Design & CAE Group Europe

CAE Support to the Design of Parts made of GF-PP*

(*Glass Fiber- Reinforced Polypropylene)

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Abstract

Glass fiber reinforced polypropylene (GF-PP) materials are replacing metal and engineering polymers in automotive structural applications. Like all glass fiber reinforced thermoplastics, GF-PP products can show anisotropy caused by fiber orientation induced by the injection process. Taking into account fiber orientation in the simulations allows the designers to improve the accuracy of the analyses and can avoid some arbitrary choices needed when using an isotropic material law.

Two methods are here presented:

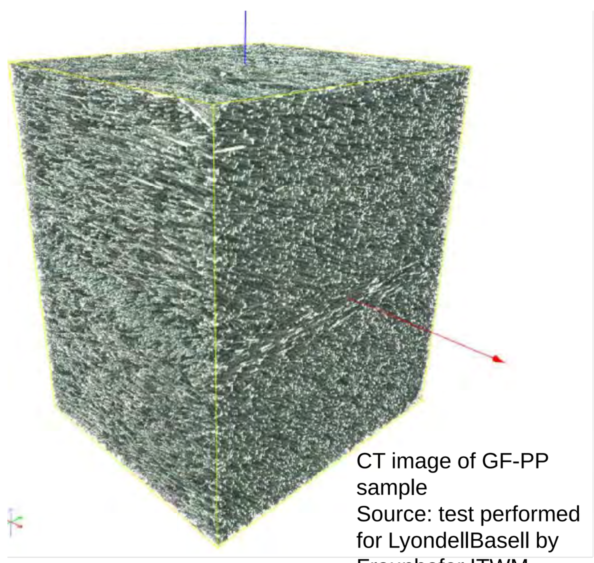
- A first approach is based on micromechanical modeling through homogenization methods available from commercial software (Digimat®). This allows coupling of the structural analysis with the fiber orientation, which is obtained from the numerical simulation of the injection process.
- The authors developed a simplified approach where the presence of the reinforcing glass fibers is kept into account using an orthotropic material law. Here the reference directions are given by the material flow direction, which can be obtained from a moldfilling analysis.

Both the approaches request very simple tensile tests for the determination of the model parameters.

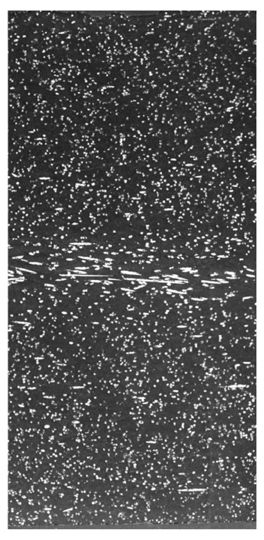
In the design phase, the choice of either approach will depend on the problem to be studied, on the resources and timing available, and on the desired accuracy.

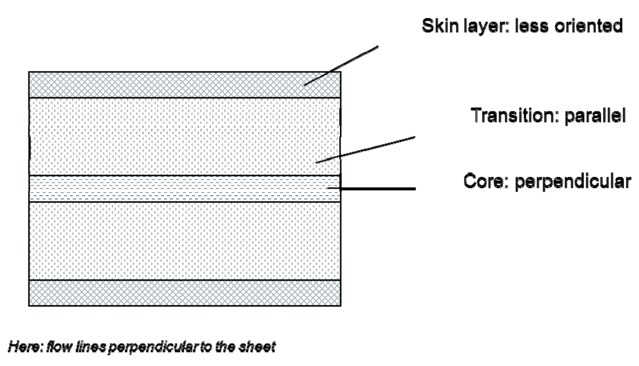
Material Structure

In a multi-phase material such as SGF-PP, the mechanical properties depend on the constitutive properties of the base materials and the composite morphology, i.e., the weight fraction, length, diameter and orientation of the fibers. These properties are induced by material processing, as in the case of injection molding. Here, a classical skin-core structure is observed and, depending on the thickness, can be more or less pronounced. Along the material thickness, a central portion, or "core", is characterized by fiber orientations perpendicular to the flow, and a lateral portion is characterized by fiber orientations parallel to the flow.



CT image of GF-PP sample
Source: test performed for LyondellBasell by Fraunhofer ITWM





Method based on Micromechanical Modeling

Two-scale models are used with a macro-scale associated to the part and a micro-scale associated to the material microstructure. The transition between the two scales can be accomplished through a homogenization process. In this case, fiber content, geometry and fiber distribution, together with the matrix properties, are the required parameters.

