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Prediction of elastic anisotropic thermo-dependent properties of discontinuous fiber reinforced composites

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Abstract.

This study is focused on the micromechanical prediction of temperature-dependent elastic properties of a composite made of a polypropylene matrix reinforced with discontinuous glass fibers. Firstly, an experimental investigation of the mechanical behavior is presented. Specimen are cut from injection-molded rectangular plates using a pattern based on fiber orientation. The microstructure is investigated by X-ray tomography at the specimen center and an average orientation tensor is calculated. Tensile tests are performed over a temperature range from ambient temperature to 85°C and dispersion of mechanical properties is rather low; moreover, they are representative of the ones measured out of an industrial injected part. Then, the evolution of elastic properties with orientation and temperature is analyzed and compared with numerical predictions calculated with Mori-Tanaka homogenization scheme.

Key words: Discontinuous fiber composite, Thermoplastic matrix, Elastic properties, Temperature effect, Micromechanical prediction

1. Introduction

Thermoplastic polymers reinforced with discontinuous fibers have been widely used for several years to reduce weight and develop new designs at competitive prices. They are used in the automotive industry with usual fiber content in the range between 30 wt% and 50 wt%, e.g. a roof bar (1), a clutch pedal (2), a fuel rail (3), an instrument panel (4), a front-end module (5). Polypropylene (PP) is commonly used with glass fibers because the composite exhibits interesting mechanical properties for a high performance over price ratio, low processing temperatures with a glass transition temperature T_g below ambient temperature (6,7) and also low water absorption (8). Such automotive components must resist demanding service life conditions, e.g. elevated temperatures (a few tens of degrees) during a few hours and meet thermo-mechanical specifications. Virtual design is then a necessity to optimize the proper use of these composites, while avoiding overestimating the part thickness. The reliability of this virtual design, based on finite element simulations, depends on the modeling of the anisotropic thermo-mechanical behavior of these materials.

The mechanical properties depend not only on fiber length or aspect ratio, shape and thickness of mold cavity but also on orientation and dispersion of the fibers. Indeed, injection-molded composites reinforced with discontinuous fibers display a very complex spatial fiber distribution (9–12) and the anisotropy related to the fiber orientation must be considered (13–15). Mechanical characterization is often performed in tension. However, as the microstructure is heterogeneous and anisotropic, the orientation of the tensile direction is defined with respect to the injection

direction but also to the fiber orientation (or microstructure). A first way is to inject samples directly in their final shape (16–18) but only one fiber orientation and one tensile direction can be investigated. The second and main trend is to consider only the central area of a rectangular plate: samples are rotated around this point and tensile tests are carried out at different directions for a fixed microstructure (1,10,19,20). However, only one sample is cut out of one plate. Several specimen can be cut with the same orientation in a plate, thus neglecting the planar fiber orientation distribution over the plate (21). However, in accordance to numerical predictions (10), X-ray computed micro-tomography reveals that distribution of fiber orientation depends on the specimen location (22). Though only a few studies consider this distribution, it has a sensitive effect on elastic properties (23). These results highlight the importance of not neglecting fiber orientation distribution over the specimen as a source of variability of the mechanical properties. Indeed, a very large dispersion in terms of stress at rupture in tension, from 40 MPa to 57 MPa, is recorded for the same load direction but for several sample locations, corresponding to an average orientation tensor component from 0.44 to 0.55 (22) for a PP reinforced with glass fibers. The idea is then to represent the microstructure by using local orientation tensors (1).

Structural parts may support in service demanding thermo-mechanical conditions and the material behavior must be tested under similar conditions. Temperature effect on mechanical behavior is not commonly observed in literature for polymer matrix composites (15,19,24), however its influence must be considered for a variety of applications, e.g. fatigue (25). Temperature ensures a predominant role in the material behavior mainly due to the viscosity of the matrix (26), e.g. Young's modulus of PP decreases by 75% at 90°C compared to its value at ambient temperature (27). The same decrease is recorded for composites, e.g. glass fiber reinforced polyamide 6-6 (24) and PP reinforced by quasi-unidirectional glass. In automotive applications, the typical temperature range is between -40°C and 130°C.

The temperature-dependent elastic behavior of an injection molded PP reinforced with discontinuous glass fibers is addressed in the present paper. Material description and experimental procedure, including sample preparation and cutting, X-ray computed micro-tomography and tensile test, are detailed in section 2. Section 3 is dedicated to experimental results on local fiber orientation, characterized by an average orientation tensor, and tensile test results under isothermal loading conditions. Finally, section 4 focuses on a micromechanical prediction of elastic properties regarding anisotropy and temperature effect, using Mori-Tanaka model.

