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Ecological boards molded from low-cost local wood particles for wall panel

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Abstract**—***This research proposes a wall panel component molded from a wood of bracatinga (Mimosa Scabrella) and a lignin-phenol-formaldehyde adhesive. The development of a product with a simple and ecological construction technology was adopted as the approach, using low-cost wood particles. A composite made of bracatinga wood particles and alternative residual lignin (lignin-phenol-formaldehyde) adhesive was developed and characterized. The designed wall panel component was prototyped in full scale to evaluate the molding process and the final quality of the product. Preliminary results obtained with the pilot experiment demonstrated that the composite had properties and values that met the requirements of the standards EN 312:2010 and NBR 14810-2:2013, for structural boards for use in humid conditions (type P5). To prove the ecological aspect of the product, CO_2 emissions resulting from its manufacture and the amounts of carbon of non-fossil origin and fixed by it (expressed as CO_2 uptake) were calculated. The final balance proved to be favorable.*

Keywords**— Wood closure panels, Molded products and reconstituted wood, Sustainable construction.**

I. INTRODUCTION

In Brazil, wood wall panels are not properly used and do not meet the requirements for tightness and hygrothermal comfort, distancing the population from construction systems that employ wood (BITTENCOURT & HELLMMEISTER, 1995).

Therefore, the purpose of this study is to develop a product or a board molded from wood particles for house wall paneling. This development can allow the formation of walls with space between the panels for better thermal and acoustic insulation, as well as water and electric installations. Due to their good ratio between mechanical strength and low density, well-designed wood products are easy to assemble into construction elements and provide considerable design freedom.

Molded products are formed from composites, which are structural molding materials consisted of a continuous polymeric phase (matrix) and reinforced by a discontinuous phase (fibers/particles). The composites are consolidated by a polymer crosslinking process (curing), in which the two phases are physically and chemically aggregated (MOSLEMI, 1974).

In this research, the process applied for molding products was based on compression. According to Razera (2006), this process allows the use of wood as a matrix, raising its concentration to 90%. This fact represents a significant increase in the use of raw material from renewable sources in the product composition.

The basic components used to manufacture wood products, molded by the compression process, are wood particles and adhesives. In this procedure, wood is reduced to small particles, which must be dried to approximately 3% humidity and mixed with the adhesive, whose type and content are defined according to the characteristics desired for the final product. During the gluing process or incorporation of the adhesive into the particles, components can be added to enhance the qualities of the product – such as catalysts, types of paraffin (acting as a waterproofing agent for particles), fungicides, insecticides, and flame retardant products – and to modify its visual appearance, e.g. dyes and pigments (MOSLEMI, 1974).

After the particle mat is formed, it is deposited in the mold for the molding consolidation phase. The compression molding process is divided into two stages, according to Moslemi (1974):

a. Pre-compression of the material to generate parts with shallow surfaces; and

b. Compression, which is capable of generating deep printing with prominent shapes and consolidates the product.

A basic molding scheme is illustrated in Figure 1. It can be observed that the metal mold defines the shape of the product consolidated by pressure and temperature.

The molds, usually made of steel or aluminum, are composed of two parts that are joined together through a male and a female part. The "female" part (hollow part of the mold) provides shape and finish to the external surface of the product, whereas the "male" part generates the internal surface of the product.

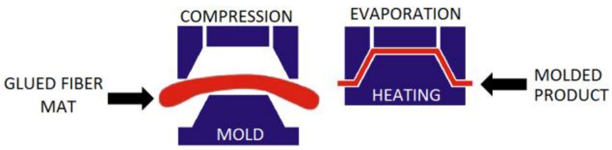

Fig.1: Scheme of the hot molding process.

Source: RAZERA (2006).

According to Razera (2006), the most relevant factors for the development of compression-molded products are those related to mold geometry and the production process. Regarding the mold geometry, the following main aspects must be considered: wall thickness, pressure direction in the mold, and uni or multidirectional pressing.

