MICROSTRUCTURAL AND EXPERIMENTAL ANALYSIS OF STRAIN RATE EFFECT FOR SHORT GLASS FIBER REINFORCED POLYPROPYLENE

Nadia Achour Renault[a], Fodil Meraghni[*,a], Laurent Peltier[a], Joseph Fitoussi[b]

[a]*LEM3-UMR 7239 CNRS, Arts et Métiers ParisTech Metz-Lorraine, 4 Rue Augustin Fresnel 57078 Metz, France*
[b]*Arts et Métiers ParisTech, PIMM - UMR CNRS 8006, 151 Boulevard de L'Hôpital, Paris 75013, France*

Abstract

The scope of this work is to study glass fiber reinforced polypropylene composites in low and high speed loading test in tension, interrupted tension, bi tension and shear. This kind of composites are commonly used in automotive industry, for structural components, in particular due to their capability to absorb energy. This study investigates the strain rate effect and the damage evolution on glass fiber reinforced PP. The glass fiber content of the material varies in the range between 0 and 60wt%. High speed loadings have been performed from quasi static to $300s^{-1}$ strain rate. To minimize the amplitude of measurement perturbation, the specimen dimension geometry has been optimized by experimental-computational procedure using finite element modeling developed for the four load case. High speed tests are conducted on

*Corresponding author. Tel.: +33(0)387375459, Fax: +33(0)387374284
Email address: `fodil.meraghni@ensam.eu` (Fodil Meraghni)

Preprint submitted to Journal *May 28, 2015*

a servo-hydraulic machine. A high speed camera allows to follow the deformation of the surface of specimens. Strain evolutions are determined by contact-less measurements (Digital Image Correlation and labels following). Damage evolution is analyzed at microscopic and macroscopic scale: the influence of micro-structure and strain rate on the damage mechanisms is studied. The material micro-structure specific to the injection molding process and damage mechanisms are analyzed by both SEM and X-ray tomography observations.Moreover, they are correlated with the macroscopic response of the composites submitted to high speed loadings mentioned above.

1. introduction

Polymeric composite are more and more used in automotive industry (Brooks, 2000) .One of the main challenges for these materials is to increase the energy absorption properties of the structural components to ensure the integrity of the cockpit and passenger safety (Ramakrishna, 1997). It is in this context of innovation that the study of the mechanical behavior of composite materials and structures under moderate dynamic loads becomes essential. Indeed, there is an increased need for constitutive laws that can integrate physical degradation kinetics dynamics and variability of the micro-structure of these materials. This work, wich is the first step of the development of a micromechanical model based on Mori Tanaka scheme, is a detailed analysis of the micro-structure and the experimental behavior of the composite both under static and moderated dynamic loading cases. Thus this manuscript is structured as follows : first the material and it's micro-structure analyzed by X- ray Tomography will be presented. Then, an overview of the tensile tests at low and high speed loading results is presented and the last part demonstrates the equi bi tensile test at low speed.

2. Micro-structural analysis

The material studied here is an injection molded composite composed by polypropylene and short fibers. The composite glass transition temperature is Tg=0°C. The particular structureof 3 layershas been obtained by the injection process and it is shown by X-ray tomography on figure 2.In order to analyze the effect of fiber concentration in the micro-structure,experimental study is performed in polypropylene with 0% (PPGF00), 30% (PPGF30), 40%(PPGF40) and 60% (PPGF60) of glass fiber. The X ray tomography allowed us to evaluate the spatial disposition of glass fiber in the composite. As we can see in the figure 1 for the PPGF40 the fibers are more concentrated in the middle layer. The size of this layer is dependent on the total fiber concentration in the material : for the PPGF60 the middle layer size corresponds to 35%of the total size while the middle layer of PPGF40 corresponds to 20% of the total size.

3. Experimental tensile tests

High speed loadings have been performed from quasi static to 258s^{-1} strain rate on glass fiber reinforced polypropylene.Tests have been conduced on polypropylene matrix(PPGF00), polypropylene reinforced with 30%wt. (PPGF30), 40%wt.(PPGF40), and 60%wt (PPGF60) of glass fiber. To minimize the amplitude of measurement perturbation, the specimen dimension

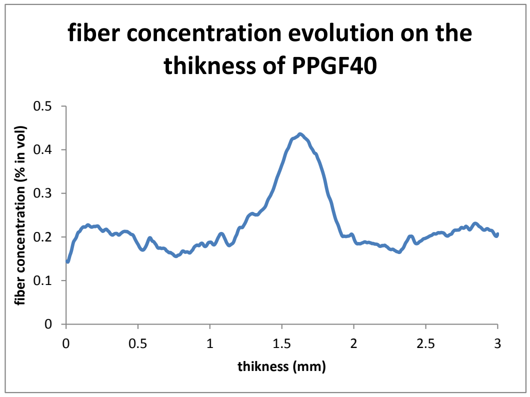

Figure 1: fiber concentration in volume through the thickness

geometry is optimized by experimental-computational procedure using finite element modeling presented here after.

