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Analysis of physical, chemical e mechanical properties of wood-particle boards containing biaxially oriented polypropylene

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ABSTRACT. Considering the increased generation of solid waste and the difficulty of proper final disposal, it is of utmost importance to study the reuse of solid waste, seeking a beneficial alternative for the population and the environment. This study aimed to produce wood particle boards incorporated with different percentage of waste from the manufacture of labels and tags, commonly known as paper shavings, containing biaxially oriented polypropylene (BOPP), aiming its reuse. Physical, chemical and mechanical tests were performed. The difference in density between the materials used to manufacture the boards influenced the production process as well as the amount of waste added. Values of moisture content and thickness swelling remained within the range set by the regulations. The results for water absorption analysis are in agreement with those in the literature on the incorporation of different types of waste in the boards. According to our findings, it was observed the importance of a homogeneous mixture of the materials, and pH control. The incorporation of waste containing BOPP into particle boards may be a promising disposal alternative for this waste, given the development of a by-product that encourages sustainable development.

Keywords: incorporation, paper scrap, particle board, analysis.

Estudo das propriedades físicas, químicas e mecânicas de painéis de madeira aglomerada com inserção de resíduos contendo polipropileno biorientado

RESUMO. É de grande importância o estudo do reaproveitamento dos resíduos sólidos, devido ao aumento de sua geração e dificuldade de disposição final adequada, a fim de buscar uma alternativa benéfica para a população e para o ambiente. O objetivo principal deste trabalho foi a incorporação de diferentes porcentagens de resíduos provenientes da fabricação de rótulos e etiquetas, conhecidos como aparas, contendo polipropileno biorientado (BOPP) em painéis de madeira aglomerada, visando seu reaproveitamento. Foram realizados testes físicos, químicos e mecânicos. Observou-se que a diferença de densidade entre os materiais influencia no processo de produção dos painéis, assim como a quantidade de resíduo adicionada. As análises de teor de umidade e de inchamento em espessura mantiveram-se dentro do estabelecido pelas normativas. Os resultados encontrados para a análise de absorção de água estão de acordo com os apresentados em literatura, para incorporação de diferentes tipos de resíduos nos painéis. De acordo com os resultados obtidos pôde-se observar a importância de uma mistura homogênea dos materiais, e o controle do pH. A incorporação de resíduos contendo BOPP em painéis de madeira aglomerada pode ser uma alternativa promissora de disposição final para este resíduo, pois desenvolve um subproduto e incentiva o desenvolvimento sustentável.

Palavras-chave: incorporação, aparas, aglomerado, análises.

Introduction

Solid waste has caused increasing concern worldwide because of the large amount generated and also the difficulty of environmentally safe disposal. This can cause serious environmental problems when disposed in inappropriate places like landfills or dumps, causing soil degradation, contamination of groundwater and water sources and air pollution. (Vitorino, Monteiro, & Vieira, 2009; Wolff, Schwabe, & Conceição, 2014).

Besides environmental damage, improper disposal in landfills causes economic loss. However, reverse logistics, reuse or proper co-processing of this waste can bring profitability to the generating company. The need to use the waste from plants using products from the forestry sector, aiming at its optimization, requires research focused on the search for the best use of this type of material, enabling the consumption of the products generated (Weber & Iwakiri, 2015).

There are numerous forms of waste reuse in civil and architectural construction, for example: manufacture of ceramic bricks incorporating industrial laundry sludge (Herek, Júnior, Pavezzi, Bergamasco, & Tavares, 2009), production of tiles with the addition of industrial waste and fiber (Soares, Leal, & Costa, 2010), manufacture of alternative boards incorporating rice husk into wood particle boards using tannin-formaldehyde based resin (Sales, Souza, & Almeida, 2011), incorporation of different percentages of bamboo into boards made of wood of pine and eucalyptus (Vivian et al., 2012), among others.

The demand for environmentally friendly materials for construction and architectural manufacturing has led to the development of compounds using natural fibers, especially lignocellulosic materials such as wood, which has been used as a reinforcing agent in polymer matrices for the production of particle boards and composites since the production of synthetic fibers shows a high environmental cost (Barros Filho, Mendes, Novack, Aprelini, & Botaro, 2011).

According to the Brazilian technical standard NBR 10.004 (Associação Brasileira de Normas Técnicas [ABNT], 2004a), wood waste can be classified as class II waste, because it is a natural and biodegradable waste. An alternative to obtain a higher value-added product is the use of these residues from the timber industry (in the form of costaneiras, refilos and shavings) for the production of particle boards (Iwakiri et al., 2005).

