Characterization of the production process of wood plastic composite from sawdust of pinus and recycled thermoplastics

Yonny Martinez Lopez
UFES

Juarez Benigno Paes
UFES

Fabricio Gomes Gonçalves
UFES

Pedro Gutemberg de Alcântara Segundinho
UFES

Luciana Ferreira da Silva
UFES

Marcos Alves Nicácio
UFES

Emily Soares Gomes da Silva
UFES

Jaqueline Rocha de Medeiros
UFES

José Guilherme dos Santos Moreira
UFES

Anna Clara Theodoro Nantet
UFES
The objective of the work is to show the characteristics of the wood plastic composite for the development of the forestry industry, these boards, due to their properties, are widely used in various areas for various purposes, placing them within the materials of greatest demand in the international market. Due to the benefit that can be acquired, it has become a highly preferred product. These boards are made from residues from both the forestry industry and recycled thermoplastics. In the work, the methodology for its elaboration is proposed. The board has good physical-mechanical properties, which guarantee its applicability. As well as the compatibility between the raw materials used in the production process.

**Keywords:** Raw Material, Technological Process, Applicability
INTRODUCTION

The wood industry has the characteristic of generating large volumes of waste during the process of exploitation and processing thereof, this occurs before the wood is introduced into the industrial process until the final product is obtained (CHAUDEMANCHE et al., 2018). These residues can contribute to the world of the economy, by being part of the production of products that come to acquire market value. Today society together with the technological revolution, have led to the largest waste production in the history of humanity (RENNER et al., 2010). However, technological improvements will simultaneously solve the problems of pollution, as well as the scarcity of natural resources (AGUILAR et al., 2018).

Some researchers suggest that waste from industrial processes, services, and residential is considered a social necessity in order to reduce the consumption of fossil fuels, its use can be a solution not only to environmental problems that the Incorrect disposition of them has provoked over the years, furthermore, brings added value to the wood in the board industry (ESSABIR et al., 2017).

The use of by-products, both forestry and other industries, are underutilized; For example: Sawdust, shavings, tips and plastics are stored in large hills or burned in boilers, without having a greater added value or achieve a higher energy efficiency, in addition to causing severe damage to the environment (MOYA et al., 2012).

There are ways to take advantage of forest residues and especially sawdust, can be used for the production of pulp, paper and fertilizers, furthermore, has broad perspectives for the board industry, for example: by mixing them with industrial waste (thermoplastics), can be obtained composites from high quality and multiple uses in civil construction. However, the reality is that in countries that do not have these technologies their use as fuel is the most common (BOUAFIF et al., 2009).

The development of new materials derived from the recycling of plastics and wood is becoming a real and advantageous alternative, opening up a whole range of opportunities and possibilities for its application in products for different areas due to the numerous advantages they present, above all, for outdoor use. These panels are made by mixing synthetic plastics and flours or vegetable fibers, and are of growing interest in the science and engineering of materials (MARTINEZ et al., 2020).

Its environmental value is evidenced by the fact that this material makes it possible to manufacture recycled and recyclable structures that favor the reuse and recovery of waste. This type of board is not damaged in the open or in contact with water, has good physical-mechanical properties, which gives it a longer life than wood and other construction materials, providing a very efficient workability.
In this investigation from the mixture of sawdust of *Pinus caribaea* var *caribaea* with thermoplastic residues and chemical additives, a forest product was elaborated that due to its low porosity, and its resistance to the physical-mechanical properties, can become a strong competitor compared to the materials commonly used in the construction of elements for homes, buildings and packaging applications both indoors and outdoors, replacing conventional boards and metals with great advantages against the effects of weathering.

**METODOLOGY**

Were developed six boards in proportions of sawdust-thermoplastic and additives as follows: T1 (40-55-5); T2 (45-45-10); T3 (50-35-15); T4 (55-25-20); T5 (60-40-0); T6 (40-60-0). To evaluate the behavior of the raw material, as well as the treatment performed to each of them, mainly related to the resin content in pinus wood, and in the crushing of recycled plastics. The raw material used in the production process of the wood plastic composite (WPC) were obtained from several productive sectors, the sawdust (*Pinus caribaea*) was obtained from the process of primary transformation of wood from the forest industry.

For its part, the thermoplastic waste was obtained from the social sector, through raw material recovery companies; it was possible to obtain thermoplastic waste corresponding to the seven groups according to their classification, which were incorporated into the production process after trituration.

