DEVELOPMENT AND CHARACTERISATION OF ECO-FRIENDLY THERMOPLASTICS E! 2819 FACTORY ECOPLAST

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ABSTRACT
A new composite emerged in the last decade of the past century that is compounded of natural fibres and of low price polymer such as HDPE or PP. It quickly became popular for floor decking, roof coverings and other extruded products. But industry avoided injection moulding of this material because of various problems with fillings, surface, shrinkage etc. In this paper these issues will be addressed and solutions for them will be presented.

In the paper the description of technology of injection moulding of wood-plastics composites compounded of various types of wood flour and polymers is presented. Procedure of injection moulding of wood-polymer composite, the selection of parameters and instructions for the mould design are specified. Also a description of advances and weaknesses of procedure is given in addition to technical obstacles that need to be overcome.

KEYWORDS: Thermoplastics, Wood-plastics composite, Injection moulding

1. INTRODUCTION

In an expanding world population and parallel with the increase of purchasing potentials, the need for materials that would satisfy the demand on world market is rapidly growing. In times when we can not expect polymer prices to be reduced and the consumption is still growing, we need to develop new materials (mixtures) that would be cheaper and at the same time offer equal or better properties. The oil supply is getting smaller every day and the pressure to become more independent from oil derivates is at the all time high, therefore there are multiple reasons to maximize the usage of renewable resources. On the other hand we have enough natural resources like wood, flax, hemp, jute… One of the very interesting areas of research in this field is in combining natural fibers with thermoplastics.

The aim of the project was to research rheological properties, compatibility between natural fibers and thermoplastics, injection moulding parameters and possible applications of the compound. Product selection has to be based on core competencies of wood-polymer composites:

- increased rigidity
- reduced wear of machine equipment in processing final products
- reduced weight as compared to the mineral fillers
- wood-like character of the product (easily sawn, drilled, ground)
- advantageous price
- acoustic properties

Wood is known for its acoustic properties and usage in musical instruments. A lot of speaker boxes are manufactured from injection moulded polymers, we assume that wood PP composite should have better properties.
Acoustic properties of a material are very simplified defined by:

- Sound radiation damping
- Sound wave resistance
- Internal losses (friction)

2. INJECTION MOULDING TECHNOLOGY

2.1 Materials

Wood and polymer are the main but not the only components in wood-plastic composite. Other additives are also added, such as coupling agents for wood and polymers, lubricants, colorants, UV-stabilizers, flame retardants…

2.2 Wood

Wasted wood has special advantages compared to other fillers: cheap in renewable source, guaranteed supply, unique look, low specific density and it is less abrasive than other fillers (i.e. glass).

Several different types of wood can be used with knowledge that the right selection greatly influences end performance of the composite. To obtain as good mechanical properties as possible wood must be ground into fine wood flour. A single wood particle measures from 0.075 mm (size class 200) up to 2.0 mm (size class 10) /1/. The ratio between the length and the width varies from 1:1 up to 5:1. Particles with larger ratio (up to 1000:1) are called fibers.

Usually 40-60 % of wood is used in the composite, the rest are matrix polymer and additives. The size of wood particles is usually from 0.50 to 1.0 mm. The more complex the product is the smaller the particles must be.

2.3 Additives for increasing compatibility of wood and polymer (coupling agents)

These additives are essential for production of composites reinforced with natural fibers. For example in the mixture of PP and wood, where one component is polar and the other nonpolar, the coupling agent is needed to reinforce adhesion of wood fibers and polymer. The interaction between wood and polymer is subject of intense research of the past few years due to its great impact on properties of composite. Without this additive the bondage between wood and polymer is very poor and in addition the wood particles can cause growth of crystals in the polymer. The most common used coupling agent is MAPP (maleated polypropylene). Besides improving mechanical properties such as tensile strength, elastic module and impact strength it also reduces absorption of water and improves resistance to high temperatures.

2.4 Advantages and weaknesses of injection molding of wood-plastics composite:

Wood-plastics composite has some distinct advantages over other polymers and composites:

- Appearance: wood fibers give to the composite an appearance and a touch of natural wood
- Colouring: WPC products are easier to colour (blue and green colours were tested, problems can occur with white colours)
- Tensile strength to weight ratio: wood fibers have low density compared to glass and minerals
- Gluing: the ability to glue surfaces increases
- Acoustic properties: wood fibers have good acoustic properties and can dampen vibration, trembling and resonance effects.

