PREDICTION OF SHRINKAGE AND WARPAGE IN INJECTED THERMOPLASTIC COMPOSITES REINFORCED WITH HEMP FIBERS

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ABSTRACT
Among the major problems encountered during the transformation of thermoplastic composites are the volumetric shrinkage and warpage caused by the temperature drop during injection into the mold cavity. Generally, this type of defect is not isotropic, particularly in the case of reinforced materials.

In this paper, we present a numerical simulation of the injection molding of thermoplastic composites in order to better predict the evolution of these materials during the transformation and to propose operating conditions likely to give the best results and to optimize the production cycle. We have studied the evolution of shrinkage and warpage in defined geometries according to the processing parameters: Temperature and pressure and injection speed. The material studied is polypropylene reinforced at different rates of short hemp fibers.

Key words: Injection molding, Processing parameters, Thermoplastic matrix, Hemp fibers, Warpage and shrinkage.

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1. INTRODUCTION
Shrinkage occurs as a result of thermal contraction (volume change fct of temperature) and compressibility (volume change fct of pressure) when the composite injected into a cavity begins to cool.
The shrinkage can be defined by the following formula:

$$S = \frac{(D - d)}{D} \times 100\%$$

D = the dimension of the mold cavity.

d = the dimension of the molded part.

Generally, the shrinkage is anisotropic: it depends on the direction, especially for short fibers reinforced materials.

This shrinkage is influenced by several parameters [1], namely material properties (including rate and type of filler and reinforcement, molecular weight and crystallization rate for semi-crystalline matrices), part and mold cavity geometries (wall thickness), the molding conditions, the shape of the injection thresholds [2, 3].

To this, Sanschagrin, B. and al. [4] added the shape ratio of the fibers and concluded that this parameter is more important than the molding parameters.

Himasekhar, K. and al. [5], Wu, Scott S. and al. [6] and, Kikuchi, Hiroyuki and al. [7], mentioned that warpage is created by internal stresses, which in turn result from anisotropic properties and non-uniformity of shrinkage.

The shrinkage anisotropic properties are mainly defined by the presence of reinforcements with a high length / diameter ratio (short hemp fiber: ratio = 22), but also by the elastic behavior different from the crystals stretched during filling (residual stresses). These shrinkage variations will lead to stresses which are able to overcome the mechanical strength of the part, which results in distortion [8,9].

The calculation of residual deformations and stresses remains a delicate problem. The complexity of physics of the phenomena involved remains difficult to incorporate. The quality of the prediction of residual stresses appears to be closely related to the quality of the material behavior modeling (viscoelasticity, crystallization, structural heterogeneity) and, on the other hand, Boundary conditions at the wall (mechanical and thermal contact, mold deformation) [10-11].

Several numerical codes have been developed to simulate the injection transformation process. The purpose of these codes is to anticipate and understand the causes of shrinkage and warpage to minimize this effect in future products.

Azevedo, Mauricio et al. [12] carried out a cooling analysis with three different injection molds and different molding conditions to study the effect of mold geometry and temperature. Analysis of the simulation results showed that the cooling water temperature was the most important parameter.

Other authors such as Shijun, Ni [13, 14] also used the Moldflow simulation software to predict the deformation of the injected parts and to conclude that the differential shrinkage and expected warpage are in good agreement with the experimental measurements.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

For industrial applications, the polypropylene homopolymer is most used. It offers the best mechanical and thermal characteristics. The characteristics of the polypropylene used are: density = 900 kg/m³, melt index I = 25 g /10min, melting temperature T = 168°C, thermal conductivity at 25°C is \(\lambda = 0.3\text{W/mK}\).

In order to improve their properties to use them as reinforcements for composite materials, Hemp fibers have been treated with alkaline solution. The used fibers have a diameter of 250μm and a length ranging from 2 to 2.5 mm. For better fiber matrix interfacial adhesion, we
have added to the mixture 5% of polypropylene grafted maleic anhydride. The granules of polypropylene reinforced at various rates of hemp fibers were produced by the extrusion process.

2.2 Geometry studied
We have studied the evolution of shrinkage and warping in geometries defined according to the processing parameters: Temperature and pressure and injection speed. The material studied is polypropylene reinforced at different rates of 10-30% of short hemp fibers. We have studied the example of an injected rectangular plate made of polypropylene reinforced with short hemp fibers whose dimensions: (length L = 110 mm, width H = 118 mm, thickness e = 2 mm).

3. RESULTS AND DISCUSSION

3.1. Influence of fibers rate
To show the influence of the reinforcement rate on the differential shrinkage in the plate, we present the evolution of differential shrinkage at different plate locations and at different temperatures.

The curves shows that the fiber ratio is inversely proportional to the differential shrinkage.

3.2 Influence of mold temperature

The curves shows that the fiber ratio is inversely proportional to the differential shrinkage.
The figure below shows the evolution of the front of the flow temperature during the filling of the cavity at different mold temperatures.

**Figure 3** Evolution of the differential shrinkage in the plate at different mold temperatures

We note that the mold temperature negatively influences the evolution of the differential shrinkage in the plate. This temperature is a determining factor in the mechanical and morphological properties of thermoplastic composites.

### 3.3. Influence of temperature and injection speed

The figure below shows the evolution of differential shrinkage in the plate at different injection speeds.

**Figure 4** Evolution of the differential shrinkage in the plate at different injection speeds.

These results show that the effect of the injection speed can be comparable to that of the mold temperature: for a low injection speed, the differential shrinkage in the plate is greater.
The figure 5 shows that the differential shrinkage increases with the change in the injection temperature. This is because the cooling rates within the cavity are very high and not uniform, and the solidified material will also incorporate internal stresses.

These stresses can be relieved once the material is ejected from the cavity. A process can be accelerated by keeping the part at high temperatures.

4. CONCLUSION
We conducted a numerical study aimed at the prediction of shrinkage in thermoplastic composites reinforced at different short hemp fiber rates. The results show the influence of the reinforcement rate and the processing parameters on the evolution of shrinkage. The reliability of the prediction results depends on input data, particularly for parts made of hemp fiber reinforced materials.

However, it is very difficult to guarantee good results in all cases. All the authors agree that the great majority of the fibers break during the plasticization, even if they can continue to deteriorate when they pass through the nozzle and the channels, or during injection into the mold [15, 16, 17].

The anisotropic properties of the shrinkage of hemp fiber reinforced materials can be influenced by their passage through injection molding tools, as well as by narrow thresholds. Significant fiber fracture can occur at these levels, affecting the anisotropic properties of the composites [18].

REFERENCES