The treatments to the raw material described in the technological design, were carried out in correspondence with the international standards specific to each evaluation, these treatments allowed to place both the wood and thermoplastics in suitable conditions for use in the technological process of the board.

**Determination of the treatments carried sawdust of Pinus caribaea**

The bulk sieve analysis is conducted to determine the distribution of the particles according to their size, due to the use of effective means for transportation, in addition to providing the optimum range of use as feedstock developing the proposed board. The distribution sieves are considered by the Tyler series, which sets a range from 2,362 mm to 0,038 mm aperture, from a sample of 100 g sawdust, and using a vibrator for 30 minutes were taken portions retained on each sieve.

The constant sample of about 1g was dried in an oven at 103 ± 2°C mass according to Technical Association for the Pulp and Paper Industries - TAPPI T12 os-75 (1992) materials were used as crucible, stove, and analytical balance (precision 0.001). The percent moisture was calculated according equation 1.
Process of extracting resin from wood sawdust of *Pinus caribaea*

Was conducted in the laboratory of chemical research at the Federal University of Espírito Santo, Brazil, according to Standard TAPPI T 257 os-76 (1978). Serial extraction 5.0 grams of the sample, using toluene, performed the procedure: ethanol as solvents for the extraction (2:1) for 8 hours, followed by extraction in 95% ethanol for 4 hours. Extraction was performed using a Soxhlet with counter flow of cold water during the time set by each solvent according to standard, then. Were dried in an oven for 4 hours at a temperature of 103 ± 2°C.

**Determination of treatments performed to thermoplastic waste**

The crushing of thermoplastic waste was performed at the Laboratory of Panels of Federal University of Espírito Santo, Brazil, using a crusher claw machine for Hyundai plastic resins with reducers 1-60 mm and a yield of 98%. After being crushed these residues were washed in water at a temperature of 25°C, using detergent to remove all impurities contained in the materials, since many of them come from the residential sector. They were then dried in the open due to the tropical conditions of the country.

**Statistical analysis**

The results were processed using the statistical tools according to SPSS version 21. The descriptive analysis was used to characterize the variables; the assumptions of normality were evaluated by the text of Shapiro-Wilk to have a better statistical inference when the assumption of normality was not met (p < 0.05). The associated statisticians were analyzed to determine the significant differences between each treatment using the Kruskal-Wallis test.

**RESULTS AND DISCUSSION**

**Evaluation of particle size distribution of sawdust**

It was determined that for every m³ of sawdust 88.3% can be used in the production process of wood plastic composite (Figure 1) as they are between the ranges established for the manufacture of particle board, the obtained values ranging from 0.04 to 0.83 centimeter. A total of 11.7% were retained on the sieve particles to be used must be crushed again, because
the dimensions of these particles are larger than 1.0 centimeter and are in the form of chips, wood chips and bark. These values are within the required parameters (*n.35 US Standard mesh*) defining the optimum particle size for these types of boards are below 0.5 centimeter. Particles smaller facilitate mixing with plastics particles (BOUAFIF et al., 2009).

In this assay, the presence of bark was not quantified, since they were removed from sawdust samples evaluated. It is considered that the typical particle shape is a parallelepiped, as sieves and mills used in the process are designed to achieve that geometry (YANG et al., 2015). In practice, an acceptable particle must meet a slenderness range between 60 and 120, 100 being the ideal case for the pine particles is approximately 70.7 which is within the allowable range.

**Figure 1.** Particle size analysis sawdust.

This value varies for fine and coarse particles, in the manufacture of wood plastic composite (WPC) while smaller the size of the wood particles technological flow is facilitated, this favors a better bonding of plastic particles of sawdust and other additives. High temperatures favor the casting of plastic resins, improves the contact between them, improves adhesion, force transmission, and in turn allows better from the palletizing process and extruded (ASHORI and NOURBAKHSH, 2010).

During the trial, it was found that the average diameter of the sieves (dpi) with sieved fractions and held mass (*x*, *y*) is about 0.70 mm. This analysis ensures that the sawdust used is an important source of raw material for the production of wood plastic composite (MARTINEZ et al., 2012).