Disadvantages:

- Thermal sensitivity: one of the most important factors when choosing material is the thermal sensitivity, because they start to degrade at temperatures greater than 200 ºC.
- Moisture sensitivity: wood fibres are, not like PP or PE, extremely sensitive to moisture.
Injection process and mould design: When injection process is taking place it is important that the melt is in the cylinder for as short time as possible. For better cavity filling hot runners are helpful. There are also some constraints regarding mould design, which are addressed later in the article.

3. INJECTION MOULDING OF WOOD-PLASTICS COMPOSITE (WPC)

Injection of WPC is not very different from ordinary injection but attention must be given to some details. In our case composite with 40 to 70 % of mass portion of wood flour has been injected. Prior to the injection granules must be thoroughly dried. The drying process took place for 4 hours at a temperature of 100 °C up to relative humidity 0,05 %.

3.1 Injection parameters

The selection of correct parameters is crucial for quality of injected products. Correct temperature is of the most importance, since at temperatures above 200 °C wood fibres start to degrade. When composite with high percentage of wood was injected (more than 50 %), the injection speed had to be increased from 30 mm/s to 70 mm/s, otherwise the melt did not fill the cavity completely. Consequently maximum pressure had risen from 46 to 71,5 MPa and packaging pressure from 30 to 50 MPa.

Mixtures were comprised of different combinations of two different kinds of polypropylene, two different kinds of wood (soft and hard) with mass share from 40 to 60 % and two different coupling agents. The combinations were composed in a way that the impact of each single ingredient can be studied. For each mixture test specimens ISO 527-1 were injected and average tensile strength, elastic module and relative elongation were calculated (Table 1).

Table 1: Dependences of tensile strength, elastic module and rel. elongation on mass portion of the wood:

<table>
<thead>
<tr>
<th>Tensile strength [MPa]</th>
<th>Elastic module E [MPa]</th>
<th>Elongation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>30,0</td>
<td>1325</td>
</tr>
<tr>
<td>40%</td>
<td>32,2</td>
<td>2806</td>
</tr>
<tr>
<td>50%</td>
<td>36,7</td>
<td>3809</td>
</tr>
<tr>
<td>60%</td>
<td>43,6</td>
<td>4214</td>
</tr>
</tbody>
</table>

It can be noticed that the elastic module and the tensile strength are linearly increasing with wood portion in the composite. Respectably the elongation is linearly decreasing when the wood portion is increasing. It has to be emphasized that with correct selection of polymer, wood and coupling agent mechanical properties are increased for up to 40% at the same wood content. While drying had no effect on the elastic module and tensile strength, the elongation was up to 2.5 times greater with the dried specimen compared to non-dried.

3.2 Linear shrinkage

Shrinkage has been measured with a standard test specimen ISO 294-4. It was measured in parallel and perpendicular direction in respect to the melt flow. Packaging pressure and coolant temperature were changed:

- Packaging pressure from 40 to 80 MPa
- Coolant temperature from 15 to 50 °C
Figure 1: Test specimen for linear shrinkage measurements

Average results of different measurements are given in the table below:

<table>
<thead>
<tr>
<th></th>
<th>Shrinkage ║ [%]</th>
<th>Shrinkage ┴ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolant temperature: 30 °C; Packaging pressure: 40-80 MPa</td>
<td>0,70-0,55</td>
<td>1,46-0,96</td>
</tr>
<tr>
<td>Packaging pressure: 60 MPa; Coolant temperatures: 50-15 °C</td>
<td>0,647-0,637</td>
<td>1,65-1,80</td>
</tr>
</tbody>
</table>

Due to the parallel orientation of wood fibres shrinkage is much greater in the direction perpendicular to melt flow. If compared to pure PP, which has shrinkage of 1.2 to 2.5 %, WPC shrinks from 0.5 to 1.5 % less.

4. INJECTION MOULDING OF INDUSTRIAL PRODUCTS

Composite with 50% of wood fibres was selected for testing on a product 250x180x155 mm in size. The influence of injection speed and mould temperatures on cavity filling and product surface was observed. The test took place at three different speeds: 55, 120 in 30 mm/s. There were no problems with cavity filling, but the injection speed has great influence on surface appearance. The best results were obtained at the speed of 55 mm/s, while at 30 and 120 mm/s the moisture is brought to the surface causing spots and stains. The surface was also observed at two mould temperatures: 30 and 60 ºC. While at 30 ºC there were some stains on the surface, they practically disappeared with raising the coolant temperature to 60 ºC.

