Fatigue behaviour of short fibre reinforced polyamide: morphological and numerical analysis of fibre orientation effects

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ABSTRACT. The fatigue behaviour of injection moulded short fibre reinforced polymers depends upon fibre orientation, as shown in experiments conducted with notched specimens injected through different injection gates. The different fatigue behaviour is related to the different local elastic properties, as determined by the different fibre orientation patterns, resulting into different strain distributions. In order to quantify the relationship between fibre orientation and elastic constants, the Cell Method was applied to volumes extracted from the specimens, reconstructed by micro-tomography and results presented.

KEYWORDS. Composite; Elastic properties; Fatigue; Mil; Short Fibre.

INTRODUCTION

The mechanical behaviour of short fibre reinforced polymers (SFRP) strongly depends upon fibre orientation. Moreover, fibre orientation is related to the manufacturing process, usually injection moulding. During injection, fibres are dispersed into the molten matrix and their final orientation is the result of complex phenomena related to fluid mechanics, such as viscosity, velocity profiles, shear flow and interactions with mould walls.
In the perspective of metal replacement by SFRP, the importance of the fatigue behaviour is increasing. Like other mechanical properties, e.g. tensile modulus and strength, the fatigue behaviour depends upon fibre orientation. In the case of simple geometries and for short glass fibre reinforced (SGFR) polyamide 6, this dependence was experimentally investigated and expressed through a relationship derived from the Tsai-Hill criterion [1]. This relationship was verified for off-axis uniaxial tests on specimens extracted from injection moulded plates and assuming that mean fibre orientation coincided with the plate's axis. Real parts display a more complex geometry, and their fatigue strength is influenced by other factors like weld lines [2] and notches [3,4].
The importance of the manufacturing process is evidenced by the different fatigue behaviours which can be observed when notched specimens of same geometry are injection moulded through different gates [4]. This appears to be due to the different fibre orientation patterns obtained [5]. It is therefore important to be able to predict the fibre orientation in real parts, and to take into account of the effect of fibre orientation when modelling the material's behaviour, e.g. when performing finite element analysis. Commercial software packages exist, which allow for this operations. However, it is also necessary to define proper experimental methods to validate fibre orientation predictions, to characterize the micro structure and to relate fibre architecture to the mechanical properties of the material.
Recently, a novel technique based on micro-tomography 3D reconstruction of the fibre structure has been introduced and quantification of fibre orientation principal directions has been shown possible by means of a global parameter, the Mean Intercept Length (MIL) [6]. In this work, we examined by this method the local properties of material samples extracted from the specimens used to study the fatigue strength of the specimens used in [4, 5] (see Fig. 1) and the effect of

injection point location was analyzed both in light of fibre orientation and of the elastic properties computed by a micro-mechanical model based on the Cell Method, introduced in [7].

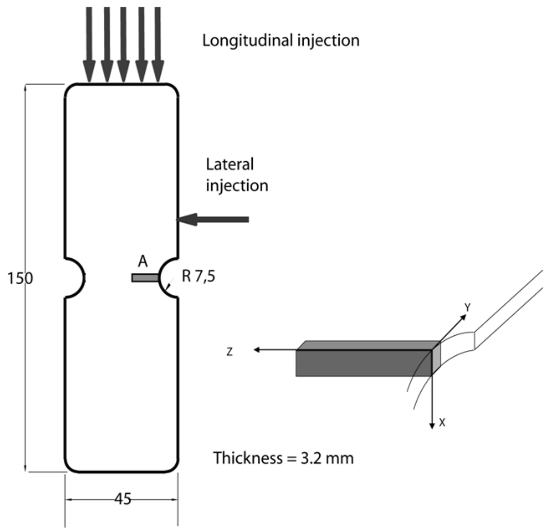

Figure 1: Specimens type, dimensions and injection gates; position of micro-CT examined samples.