3.1. Specimen optimization

The aim of this optimization is to obtain the specimen dimensions which allow to reach a strain rate of 150 to $200s^{-1}$ and minimize the amplitude of measurement perturbation. The methodology used here, developed by Fitoussi and al (J. Fitoussi, 2005), (Jendli et al., 2009), consist in both using a damping joint to limit the shock waves and simulating the experimental tests by varying the specimen geometry in order to reach a uniform deformation of $200s^{-1}$ in the specimen central area.

3.2. High speed tensile tests

High speed tensile tests are conducted on a servo-hydraulic machine. A high speed camera allows to follow the deformation of the surface of speci-

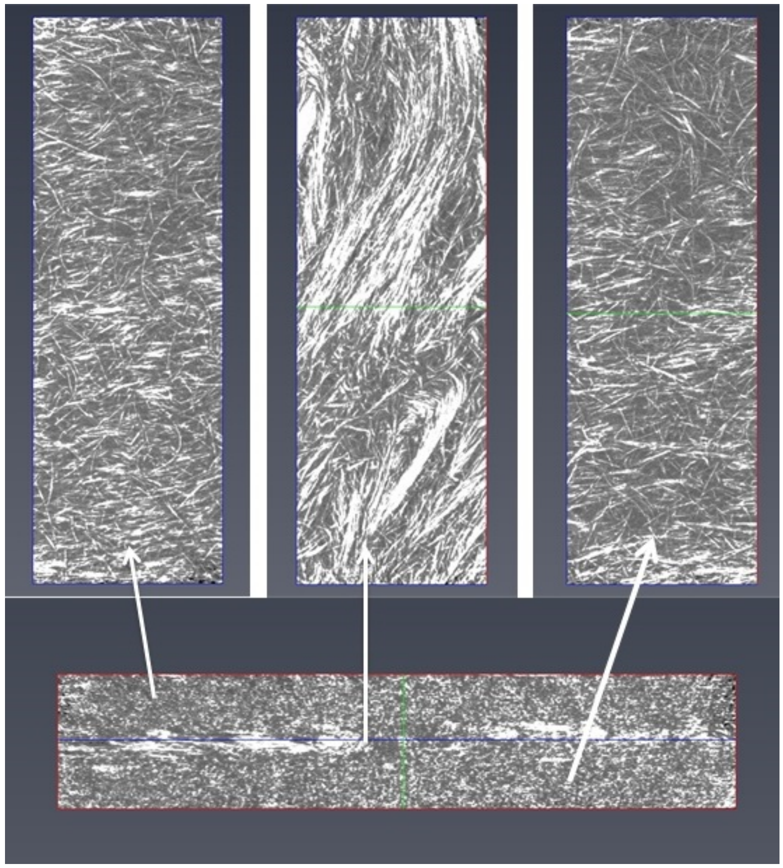

Figure 2: micro-structure of PPGF40 observed on X-ray tomography

mens. Strain evolutions are determined by contact-less measurements (Digital Image Correlation for quasi static and labels following for the others).

As we can see on the example of $\boldsymbol{\sigma} - \boldsymbol{\varepsilon}$ diagram from the figure 3, the overall behavior of the glass fiber reinforced polypropylene vary significantly compared to low strain rate loading. The young modulus is calculated by linear regression on the linear part of the curves. Strain rate has an important influence on the composite behavior, in particular on the composite Young

