STUDY AND OPTIMIZATION OF THE INJECTION MOLDING OF COMPOSITES BASED ON SHORT HEMP FIBERS

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ABSTRACT

We present a study of the injection molding process of thermoplastic biocomposites reinforced with short hemp fibers. Our goal is to control the industrial process and optimize formatting parameters to highlight the qualities of this fiber as reinforcement for thermoplastic matrices.

In this work we develop an experimental design with four parameters and three levels in order to highlight the impact of major transformation parameters (mold temperature control, pressure, speed and injection temperature) on the structural morphology and the mechanical behavior of molded parts on the one hand, and the optimization of injection production cycles in a view of improved productivity and quality on the other hand.

Key words: Thermoplastic composites- Injection molding- experimental design- Short Hemp fibers- Quality- Productivity Mechanical properties- optimization of processing parameters.


1. INTRODUCTION

The composites based on natural fibers are more environmentally than synthetic fibers. They use during their life cycle less energy than fiberglass composites and generates fewer air emissions. Production of natural fibers has a lower environmental impact than glass fibers. Another focus is the potential for recycling and biodegradability of composites reinforced natural fibers and the revolving nature of the fibers.

Several plant fibers were studied to reinforce polymers such as flax, hemp, palm, jute, banana, bamboo, cotton, wood, jute, kenaf, hemp, sisal, the pineapple, coconut.... [1-2-3]. The polypropylene composite reinforced with hemp fibers have the following
properties: lightness and resistance to external agents and aesthetics and ease of implementation and average resistance [5-6-3-4], which positions them as convenience fiber for applications requiring less weight as in the automotive industry [7-8].

The injection molding process is the most used for the processing these composites. This process can produce parts with various sizes and with complexes geometries. It remains an economical process and well suited to mass production. Therefore, controlling the injection molding process is required [9-10]. This approach may be possible by increasing the production of quality parts and/or by reducing the global time of the injection cycle. The goal is to find the optimal settings to ensure firstly, parts having the required properties and also optimizing production cycles [11-12-13]. The performances of injected thermoplastic composites are conditioned, for a large part by intrinsic properties of the reinforcing fiber and the matrix, but also depend on the thermomechanical history of filling and interface matrix/fiber. The behavior of the reinforced material during the flow in the processing tooling is very complex [22]. Several authors have studied the influence of extraction method and fibers treatment on the final properties of composites [14-15-16], they all agree on the importance of treatment for better adhesion fiber/matrix to obtain finally the best performance of the composite [16-17-18-19-20-21]. On the other hand, knowledge of the influence of thermomechanical processing parameters on the microstructure of thermoplastic composites is used to define the optimal processing conditions considering the application, the environment and the solicitation mode of the part to be produced. [23-24-25].

2. EXPERIMENTAL PROCEDURE

The present work is to establish an experimental design with four parameters and three levels. The aim is to highlight the impact of key process parameters (mold temperature - pressure - injection speed and temperature), on the structural morphology and the mechanical behavior of molded parts the one hand, and on the other hand the optimization of the injection production cycles in order to improved productivity and quality.

The injection process is dependent on the following signal noise effects:

- Internal noise, intrinsic to the process and that we could not eliminate: hydraulic response, temperature variation, heat transfer fluids, pressure drop, and imprecise communication. This noise has a very low level in our case because the production machine is equipped with hydraulics systems and last generation command.
- External noise, that we can make correction if necessary ie humidity, temperature, wear of the valve, material viscosity change. We experience the effect of these parameters that we can't control completely, but their effects remains very limited through the advance control of the raw material on one hand and the organization of the production workshop on the other hand.

2.1. Materials

Isotactic polypropylene is most used in the automotive industry; it offers the best mechanical and thermal characteristics. In the present work, it is presented in the form of white sphere because the polypropylene used is polymerized in the fluidized bed. The density of polypropylene is \( \rho = 905 \text{kg/m}^3 \), melt index I = 15g /10min and melting temperature T = 168 °C.
In order to improve their properties to use them as reinforcements for composite materials, Hemp fibers have been treated with alkaline solution (2% No$_2$SO$_3$ and 5% NaOH). The used fibers have a diameter of 250 μm 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. Polypropylene reinforced with short hemp fiber was produced by extrusion and injection molding of standard specimens Figure1.

![Figure 1 Standardized tensile Specimen](image)

2.2. Experimental setup
To study the behavior of composites submitted to the various injection parameters, we used an industrial injection molding machine with strength closing of 160 tons and equipped with a standard screw 45 mm in diameter.