**Evaluation of the moisture content of the sawdust from Pinus caribaea**

The moisture content of the particles of sawdust have an important role in the manufacture of particleboard, including WPC, this contributing to rapid transport of heat energy to
the board, allowing their internal binding properties are better, and facilitating the function of each of the additives used (MARTINEZ et al., 2020).

It has been estimated that in 1 kg of sample of sawdust has 0.2 kg of moisture determined in laboratory by gravimetric (oven at 103 ± 2°C, and has 0.8 kg of dry matter). On an industrial scale, this procedure is performed in suspension-type dryers with gases, either combustion gases, hot air or both, the inlet and outlet temperature ranges between 117 and 175°C respectively.

Particles and water vapor generated leaving the dryer are sent to cyclones, which separate the vapor particles, releasing steam into the atmosphere and at the bottom a stream of particles with adjusted moisture for use as raw material in the manufacture boards. It is considered having good moisture according rule, particles with up to 6% moisture (MARTINEZ et al., 2012).

The initial moisture content of sawdust of *Pinus caribaea* is 20%, which determined that for use as raw material, must meet the standards established in this regard. This implies a reduction of at least 15% necessary to have adequate raw material in the production of particleboard, which establishes 3 to 6% moisture, considering its ideal state between 1 to 2% of moisture.

The stability of the moisture content of the sawdust samples used in the manufacture of boards one WPC sawdust was obtained average moisture content of 3.5%, which complies with the parameters of humidity of the particles to be used as feedstock in the manufacture of boards (HOSSEINIHASHEMI and BADRITALA, 2017).

Similar moisture contents have been reported by several authors, for compounds made based on wood flour and thermoplastic by injection molding using wood with a moisture content of 3% prior to processing for WPC without the use of additives (HAO et al., 2018). For WPC, moisture content is considered essential for the technological process, controlling the temperatures to which the wood (sawdust) is subjected in the drying, mixing, granulating and extruded process is important.

It is considered that very high temperatures can degrade the extractable and lower molecular mass carbohydrates present in greater quantities in the wood cell wall, which can undergo unwanted physical transformations. The gases and the resulting water vapor can be encapsulated by the thermoplastic matrix during formation of the board, which favors increased moisture content of the compounds, so it is advisable to work with particles having a low percentage of moisture as set standards (SHEBANI et al., 2009).
Evaluation of the process of extracting resin sawdust

In the industrial process for the production of wood plastic composite, it has shown that the resin content of pinewood deteriorates equipment primarily to the shaft or worm extruder, given by the explosions, which occur at temperatures above 200°C. This phenomenon occurs from the formation of flammable gas inside the extrusion and pelletizing equipment (Figure 2).

Figure 2. Effect of components of pine resin in the technological process of WPC.

The flammable gases lead to violent internal imbalances not only in equipment but also in affect the sintering process with the consequent deterioration in the quality of the composite to produce. Pinaceae resins are a major source of terpenes and terpenoids, forming part of the extractable substances (3 to 4%) of these wood tree species (pinus).

The resins present in the wood of Pinus caribaea are between 3.73 to 3.90% in toluene: ethanol and ethanol between 1.98 to 2.09% for ages 10-15 and 35. Resins or oleoresins are a mixture of resin acids (diterpenoicos acids) dissolved in a mixture of terpene hydrocarbons, of which by stripping with steam pine resin, a volatile fraction known as turpentine oil is obtained or turpentine (16 - 20%).

Another component of pine resin as a nonvolatile fraction is known as rosin (64-70% of the mass of resin). It is obtained as solid residue from the distillation of the resin. This component adds to the imbalances that occur during the technological process, as well as internal explosions caused by the turpentine, the accumulation of solids on the inner walls of the machinery causes them breaks (RENNER et al., 2010).

These breaks are given because of a greater effort in moving the material through the internal mechanism of the pelletizing and extrusion machinery (helical screw heating jacket), until his departure for the respective molds, which causes wear on the entire mechanism.
The extraction process of the resin not only promote efficiency in the production flow for plastic timber, by reducing the frequency of breaks in the equipment and reduce quality problems in forming the composite.

From the distillation of resin obtained from sawdust you can get various components (turpentine and rosin), which have many industrial uses, thus closing the cycle of use of all resources in the development process the board, thus achieving a sustainable process. During the extraction process 3.7% extractible were obtained, these results are consistent with the content of extractible for this species (*Pinus caribaea*) which ranges from 3 to 4 %, and further finds that the resin is in 3%. This extraction process may be performed using other organic solvents such as toluene, chloroform, benzene, and mixtures thereof with ethanol in the ratio 2:1 (HORTA et al., 2017).