2. Material and experimental procedure

2.1 Material

In this study, a glass fiber reinforced PP named PPGFL40 is considered, with a fiber content of 40 wt%. Rectangular plates of dimensions 179 mm x 240 mm, with a constant thickness of 2.75 mm, are injected in industrial conditions at Technocentre Renault. The injection speed is 30 mm.s⁻¹ and the mold temperature 250°C.

A calcination method is chosen to verify the fiber content. Five samples of 2.75 x 10 x 20 mm³ dimensions are cut from three different plates and heated up to 750°C during 30 min according to the standard NF EN ISO 1172. The average dispersion of fiber content between plates is less than 2.8% whereas samples from the same plate exhibit a maximum relative gap of 3.5%. The maximum relative gap reaches an acceptable 5% regarding the 40% aimed at

during elaboration of the material. This weak dispersion of the fiber content shows a good control of the injection process. The initial fiber length is 11 mm with a diameter of 17 μm . These values are common ones for such a composite, e.g. (28,29). To determine the fiber length after injection, specimens are incinerated and then dispersed in a dilute solvent to separate the fibers. The fiber length is measured with an optical microscope on ten specimens showing almost a hundred fibers each and extracted from several areas. The resulting fiber length average is 1.5 mm and the median value is around 0.8 mm. The smallest value is around 0.3 mm when a maximum of 11 mm is sometimes reached, and therefore the composite should be qualified as semi-long fiber material (28,30).

Three temperatures representative of common industrial specifications are considered in this study: 23°C, 60°C and 85°C. Only positive temperatures are chosen, to represent desert-like conditions responsible for creep. Main properties of each constituent of PPGFL40 are specified in Table 1. Fiber elastic properties are considered unchanged in this range of temperature.

Glass fibers			PP matrix				
E_f [MPa]	ν_f	ρ_f [g.cm ³]	E_m [MPa]			ν_m	ρ_m [g.cm ³]
			23°C	60°C	85°C		
72000	0.23	2.6	1720	792	587	0.24	0.946

Table 1. Fiber and matrix properties at several temperatures (Renault data). Young's modulus, Poisson's ratio and density E_i , ν_i , ρ_i subscript $i=f$ or m for fiber or matrix respectively.

Dynamic Mechanical Analysis (DMA) tests are carried out with a viscoanalyser ARES G2 - TA Instruments at Technocentre Renault. Samples dimensions are 56 x 10 x 2.75 mm³. They are cut from injected plates in several areas at 0° and 90° regarding the injection direction. Analysis is performed at 1 Hz in torsion mode and the temperature run from -30°C to 150°C at a heating rate of 2°C/min under a controlled sinusoidal strain of 0.15%. Evolution of the storage modulus G' and loss factor $\tan \delta$ versus temperature is shown in Fig. 1 for unfilled PP and PPGFL40, for two samples. As the temperature rises, the storage modulus decreases continuously when the loss factor increases and two peaks can clearly be seen. The first one corresponds to the glass transition and occurs around 0°C. The second one, at around 90°C, corresponds to the beginning of melting. Incorporation of fibers reduces $\tan \delta$ peak height by restricting the movement of macromolecules (31). Temperatures which are considered in this study are situated in a same relaxation state from 23°C to 85°C. Though the dispersion is higher for the composite, the reproducibility for both matrix and composite is satisfying.

Fig. 1. G' and $\tan \delta$ obtained with DMA at 1 Hz between -30°C and 150°C for PP and PPGFL40.