Wall thickness of the pieces must be constant, as far as possible. When the product design requires different thicknesses in the various sections of the pieces, the transition from one thickness to another should be gradual. The corners of the pieces – except for those formed in the mold closing plane – must be rounded and have a wide radius, with values between 0.2 and 0.5 times higher than the thickness of the product walls. Demolding angles, draft angles, and extraction angles are inclinations attributed to the cavities and contours of the male molds to facilitate the demolding process (VERONESE, 2013).

During the design of molds for wood particle composites, the arrangement of openings must be strategically planned in order to avoid the concentration of steam and moisture (arising from the moisture of the particles and the resin composition), which can lead to the delamination of the inner layers of the product (MOSLEMI, 1974).

The factors inherent to the production process are mold heating (regarding the material), press closing speed, specific pressure, heating time, curing time, and demolding time (RAZERA, 2006).

The main raw materials used to manufacture molded wood boards are wood particles and adhesive. In the production process, the adhesive and other additives are incorporated into the particles. Then, they are molded and pressed at high temperature and pressure.

It is worth noting that molded wood products – such as the one developed in this research – can be easily coated with films of excellent aesthetic aspect by means of application technique at high or low pressure. However, this operation was not the object of this research.

1.1. SUSTAINABILITY OF WOOD PRODUCTS FOR THE CONSTRUCTION INDUSTRY

One of the main objectives of the construction industry nowadays is to construct sustainable buildings and increase environmental awareness. Wood products have technical and aesthetic properties that make them desired in various applications, but their main advantage is their low environmental impact, due to its renewability and ease of reuse by recycling (AZAMBUJA, 2018). Producing wood products consumes much less energy than other materials (FAO, 1990). As aforementioned, wood products allow several reuse options, which makes them excellent material to be used within the context of a circular economy or reverse logistics. Wood products also have, as advantage, a significantly smaller carbon footprint than steel, ceramic or concrete products (TELLNES et al., 2017). In addition to it, since trees absorb CO_2 from the atmosphere and store or sequester carbon in their biological structure, wood generates lower environmental impact in comparison to other construction materials. Therefore, wood products have become an interesting alternative to several traditional construction solutions, being a “trendy” building material in the 21st century.

Even though wood products pass through some forms of rapid degradation due to their biological origin, given the proper design, construction, and maintenance, they can be as durable as other construction materials such as steel and concrete (FOLIENTE, 2000).

1.2. BRACATINGA

The wood used in this research was bracatinga (Mimosa scabrella Benth), a native species of great presence in the forest landscape of Southern Brazil (FRANCK FILHO, 2005). It is a hardwood species, with 4 to 18 m in height and 20 to 30 cm in diameter at breast height (DBH), reaching up to 29 m in height and 50 cm or

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more in DBH in adulthood. Its wood density is moderate (0.65 to 0.81 g/cm³) at 12 and 15% humidity (CARVALHO, 2003).

Bracatinga is known for its speed to form forests and presents a short rotation, having a surprising growth in the first six years of life. In traditional forests, the most common cutting ages are 6 to 8 years old. Due to its characteristics, it is used very little to manufacture straight wood pieces. Thus, it is applied mainly as shoring in the construction industry and as fuel firewood. Many rural producers cultivate it as an income alternative. The selling price of firewood is low, compared to other common forest species in the region, such as Pinus elliottii and Eucalyptus viminalis (EMBRAPA, 1988).

Most bracatinga forests do not have certifications such as FSC (Forest Stewardship Council) due to the limitations imposed by their low added value. Nonetheless, since they are majorly of secondary origin and managed by humans, it can be stated that it is relatively easy to obtain management certifications and that certified natural forests have been significantly increasing in Southern Brazil (ALVES et al., 2011 and STEENBOC et al., 2011). It is worth mentioning that, in order to avoid encouraging deforestation, the sustainability of this wood is only valid when it is originated from plantations or from sustainable management, with the proper certification by the FSC or another recognized entity (DI GIROLAMI, 2018).

During cutting, the straightest stems are separated and sectioned in lengths of 3 to 5 m to be employed as construction shoring. It is not uncommon for the shoring extraction to be performed before the final cut, at 5-6 years old, to meet the financial needs of the owner (EMBRAPA, 1988). Concerning the pieces that were employed in the construction industry, collection and recycling chains have been operating in large cities in Southern Brazil, mainly to transform them into firewood. Figure 2 illustrates one of the bracatinga pieces that was used in the research.