EXPERIMENTAL RESULTS

The experimental results of the fatigue tests are shown in Fig. 2. It is clearly shown that longitudinal injection yielded higher fatigue strength than lateral injection. In order to investigate whether the observed variations in fatigue behaviour were related to differences in fibre orientation at notches as a consequence of the different injection points, samples extracted in the location A of Fig.1, close to the notch, were analyzed over a 5mm portion of the gauge section. Micro-CTs with a resolution of 9 μm were obtained at the SYRMEP beamline of Elettra synchrotron light source (Trieste, Italy) using Phase Contrast (PHC) imaging techniques. The core layer (mid plane) of each reconstructed sample was divided into a series of cubic Volumes Of Interest, VOI, 80x80x80 voxel^3, that were singularly analyzed (Fig.3).

The morphological characterization by MIL (using Quant3D software) is discussed in detail in [6]. Results are shown in Fig.4. It clearly appears that the location of the injection gate influences both the preferred fibre orientation angle and the index of anisotropy.

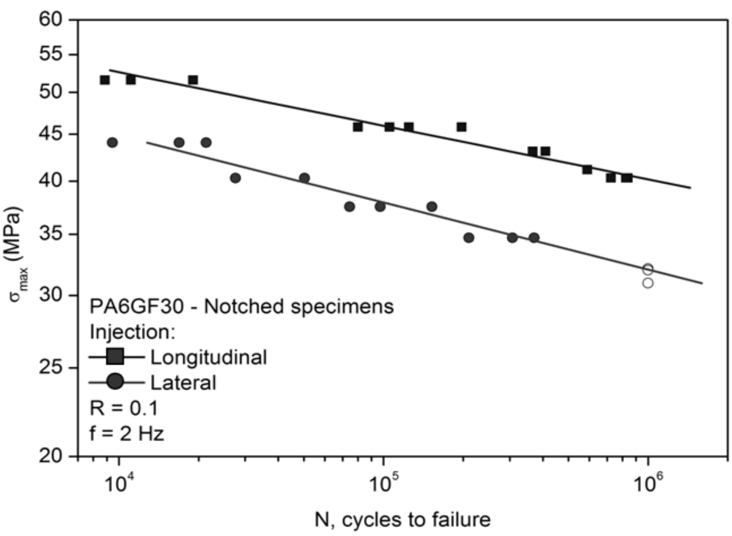

Figure 2: S-N curves for specimens with lateral notches.

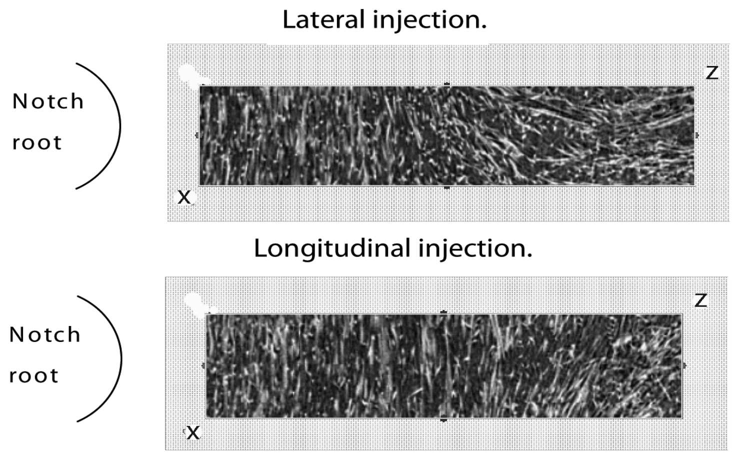

Figure 3: Lateral and longitudinal injection, point A, core layer: μ-CT reconstruction.