2.2 Cutting pattern of tensile specimen

To cover the whole plate in an easy way, orientation intensity is observed by terahertz 2D imaging based on reflection and transmission of high frequency waves, located between infrareds and microwaves in the electromagnetic spectrum (32). Result is shown in Fig. 2(a); a value of 1 (red areas) represents a strong fiber orientation in a direction which is not known. Two methods are considered for the tension, i.e. aligning the tensile direction with the injection direction, at several locations in the plate and rotating the tensile direction. The cutting pattern is defined based on the results of Fig. 2(a) and is shown in Fig. 2(b). Only three main angles relatively to the injection direction are considered to limit the number of mechanical tests: 0° , 45° and 90° . It is possible to cut out seven samples in the same plate corresponding to five configurations, three in the longitudinal direction (named L1, L2 and L3) considering the plate symmetry (22) and two in the transverse one (called T1 and T2). Two more configurations are taken in a different plate at 45° (45-1 and 45-2). This cutting pattern has the benefit to cover a large range of fiber orientations and to avoid a waste of materials. Specimen cutting is done by low speed machining and a cooling system and proper knife edge angle to avoid affecting material properties. Samples have a dog-bone shape with a gauge area of $50 \times 10 \text{ mm}^2$ and dimensions according to the standard NF EN ISO-527-b (14,24). They are stored several days in a controlled atmosphere room, with temperature and hygrometry rate regulated respectively at 23°C and 50%. Tensile tests are carried out at three temperatures under isothermal conditions, i.e. 23°C , 60°C and 85°C , representative of potential service life conditions. It should be emphasized that ambient temperature is not strictly imposed at 23°C , whereas it is regulated at higher values. Mechanical tests are carried out on an Instron electro-mechanical testing machine with a load cell of maximum capacity 10 kN. The distance between the fixed grip and the moving one is initially set at 108 mm. The local displacement is measured with an extensometer of 25 mm gauge length set in the middle of the sample. Tests are performed at several crosshead speed, corresponding to almost constant strain rates of 10^{-5} , 10^{-4} and 10^{-3} s^{-1} . For each configuration, 3 to 5 tests are conducted at room temperature, to check the reproducibility. And, as it is very good, at least two samples are tested at higher temperatures. After pre-conditioning at the test temperature, the isothermal test is started. At least 30 min are required to reach the temperature of the test with the

maximum rate of 5°C/min. To control the temperature, thermocouples are located on the sample and on the grips. Cauchy stress and logarithmic strain are calculated from raw data and used to plot the graphs.

Fig. 2. Fiber orientation intensity obtained by terahertz analysis on PPGFL40 plate (a) and cutting pattern for 0°, 90° and 45° samples, regarding the direction of injection, highlighted by the black arrows. Dotted lines correspond to areas observed by X-ray micro-tomography (b). The injection gate is located at the top of the plate.

2.3 X-ray micro-tomography

The local microstructure is also experimentally investigated by means of X-ray micro-tomography, which is the most common non-destructive method used to observe fiber orientation (33,34). Only central areas of the tensile specimen are considered with sample dimensions of 10x20x2.75 mm³ and cut out of two injected plates. Water jet cutting is used to avoid pulling out of fibers. Several 2D scans are taken with specific values given in Table 2 and 3D images are then built with a dedicated algorithm; image analysis is carried out by (35).

X-ray source	Energy	Projections number	Break time	Voxel size	Analyzed volume
ESRF, BM05	90 keV	4500	0.12 s	2.25 x 2.25 x 2.25 μm ³	3.0 x 8.8 x 19.3 mm ³

Table 2 . X-ray micro-tomography parameters.

To derive quantitative data, the average orientation tensor $\mathbf{A}$ (36) in the thickness of each specimen is calculated from X-ray micro-tomography analysis. The fibers appear in white and the matrix in grey in the reconstructed images and the voxel size is given in Table 2. The orientation vectors $\mathbf{p}^i$ of the fibers are calculated with a method based on grey nuance gradient around fiber neighboring and using a dedicated tool developed by Novitom. Then, the second order orientation tensor is calculated based on orientation vectors $\mathbf{p}^i$ for all voxels N of the fiber phase in the chosen frame, with equation 1. Only the components A_{xx} and A_{yy} (the frame is defined in Fig. 2b) are given here because they correspond to the highest values.

$$A = \frac{1}{N} \sum_{i=0}^N p^i \otimes p^i \quad (1)$$

3. Results

Monotonic uniaxial tensile tests are performed at ambient and elevated temperatures for several fiber orientations, to highlight the fiber orientation effect and to check the reproducibility between two different plates. Moreover, the local fiber orientation is characterized by the components of the orientation tensor, averaged over the sample thickness.