Fundamental items of this approach are then:

Prediction of Fiber orientation, transferred to the structural mesh

Dedicated software as Digimat®-MAP by e-Xstream are used to map the fiber orientation, predicted by moldfilling analysis onto a Mid-plane TRI mesh, into a shell – QUAD mesh (Fig. a below)

The fiber orientation is predicted using a transport equation for the orientation tensor components aij . Appropriate parameters – as the fiber interaction coefficient Ci - must be determined. This is a critical point: a validation phase is mandatory for reliable predictions. Here a comparison with measurement from X-ray tomography is shown (Fig. b, below)

$$\frac{Da_{ij}}{Dt} = -\frac{1}{2}\left(\omega_{ik}a_{kj} - a_{ik}\omega_{kj}\right) + \frac{\lambda}{2}\left(\dot{\gamma}_{ik}a_{kj} + a_{ik}\dot{\gamma}_{kj} - 2\left[a_{ijkl} + \left(1-\frac{1}{SRF}\right)\left(L_{ijkl} - M_{ijmn}a_{mnkl}\right)\right]\dot{\gamma}_{k}\right) + 2\frac{C_I}{SRF}\dot{\gamma}\left(\delta_{ij} - (3)a_{ij}\right)$$

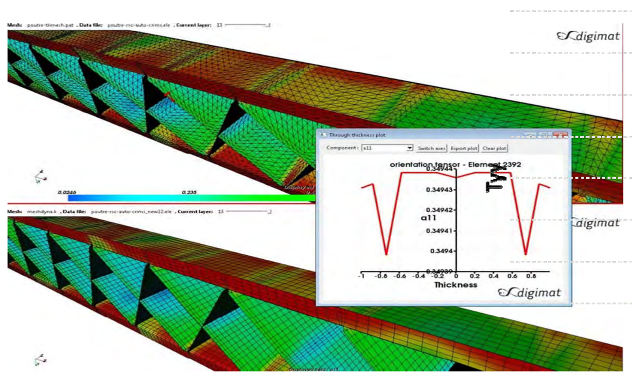


Fig. a: Orientation tensor mapped from the TRI mesh used in moldfilling analysis to the QUAD mesh used in structural calculations

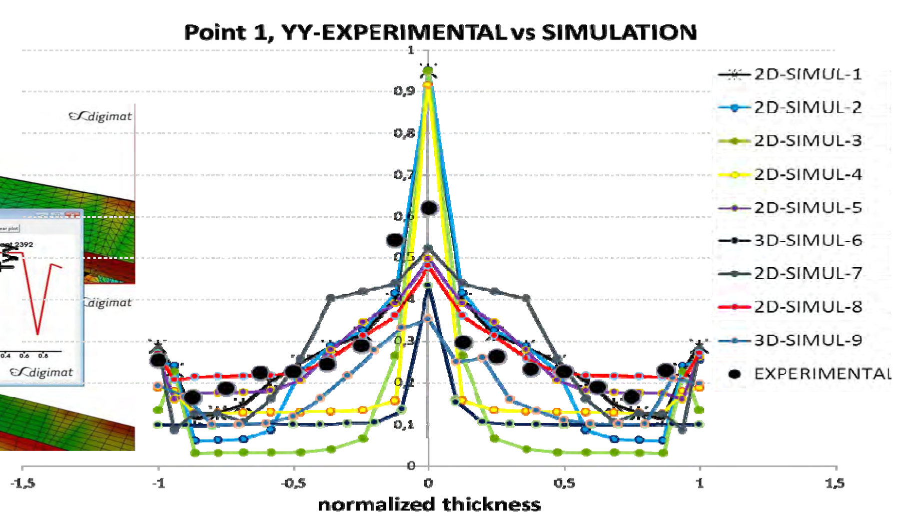


Fig. b: Comparison between orientation tensor values predicted and measured on a GF-PP sample

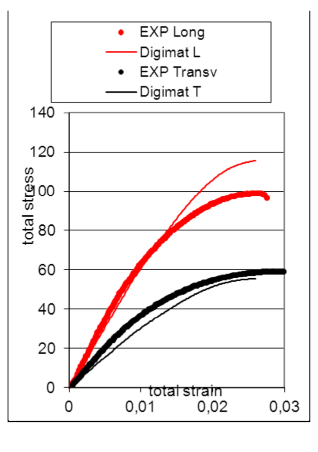


Fig. c: Comparison between measured and simulated tensile stress-strain curves on specimens cut from a plaque along different orientations

Material laws based on Homogenization method

Mean field homogenization software – like Digimat® – are used to predict the non linear constitutive behavior of a multi-phase material, combining the characteristics of each single phase into an homogenized law for the composite.

Parameter identification through optimization

Reverse Engineering is used by simulating the tensile test on specimens cut from injection molded plaques along to different orientations with respect to the flow to identify the material law parameters (Fig. c above).