Fig.2: Bracatinga shoring at the UFPR Panel Laboratory.

Source: The authors.

Within this context, owing to environmental and economic aspects, the use of a local tree species to manufacture pressed boards is extremely interesting, as it has low cost and is easily replanted and recycled. Therefore, it fits perfectly within the objectives of a circular economy, which promotes the responsible and cyclical use of resources, contributing to the sustainable development, in accordance with the recommendations of the European Promotional Products Association (EPPA), Basic Works Requirement 7 (BWR-7) (EUROPEAN COMMISSION, 2016).

Given these facts and their physical characteristics, wood-based materials have now been considered a promising resource for the construction of buildings in the 21st century. Wood products can be locally manufactured, with minimal transport costs and in an environmentally friendly manner (ROBERTS, 2020).

1.3. ADHESIVE

The lignin-phenol-formaldehyde adhesive used in this research is produced from the partial replacement of phenol by the lignin exceeded from the wood pulping process. Therefore, it uses raw material from a non-fossil renewable source and from industrial production scraps, as well as reduces the use of components synthesized with phenol mixed with conventional adhesives (DIAS 2014; ZHANG et al. 2013; BERTAUD et al. 2012; RAMIRES 2010; TEODORO 2008). The replacement of phenol by lignin in the phenol-formaldehyde adhesive may vary from 15% (GOTHWAL, MOHAN AND GHOSH, 2010) up to a maximum proportion of 30% (KOUISNI et al. 2011).

Therefore, this study aimed to evaluate the feasibility of producing molded boards of bracatinga wood particles glued with lignin-phenol-formaldehyde resin as a wall panel component for contemporary buildings.

1.4. CARBON FOOTPRINT OF WOOD PRODUCTS

CO_2 emissions from wood products for use in the construction industry have two approaches. Firstly, there are always emissions related to obtaining raw material and manufacturing the product, even if it is simple sawn timber. Emissions can occur during planting, harvesting, and processing. Overall, products manufactured more industrially have higher emission factors (EF) (RUUSKA, 2013). Secondly, wood products must be divided into those that have long-term use in the construction – e.g. doors, windows, floors, ceilings, and roofing structures – and temporary products – such as molds, wood scraps, shoring, and hoarding.

For temporally used products, emissions that occur in the degradation of the wood employed must also be considered. The wood degradation causes its oxidation, a reaction through which the carbon contained in plant tissues combines with the oxygen in the atmosphere to form CO_2. This process happens in an eventual burning or biological degradation in contact with the air (INGERSON, 2009). Emissions must be determined considering that the total carbon contained in the wood is oxidized and converted into CO_2eq. The carbon content (CC) of the different wood species ranges from 0.40 to 0.45 (OLIVEIRA et al. 2011). To calculate the amount of CO2eq emitted, equation 1 is employed.

Mass of CO_2eq emitted = Wood weight x CC x 3.667 (1)

The value 3.667 is the ratio between the carbon atomic mass and the molecular mass of carbon dioxide.

On the one hand, for temporally used wood products, production EF plus emissions from its degradation must be considered in order to calculate emissions. On the other, for wood products with long-term use, there is no need to calculate emissions from their degradation; however, emissions from their production EF must be considered These emissions must be reported in items A1 to A3 of the Life Cycle Assessment (LCA) (ISO 14040:2006 and ISO 14044:2006).

Regarding wood products, the mass of the CO_2 sequestered and fixed by the wood (CO2 uptake) as stored carbon must also be considered, and its amount must be the same that will eventually be emitted by its degradation. The standards ISO 14040:2006 and ISO 14044:2006 recommend that the amount of CO_2 with regards to the stored carbon in products of non-fossil origin should be mentioned in item D (Benefits and loads beyond the system boundary, Reuse-Recovery-Recycling potential) of the LCA studies. A final evaluation of the impact of the product on the greenhouse gas emission can be conducted by subtracting the stored carbon from the production emissions.