**Evaluation of plastic waste**

The recovery of such waste falls mainly in the Enterprise for Raw Materials Recovery, which primarily feeds on two sectors, residential, where an insufficient part of this waste is recovered, which form part of the environmental pollution they cause. These low indicators imply a political work to enhance community and environmental education work to ensure that stakeholders become involved in the recycling process of this raw material, followed by a remuneration that encourages collection. For its part, the state sectors from its productions plastic waste that can be recycled and incorporated into the production of this type are generated.

According to research many of these residues are given away (20%) or sometimes burned by some institutions (10%), and sometimes they are taken to the company’s premium (30%) field, being mostly land filled (40%) generating all these actions a significant environmental impact to the environment (HOSSEINIHASHEMI and BADRITALA, 2017).

These residues are an important part of the technological process due to its function as a binder in the formation of the proposed board also it showed that the impact on the physical-mechanical such board properties is very positive mainly in the aspect of resistance board, low porosity and high impermeability (CHAUDEMANCHE et al., 2018).

With the use of recycled plastic are allowed to eliminate the import of plastic pellet, which is currently the raw material used by the producer in the production process. From the potential of plastic waste, it can be estimated that they guarantee stable production of boards (KESKISAARI and KÄRKI, 2018).

**Technological process of wood plastic composite**

The technological schemes for wood plastic board manufacturing in order to obtain a good quality board complying with the characteristics and properties for which it was designed
is proposed (MARTINEZ et al., 2012). The board is produced by introducing the pelleted material in the extruder at a higher 100°C; this is a continuous process employing a screw conveyor, where the material is transported from the hopper, through the chamber of heating up the spout. This material exits the extrusion die into a semi-soft state, through the mouth open mold taking the product shape to be obtained, it slides on a bench where it is cooled with air or water, hardening as it cools (ORTEGA et al., 2019).

Depending on their size and shape, they are stretched, cut to the required lengths and acquire their hardness artificially to achieve the proper properties. During this process, the board is coming out with a texture itself as a natural finish that exonerates him from any paint, varnish or other products used in the various conventional boards to improve their finishing (AGUILAR et al., 2018).

The color of WPC depends largely on the color of the wood and the polymer used. This can be modified after the process with a lacquer or during processing with a color concentrate, which if well designed, can have flow lines resembling normal wood grain. Although aging for other types of particleboards and fiber takes place in ovens at 200°C for a period ranging from 4 to 8 hours, it is not beneficial for WPC because they may be deformed (Figure 3) (SOCCALINGAMEA et al., 2015).

**Figure 3.** Flow diagram of the technological process of the wood plastic composite.
The humidity is the most important when analyzing the causes of the dimensional changes of wood and its products, in the process of cooling to achieve equilibrium moisture factor (ZHANG et al., 2018). The dimensional stability of the board will be achieved once it achieves equilibrium moisture, this being the most appropriate for the commissioning of the board time (TAUFIQ et al. 2018).

This process is important in the case of HDF, whereby a wetting step at the end of the manufacturing process is integrated (TENORIO et al., 2012). Appearance matching to achieve equilibrium moisture of WP, because it is thought that this balance is achieved by leaving them at room temperature for a period of 4 to 5 days under conditions of relative humidity of 75 ± 2% temperature of 25 ± 2°C prior to the physical-mechanical tests (LIU et al., 2010).

**Physic-mechanical properties**

Raise the knowledge of the physical and mechanical properties of the boards is essential for the development of the forest industry; their knowledge enriches the technical information about them; and favors the decision-making on the use of industry (ASHORI and NOURBAKHSH, 2010). The control of each one of the physical and mechanical properties guarantees the quality of the product for a specific use (TARRÉS et al., 2019). Table 1 shows the average values of the physical-mechanical tests evaluated.

