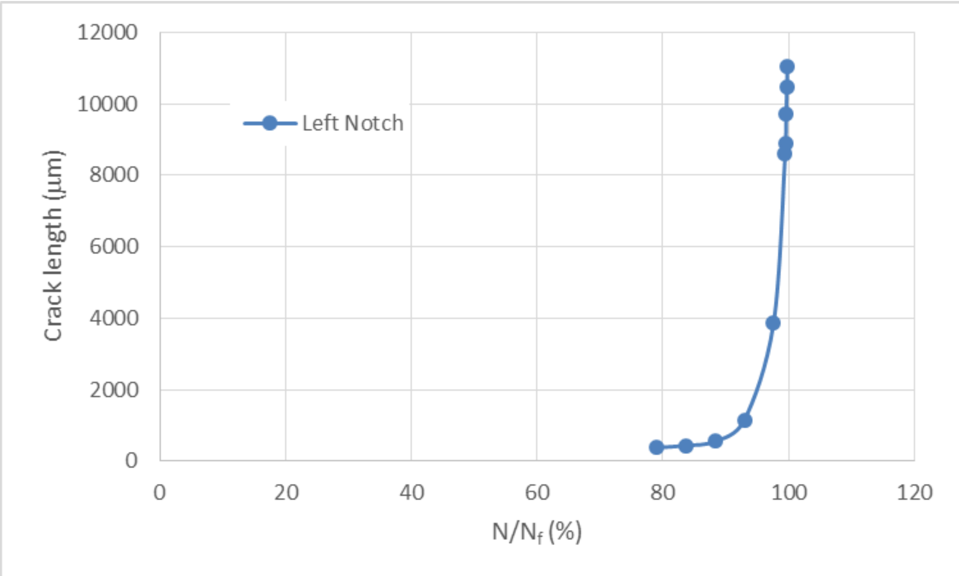

Figure 10. Crack propagation in the 2 mm specimen

In the 0.5 mm specimen, the first crack became visible (350 µm) at one of the notches after 50% of N_f, the specimen's life. It remained the dominant crack, although a second crack stemmed from the other notch after 60% of N_f but propagated more slowly.

In the 1 mm specimen, two cracks propagated almost simultaneously and at the same speed from both notches, but could be detected (200 µm) only after 80% of N_f. Also in the case of the 2 mm specimen a single crack was detected (400 µm) at 80% of N_f and propagated rapidly. In this case it was possible to monitor the crack propagation during the very last cycles, by observing the specimen every 100 cycles.

Compared with fatigue crack observations in the specimens made of polyamide 6 reinforced with 30%w glass fibres (PA6GF30), having the same geometry as those used for these experiments, it appears that in the case of notch radii greater or equal than 1 mm, cracks of detectable size appeared

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later in the case of PA66GF50 (80% of N_f) than in the case of PA6GF30 (40% of N_f). A similar trend can be observed in the case of 0.5 mm notches, although cracks appeared earlier than in the 1 mm and 2 mm cases. Crack propagation started at about 15% of N_f in the specimen made of PA6GF30 with 0.5 mm notch tip radius, while the same phenomenon was observed after 50% of N_f in the PA66GF50 specimen. This difference is likely to be related to the more unfavourable FOD at notches found in the PA6GF30 specimens, as shown in Fig. 9.

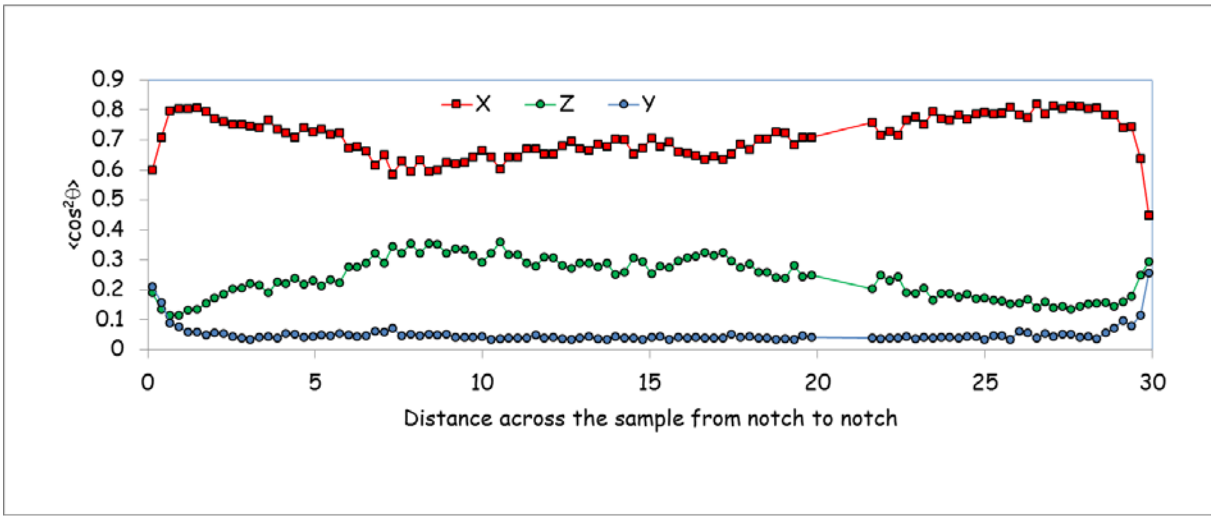

Figure 9. FOD in the 0.5 mm specimen made of PA6GF30 studied in [5]

4. Conclusions

Fatigue tests were conducted on notched specimens made of PA66GF50 and crack propagation was monitored in some specimens. Fibre orientation was also carefully measured throughout the whole gauge sections. The following conclusions can be drawn:

- fatigue crack propagation in notched specimens made of PA66GF50 begins later than in previously tested specimens made of PA6GF30, having the same geometry;
- the notch radius affects the relative (with respect to N_f) duration of crack propagation phase only for the smaller value of 0.5 mm
- part of the different behaviour of the specimens made of PA6GF30 tested in [5], particularly those with 0.5 mm notch tip radius, could be ascribed to the different FOD

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