20th International Conference on Composite Materials
Copenhagen, 19-24th July 2015

# TROUGH PROCESS MODELLING FOR THE FATIGUE LIFE ASSESSMENT OF INJECTED NOTCHED SAMPLES: DIFFERENT APPROACHES FOR THE FATIGUE CRITERION APPLICATION

C. Nadot-Martin[1], S. Castagnet[1], A. Bernasconi[2] and E. Conrado[2]

[1]Département Physique et Mécanique des Matériaux, Institut Pprime – CNRS – ENSMA – Université de Poitiers UPR 3346, Futuroscope Chasseneuil Cedex, France
Email: carole.nadot@ensma.fr, web page: http://www.pprime.fr

[2]Politecnico di Milano, Dipartimento di Meccanica, Milano, Italie
Email: andrea.bernasconi@polimi.it, web page: http://www.polimi.it

**Keywords:** PA6 GF30, Through Process Modelling, Fatigue criterion, Stress-strain gradients, Fibre orientation

## ABSTRACT

The study is based on a previously proposed methodology for multiaxial fatigue life assessment of injection-molded components (called 'Through Process Modelling' (TPM)). The TPM allows linking the injection process simulation to the fatigue life assessment with a fatigue criterion, through the computation of local fields in the part as a function of the variable fibre orientation. One of the major advantages of such an approach is to account for microstructure orientation influence, due to injection process, on fatigue life. Considering the good results obtained in previous works for standard samples, the aim of this work is to optimize the TPM for further efficient application on industrial parts. In this context an open issue concerns the way to apply the fatigue criterion in the presence of stress-strain gradients due to the complexity of the part geometry and induced microstructure. To this aim, two different averaging methods in order to apply the criterion (at the end of the TPM) will be compared. This will be done for injected notched specimens considered as intermediate components between standard samples and industrial parts. Results point out one of the major advantage of the TPM, namely its ability to predict the difference between the fatigue lives of variably injected samples with the same shape (i.e. with the same notch radius but different injection geometry).

## 1 INTRODUCTION

The automotive industry needs to reduce the weight of vehicles for environmental and economical purposes. One way to reach this goal is to use reinforced thermoplastics for the design of mechanical structures because of their high ratio "fatigue strength / density" compared with metallic materials. As in service failures must be avoided, fatigue characterization is necessary to optimize the design of thermoplastic parts.

A specific methodology for multiaxial fatigue life assessment of injection-molded components was previously proposed to this aim [1]. This approach is able to account for microstructure orientation influence, due to injection process, on fatigue life. The TPM has been previously validated by using as a reference a large multiaxial fatigue database for PBT-PET GF30 and PA66 GF35 involving injection-molded standard specimens under various fatigue loadings (tension, torsion, combined tension-torsion, pure shear). Very good results were obtained for both materials with an energetic fatigue criterion [2].using only one S-N line under tension for the identification.

For further correct employment of the TPM to industrial parts for which the complexity of the geometry and induced microstructure may generate important stress-strain gradients, it is now essential to optimize the way to apply the fatigue criterion used at the end of the TPM. The analysis is here performed on injected notched samples submitted to fatigue tensile tests with a load ratio of R= 0.1. Two different injection gates (longitudinal and side) are considered as well as three different notch radius values 0.5 mm, 1 mm and 2 mm.

## 2 INJECTION-MOLDED NOTCHED SAMPLES AND FATIGUE TESTS

A Polyamide 6 containing 30% mass short glass fibres (PA6 GF30) is investigated. Notched samples have been injection-molded with two different injection gates (longitudinal and side) as depicted in Fig. 1 (left). Three different notch tip radii are considered (0.5 mm, 1 mm and 2 mm). Thickness is 3.2 mm for every specimen. All specimens are conditioned using standard conditions of 23°C and 50% relative humidity.

Fig. 1 displays the vertical component of the orientation tensor obtained from Moldflow® simulations for longitudinally (center) and laterally (right) injected samples. As well-known now, short fibre reinforced thermoplastics exhibit a multilayer microstructure; in Fig. 1, information is given in the middle layer in the flat specimens. Maps clearly illustrate that the local orientation is significantly different for both processes, especially in the notch tip area. Whatever the injection method, orientation at the notch tip is dissymmetrical.

Every type of notched specimens is submitted to tensile fatigue tests with a load ratio of R= 0.1 and a 4 Hz frequency. The tests are force controlled and the signal wave force is sinusoidal.