Simplified method based on orthotropic material laws

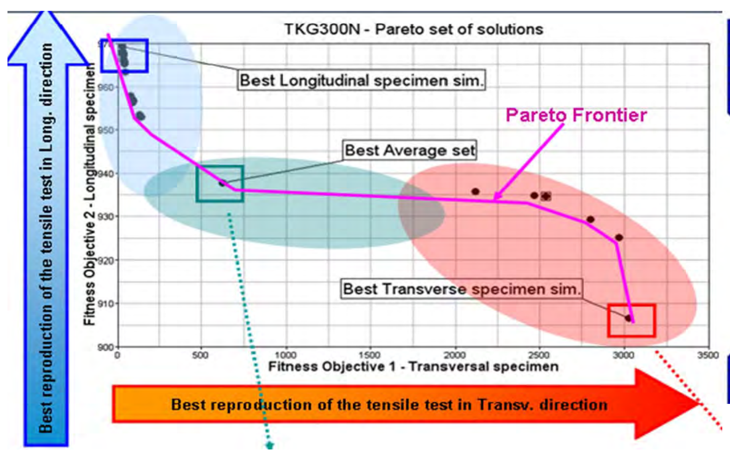
A simplified method based on an orthotropic non-linear material law with an already existing Ls-dyna (MAT_103) has been developed. Fundamental items of this approach are:

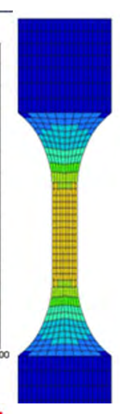
Selection of an anisotropic material law (LS-DYNA MAT_103)

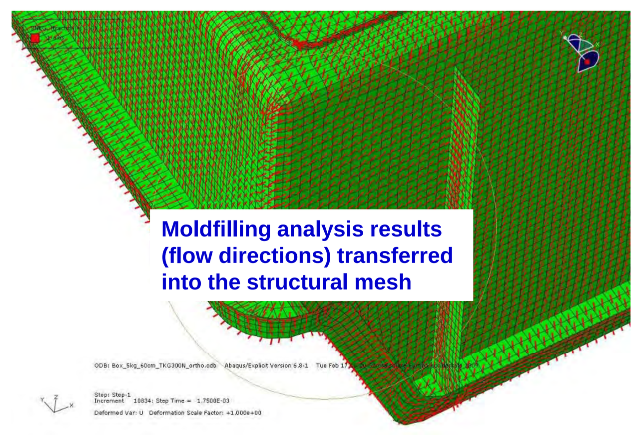
The selected law (Ls-dyna MAT_103) is isotropic elastic - anisotropic viscoelastic; its parameters are identified through the simulation of the tensile test on two different orientations using MOGA (Multi-Objective-Genetic-Algorithm) based optimization.

By so doing, a Pareto diagram is built onto which the best set of parameters is identified.

As for the approach based on micromechanics, using specimens cut from injection molded plaques is of paramount importance to have the desired orientation with respect to the flow and similar to the one obtained in the real parts.







Moldflow predicted flow direction as material orientation

Flow direction from a simple filling analysis is transferred to FEA model as material orientation to be used as reference system for an orthotropic material law.

Failure criteria

A critical step which is common to both approaches is the definition of appropriate failure criteria.

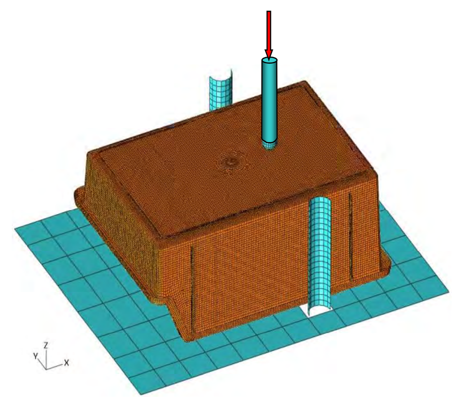
Best results are achieved when failure criteria are implemented with characteristics such as:

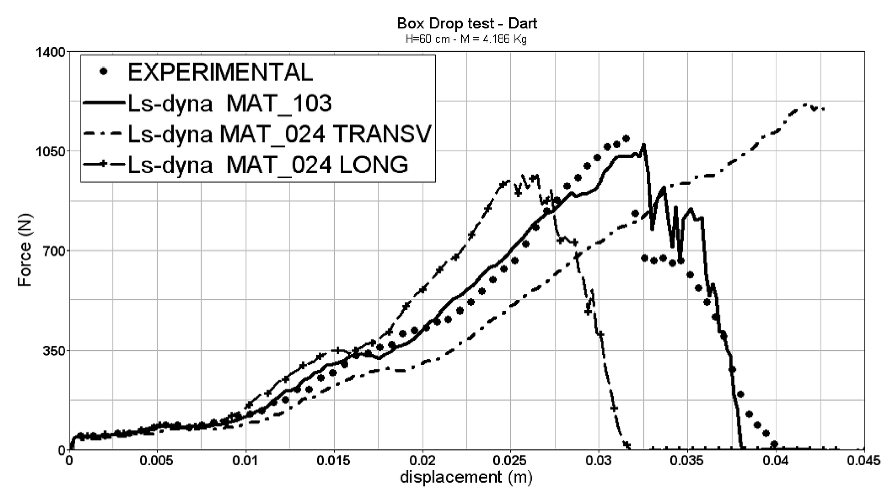
- Anisotropic (Orientation dependent)
- Strain rate dependent
- Sensitive to differentiation tension/ compression