The binder for the production of particle boards can be a urea-formaldehyde (UF) type resin, which is widely used in the manufacture of particle boards forming a composite material, besides being a stabilizer economically viable found in the market (Cabral, Vital, Della Lucia, & Pimenta, 2007).

A composite consists of reinforcement (structural component) and a continuous matrix (matrix component) that surrounds the other phase. These components are not completely dissolved and act synergistically, and properties of the set are superior to those of the components separately (Mano & Mendes, 1999).

Plastic materials based on synthetic products are increasingly used in our daily lives, mainly due to their low cost, easy processing, high applicability and durability. The latter characteristic is the greatest disadvantage of their application in the manufacture of disposable packaging (Taghizadeh, Sarazin, & Favis, 2013).

A biaxially oriented polypropylene pre-polymer used in the manufacture of labels and stickers may be used as a crosslinking agent for obtaining wood particle boards. The main advantages of polypropylene for the manufacture of flexible packaging, at the expense of other materials, include: low cost, high solvent resistance, easy molding and coloration and high resistance to bending fracture, high impact resistance and good thermal stability (Carvalho, Mansur, Vasconcelos, & Oréfice, 2007).

Industries manufacturing labels and stickers, aiming to provide information to consumers, require materials with high print quality, by using this biaxially oriented polypropylene film, as they meet the desired goal with the use of this material (Carvalho et al., 2007).

In the process of manufacturing these labels and stickers, many paper shavings are produced. These shavings are adhesive, so, they have glue in their composition. They are generated by companies in large quantities and do not have any recycling or reuse, then being directed for waste collecting companies, and these direct them to industrial landfill (Al-Salen, Lettieri, & Baeyens, 2009).

Wood particle boards containing fiber are characterized by transformation of wood into small particles, dried, mixed with thermosetting synthetic resin, randomly distributed, shaped under heat and pressure generating a board. This process, when using waste from different sources, can contribute to promoting the proper disposal of waste (Chamma & Leão, 2008).

Factors that influence the production of wood particle boards as final product are: specific mass, density, particle geometry, moisture content, type and amount of resin, mattress forming method and pressing parameters (Weber & Iwakiri, 2015).

Considering the above, this study presents a sustainable alternative to the use of waste from the manufacture of labels and stickers containing biaxially oriented polypropylene. In this way, we sought to make them primarily useful by replacing wooden parts with a percentage of this waste, obtaining a quality product for commercial use in the furniture industry.

Material and methods

Collection and preparation of materials

The wood used in this work came from Pinus hardwood logging, in the form of sawdust, of the Lopes and Diniz carpentry, city of Londrina, state of Paraná. Wood particles used were those retained on the 1.40 mm mesh size.

The waste collected (25 kg) consisted of biaxially oriented polypropylene, better known as paper shavings (waste of labels and tags). These were purchased in the form of bobbins with a width ranging between 10 and 15 cm, from the company Inovaflex Rótulos e Etiquetas, in the city of Maringá, state of Paraná. After manual cutting, were obtained samples in particle size meshes of 1.2, 0.6, 0.4, 0.25, 0.15 and 0.075 mm, according to NBR 7181 (Associação Brasileira de Normas Técnicas [ABNT], 1984).

The materials, wood and waste, were stored individually in plastic bags with a capacity of 50 kg.

Also, 6 kg urea formaldehyde resin (UF) and 500 g catalyst ($(NH_4)_2(SO_3)$) PA of Vetec were purchased.

Raw materials were analyzed for the following parameters: moisture and density and pH, according to the methodology of the Adolfo Lutz Institute (Instituto Adolfo Lutz, 1985); particle size, NBR 7181 (Associação Brasileira de Normas Técnicas [ABNT], 1984), and metals NBR 10.004 (Associação Brasileira de Normas Técnicas [ABNT], 2004a).

The opening of the samples was held by digestion with aqua regia. These solutions were subjected to reading of metals by plasma atomic absorption spectrophotometer, model ICP - OES - Optima – 5200 / Plasma - Perkin Elmer. Solubilization and leaching tests were performed according to NBR 10.005 (Associação Brasileira de Normas Técnicas [ABNT], 2004b) and NBR 10.006 methodologies (Associação Brasileira de Normas Técnicas [ABNT], 2004c), NBR 10.005 and NBR 10.006 methodologies, both of (Associação Brasileira de Normas Técnicas [ABNT], 2004b and c), respectively.

