THROUGH PROCESS MODELING FOR THE FATIGUE LIFE ASSESSMENT OF NOTCHED INJECTION-MOLDED SPECIMENS

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Abstract

The study is based on a previously proposed methodology for multiaxial fatigue life assessment of injection-molded components (called 'Through Process Modeling' (TPM)). The present contribution focuses on stress concentration effects induced in notched samples. Purely macroscopic approaches are unable to capture the different mechanical responses of variably injected parts with the same shape. A high interest of the present method is to take into account the difference of fiber orientation resulting from the process. After briefly reminding the TPM method, it will be shown that good lifetime estimations are obtained for laterally injected samples, from a fatigue criterion identification based on longitudinally injected ones.

1. Introduction

Reducing vehicles weight is a huge challenge for automotive industry. Reinforced thermoplastics can offer interesting alternate solutions –especially because of their interesting "fatigue strength / density" ratio– provided that reliable prediction tools can be used to design structure components. To avoid in-service failures, fatigue characterization and relevant fatigue criteria are needed. In the case of short-fiber reinforced thermoplastics, a key issue deals with taking into account the orientation effect of fillers. One way is to formulate anisotropic fatigue criteria inspired from laminated composites. They very often require several S-N curves for identification. An alternate method is the 'Through Process Modeling' (TPM) approach we proposed a few years ago [1]. It 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 fiber orientation at each point of the part. The relevance of the TPM has been previously discussed based on a large multiaxial fatigue database for PBT-PET GF30 and PA66 GF35 in standard injection-molded samples and various fatigue loadings (tension, torsion, combined tension-torsion, pure shear). Very good results were obtained for both materials with an energetic fatigue criterion using only one S-N line under tension for the identification.

Industrial parts display complex geometry with possibly high stress concentration areas. These regions coincide with highly disordered fiber orientations. The relative effect of macroscopic stress concentration and fiber disorientation on fatigue life is not clear. A major interest of our approach is to be able to distinguish both effects. An evaluation of the TPM method is presented here in flat injected notched specimens.

2. Injection-molded notched samples and fatigue tests

A Polyamide 6 containing 30% mass short glass fibers (PA6 GF30) is investigated here. 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 in the study (0.5 mm, 1 mm and 2 mm). Results given in the present paper will only concern the 2mm notch tip radius. Thickness is 3.2 mm for all specimens. All specimens are conditioned using standard conditions of 23°C and 50% relative humidity.
Figure 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 fiber reinforced thermoplastics exhibit a multilayer microstructure; in Figure 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.