Taking bracatinga as an example – which has a CC of 0.44 of its mass (OLIVEIRA et al., 2011) –, the amount of CO_2 stored will be 1.61 times the mass of bracatinga wood.

Moreover, when observing the values of the emissions and stored carbon, it is clear that wood products store much more carbon than they emit (RUUSKA, 2013). Thus, the sustainable planting/management rotation of wood along with the use of wood in products for long-term applications or use is an extremely efficient manner to remove carbon from the atmosphere.

II. MATERIAL AND METHODS

Firstly, the form by which the board prototypes were manufactured is described, and then, the evaluation of how these boards impact on global warming is explained.

2.1. THE PRODUCTION OF BOARD PROTOTYPES

Based on the definition and detailing of the system [Mold x Molding x Final product] used for the manufacture of molded boards of wood particles, the following parameters were evaluated: particle mat forming in the three-dimensional mold, heat transfer from the mold to the composite, demolding, product forming, detail reproduction, and surface finish. Figure 3 presents the molds of marine grade aluminum used to manufacture molded boards as a wall panel material, and figure 4 illustrates a section of the wall panel assembly, resulting from the overlap of some contiguous components.

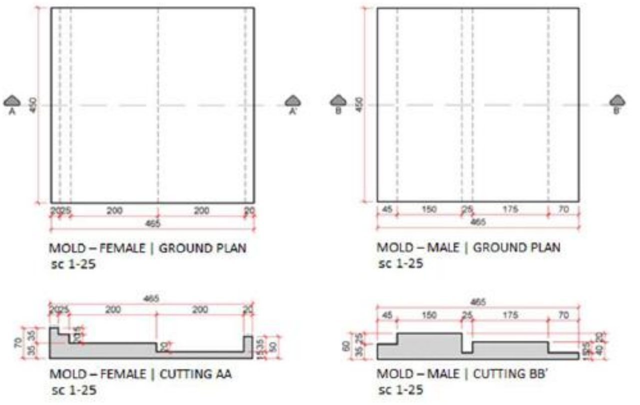

Fig.3: Ground plans of the male and female board molds for board production.

Source: The authors.

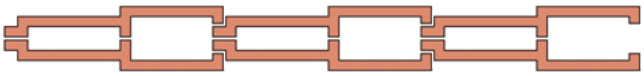

Fig.4: Section of the wall panel assembly, resulting from the overlap of some contiguous components.

Source: The authors.

The materials used in the molded board manufacture were bracatinga wood particles and lignin-phenol-formaldehyde adhesive. Bracatinga wood was obtained from construction shoring, which had a diameter between 10 and 15 cm and a length of 300 cm. The experimental lignin-phenol-formaldehyde (LPF) adhesive was supplied by a paper and pulp company in the state of São Paulo, and its calculated solid content was 49.4%. The lignin-based adhesive was produced with the replacement rate of 25% of phenol, according to the manufacturer.

To generate bracatinga particles, struts were processed in a disc chipper to be transformed into chips (primary reduction), with a nominal thickness of 0.7 mm. Once they were air-dried, the chips were processed in a hammer mill to be converted into particles (secondary reduction), using sieves with 12 mm and 6 mm meshes.

After milling, the particles were sieved in an automatic classifier, with a 30 mesh (0.60 mm) sieve, to remove "fines". Then, the particles were dried in a conventional kiln at 103ºC up to 3% humidity and were stored in plastic packaging to minimize the absorption of humidity from the environment.

After weighing the components based on the nominal density (ND) of 0.800 to 1.00 g/cm³, the resin content of 12%, and the paraffin emulsion of 1%, six prototypes were manufactured, and the final form of the molded boards was evaluated and adjusted.

To produce molded boards, the parameters presented in Table 1 were adopted.

Table 1. Experimental design for the product prototype.

Resin type	Nominal density of the product	Resin content	Pressing time	Pressing temperature	Specific pressure
Lignin-phenol-formaldehyde (LPF)	0.80 to 1.00 g/cm3	12%	15 min	180ºC	80 kgf/cm²

Source: The authors.