Production of wood particle boards

For the manufacture of wood particle boards, a hydraulic press with heating platens (SIRMA) was used according to Li, Cai, Winday and Basta (2010), in the facilities of the Madeireira Ibiporã, in Ibiporã, state of Paraná, as the press was provided by this company.

The density of the boards was set to 700 kg m^{-3} to obtain medium density boards.

After weighing and mixing the materials, the mass of particles was shaped and compressed forming a particle mattress. This process was conducted in a shape with 1000 x 400 x 100 mm dimensions. This particle mattress wrapped in aluminum foil was cold pre-pressed and then hot pressed.

Upon pressing, the boards were allowed to reach thermal equilibrium with the ambient temperature for removal from the press. After reaching the external temperature, the specimens of each board were taken and identified according to quantity and size. Specimens were identified for physical and mechanical tests, according to NBR 14.810-3 (Associação Brasileira de Normas Técnicas [ABNT], 2006b). Chemical analyses were performed according to NBR 10.004 (Associação Brasileira de Normas Técnicas [ABNT], 2004a).

Characterization of wood particle boards

Boards were characterized by tests of density, moisture content, water absorption, thickness swelling and static bending according to NBR 14.810-3 (Associação Brasileira de Normas Técnicas [ABNT], 2006b); which was performed in a universal testing machine (EMIC) with 5 KN load cell.

Statistical analysis

For statistical analysis, first, the study was arranged in a complete 2^3 factorial design with central point, assessing the factors: amount of resin, waste and temperature at two levels. Statistical data were analyzed using the software Design-Expert®. Table 1 shows the levels and factors used to perform the experimental design.

Table 1. Factors and levels of factors used in the complete 2^3 factorial design for the production of wood particle boards.

Factor	Variable	Unit	Type	Level (-1)	Level (0)	Level (+1)
A	Resin	%	Numerical	6	12	18
B	Waste	%	Numerical	10	30	50
C	Temperature	ºC	Numerical	130	150	170

Table 2 lists the lower (-1) (lower values) and higher (+1) levels (higher values) and central points (0) of the variables amount of resin (A), amount of waste (B) and temperature (C). All experiments were performed in duplicate and at random, which generated a total of 20 experiments.

Table 2. Complete 2^3 factorial design, in duplicate, with central point.

Samples	Factors		
	A Resin/%	B Waste/%	C Temperature/ºC
1.1 and 1.2	(-1) 6	(-1) 10	(-1) 130
2.1 and 2.2	(-1) 10	(+1) 50	(-1) 130
3.1 and 3.2	(+1) 18	(-1) 10	(-1) 130
4.1 and 4.2	(+1) 18	(+1) 50	(-1) 130
5.1 and 5.2	(-1) 6	(-1) 10	(+1) 170
6.1 and 6.2	(-1) 6	(+1) 50	(+1) 170
7.1 and 7.2	(+1) 18	(-1) 10	(+1) 170
8.1 and 8.2	(+1) 18	(+1) 50	(+1) 170
9.1 and 9.2	(0) 12	(0) 30	(0) 150
10.1 and 10.2	(0) 12	(0) 30	(0) 150

Results and discussion

Material characterization

Table 3 presents the results of the physical tests on wood particles and waste. The moisture content found in the raw materials is within the optimum range for producing the boards, thus favoring the use of these materials. This moisture content allows for a greater penetration of glue, because very dry particles complicate handling, requiring a greater amount of resin and producing easily disintegrating boards and very moist particles can interfere with the board quality in the pressing process, such as blistering and the bursting of the boards.

Table 3. Physical properties of particles of wood and waste.

Analysis	Results		
	Wood	Waste	Standard (NBR14810-3, (Associação Brasileira de Normas Técnicas [ABNT], 2006c)
Moisture (%)	8.0	3.60	3.00 a 12.00
Density (g cm^{-3})	1.53	5.06	-
pH (mm)	4.2	6.8	-

The density of waste particles was higher compared to the wood particles. This difference in density can result in low values of mechanical properties, favoring blistering in heating process for the manufacture of wood particle boards.

In relation to the pH, the value found for waste was 6.8 and for wood particles was 4.2. The pH influences the final quality of the manufactured board. These pH values indicate low acidity (less than 7.0), which may have contributed to the occurrence of pre-curing of formaldehyde-based resin before the pressing process, weakening the bonds of the resin. This also contributed to the low values of mechanical properties.