The injection parameters studied as well as the three adjusting level are presented in Table 1.

<table>
<thead>
<tr>
<th>Test N°</th>
<th>Parameters (factors)</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mold temperature</td>
<td>20 °C</td>
<td>40 °C</td>
<td>60°C</td>
</tr>
<tr>
<td>2</td>
<td>Injection pressure</td>
<td>35Mpa</td>
<td>45Mpa</td>
<td>55Mpa</td>
</tr>
<tr>
<td>3</td>
<td>Injection speed</td>
<td>15mm/s</td>
<td>25mm/s</td>
<td>35mm/s</td>
</tr>
<tr>
<td>4</td>
<td>Injection temperature</td>
<td>180°C</td>
<td>190°C</td>
<td>200°C</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION
The full factorial design of four factors with each factor at three levels requires $3^4 = 81$ combinations. For all combinations, it is impossible to achieve many experiments.

Taguchi introduced the use of the indicator (S / N) to determine the quality of the implemented features. Ozcelik, B, al [28] developed Taguchi analysis and considered the S / N ratio as a performance measure to develop products and processes. The operation where the process with the highest values of $S / N$ always gives the best characteristics and optimum quality. Thus, the $S / N$ ratio is calculated using Equation 1:

$$
\frac{S}{N} = -10 \log_{10} \left[ \frac{1}{N} \left( \sum_{i=1}^{n} \frac{1}{y_i^2} \right) \right]
$$

Where $y_i$ is the value of the desired characteristic for the $i^{th}$ test and $n$ is the number of test, and $N$ is the total number of data points.

Based on the Taguchi method can reduce the number of experience using orthogonal arrays of the method.
Based on the Taguchi method can reduce the number of experience using orthogonal arrays [27]. In total nine tests were scheduled to study the four injection parameters (Table 2). This method reduces the number of tests to 9. The samples produced from these test will be prepared for morphological analysis and mechanical characterization.

<table>
<thead>
<tr>
<th>Table 2 Orthogonal array</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor</strong></td>
</tr>
<tr>
<td><strong>Test</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>4</td>
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<tr>
<td>5</td>
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<td>6</td>
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<tr>
<td>7</td>
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<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
</tbody>
</table>

3.1. Mechanical characterization
Tensile tests were conducted at 22 °C with a humidity of 50%, in line with the ISO 527. The displacement speed was 50mm/min. The values presented are averages from 7 samples. Table 3, shows an example of the result obtained for polypropylene reinforced with 25% short hemp fibers.

<table>
<thead>
<tr>
<th>Table 3 Evolution of the average tensile strength of polypropylene reinforced with 25% short hemp fibers as function of the injection parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameters</strong></td>
</tr>
<tr>
<td><strong>Test</strong></td>
</tr>
<tr>
<td>1</td>
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<tr>
<td>2</td>
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<td>3</td>
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<td>9</td>
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</tbody>
</table>

The objectives of this study are to demonstrate the stability of the production process and therefore its capability by acting on key implementation factors. This was demonstrated by the low dispersion of results, despite the limited number of samples analyzed in each case.
Furthermore, we tried to show the most influential parameters on some mechanical properties of manufactured parts and possibly their interactions; knowing that a finer and more comprehensive study should be conducted to better assess the impact of the main parameters of processing on different mechanical and morphological characteristics of composites based on plant fibers, which are very difficult materials to implement.

The results of the experimental design shows a marked improvement in the average breaking stress for a mold temperature of 60°C; an injection pressure of 45 MPa, an injection speed of 25mm/s and an injection temperature of 190°C. Furthermore, the lowest values are obtained for the lower mold temperature and injection temperature which can be explained by the cooling high speed. These temperatures resulting in the formation of a thick molding skin (instantly solidified layer during filling of the mold cavity) affecting the tensile strength of our material.

The result of the analysis shows a clear influence of the mold temperature followed by the injection temperature and then the lightly the injection pressure. A clear interaction of the effects of the material temperature and the mold temperature was demonstrated.

3.2. Thermomechanical characterization

Studied composites contain between 20 and 25% of short hemp fibers molded by injection molding according to the following conditions: mold temperature = 40 °C, injection temperature = 190°C, injection pressure = 35MPa, speed injection = 30mm/s. The thermomechanical analysis of the composite were performed over a temperature range of -40 ° to 90 °C and under a range of frequencies ranging from 1 Hz to 10 Hz. These analyzes revealed no significant change in the transition temperature, when the fiber content was increased or coupling agents were added.