In order to facilitate the demolding process and prevent the composite from adhering to aluminum, a demolding product was spread over the mold surface. After the deposition of the particles, the pieces were manually pre-pressed to accommodate them. Following the cold pre-pressing, the mold was positioned in the previously heated press. Once in contact with the press platens, the aluminum of the mold began to heat up. Then, the temperature of the particle mat was monitored using a thermostat until its central portion reached the approximate value of 110ºC. Upon reaching the determined temperature, the 15-minute pressing countdown commenced. After the established pressing time ended, the mold was removed from the press and demolded.

2.2. BOARD CHARACTERIZATION

Specific specimens were prepared for the characterization tests of the board material. They had ND of 0.75 g/cm3 and 0.95 g/cm³ and were pressed for 15 minutes. In order to perform verifications and comparisons, the European standard EN 312:2010 and the Brazilian standard NBR 14810-2:2013 were employed. When these standards had not presented limits or comparative values, references from the literature were used. Initially, the densities were measured and the compaction ratios (CR) were evaluated, based on the bracatinga wood density of 0.52 g/cm³. Water absorption (WA) and thickness swelling (TS) values were also measured after 2 and 24 hours of immersion in water. The mechanical properties evaluated by means of the static bending test were modulus of rupture (MOR) and modulus of elasticity (MOE). The following tests were also performed: perpendicular tensile (PT), edge screw withdrawal resistance (SWRe), and surface screw withdrawal resistance (SWRs).

To analyze the results, the verification of the data normality was adopted through the identification of outliers, and to evaluate the homogeneity of variances, Bartlett's test was applied. Analysis of variance (ANOVA) was applied in the statistical analysis to verify the significant effects of treatments at a 5% probability of error. Tukey's test was also applied to compare means, in case of significant differences between treatments, at a 95% probability level.

Six board prototypes were molded and visually evaluated for surface quality, form, and apparent density of the pieces. The observed response variables consisted of characteristics of the molding process such as heat transfer of the mold, product consolidation, demolding, detail reproduction, and surface finish.

2.3. BOARD EFFECTS ON GREENHOUSE GAS EMISSIONS

To calculate the amount of carbon fixed in the wood particle board studied, the amount of carbon present in the wood and in the fraction of the resin composed of lignin (residue from the pulp industry) was considered. Both bracatinga particles and lignin are natural products from planting trees, thus their carbon does not origin from fossil. Calculations were conducted considering the unit of one square meter of the board based on the results of the mean prototype mass. The prototypes had a continuous section of 0.40 m of useful width, and a mass of 8.05 kg per meter of length.

To calculate the carbon present in bracatinga particles, the species CC (0.44), published by Oliveira et al. (2011), and the mean particle mass per square meter of the board (87%) were considered. In addition to it, to estimate the carbon present in the resin, the following characteristics were evaluated: content of resin present in the board (12%), mass of resin solids (10%), lignin content of the resin (25%), and carbon content of the lignin molecule – $C_9H_{10}O_2$, $C_{10}H_{12}O_3$, $C_{11}H_{14}O_4$ (66.65%)

The results of these calculations are always presented in the form of CO_2 mass, even though the mass of the chemical element carbon present in wood and lignin is determined. The transformation from carbon to CO_2 is executed by means of multiplying the results by 3.667, which is the mass ratio between a CO_2 molecule and the atomic mass of the chemical element carbon.

To calculate the production emission factor (EF) of the bracatinga board studied, its production EF per kg was estimated considering the EF of a similar industrial product in HDF (High-Density Fiberboard) since it is an industrialized product. The production EF of HDF boards from Fritz EGGER GmbH & Co. OG (Germany) was used as a basis. The industrial product used as a reference has a density of 0.900 g/cm³ – similar to the one of the board studied in this research –, and its mass is composed of 82% wood particles, 5 to 7% water, 11% urea-formaldehyde (UR) glue, and less than 1% paraffin.

III. RESULTS AND DISCUSSIONS

3.1. RESULTS OF THE MOLDED BOARD PROTOTYPES

The best results were obtained by forming the particle mat in the horizontal position, inside a forming box, and by positioning the female mold underneath the male one, as presented from figure 5a to 5d.

Fig.5: Molding images of the particle mat forming.

