MODELING THE FILLING PHASE OF INJECTION PROCESS OF TECHNICAL PARTS WITH THERMOPLASTICS COMPOSITES BASED ON HEMP FIBERS

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ABSTRACT

The injected thermoplastics composites grow considerably in different industrial fields and provide increasing performance allowing manufacturers to consider innovative and competitive technical solutions. The extent of their physical and mechanical and aesthetic performance is constantly developed. However, the level of control of production technologies must be sufficiently high to better meet the specifications in terms of quality and performance and productivity, but also costs.

In this paper, we present a numerical simulation of thermoplastic composites injection molding, in order to better predict the behavior of these materials during processing and propose operating conditions to give the best results and optimize the production. We studied the evolution of certain defects depending on implementation parameters: Temperature and pressure and speed of injection. The tested material is polypropylene reinforced at different rates (10 to 30%) of hemp fibers.

Key words: Thermoplastic Composites, Injection Molding, Experimental, Short Hemp Fibers, Parts Quality, Processing Parameters.

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1. INTRODUCTION

Modeling of the filling the mold cavity during an injection cycle is difficult. On one hand, the geometry of the molded parts is often complex: multi-cavity mold, curved surfaces, three-dimensional parts. On the other hand, the filling thermorheology depends also on the polymer characteristics. It exists in the literature many studies on filling molds with simple geometry: rectangular cavity, cylinder, disc injected through the center Pearson, Kamal and Koenig [1-2-13] modeled the flow in disk geometry with pseudoplastic and thermo-dependent behavior law without considering the thickness solidified and neglecting the unsteady...
terms. Wu and al [4] have used the same geometry with consideration of the solidified thickness and thermal-mechanical coupling.

Modeling flow in flat plate geometry was the subject of many studies. White then Titomanlio [5-6] proposes one-dimensional models. Van Wijngaarden and al [7] studied a two-dimensional model: The inlet flow rate is constant until a limit value of the pressure at the start of the plate. In addition, the calculation is carried out at constant pressure (and rate flow decreases with time). The retained behavior law is a thermo-dependent power law.

This work consists in modeling the behavior of a thermoplastic composite based on short hemp fiber during the filling phase of the injection molding process. Rheological tests on the online rheometer at different temperatures allowed us to determine a thermo-dependent behavior law for each composite formulation in industrial conditions. This law will be used thereafter as input data for more accurate modeling of the filling phase.

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 = 900kg/m$^3$, melt index $I = 25g /10min$, melting temperature $T = 168°C$, thermal conductivity at 25°C is $\lambda = 0.3W/mK$.

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 250 $\mu m$ 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 of the mold cavity
The mold cavity allows molding complex part for technical use in the automotive field. The finite element mesh components are triangles, which helped to limit the calculation time.

The actual injection conditions (time and pressure) are considered in the simulation.

2.3. Simulation approach
The originality of our simulation work is the introduction of a thermo-dependent rheological behavior law determined experimentally using rheological measurements on an online rheometer developed in our laboratory [8-9].
The determination of the thermo-dependent power law is made from measurements at three
temperatures. Through the curves equations determined above, we deduce the coefficients of power law:

$$\eta = A \dot{\gamma}^B wr \exp(CT)$$  \hspace{1cm} (1)

The plot $\log \eta = f(\log \dot{\gamma})$ determines by a linear regression the viscosity behavior law according to $\dot{\gamma}$ at each temperature.

The representative power law of the rheological behavior of polypropylene reinforced with 25% of weight short hemp fibers in the studied temperature range can be written:

$$\eta = 2063 \times 81 \dot{\gamma}^{-0.62} \exp(0.013T)$$  \hspace{1cm} (2)

This relationship will be used to model the composite flow in a mold cavity.

Following the same approach, it was determined behavior laws for pure PP and PP with different rates of fiber.

Figure 2 Simulation approach [10]
3. RESULTS AND DISCUSSION

3.1. Evolution of the pressure and temperature during the filling of the mold cavity

We are interested in analyzing the evolution of the pressure during filling especially at the injection location. This pressure determines the complete filling of the mold cavity and the fiber orientation which entails the performance and appearance of the final part.

![Pressure Evolution at the Injection Location](image1)

**Figure 3** Pressure evolution at the injection location during the filling phase

During filling, the volume of the mold cavity is filled at a relatively low pressure. The pressure curve mainly depends on the material resistance to flow into the mold and in particular: the reinforcement content - the section of the channels and cavity - the distance traversed by the material in the mold- the viscosity of the molten material - the injection speed – the material temperature - the mold temperature. Figure 4 shows a prediction of the temperature evolution in the mold cavity.

![Temperature Evolution in the Mold Cavity](image2)

**Figure 4** Evolution of temperature in the mold cavity
The evolution of the temperature in the mold governs the cooling time. This also depends on the part thickness and the material temperature and his thermal diffusivity.

The cooling time must be determined for a temperature in the core of the part, giving no deformation at mold release and for a residual pressure value in the part causing no depression when the part is no longer in contact with mold walls. This phase is crucial to the quality of the manufactured part and productivity.

3.2. Effect of the injection location on the filling time

We are interested in estimating the filling time of the mold cavity depending on the position of the injection location.

![Figure 5](prediction_of_part_filling_time_at_two_different_positions_of_the_injection_location.png)

**Figure 5** Prediction of the part filling time at two different positions of the injection location.

We note a difference of 0.18s, allowing a significant gain on the cycle time, especially if we think on an industrial scale on high rates. Furthermore, it remains to analyze the presence of defects on both configurations in particular weld lines.

3.3. Prediction of defects in the part

Several types of defects can occur in the molded parts, in this section we will focus on the influence of the position of the injection location on the appearance of certain defects such as air traps and weld lines.

![Figure 6](prediction_of_air_traps_occurrence_in_the_part_at_different_positions_of_the_injection_location.png)

**Figure 6** Prediction of air traps occurrence in the part at different positions of the injection location
After observation of Figure 6, it is observed the presence of many air traps in the second design, but generally this problem is encountered in the processing of composites with vegetable fibers. The fibers water content is one of the limiting parameters for hemp fiber, which has a direct influence on the molding: the viscosity of the material and the mechanical properties and surface appearance of molded parts.

The presence of humidity in the material can cause poor adhesion fiber / matrix and contribute to the formation of internal bubbles in molded parts [11, 12]. Specific treatment for hemp fiber is required, (steaming the fibers before mixing).

The appearance of a weld line is a major problem both aesthetically and mechanically in the design of injected part with thermoplastic composites.

![Figure 7](image)

**Figure 7** Prediction of weld lines appearance in the part at different positions of the injection location

Figure 7 shows that the injection location has an influence on the appearance of weld lines in the room, in particular in areas with irregular geometry. The first design is still the best.

Weld lines are formed when two melt fronts come into contact at low speed. Especially in areas of geometric variations: Change in thickness – holes - the presence of insert [13-14]. These weld lines cause in addition to the drop in the mechanical properties of the parts, optical imperfections in particular when using high shine material [15].

5. CONCLUSION

We conducted a numerical simulation of filling of an industrial part for technical use in the automotive industry. Our simulations were based on a behavior law of the material experimentally determined. [16]

We have shown the influence of the injection location on the part quality and on the presence of certain defects such as air traps and weld lines and finally on the filling time. Our results are in good agreement with experimental results. [17]

Moreover, this work has allowed us, at first, to validate the part design, then, analyze the impact of the production cycle parameters on both the quality of the produced parts and productivity.

REFERENCES


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