![Figure 2](http://www.iaem.com/IJMET/index.asp)  
**Figure 2** Thermomechanical behavior of composite PP/short hemp fibers at different frequencies
3.3. Morphology
In a view to understand the interaction between the conditions of implementation and characteristics of parts manufactured in composites based on short hemp. We conducted a series of morphological analyzes using optical microscopy depending on the used parameters.
Figure 3 shows the evolution of fibers distribution along the standard test specimen at different injection speed. A better distribution is presented for the speed 30mm/s, for the other speeds a high concentration is noticed at the end of filling. For the high speed the specimen surface condition is better.

![Figure 3](image)

**Figure. 3** Visualization by reflection microscopy of composite PP + 25% hemp implemented with different injection speed
(a) 15 mm/s, (b) 25 mm/s, (c) 35 mm/s

On the other hand, Figure 4 shows the evolution of the morphology along the specimen at different mold temperature. The process remains stable and without filling problems for both temperatures except that some burns are noticed after filling at 70 °C, all of the fibers are oriented in the flow direction.
Observation of injection molded parts showed the influence of processing parameters on the distribution of the fibers, which partly explains the variation in the mechanical properties according to the loading direction.

3.4. Process optimization

The average for each level of the factors of Taguchi plan is summarized in Table 4: At a high level of mold temperature and the injection temperature, the tensile strength takes its maximum value. The mold temperature is the most influencing parameter in the process monitoring the injection temperature. The pressure and speed of injection is the least influencing parameters.

<table>
<thead>
<tr>
<th>Level</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42,00</td>
<td>43,67</td>
<td>43,67</td>
<td>42,67</td>
</tr>
<tr>
<td>2</td>
<td>44,00</td>
<td>43,67</td>
<td>43,67</td>
<td>44,67</td>
</tr>
<tr>
<td>3</td>
<td>45,00</td>
<td>43,67</td>
<td>43,67</td>
<td>43,67</td>
</tr>
<tr>
<td>Delta</td>
<td>3,00</td>
<td>0,00</td>
<td>0,00</td>
<td>2,00</td>
</tr>
<tr>
<td>Range</td>
<td>1</td>
<td>3,5</td>
<td>3,5</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 5 shows the average of main effects influencing the tensile strength of the composite polypropylene reinforced with 25% hemp fiber. The great influence on the tensile strength is due to the mold temperature. When this factor is at level 1 (20 °C), the average value of the breaking stress is 42,00MPa and Level 2 (40 °C) the average value is 44.00 MPa and at level 3 (60 °C) the average value is 45.00 MPa. For pressure and the injection speed the tensile strength remains constant at all levels of the two factors (about 43.67 MPa). For the injection temperature increased tensile strength is
observed when this factor is at level 2 (190 °C), the value for the stress is about 44.67 MPa.

![Visualization of the main effects influencing the stress at break](image)

**Figure 5** Visualization of the average of the principal effects influencing the stress at break

In our case the optimum parameters combination for a better tensile strength for composite PP/hemp fiber is shown in Table 5.

**TABLE 5** optimal Condition for a maximal breaking stress

<table>
<thead>
<tr>
<th>Mold temperature °C</th>
<th>Injection pressure (MPa)</th>
<th>Injection speed (mm/s)</th>
<th>Injection temperature °C</th>
<th>Average breaking stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>45</td>
<td>25</td>
<td>190</td>
<td>46</td>
</tr>
</tbody>
</table>

5. CONCLUSION

Natural fibers such as industrial hemp have been identified as attractive reinforcements for thermoplastic polymers. They are economic and abundant and renewable, and have good specific properties due to their low densities compared to synthetic fibers.

Taguchi method allowed us to highlight, with a minimum of tests, the influence of injection parameters on the mechanical properties of manufactured parts, then optimize production cycles while controlling the quality of injected products.

The results of the experimental design shows a clear improvement in the average tensile strength of the polypropylene reinforced with 25% short hemp fiber, for a mold temperature of 60 °C and an injection pressure of reinforced and an injection speed of 25mm/s and an injection temperature of 190°C, with an indication of the stability level of the producing process with the predefined settings parameters.

The analysis of the results highlights the effects of major implementation parameters and their interactions on the tensile strength of the injected thermoplastic composite. Other studies are underway to complete these results and specify the level...
of the effects of various parameters on the mechanical and morphological behavior of injected composite with a better control of external noise effects.

**REFERENCES**

Study and optimization of the injection molding of composites based on short hemp fibers