Source: The authors

After demolding and cooling, the prototypes were squared and had their height reduced to 15 cm (figure 6a and 6b). Figures 7a and 7b illustrate the molded components after squaring and cutting.

Fig.6: Squared prototype.

Source: The authors

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Fig.7: Molded components after squaring and cutting.

Source: The authors

The mean density values obtained from the prototypes ranged between 0.781 g/cm³ and 0.977 g/cm³. This difference can be attributed to the loss of material in the particle mat forming and in the prototype pressing, to the return of thickness due to the prototype swelling after pressing and cooling, and to the consequent increase in volume and reduction in density.

Regarding the mat forming, satisfactory results were observed in the mold horizontal position. The prototype (#1) presented low densification and poor formation in the vertical position, especially regarding the connecting flaps.

3.2. RESULTS OF THE BOARD CHARACTERIZATION

Boards with ND of 0.750 g/cm^3 presented mean density values ranging from 0.730 g/cm^3 to 0.740 g/cm3, and all boards with ND of 0.950 g/cm^3 had the density value of 0.910 g/cm3. CR mean values varied from 1.40 to 1.44 for boards with ND of 0.75 g/cm^3 and from 1.75 to 1.76 for boards with ND of 0.95 g/cm3. These values are in accordance with Moslemi's (1974) minimum recommendation of 1.30.

Concerning the mean values of WA for boards with ND of 0.95 g/cm^3, the results for 2 h and 24 h were, respectively, 6.71% and 23.24% of the increase in mass. These results demonstrated statistically significant differences; however, the standards EN 312:2010 and NBR 14810-2:2013 do not specify requirements for WA testing.

TS mean results after 2 hours of immersion were 4.23% (ND of 0.75 g/cm^3) and 18.70% (ND of 0.95 g/cm3), and after 24 hours, they were 23.24% (ND of 0.75 g/cm^3) and 44.49% (ND of 0.95 g/cm^3). These results also demonstrated statistically significant differences. Regarding TS, the aforementioned standards specify that structural boards to be used in wet conditions (P5), with a nominal thickness between 13 and 20 mm, must meet the TS maximum value of 10% after 24 hours. No comparative values of WA and TS were found in the literature for structural boards manufactured with humidity-resistant resin. However, the mean values for TS after 24 hours obtained in this research were lower than the results found in studies that used pine boards manufactured with urea-formaldehyde resin.

The mean results for the static bending tests of MOR and MOE were, respectively, 25.41 MPa and 30.83 MPa for ND of 0.95 g/cm^3. With regards to MOR and MOE results, statistically significant differences were found; however, all boards with ND of 0.95 g/cm^3 met the minimum requirement of 16 MPa for MOR and 24.00 MPa for the MOE, according to the standard EN 312:2010.

PT mean values ranged from 0.69 to 1.58 MPa. These results also had statistically significant differences; however, all of them presented mean values higher than the minimum value of 0.45 MPa, recommended by the standard EN 312:2010.

Boards with ND of 0.95 g/cm^3 had the SWRe mean value of 2879 N, and the SWRs mean value of 2574 N. The results of these two tests demonstrated statistically significant differences between the boards tested.

Even though no comparative values were found in the literature for the mechanical properties of structural boards manufactured with humidity-resistant resin, the results of this study were satisfactory in comparison to those presented by researchers for pine structural boards manufactured with urea-formaldehyde resin.

3.3. MOLDED BOARD RESULTS REGARDING GLOBAL WARMING

Based on the bracatinga particle mass of 17.51 kg/m^2 of the board and the CC of 0.44, the carbon mass present in these particles was calculated for 7.71 kgC/m^2 of the board. The corresponding fixed CO_2 mass was 28.26 kgCO_2/m^2.

The calculated resin mass was 2.42 kg/m^2 of the board, and the lignin mass contained therein weighted 0.060 kg/m^2. From this value and the percentage of carbon in lignin (65.65%), the carbon mass fixed in the resin was determined. The result was 0.040 kgC/m^2, and the corresponding fixed CO_2 mass was 0.148 kgCO_2/m^2. Thus, the total CO_2 fixed (or CO_2 uptake) by the board in the wood and the resin, was 28.41 kgCO_2/m^2 of the board.