### Table 1. Evaluation of the physic-mechanical properties of the WPC

<table>
<thead>
<tr>
<th>Treatments</th>
<th>CH (%)</th>
<th>D (kg m⁻³)</th>
<th>ABA 72h</th>
<th>H (%)</th>
<th>F (Mpa)</th>
<th>C (Mpa)</th>
<th>T (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controle</td>
<td>5,26</td>
<td>1020</td>
<td>0,61</td>
<td>0,31</td>
<td>15,20</td>
<td>120,12</td>
<td>20,3</td>
</tr>
<tr>
<td>T 1</td>
<td>5,58</td>
<td>1022</td>
<td>0,60</td>
<td>0,30</td>
<td>15,24</td>
<td>120,23</td>
<td>21,3</td>
</tr>
<tr>
<td>T 2</td>
<td>5,55</td>
<td>1025</td>
<td>0,60</td>
<td>0,30</td>
<td>15,28</td>
<td>124,30</td>
<td>22,7</td>
</tr>
<tr>
<td>T 3</td>
<td>5,42</td>
<td>1027</td>
<td>0,50</td>
<td>0,28</td>
<td>15,25</td>
<td>126,16</td>
<td>23,4</td>
</tr>
<tr>
<td>T 4</td>
<td>4,54</td>
<td>1041</td>
<td>0,44</td>
<td>0,25</td>
<td>16,25</td>
<td>132,24</td>
<td>24,4</td>
</tr>
<tr>
<td>T 5</td>
<td>4,35</td>
<td>1045</td>
<td>0,31</td>
<td>0,20</td>
<td>16,41</td>
<td>136,32</td>
<td>26,2</td>
</tr>
<tr>
<td>T 6</td>
<td>4,13</td>
<td>1052</td>
<td>0,22</td>
<td>0,16</td>
<td>17,52</td>
<td>138,10</td>
<td>28,3</td>
</tr>
</tbody>
</table>

CH: Moisture content; D: Density; ABA: Water absorption; H: Swelling; F: Flexion; C: Compression; T: Traction.

As can be seen in each of the physical-mechanical properties, taking into account the statistical analysis performed, it can be estimated that the chemical additives dosages are not significant for the properties evaluated, since the results obtained in those treatments where they were not used additives, they obtained good results.

It is important to note that the chemical additives used in the technological process of plastic wood boards can contribute to the formation of the same, as well as attribute specific properties according to their functions (HAO et al., 2018). Investigations developed for this type of board allow corroborating that the application of chemical additives is not
necessary to obtain boards of good response before the physical and mechanical properties (MOYA et al., 2012).

Among the physical properties, it can be estimated that the density is a favorable indicator that determines desirable responses of the boards. The quality is higher in those whose density is higher. In the case of the plastic wood boards produced in the research they all showed to have density greater than 1000 kg m\(^{-3}\). This guarantees that they can be used in different construction conditions, these characteristics differ greatly in relation to conventional boards, which have lower densities and their uses are limited (MARTINEZ et al., 2020). The average density values for the WPC evaluated are presented in table 1, column 3.

It shows that the density increased as the thermoplastic dosages increased, varying from 1020 to 1052 kg m\(^{-3}\). Similar values have been reported by different researchers, for thermoplastic compounds and sawdust of different species manufactured by injection molding, extrusion and compression (NGUEHO et al., 2010)

For example, some researchers have obtained different results related to different dosages of raw material in the manufacture of plastic wood boards. In their research, they show density values of 1100 kg m\(^{-3}\) using recycled polypropylene (PP) plus 50% of coniferous wood fibers and 4% of chemical additives by injection molding (Turku et al., 2017).

Others show density values of 1029 kg m\(^{-3}\) from high-density polyethylene (HDPE) plus 50% sawdust from *Pinus radiata* and 5% chemical additives through compression molding (THANATE and KAMPANART, 2018). As well as density values of 1080 kg m\(^{-3}\) from high density polyethylene (HDPE) plus 50% coniferous sawdust without additives by extrusion molding (VILASECA et al., 2018).

However, the boards obtained in this research showed similar values and in some cases superior to the results of some researchers mentioned above, this demonstrates the feasibility of the proposed technological design, as well as the treatments performed on each of the raw materials used.

**CONCLUSIONS**

Industrial waste such as sawdust and plastic are a significant source of raw material for the board industry, their use contributes not only to mitigate the severe effects caused to the environment, but its conversion into composite with greater benefit.

The technological process guarantees the production of high quality plastic boards and, the treatments to the raw material enables the protection of the equipment in the production process. The physical-mechanical properties of these boards allow their applicability in various fields of construction given their resistance to weathering.
REFERÊNCIAS