3.1 Fiber orientation

Fig. 3 shows the heterogeneity of the microstructure, characterized by a skin-core structure (28). The fiber orientation is mainly composed of two skin layers with preferential orientation parallel to the flow direction, and a core region with orientation perpendicular to the flow and in the plane of the part, which is classical for injected parts. Such a distribution is sometimes neglected, especially in industrial cases, to simplify the mechanical investigation and material behavior representation. As a consequence, an average orientation tensor (36) over the thickness is introduced in constitutive equations and this approach gives a reliable prediction of the elastic properties (20,37,38). A similar approach is then considered in this study. Fig. 3(b) shows fibers mainly oriented in the injection direction corresponding to the L1 configuration contrary to Fig. 3(c) which displays a random orientation for the L3 one. This planar distribution of the fiber orientation is also highlighted in (4) for an industrial part in PP reinforced by 20 wt% of glass fibers. Experimental evaluation of the orientation tensor components is given in Table 3 for five configurations showing a stark contrast. Whatever the orientation, A_{zz} is very small, of the order of 0.037. Moreover, all the non-diagonal components are very close to zero. Except for L1, which is a rather oriented configuration, all the other components are very close to 0.5. In addition, L1 is the only one to show a relative gap between A_{xx} and A_{yy} superior to 50%. On the contrary, L3 and T1 exhibit a higher A_{xx} value than A_{yy} . It can be seen that A_{yy} values for L1 and L3 are very different, with a relative gap around 39%, though they both correspond to tension in the injection direction. However, for a PP reinforced by 30 wt% of glass fibers and similar plate thickness (22) obtain close values, respectively around 0.7 and 0.615 (gap of 0.09). L3, T1, T2 and 45-2 exhibit all values close to 0.5 for both components. And the relative gap between these two components is of the order to 10%.

Configuration	A_{xx}	A_{yy}
L1	0.272	0.688
L3	0.549	0.416
T1	0.507	0.453
T2	0.466	0.496
45-2	0.451	0.508

Table 3. Experimental orientation tensor components for the five configurations with y the injection direction.

Fig. 3: X-ray micro-tomography images (a) skin-core structure in the thickness (b) on the outer surface for L1 and (b) L3. Fibers are white while the matrix is in grey and porosities are in black. The injection gate is located at the top of the plate and the black arrows are parallel to the injection direction.

3.2 Mechanical behavior in tension

Fig. 4 shows results of tensile tests performed up to rupture at room temperature for the different configurations. Samples are cut out from two different plates obtained with similar process conditions and respectively named A and B. Testing results highlight a very good reproducibility for each orientation. A small dispersion is evidenced for each orientation and the relative gap on the stress level, calculated with respect to the minimum value, quantifies this dispersion. In the longitudinal direction, at 1.8% strain, a relative gap of 1% is calculated for L1, whereas they are equal respectively to 4.8% and 7.7% for L2 and L3. Despite their close location to the injection gate, at a strain of 1%, T1 has a relative gap of 0.2%, respectively 3.9% for T2. In addition, regarding 45-2, a gap of 3% is calculated at a strain of 1.5%. L1, T1 and 45-1 show the highest reproducibility whereas L3 shows the lowest one. L3, which seems to be the most random configuration in terms of fiber orientation, gives the highest dispersion in stress level. Though clusters are sometimes visible on X-ray micro-tomography images, the fiber volume fraction exhibits a weak dispersion on the plate; however, the fiber length exhibits a wide range of variation, with non-negligible fiber curvature.

Fig. 4. Tensile test on PPGFL40 at 23°C and 10^{-4} s^{-1} for several configurations. A and B stand for two different plates.

The anisotropy of the mechanical behavior is rather strong, with a maximum stress level along the injection direction which can be divided by two for other configurations. L1 reaches the highest level of stress which is around 110 MPa. From L1 to L3, the stress level is reduced by 20 MPa. For each configuration, a strongly non-linear behavior is observed. It can also be seen that there is a clear distinction of the stress levels, without any overlapping of the curves. This validates the proposed cutting pattern and leads to a high reproducibility for each configuration, higher than results in literature (21,22). Each configuration corresponds to a different average orientation tensor, with a particularly obvious difference for L1. Though the average orientation tensor is a local information, compared to the global information of the stress level, it seems that such a representation is relevant to distinguish the mechanical behavior.

Fig. 5 shows results of tensile tests performed for the same fiber orientations at 85°C. For more visibility and to limit the number of tests, the analysis at elevated temperature is shown for only five orientations which are L1, L3, T1, T2 and 45-2. Only two representative curves for each configuration are presented. Same trends regarding the mechanical behavior observed at 23°C are noticed at 60°C and 85°C. The weak dispersion of mechanical response is similar in temperature and is even enhanced for some orientations. Fig. 6 shows results of tensile tests for L1 and L3 at each temperature. It evidences the strong influence of the test temperature on the stress level. This effect does not depend on the fiber orientation. Indeed, similar decrease in term of stress level is observed with a maximum gap in between 20 and 30 MPa at the same strain level. The general trend is observed for other configurations.