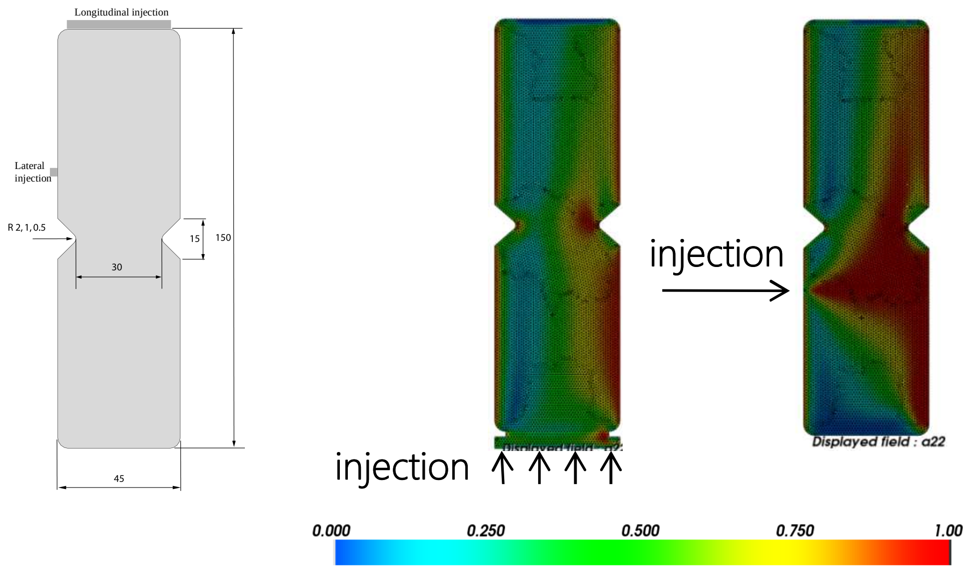


Figure 1: Sample geometry (left) and vertical component of the orientation tensor in the medium layer of longitudinally (center) and laterally (right) injected notched specimens (Moldflow®).

## 3 DESCRIPTION OF THE TPM

Injection process simulation (in the present case, conducted with Moldflow® software) provides the orientation tensor at each point of the part. Then, Digimat® software is employed to link the injection simulation to the Finite Element analysis of the part (in the present case, conducted with Abaqus® software). More precisely, Digimat® allows transferring the orientation tensor from the Moldflow® mesh to the Abaqus® mesh on the one hand, and computing the local effective elastic properties at each point of the part on the other hand. This latter calculation is done with a two steps homogenization procedure based on the Mori-Tanaka scheme and an orthotropic closure approximation.

From the effective elastic properties thus calculated at each point, the loading parameters and the boundary conditions, the elastic response of the part can be computed.

Finally, mechanical fields as a function of local fibre orientation are used as input data for the fatigue lifetime criterion. The principle of the TPM is illustrated in Fig. 2.

The type of the fatigue criterion, as well as the way of applying it (average method over the thickness, “hot spot” method,…), are distinct issues from the TPM method itself. Both can be customized within the TPM framework. Different fatigue criteria using only one S-N line for the identification were compared for un-notched specimens. The energetic criterion due to [2] was shown to give very good results, see [1] for details.

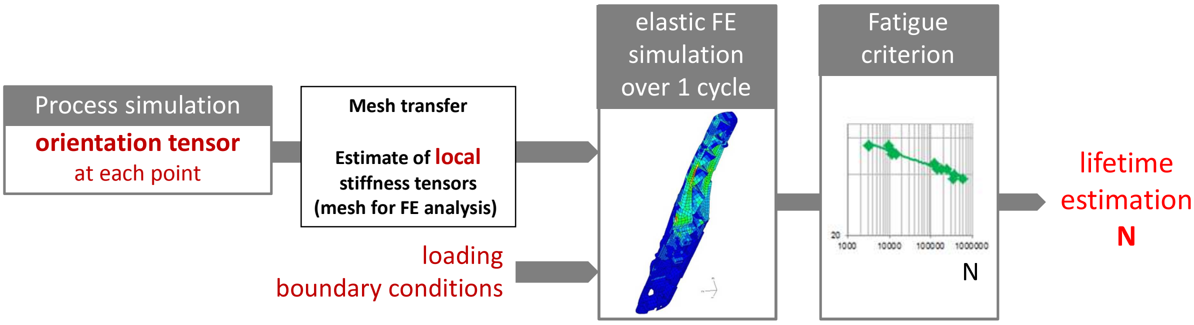


Figure 2: Through Process Modelling (TPM) approach, [1].