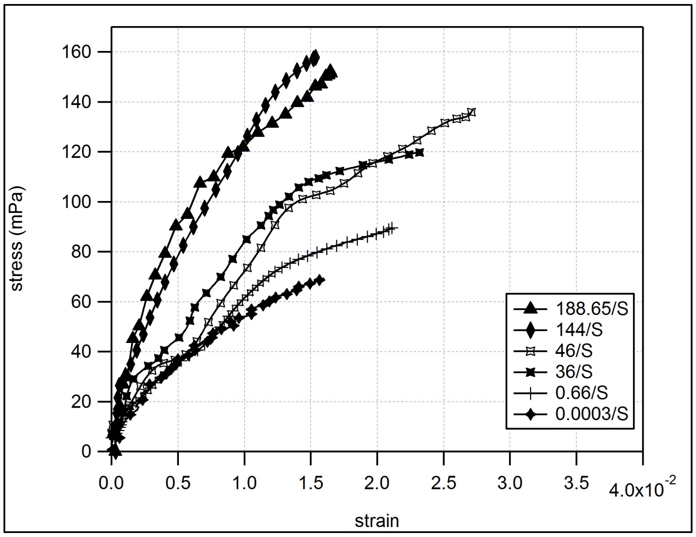

Figure 3: PPGF40 behavior at different strain rates on flow direction

modulus, the maximum stress and the threshold stress between the linear and non linear regions. In the case of the pure matrix (PPGF00) the strain rate increase involves an increase of the yielding and a decrease of the ultimate strain. The ultimate stress is also expanded but the Young modulus is not affected by the strain rate.

Figure 4 shows the evolution of Young modulus for glass fiber reinforced polypropylene at 40% . One can observe that when the strain rate increases, the Young modulus increases. The total response is characterized by two steps : a low increase until a strain rate deformation of $80s^{-1}$ and a high one above the a strain rate of $80s^{-1}$.

Figure 5 shows the constraints thresholds evolution for glass fiber reinforced polypropylene at 40% . One can observe that the strain rate has the same effect as in the case of the Young modulus : the constraint thresholds

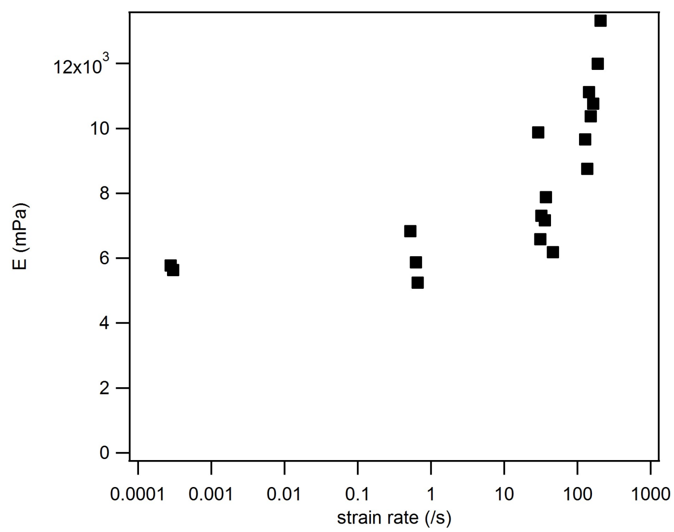

Figure 4: evolution of the Young modulus with the strain rate for the PPGF40 on the flow direction

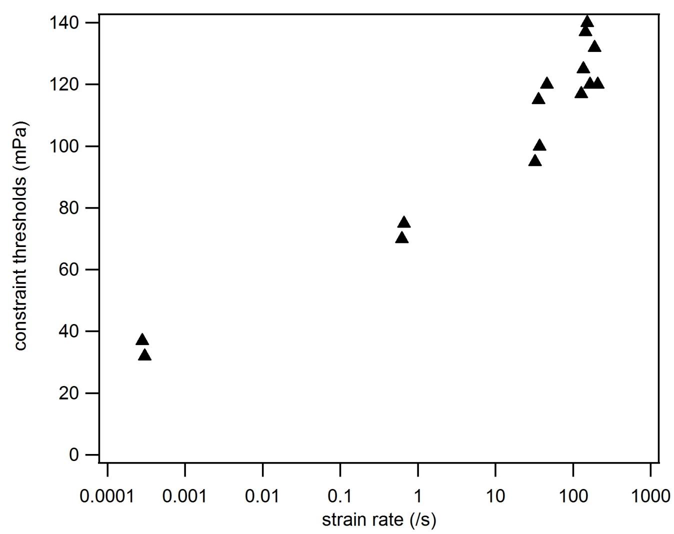

Figure 5: Evolution of the stress thresholds with the strain rate for the PPGF40 on the flow direction

increase with the strain rate and this increase is more significant for strain rates above $80s^{-1}$.

4. Experimental bi-tensile test

Bi-tensile test have been conduced on the glass fiber reinforced polypropylene at 30%, 40%, and 60%. Tests have been driven in displacement. a stretching of 0.1mm.s^{-1} is imposed in the two directions. the deformation field evolution is presented in figure 6.