Fig. 5. Tensile test on PPGL40 for all orientations at 85°C, at 10^{-4} s^{-1} and for five configurations.

Fig. 6. Tensile test for L1 and L3 at different temperatures.

The influence of strain rate is investigated for three values, i.e. 10^{-5} s^{-1} , 10^{-4} s^{-1} and 10^{-3} s^{-1} . Table 4 gives the initial slope of the stress-strain curve, referred as E_0 , at three strain rates for L1 and L2. They are calculated on the corresponding stress/strain curves in the strain interval from 0.05% to 2.5% according to the standard NF EN ISO 527-1 and the value is averaged on several samples. It increases slightly when the strain rate increases. However, this effect is rather weak, with an average increase around 3%, compared to the anisotropy effect.

	10^{-5} s^{-1}	10^{-4} s^{-1}	10^{-3} s^{-1}
L1	8127.54	8207.33	8460.94
L2	6889.35	7139.82	7547.73

Table 4. E_0 (MPa) at 23°C obtained at several strain rates for L1 and L2.

The evolution of E_0 at three strain rates is also considered at 23°C and 85°C for L1, cf. Table 5. The maximum relative gap is of 7.9% at 23°C and almost three times higher at 85°C which shows the viscoelastic effect. Nevertheless, some overlapping is observed at both temperatures. In the following section, only anisotropy and thermal dependence are considered.

Strain rate (s^{-1})	23°C		85°C	
	$E_0^{\min}$ (MPa)	$E_0^{\max}$ (MPa)	$E_0^{\min}$ (MPa)	$E_0^{\max}$ (MPa)
10^{-5}	8025.50	8229.58	4319.06	4783.75
10^{-4}	8185.54	8228.22	5154.26	5417.63
10^{-3}	8259.78	8662.10	5178.00	5460.50

Table 5. Maximal and minimal values of E_0 at 23°C and 85°C obtained at several strain rates for L1.

4. Prediction of elastic properties

The initial slope E_0 is derived from stress/strain curves and an average value is calculated on at least two samples for each orientation and each temperature. Fig. 7 shows experimental E_0 of PP and PPGFL40 obtained for several temperatures. At 23°C for PP, a value of 1000 MPa is proposed by (27), similarly to (22). However, higher values of 1650 MPa and 2000 MPa are also obtained (23,39), or also 566 MPa at 85°C for (40) which are closer to the average values respectively of 1700 MPa and 587 MPa measured in this study (cf. Table 1). Such a variation for PP modulus is therefore significant and is probably due to crystallinity rate resulting from different injection parameters. For each specimen, E_0 clearly decreases with the rising temperature. E_0 is predicted with equation 1, proposed for PP and quasi-unidirectional glass fiber/PP composites (27). Based on this equation, a compromise is found for all configurations, except T2, by reducing the value of n from 2.3 for PP to 0.87 for the composite against 2.6. T2 is removed due to an inverse trend, i.e. E_0 is close to T1 at a 23°C but much higher at 60°C and 85°C.

$$E(T) = E(RT) * \left(\frac{168 - T}{168 - 23} \right)^n \quad (1)$$

Fig. 7. Variation of E_0 for each fiber orientation at three temperatures and evolution predicted by the equation proposed in (27) for PP and PPGFL40.

Evolution of E_0 for each configuration and temperature is also highlighted in Fig. 8. The highest dispersion is found at 23°C and mostly in the injection direction. Very close values of E_0 for 45-2, T1 and T2 are found, which is consistent with results from literature (15). E_0 significantly reduces from in-flow direction to perpendicular-to-flow direction at all temperatures and strain rates. At 23°C, the dispersion among all configurations is 33 % regarding the highest value. For a similar material at 23°C, a dispersion of 50 % is obtained with specimen cut out from a 100 x 20 mm² plate and a gate in the middle of the longest edge (23). At 60°C and 85°C, dispersion is about 42%. The cutting pattern proposed in this study, based on fiber orientation, thus minimizes the dispersion. At 23°C, T1 displays a higher E_0 value than T2, but this trend is changed at elevated temperatures. Because T2 is close to the injection gate, skin-core effect and dispersion could explain these results. Configuration 45-2 displays E_0 with the smallest value compared to other directions, whatever the temperature.