Figure 1(a) shows the particle size curve for the waste. The diameter of waste particles is within the range 0.08-2.0 mm, and most was retained on 16 mesh sieve, i.e., 1.2 mm.

The particles resulting from waste cutting are large, which may affect the board resistance, because smaller particles increase the contact surface, enhancing the absorption of the resin for generating a resilient board.

Figure 1(b) illustrates the particle size curve for the wood. The highest percentage of particles (45.56%) corresponds to the fraction of particles retained on the mesh (≤ 4.0 mm). The mesh (1.40 ≤ x ≤ 2.0 mm) corresponds to 36.85% of the material composition, while the content retained on the meshes (1.0 ≤ x ≤ 0.50 mm) is around 14.76%. Wood fractions used were those retained on the mesh 1.40 mm, in order to improve the homogenization of the mass and absorption of the resin, with the increase of the contact surface.

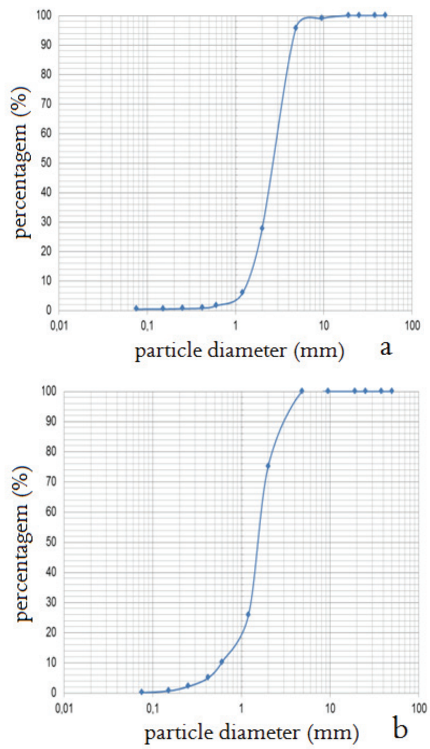

Figure 1. Particle size curve for particles of (a) waste and (b) wood. Test performed according to NBR .

In the reported tests, it was observed that the use of small particles favors the perpendicular tensile strength but causes a reduction in the rupture stress and the elasticity modulus. As a result, it was used DGM particles of the intermediate mesh to benefit both the mechanical properties.

Table 4 presents the metals and their respective values determined in the waste sample, and the results for the solubilization and leaching tests.

The metals found in the waste were aluminum, copper, chromium, iron and nickel. These metals are derived from dyes present in the material.

All values of the metals analyzed (Table 4) are within the range set by the NBR 10.004 (Associação Brasileira de Normas Técnicas [ABNT], 2004a), leaching tests, NBR 10.005 (Associação Brasileira de Normas Técnicas [ABNT], 2004b) and solubilization test NBR 10.006 (Associação Brasileira de Normas Técnicas [ABNT], 2004c). Only the metals lead and chromium have normative standards, but they were no longer detected in the solubilization test.

The analysis of metals in wood, leached and solubilized extracts did not detect the presence of any of the metals listed in Table 4, metals required for analysis by NBR 10004 (Associação Brasileira de Normas Técnicas [ABNT], 2004). Thus, materials, waste and wood, are in accordance with the technical standard NBR 10004 (Associação Brasileira de Normas Técnicas [ABNT], 2004a), not exceeding the maximum limits, indicating that these samples have no hazard characteristics and are then classified as Class II waste, non-hazardous and inert.

Analyses on wood particle boards

The results obtained in the tests of density, moisture content, thickness swelling, water absorption and modulus of elasticity (MOE) are shown in Table 5. Density values were below the value set by the NBR 14.810-2 (Associação Brasileira de Normas Técnicas [ABNT], 2006a) to classify a wood particle board as having medium density (between 551 kg m^{-3} and 750 kg m^{-3}).

This is due to two main factors, one is the failure in mixing, since the process was carried out manually; and the other is the concentration of UF resin used, as this characteristic was also found in the literature (Cabral, Vital, Della Lucia, & Pimenta, 2007) , in which the homogeneous distribution of the resin is critical to provide uniformity throughout the product.

With the aid of data in Table 5 and the software Design Expert, we obtained the results of the planning for the responses of the moisture content and the modulus of elasticity (MOE). These results of planning, considering the ANOVA, are listed in Tables 6 and 7, respectively. Regarding the MOE, NBR 14.810-2 (Associação Brasileira de Normas Técnicas [ABNT], 2006a) does not set a threshold value.