The difference between wood plastic composite and unfilled polypropylene was also measured. For best results the wide opening in the product was chosen (Figure 2). The width with WPC composite was 174.75 mm, while with pure PP the width was 173.15 mm. This confirms previous assumption that shrinkage of pure PP is around 1% greater than that of wood plastic composite. For promotion as well for the dissemination of project results another industrial case was selected as present in Figure 3. The part has a relatively simple geometry therefore it was possible to produce boxes with 70% of wood particles.
5. INJECTION MOULDING OF A LOUDSPEAKER BOX

When defining project objectives the project team studied possibilities where WPC could be competitive. As WPC have good acoustic properties a decision was taken to produce and test a loudspeaker for mass applications where a ratio between quality and price could be competitive.

In usual practice car audio systems use loudspeakers done from different polymers therefore a loudspeaker produced from WPC could have some privileges. After several trials the material and box were selected as presented in Figure 4.

5.1 Results

The project was very successful. We defined the technological parameters for injection moulding (processing temperatures, screw geometry) and correct palletizing process for making the compounds for injection moulding and extrusion. Also an expert with a doctor degree in acoustics was hired for this specific part of the project.

One of the most common materials for loudspeaker boxes, including the high-quality products, is MDF (medium density fibreboard). Therefore we denoted acoustic properties which are significant for this material as the referential properties. Acoustic properties of a material are de-
fined by (i) sound wave resistance, (ii) damping of sound radiation, and (iii) factor of viscous damping. In comparison to sound boards of musical instruments which should radiate their vibration energy into surroundings as much as possible (in addition to minimal internal losses), function of loudspeaker boxes is different.

More precisely, damping of sound radiation for sound boards of musical instruments has to be relatively high, and sound wave resistance should be low. The energy contained in vibrations of a loudspeaker diaphragm has to be absorbed in a proper way which means that intensity of absorption should be neither too high nor too low. We can say that sound wave resistance of a material for loudspeaker boxes has to be relatively high in order not to amplify resonant frequencies of a whole loudspeaker. Damping of sound radiation, thus radiating of sound into surroundings has to be relatively low. However, too high sound wave resistance means insufficient transition of acoustic energy into the loudspeaker box which can result in phenomena like echoes and standing waves.

A nice example of this is high value of sound wave resistance for aluminium. It is not hard to understand that aluminium loud speaker box would result in undesired effects like standing waves and consequently resonant vibrations of loudspeaker diaphragm. It is logical that purpose of a loudspeaker box is not to emphasize certain frequencies, but on the contrary, to prevent this phenomenon. On the other side, too low sound wave resistance correlates with a relatively low sound impedance and fast sound energy drain into the loudspeaker box. This can result in short-lasting but distinctive resonant frequencies of loudspeaker box. Finally, this can lead toward high sound energy losses, especially if relatively low sound wave resistance appears together with relatively high factor of viscous damping (high losses due to internal friction).

It is reasonable to conclude that acoustic properties measured for MDF are optimal ones. Thus one can say that the most suitable material for loudspeaker boxes among the tested ones is wood fibre filled PP. Because both damping of sound radiation and sound wave resistance for this material are slightly lower in comparison to MDF, a question occurs, how to increase these two parameters and not to significantly affect factor of viscous damping which corresponds to that one for MDF.
Finally some comparisons were made with JVC box of the same shape and size as the "Eureka" box and a high end speaker made by Nakamichi.

- A significant reduction of loudness (output power level) in range ca. 200 – 350 Hz was measured for EUREKA speaker in comparison with other two speakers.
- Hearing tests showed that EUREKA speaker sounds not different than JVC speaker; a small lack of basses and/or improvement of high frequencies is significant for EUREKA speaker.

6. CONCLUSION

Wood-plastics composites are definitely materials of the future. Mechanical properties are increased almost linearly with addition of natural fibres. Choosing the right coupling agent is of the most importance, since it can improve performance up to 30 - 40% in comparison to poorly chosen one. Also one important quality is gained: the touch and warmth of wood, which is especially important for floor decking, laminates, garden furniture etc. Even though viscosity is rising with the addition of wood flour, the tests have shown that there are no major obstacles for injection moulding. Prediction of shrinkage is harder because of wood fibre’s orientation, but this is the case in all fibre reinforced materials. Nevertheless comparison of simulated and injected
parts has shown good prediction of injection moulding process, which is very important and helpful when designing wood plastic composites /2/. In the project a special study on recycling /3/ showed that WPC are not significantly losing mechanical properties after several recycling operations. In the future longer wood fibres will be introduced, which will even strengthen composite to the point, where they could be compared to glass reinforced composites.

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7. REFERENCES