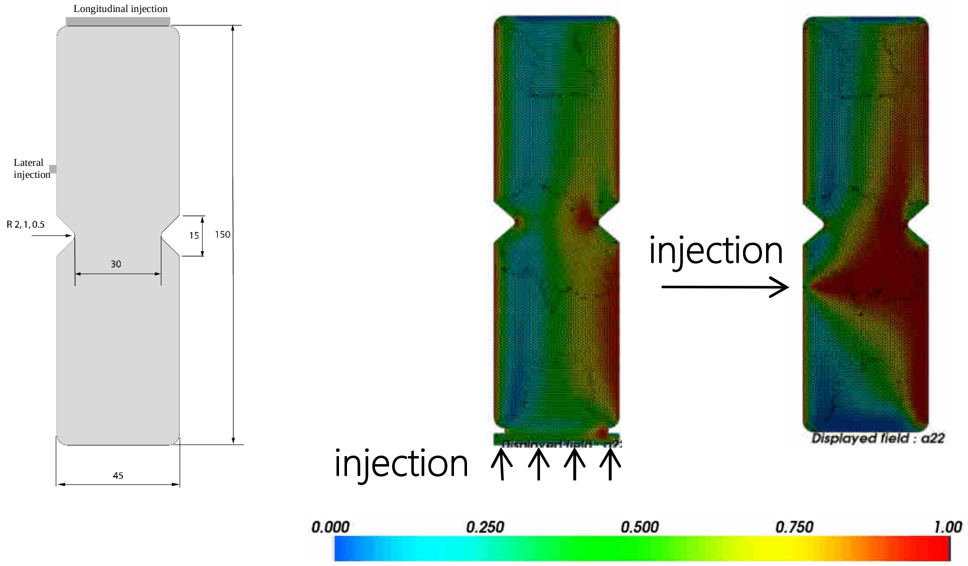

Figure 1. Sample geometry (left) and **f**ields of the vertical component of the orientation tensor in the medium layer of longitudinally (center) and laterally (right) injected notched specimens (Moldflow®)

3. Results

3.1 Short description of the TPM method

Fig. 1 summarizes the TPM methodology as proposed by [1] for injected components.

Injection process simulations (in the present case, conducted with Moldflow® software) provide the fiber orientation tensor at each point of the part. After transferring this information into the final mesh of the Finite Element Code (in our case, Abaqus® software), the local effective elastic properties are estimated at each point of the part, from a Mori-Tanaka method. In our case, these two steps are performed using Digimat® software.

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 (in our case, from the Finite Element software Abaqus®).

Finally, mechanical fields as a function of local fiber orientation are used as input data for the fatigue lifetime criterion. The type of the fatigue criterion, as well as the way of applying it (average method over the thickness or "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 in un-notched specimens. The energetic criterion due [2] was shown to give very good results.

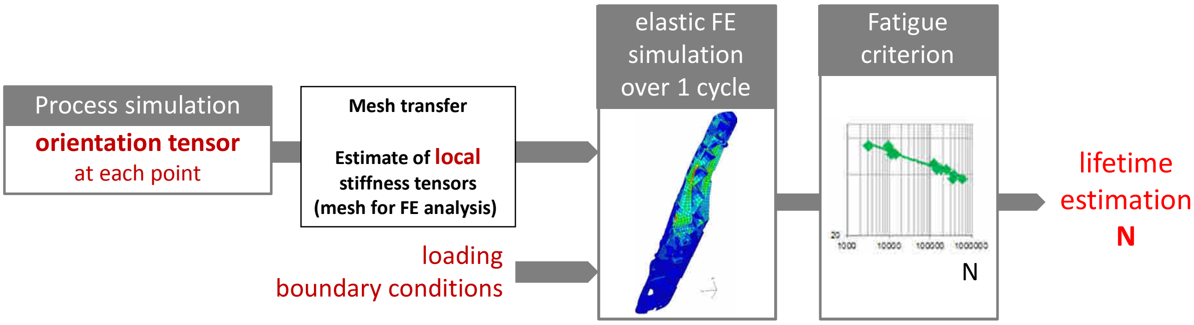

Figure 2. Overview of the Through Process Modelling (TPM) approach

3.2 Application to notched samples

In the present work, the energetic criterion due to [2] is maintained. Several identification strategies can be used to identify the fatigue criterion parameters, in un-notched specimens or differently injected notched ones. In the present example, parameters of the fatigue criterion were identified from one single S-N curve in longitudinally injected samples.

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– will be discussed. Indeed, the averaging process over the thickness of each element is relevant for un-notched specimens in which mechanical field gradient are mainly due to microstructure gradients through the thickness. But here, the notch induces out-of-plane gradients too.

An indication of the consequence of orientation on the local stress field at the notch tip is given in Figure 3. The longitudinal stress component is mapped in the middle layer of the specimen. For each specimen, slight differences can be observed between the two notch tips, consistently with the orientation dissymmetry pointed out in Figure 1.

Maps of the orientation tensors for each notch radius and injection direction allows 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).