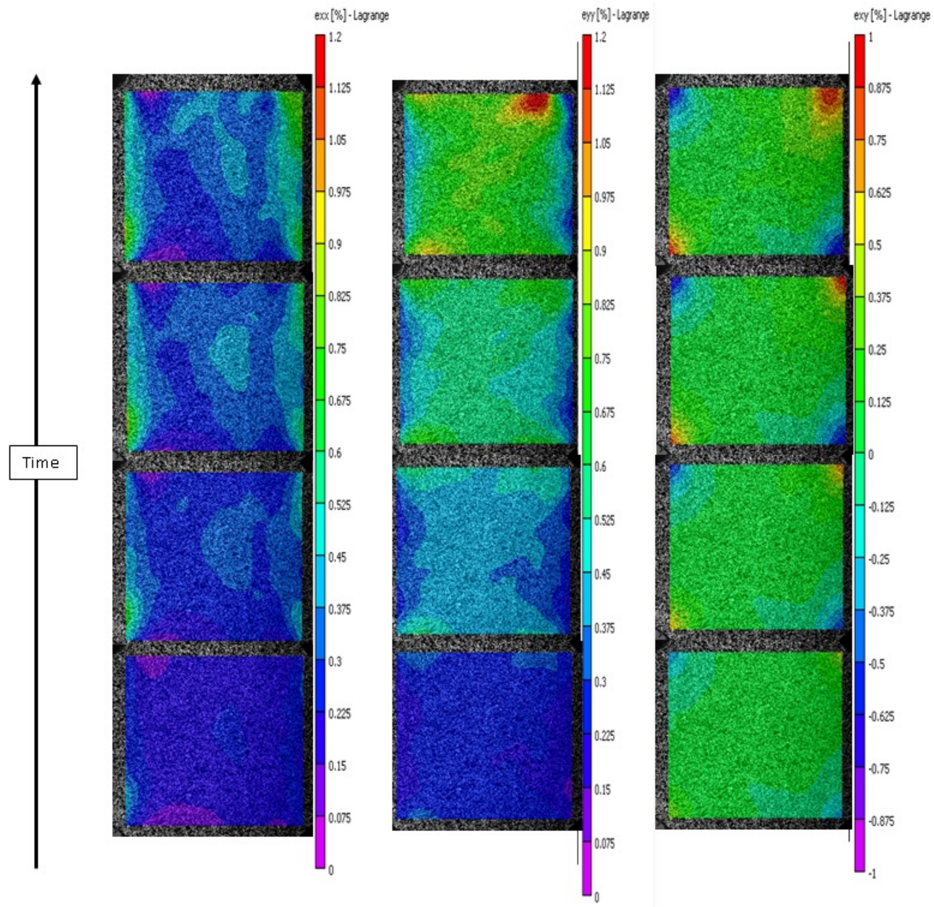

Figure 6: evolution of the deformation field in a biaxial tensile test for the PPGF40

5. Conclusion

This paper presented an overview of the micro-structure and a part of the experimental characterization of a glass fiber reinforced polypropylene. This work is the first step of the development of a micro-mechanical constitutive law integrating the micro-structural effects. The composite micro-structure observed is a typical one for an injection molded composite with 3 major layers whose size depends on the fiber concentration. The high speed tensile tests have permitted to observe the effect of the variation of the strain rate on the composite behavior for different concentrations of fibers. The threshold stress and the Young modulus are very closely related to the strain rate in both the pure matrix and the composite. For the Young modulus, this evolution is even more pronounced when the strain rate exceeds $80s^{-1}$. Finally, bi-tensile tests have been conduced on composite at two strain rates to evaluate the material behavior in a multidirectional case. These results will allow us to develop, identify and validate a micro-mechanical model based on Mori-Tanaka homogenization scheme.

References

Brooks, R., 2000. Composites in automotive application design. Comprehensive Composite Materials 6, 341–363.

J. Fitoussi, F. Meraghni b, Z. J. G. H. D. B., 2005. Experimental methodology for high strain-rates tensile behaviour analysis of polymer matrix composites. Composites Science and Technology 65, 2174–2188.

Jendli, Z., Meraghni, F., Fitoussi, J., Baptist, D., 2009. Multi-scales modelling of dynamic behaviour for discontinuous fibre SMC composites. Composites Science and Technology 69 (1), 97–103.

Ramakrishna, S., 1997. Microstructural design of composite materials for crashworthy applications. Material Design 18, 167–173.