In order to estimate the production emissions of the board, the EF per kg obtained from the literature and the mean mass of the particle board prototypes were used, resulting in an EF of 13.31 kgCO_2eq/m^2.

A final balance is achieved by subtracting the amount of emissions from the amount of fixed or sequestered carbon, and the favorable balance of 15.10 kgCO_2/m^2 is reached.

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IV. CONCLUSIONS

Based on the design of a wall panel component, prototypes were manufactured for a qualitative evaluation of the production process and of the results obtained.

The greatest difficulty found in manufacturing the prototypes was the particle mat forming, initially formed by the mold in the vertical position and deposition of particles glued by the upper portion of the set, which resulted in low densification of the prominent parts. By forming the particle mat in the horizontal position, with the aid of a manual pre-pressing using a hydraulic press, there was a significant improvement in the densification of the prominent parts, as well as in the product as a whole. This fact resulted in a better reproduction of mold details and surface finish.

The prototypes that presented the highest mean density were the ones that resulted in products with better surface finish and detail formation (connecting flaps). The densities obtained met the requirements of the Brazilian standard NBR 14810-2:2013 (Medium density particleboards), for structural boards for use in humid conditions (type P5).

In general, the prototype boards met the parameters of the European standard EN 312:2010 and the Brazilian standard NBR 14810-2:2013.

As for the ecological impact of the carbon footprint, the final balance of carbon emissions and carbon fixation or sequestration was presented, resulting in a favorable value of 15.10 $kgCO_2/m^2$. Thus, products molded with wood particles and lignin-phenol-formaldehyde adhesive can provide excellent results.

REFERENCES

[1] Alves RR, Jacovine Lag e Silva ML. Plantações florestais e a proteção de florestas nativas em unidades de manejo certificadas no Brasil. Revista Árvore, Viçosa-MG, Brasil, v.35, n.4, p.859-866, 2011.

[2] Azambuja RR, CASTRO VG, TRIANOSKI R, IWAKIRI S (2018). Recycling wood waste from construction and demolition to produce particleboards. Maderas: Ciencia y Tecnología, Concepción, Chile. DOI 10.4067/S0718-221X2018005.

[3] Bertaud, F. et al. Development of green adhesives for fiberboard manufacturing, using tannins and lignin from pulp mill residues. Cellulose Chemistry and Technology, v. 46, n. 7-8, p. 449-455, 2012.

[4] Bittencourt, R. M.; Hellmeister, J. C. Concepção arquitetônica da habitação em madeira. São Paulo: EPUSP, 1995. Boletim técnico da Escola Politécnica da USP. Departamento de Engenharia de Construção Civil, BT/PCC/155.

[5] Carvalho, P. E. R. Espécies Arbóreas Brasileiras. Brasília: EMBRAPA Informação Tecnológica; Colombo-PR: Embrapa Florestas, 2003.

[6] Di Girolami E, ARTS BJM (2018). Environmental impacts of forest certifications. Forest and Nature Conservation Policy Group, Wageningen University and Research.

[7] Dias, L. M. S. Síntese e caracterização de adesivos de lignina kraft de eucalipto. Dissertação (Mestrado em Ciência e Tecnologia da Madeira) – Universidade Federal de Lavras, Lavras, 2014.

[8] EMBRAPA (1988). Manual técnico da bracatinga (Mimosa scabrella Benth), EMBRAPA, COLOMBO – PARANÁ. 88 p.

[9] EN 312:2010. Particleboards. Specifications. European Committee for Standardization, Brussels, Belgium.

[10] EUROPEAN COMMISSION (2016). Economic Impacts of the Construction Products Regulation - Final report. Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Directorate C — Industrial Transformation and Advanced Value Chains, Unit C.1 — Clean Technologies and Products. European Commission B-1049, Brussels, Belgium. 115 p.

[11] FAO (1990) Energy conservation in the mechanical forest industries. FAO Forestry Paper 93. Food and Agriculture Organization of the United Nations, Rome.