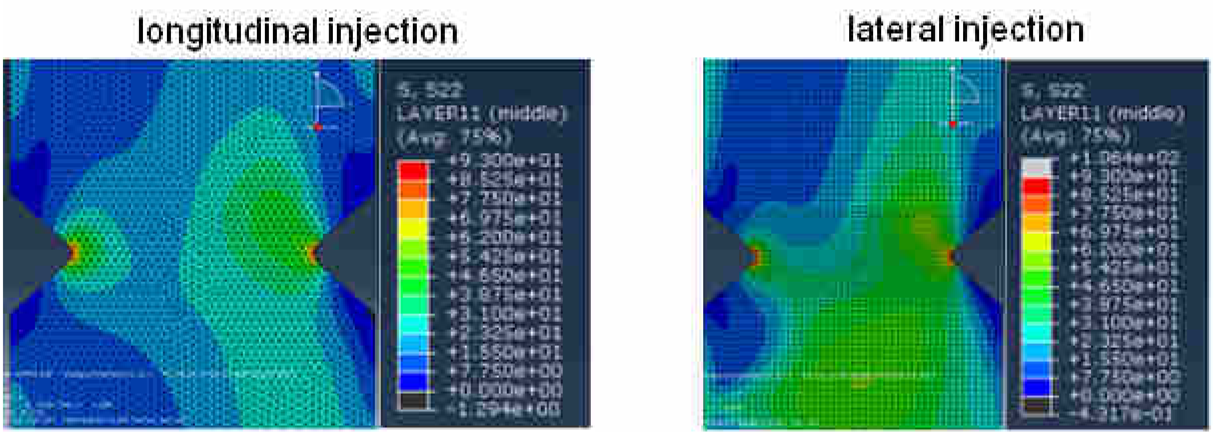

Figure 3. Difference of longitudinal elastic stress fields calculated in the middle layer for the longitudinally (left) and laterally (right) injected specimens (corresponding to the orientation maps given in Figure 1)

Figure 4 displays the number of cycles to failure estimated from the TPM, as a function of the experimental values, for laterally injected samples. The straight curve stands for the perfect prediction. Good conservative lifetime estimations are obtained.

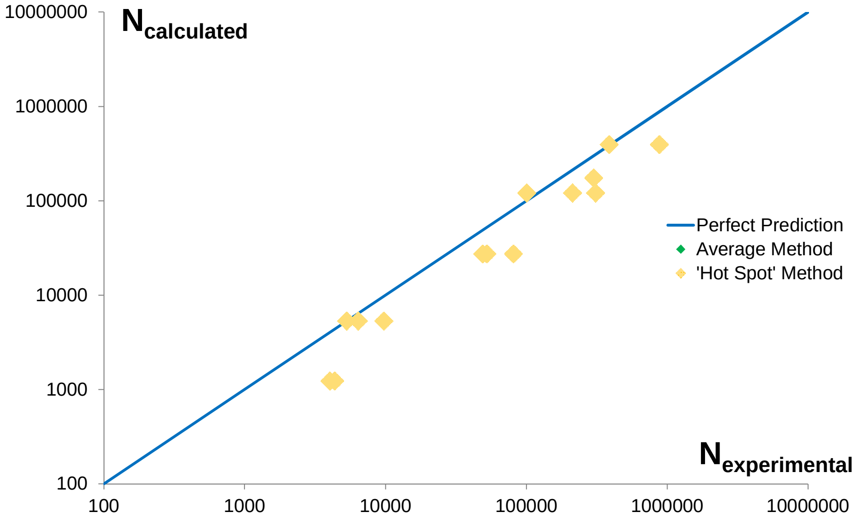

Figure 4. Validation of lifetime estimation in laterally injected samples

References

[1] B. Klimkeit, Y. Nadot , S. Castagnet, C. Nadot-Martin, C. Dumas, S. Bergamo, M.C. Sonsino, A. Buter. Multiaxial fatigue life assessment for reinforced polymers. *International Journal of Fatigue*, 33, 766-780, 2011.

[2] D. Kujawski, F. Ellyin. A unified approach to mean stress effect on fatigue threshold conditions. *International Journal of Fatigue*, 17, 101-106, 1995.