The p value (Prob > F) denotes the probability of obtaining a test statistic equal to or more extreme than that observed in a sample under the null hypothesis.

Table 4. Metal levels determined in the sample of waste, using the atomic absorption, leaching and solubilization method.

	Waste				
Metals	Results (mg kg^{-1})				
	Metals	Leaching	Leaching limit NBR 10004 (Associação Brasileira de Normas Técnicas [ABNT], 2004a)	Solubilization	Solubilized limit NBR 10004 (Associação Brasileira de Normas Técnicas [ABNT], 2004a)
Aluminum	1.6	1.0	-	n.d*	2.00×10^{-1}
Arsenic	n.d*	n.d*	1.0	n.d*	1.0×10^{-2}
Barium	n.d*	n.d*	7.00×10^{1}	n.d*	7.00×10^{-1}
Cadmium	n.d*	n.d*	5.00×10^{-1}	n.d*	5.00×10^{-3}
Calcium	n.d*	n.d*	-	n.d*	-
Lead	1.4	2.10×10^{-1}	1.00	n.d*	1.00×10^{-3}
Copper	0.20×10^{-1}	n.d*	-	n.d*	2.00
Chromium	1.0×10^{1}	1.20×10^{-1}	5.00	n.d*	5.00×10^{-2}
Iron	5.2×10^{2}	1.3×10^{-2}	-	n.d*	3.00×10^{-1}
Nickel	3.5×10^{1}	n.d*	-	n.d*	-
Manganese	n.d*	n.d*	-	n.d*	1.0×10^{-1}
Mercury	n.d*	n.d*	1.0×10^{-1}	n.d*	1.0×10^{-3}
Potassium	n.d*	n.d*	-	n.d*	-
Silver	n.d*	n.d*	5.0	n.d*[1]	5.0×10^{-2}
Selenium	n.d*	n.d*	1.0	n.d*	1.0×10^{-2}
Sodium	n.d*	n.d*	-	n.d*	2.00×10^{2}
Zinc	n.d*	n.d*	-	n.d*	5.00

n.d* - undetected

Table 5. Mean values of the physical tests of density, moisture, thickness swelling and water absorption and static bending (MOE) in wood particle boards.

	Parameter						
Treat.	Density (kg m^{-3})	Moisture (%)	% IE 2h	% IE 24h	% AA 2h	% AA 24h	MOE (MPa)
1.1 and 1.2	447.59	14.23	9.37	16.40	65.56	110.53	5.61
2.1 and 2.2	391.92	14.27	8.20	15.05	61.72	105.17	3.17
3.1 and 3.2	410.91	15.78	7.54	12.53	66.71	89.00	3.87
4.1 and 4.2	560.26	11.11	11.12	17.49	70.25	90.58	2.71
5.1 and 5.2	376.10	14.62	10.47	15.92	79.58	91.19	2.82
6.1 and 6.2	310.52	19.59	4.84	8.03	67.99	84.4	2.43
7.1 and 7.2	446.91	13.68	6.16	12.54	55.42	76.48	6.06
8.1 and 8.2	446.23	12.99	10.77	14.52	63.82	87.05	1.96
9.1 and 9.2	514.32	12.22	5.59	13.04	49.47	70.13	3.67
10.1an10.2	552.52	12.18	7.40	10.63	81.14	91.82	2.47

In other words, assuming the p-value of 0.0500, it can be concluded that there is a chance that only 5.00% the result is a coincidence. Therefore, P values below 0.0500 represent greater reliability to the test (Bussab & Morettin, 2003).

Thus, in Table 6, the moisture content for the adopted model was significant because the p-value obtained was 0.0223, and the lack of fit was 0.1935, greater than 0.05, which makes this lack of fit non-significant, which is desirable.

Among the major effects, only the amount of resin was significant. The effects of AC and BC interactions were statistically significant for the model, with $p < 0.05$, as the sum of the squares indicates that the temperature influences the model, being statistically influential on responses of AC and BC interactions.

The F-value represents the difference between the factor and the sample. This value is calculated by dividing the variance between the factorial by the variance of each sample. The higher the F-value, the greater the difference between groups compared to the difference between each experiment. From Table 6, it is observed that the amount of resin was the most influential factor in the manufacture of particle boards. This can also be observed by analyzing Figure 3(a), where it is shown the response surface for the moisture content depending on the amount of waste and resin. Thus, the increase in the amount of resin reduces the moisture content, which positively influences the manufacture of wooden boards. Data on Figure 3(a) indicate that the factors influencing positively the manufacture of particle boards were the amount of resin and of waste.