[12] Franck Filho, F. H. Seleção de espécies arbóreas nativas da região Sul do Brasil para reflorestamento e emprego na arquitetura e no design. Dissertação (Mestrado Profissionalizante em Engenharia Civil) – Universidade Federal do Rio Grande do Sul, Porto Alegre, 2005.

[13] Foliente GC (2000) Developments in performance-based building codes and standards. Forest Prod J 50(7):12–21.

[14] Gothwal, R. K.; Mohan, M. K.; Ghosh, P. Synthesis of low coast adhesives from pulp and paper industry waste. Journal of Scientific & Industrial Research, v. 69, n. 5, p. 390-395, mai. 2010.

[15] Ingerson A (2009) Wood Products and Carbon Storage: Can Increased. Production Help Solve the Climate Crisis?. The Wilderness Society. Washington, D.C. USA. 47 p. ISBN 978.1.975371-16-B.

[16] ISO 14040:2006. ISO - International Organization for Standardization. Environmental management -- Life cycle assessment -- Principles and framework. Geneva, Switzerland.

[17] ISO 14044:2006. ISO - International Organization for Standardization, Environmental management - Life cycle assessment - Requirements and guidelines. Geneva, Switzerland.

[18] NBR 14810-2:2018. Painéis de partículas de média densidade - Parte 2: Requisitos e métodos de ensaio. Associação Brasileira de Normas Técnicas, São Paulo, SP, Brasil.

[19] Kouisni, L. et al. Kraft lignin recovery and its use in the preparation of lignin-based phenol formaldehyde resins for plywood. Cellulose chemistry and technology, v. 45, n. 7-8, p. 515-520, 2011.

[20] Moslemi, A.A. Particleboard. Carbondale and Edwardsville: Southern Illinois University Press, 1974.
[21] Oliveira EO, Nakajima NY, Chang M, Haliski M (2011) Determinação da quantidade de madeira carbono e renda da plantação florestal. EMBRAPA Florestas, Colombo PR. ISSN 1980-3958.
[22] Ramires, E. C. Biocompósitos a partir de matrizes poliméricas baseadas em lignina, tanino e glioxal reforçadas com fibras naturais. Tese (Doutorado em Ciências) – Universidade de São Paulo, São Carlos, 2010.
[23] Razera, D. L. Estudo sobre as interações entre as variáveis do processo de produção de painéis aglomerados e produtos moldados de madeira. Tese (Doutorado em Ciências Florestais) – Universidade Federal do Paraná, Curitiba, 2006.
[24] Roberts D (2020). The hottest new thing in sustainable building is, uh, wood. Vox- New York, USA.
[25] Ruuska A (2013) Carbon footprint for building products. ECO2 data for materials and products with the focus on wooden building products. VTT Technology 115. VTT Technical Research Centre of Finland. Espoo, Finland, 126 p. ISSN-L 2242-1211.
[26] Steenbock W, Siminski A, Fantini AC e dos Reis MS. Ocorrência da bracatinga (Mimosa scabrella Benth.) em bracatingais manejados e em florestas secundárias na região do planalto catarinense. Revista Árvore, Viçosa-MG, Brasil, v.35, n.4, p.845-857, 2011.
[27] Tellnes LGF, Ganne-Chedeville c, Dias A et al (2017) Comparative assessment for biogenic carbon accounting methods in carbon footprint of products: a review study for construction materials based on forest products. DOI:10.3832 / ifor2386-010
[28] Teodoro, A. S. Utilização de adesivos à base de taninos na produção de painéis de madeira aglomerada e OSB. Dissertação (Mestrado em Tecnologia e Utilização de Produtos Florestais) – Universidade Federal Rural do Rio de Janeiro, Seropédica, 2008.
[29] Veronese, S. Estudo da aplicação de compósito madeira/plástico em gabinete de eletrodomésticos "linha branca". Dissertação (Mestrado em Design) – Universidade Federal do Paraná, Curitiba, 2010.
[30] Zhang, W. et al. Lignocellulosic ethanol residue-based lignin-phenol-formaldehyde resin adhesive. International Journal of Adhesion and Adhesives, v. 40, p. 11-18, 2013.