Moreover, from a technological point of view, these values obtained on samples cut out from a rectangular plate are compared to the ones measured on samples taken out of an industrial part (a front door made of the same material) in several areas and at different orientations to the injection direction. It is shown that they are representative of the industrial ones (41), thus highlighting the interest of the cutting pattern to evaluate a relevant range of mechanical properties.

Mori-Tanaka micromechanical model is then used to predict elastic properties, based on the average orientation tensor, fiber and matrix properties, fiber length ratio and temperature (42). This model is implemented in the software Digimat (43). Such a model has become very popular, as it leads to reasonable predictions in linear elasticity with fiber volume fractions up to 30% and out of simplicity's sake. The ability of such a micromechanical model to predict the elastic anisotropic properties of a 35 wt% short glass fiber reinforced polyamide 66 was already checked, based on numerical orientation tensors (20). Elastic properties in the configuration with fibers aligned to the injection direction are well described whereas some discrepancies are shown for other orientations.

In the present paper, the elastic tensor of the composite is calculated from i) the elastic tensors of the constituents, which is temperature-dependent for PP, ii) the fiber volume fraction and iii) the fiber shape factor. This factor, defined as the ratio of the fiber length over the fiber diameter, presents a large distribution coming from the relatively large variation of the fiber length. Therefore, three different values, i.e. 47, 36 and 25 are considered in this study. It should be stressed out that 47 is the value calculated from the median fiber length after the injection process. Fig. 8 presents a comparison between experimental values and numerical predictions for five configurations. It can be seen that the evolution of E_0 at ambient temperature is correctly predicted, though slightly overestimated for a shape factor equals to 47, except for L3. The best compromise for the different configurations and temperatures is obtained for the shape factor of 47, though the intermediate value of 36 also leads to close predictions for T1 and 45-2 configurations.

For the L3 configuration, the orientation tensor component A_{xx} is somehow surprisingly higher than A_{yy} , which can come from a limitation of the use of the average orientation tensor to fully represent the inhomogeneity of microstructure. For T1, T2 and 45-2, the two component values are close. Nevertheless, the evolution of E_0 seems related not only to the component value but also to the gap between A_{xx} and A_{yy} , this one being maximum for the strongly-orientated configuration L1 and of the order of 10% of the maximum component for T1, T2 and 45-2.

Mechanical properties of configuration L3 are clearly underestimated. A further trend should be to consider the full heterogeneity of the microstructure, without any average over the thickness.

Concerning the thermal dependence, the decrease of E_0 comes only from the PP properties. Except for L3 and T2 configurations, the slight overestimation of the predictions at 23°C and 60°C increases significantly at 85°C. It could come from an overestimation of the Young's modulus of PP at this temperature; indeed, the presence of fibers and the injection conditions of the composite may affect the properties of the material, different when tested by itself or a composite.

It can be concluded that such an approach gives a realistic prediction of the anisotropic thermo-dependent elastic properties of the material, though some configurations necessitate taking account of the full heterogeneity, i.e. in the thickness, of the material.

Fig. 8. Experimental dispersion (full circle) on E_0 for each configuration at three temperatures and a strain rate of 10^{-4} s^{-1} . The three colors correspond to different temperatures. The measured variation is also highlighted with error bars. Predicted values with Mori-Tanaka's model, using three different shape factors, are also plotted. The cross, square and full triangle respectively corresponds to shape factor values of 47, 36 and 25.

5. Conclusions

This study is dedicated to the thermo-mechanical characterization of a discontinuous glass fiber reinforced PP with a mass fraction of 40%, with a focus on the prediction of the anisotropic thermo-dependent elastic properties. Rectangular plates are injected using the same conditions as industrial parts. Samples are cut out following an original pattern that leads to a large range of stress levels and elastic properties, comparable to those recorded out of an industrial part. Tensile tests are performed at three different temperatures. It is shown that the dispersion on the mechanical properties is rather low compared to other patterns proposed in the literature. The initial slope of the stress-strain curve decreases with temperature by a factor of 1.5 between 23°C and 85°C. Predictions of the elastic properties with Mori-Tanaka micromechanical model are compared with experimental values, for different temperatures and configurations. The overall trend at ambient temperature is correctly described; however, the elastic properties of the configuration presenting a highly heterogeneous microstructure are underestimated.

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