Summary of ANOVA (Table 7) run for the modulus of elasticity (MOE) evidenced that the model was significant with p equal to 0.0002, and the lack of fit was 0.1020, namely non-significant, proving that the manufactured board has satisfactory conditions for this parameter.

As observed in the moisture analysis, the amount of resin was again the factor with greater influence on the model and the interaction between the resin amount and the temperature was also significant, since the resin improves the structural strength of the particle board. Figure 3(b) may confirm this, where the response surface obtained for MOE analysis according to the amounts of resin and waste show that increasing the amount of resin significantly improves the load supported by wooden boards.

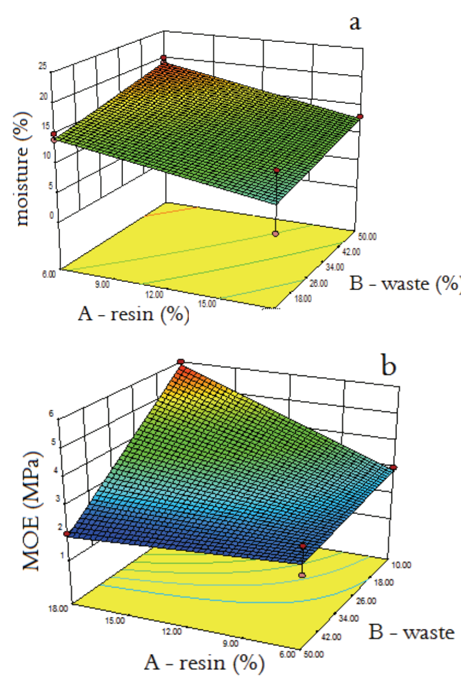

Figure 3. (a) Response surface obtained for moisture content according to factors A and B; (b) Response surface obtained for MOE according to factors A and B.

Table 6. Analysis of variance (ANOVA) for factors A, B and C and their interactions on the response of moisture content.

Source	Squared Sum	Degrees of freedom	Squared mean	F-test	p
Model	133.44	7	19.6	3.73	0.0223
A – resin	39.06	1	39.06	7.64	0.0172
B – waste	5.06	1	5.06	0.99	0.3394
C - temperature	0.062	1	0.062	0.012	0.9138
AB	7.56	1	7.56	1.48	0.2473
AC	33.06	1	33.06	6.47	0.0258
BC	45.56	1	45.56	8.91	0.0114
ABC	3.06	1	3.06	0.70	0.4540
Residual	61.36	12	5.11	-	-
Lack of fit	9.11	1	9.11	1.92	0.1935
Pure error	52.25	11	4.75	-	-
Total	194.80	19	-	-	-

Table 7. Analysis of variance (ANOVA) for factors A, B and C and their interactions on the response of MOE.

Source	Squared Sum	Degrees of freedom	Squared mean	F-test	p
model	28.44	7	4.06	10.80	0.0002
A - resin	0.062	1	0.062	0.17	0.6907
B - waste	14.06	1	14.06	37.40	<0.0001
C – temperature	0.56	1	0.56	1.50	0.2448
AB	0.56	1	0.56	1.50	0.2448
AC	5.06	1	5.06	13.46	0.0032
BC	0.56	1	0.56	1.50	0.2448
ABC	7.56	1	7.56	20.11	0.0007
Residual	4.51	12	0.38	-	-
Lack of fit	1.01	1	1.01	3.18	0.1020
Pure error	3.50	11	0.32	-	-
Total	32.95	19	-	-	-

Conclusion

The manufacture of an alternative product offers economic, social and environmental benefits related to lower resource consumption and reuse of materials. The manufacture of wood particle boards incorporated with waste containing bi-axially oriented polypropylene has proved an option that meets these benefits when working at high temperature and low incorporation of waste.

Wood particle boards incorporating waste were not classified as having medium density, as they did not reach values in the range 551-700 Kgf cm^{-2}, and were characterized as low density boards.

It is required a more homogeneous mixture of the materials to obtain better results. The acidic pH of the wood particles used directly affected the faster curing of the resin, causing disintegration of the boards. These parameters have great influence on the low density of the board tested herein, but further adjustments in the manufacturing process can be done so that these parameters can be achieved.

The values for the mechanical parameters analyzed are within the standards.

Our findings indicate the need for maintaining high resin content to maintain the quality of the boards obtained.

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