Validation

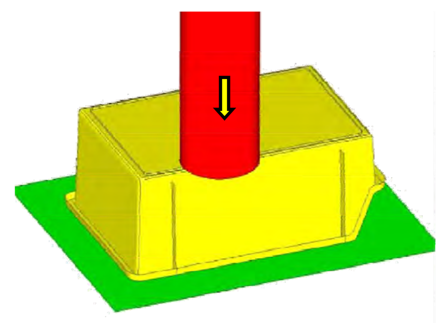
Several benchmark tests were carried out to validate both the approaches proposed.

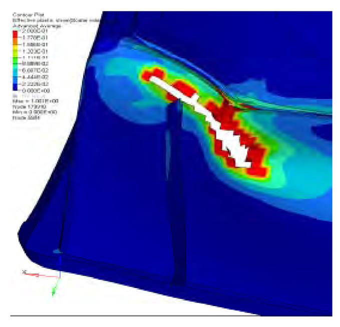
• A first drop test on an injection molded GF-PP box was used to compare the computed force vs. displacement with the experimental curve. The anisotropic simulation using the simplified method was compared with the isotropic analyses, showing a definitely better accuracy (shown below).



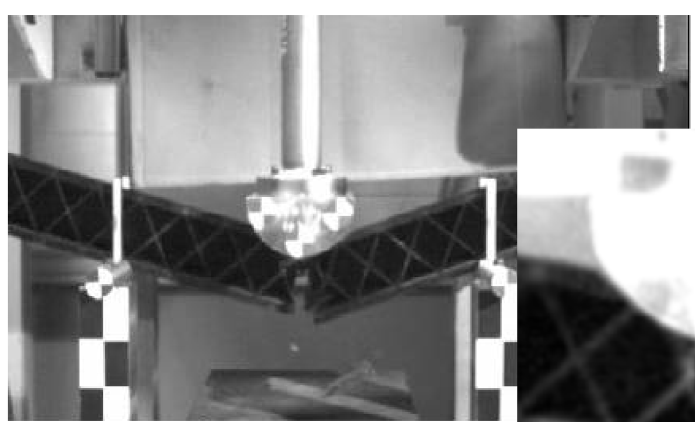


• A second drop test on the same box but with an impactor of larger dimensions was used to compare the fracture patterns. The results, using the simplified method, show a good agreement with the experimental pattern under a great variety of testing conditions and materials. Shown below is an example reported with a GF-PP having a soft matrix.

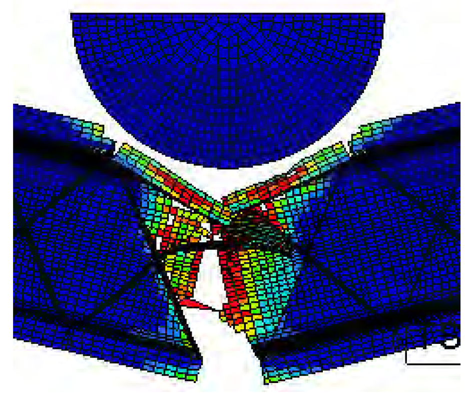




• An impact test on an industrial part as a ribbed beam is proposed for a deeper investigation of the rupture pattern using a different failure criteria. The results, using a Tsai-Wu model coupled with Ls-dyna MAT_103, show a very accurate reproduction of the failure pattern.



Courtesy from Faurecia Seatings



Conclusions

• Anisotropic materials as GF-PP can be properly modeled using an orthotropic material law, as Ls-Dyna MAT_103, or more complex approaches as those based on micromechaiical modeling.

• In both cases, the information from the injection process is critical for the accuracy of the solution and needs to be carefully evaluated and transferred to the structural analysis.

• The results are definitely more accurate than simply using isotropic methods.

References

[1] M.Nutini, M.Vitali, "Simulating anisotropy with Ls-dyna in glass-reinforced, polypropylene-based components", Ls-dyna Anwenderforum, Bamberg 2010

[2] C.Ferrari, C.Garcia, M.Nutini, "Assessment of Fiber Orientation in Injection-Molded SGF-PP items", Connect! Moldflow Users Meeting 2011, Frankfurt, 2012

[3] M.Nutini, M.Vitali, "Simulating failure with Ls-dyna in glass-reinforced, polypropylene-based components", Ls-dyna German Users Forum, Ulm, 2012