## 4 RESULTS FOR NOTCHED SAMPLES

In the present work, the energetic criterion due to [2] is maintained.

The way of applying the fatigue criterion in the case of high stress and/or strain gradients –and more precisely that of computing the equivalent mechanical parameter involved in the fatigue criterion– constitutes an open issue. Indeed, the averaging process over the thickness of each FE element used in [1] is relevant for un-notched specimens in which mechanical field gradient is mainly due to microstructure gradient through the thickness. But here, the notch induces out-of-plane gradients too.

In this context two different averaging methods in order to apply the criterion (at the end of the TPM) will be compared for notched samples described in Section 2 (with 3 different notch radii and 2 different injection gates), namely in the presence of a wide range of stress-strain gradients which are representative of those encountered in industrial components. Moreover, maps of the orientation tensors for each notch radius and injection direction allow a better understanding of such field gradients (influence of the severity of the notch for a given injection direction and of the microstructure orientation for a given notch radius). As an illustration, the longitudinal stress component is mapped in the middle layer of the specimen for a given notch radius of 2mm and the two injection geometries (Fig. 3). In both cases, a difference can be observed between the two notch tips, consistently with the orientation dissymmetry pointed out in Fig. 1. In addition to the dissymmetry, the maps are different for the two injection geometries. These observations result from the microstructure orientation which is different in the two cases even if the applied load and the shape of the samples are the same. A major interest of our approach is to be able to predict the difference between the S-N lines of both type of samples, as illustrated in Fig. 4 for a given notch radius of 2mm. This would be impossible without taking into account fibre orientation to compute the mechanical equivalent parameter involved in the fatigue criterion.

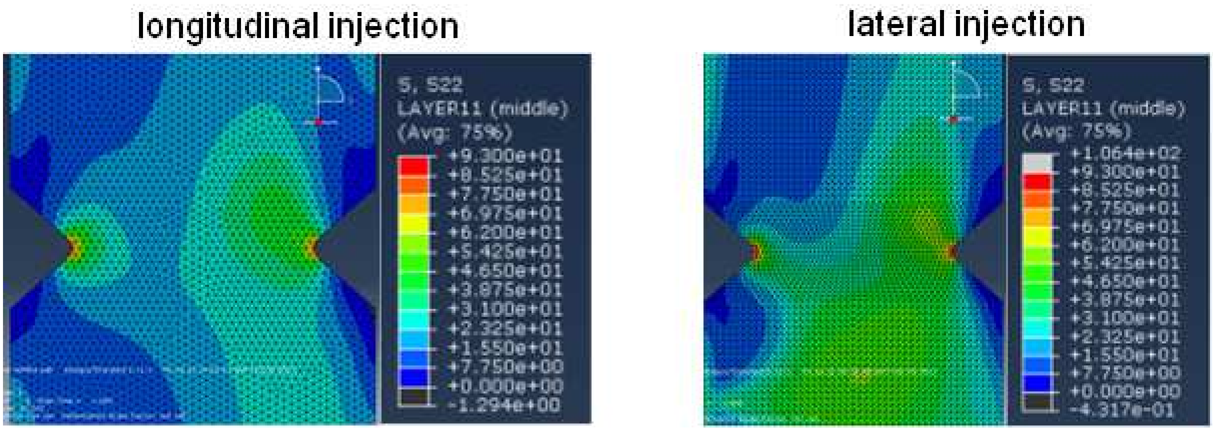


Figure 3: Difference of longitudinal elastic stress fields calculated in the middle layer for the longitudinally (left) and laterally (right) injected specimens (corresponding to the orientation maps given in Fig. 1).

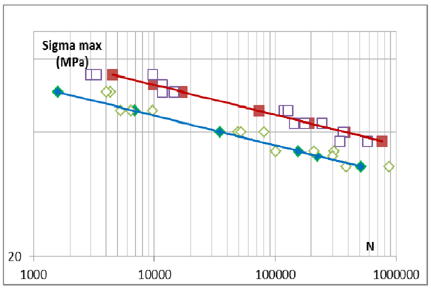


Figure 4: Simulated S-N lines for the longitudinally (red) and laterally (blue) injected specimens.

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