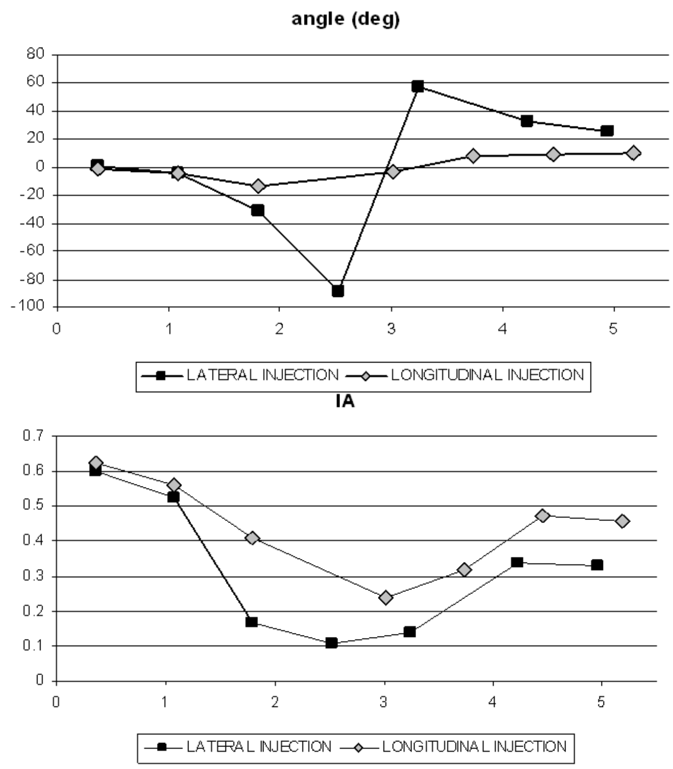

Figure 4: Preferred fibre orientation with respect to specimen y axis (above), and
Index of Anisotropy IA (below), at different z positions (mm), core layer.

The Cell Method model has already been used for this material in [8]. Material properties in each cell of a 812905 cells mesh were scaled based on the base material (matrix and glass fiber) properties and the apparent elastic moduli along the specimen axis (load direction in the fatigue tests) Ex were computed by simulation. Results are shown in Fig.5. It appears that the differences in mean fibre orientation and index of anisotropy shown in Fig. 4 result into different local values of the local elastic modulus Ex, as predicted by the Cell Method applied to the reconstructed micro-structure of the samples.
These results indicate that by this method it is possible to estimate the dependence of the local material's properties upon fibre orientation distribution. Further research is required in order to explain the different fatigue behaviour. However, based on these preliminary results, it is possible to infer that different local elastic properties can determine different strain distributions over the entire specimen (as observed by Digital Image Correlation measurements [6]) and consequently influence the fatigue behaviour.

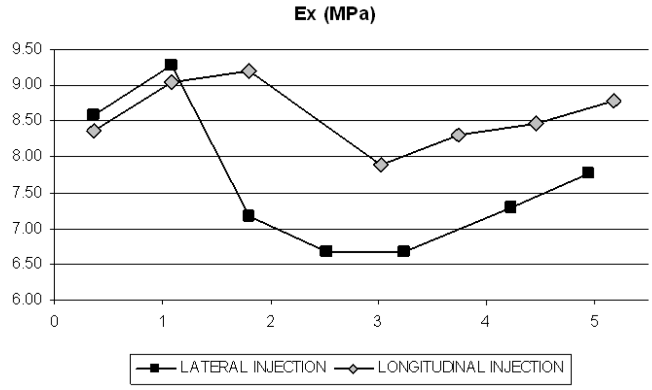

Figure 5: Apparent elastic modulus (MPa) along specimen x axis, at different z positions (mm), core layer.

CONCLUSIONS

Differences have been observed in the fatigue behaviour of short fibre reinforced polyamide notched specimens depending on injection point location. These experimental results might be attributed to different strain distributions due to variations of the local apparent elastic properties along the specimen section, which in turn are closely related to changes in fibre orientation occurring during the manufacturing process and consequently to different local elastic constants. In order to precisely quantify these effects, the Cell Method applied to the micro-structure reconstructed by micro tomography was successfully applied. Further investigation is needed to confirm these preliminary results.

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