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Effect of density and resin on the mechanical, physical and thermal performance of particleboards based on cement packaging

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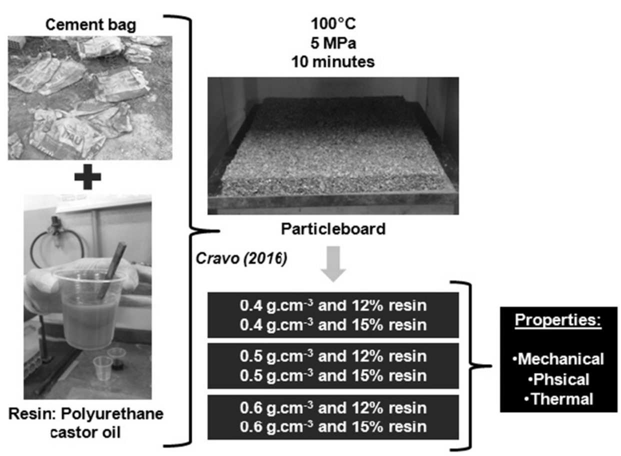
HIGHLIGHTS

- Density and Resin factors act independently for the mechanical and thermal properties.
- For physical and thermal properties, the Density and Resin factors behave in a dependent manner.
- It is possible to reduce the resin content by 3% for MOR, as long as the density is 0.54 g cm^{-3}.
- For WA, it is possible to reduce the amount of resin to 12% for the panels (0.40 e 0.50 g cm^{-3}).
- For thermal conductivity, it is possible to reduce the amount of resin to 12%.

GRAPHICAL ABSTRACT



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ABSTRACT

This study investigated the potential use of cement bags disposed in civil works as a raw material for the manufacture of particulate boards. The cement bags were recycled particles and these particles used to manufacture panels for three different densities (0.4, 0.5 and 0.6 g cm^{-3}) and two levels (12 and 15%) of resin (polyurethane castor oil). The results showed that the density and the resin differently influence the performance of mechanical, physical and thermal panels, which suggests the possibility to reduce by 3% the amount of resin in the formulation of the panels.

1. Introduction

Particleboards are timber derived products, which are manufactured from different wood fragments by the incorporation of a synthetic adhesive, and the applying of heat and pressure by hot pressing. These panels have been widely used for the production of cabinets, shelves, doors, among others [1].

However, the increasing demand of wood from forest industries has been affected by the reduction of forest areas, because between 1999 and 2010, there was a decline of 5.3 million hectares per year [2]. In this scenario, researchers have conducted several studies in

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order to identify other lignocellulosic biomass that can meet the demand of the forest industries. Among these alternatives, agricultural waste has shown remarkable potential for manufacturing wood particleboards, since these exhibit similar chemical compositions to wood fibers [3,4].

So far, the scientific literature describes more than 30 types of agricultural waste used as alternative biomass for the production of particleboards, with a trend to increase in the future [5]. Sunflower stalks, hazelnut husk, peanut hull, grass clippings, sugar cane bagasse, walnut shell, almond shell, stalks kenaf and sorghum are some of the byproducts evaluated for the manufacture of particleboards with application in the furniture industry [5–13].

For the manufacture of these panels, the adhesive is one of the key factors due to their significant technical and economic implications, reaching up to 50% of the total price [14,15]. Some studies have revealed that the change in resin content significantly affects the physical and mechanical properties of particleboards [13,16,17].

In addition to agricultural waste, another solid waste that has drawn attention is the discarded cement packaging after its use in civil works. When discarded in construction, this packaging is burned or dumped into landfills, resulting in environmental contamination, such as damage to soil, air and groundwater. Therefore, recycling is an alternative to solve this problem [18]. The production of particleboards based on cement packaging is an option for recycling this waste [19].

To date, the literature only describes the physical-mechanical performance of these panels for three different densities, leaving an uncertainty concerning the performance of these panels when the variation of density and resin content occurs together.

Based on the foregoing, the aim of this study was to explore the relationship between the different densities and resin content and the mechanical, physical and thermal properties of particleboards made out of cement package.

2. Material and methods

2.1. Production particles

Bags from cement packages were collected in civil works and placed into a container with 120 L of water for the removal of residues that were stuck on the inner side. After washing, packaging was manually torn to generate smaller particles. Then, the particles were transferred into a vertical pulper (MRF 31450) with 190 L of water for 12 h in order to transform the mass of particles into pulp. Then, with the aid of a sieve (0.150 mm) the excess water was removed and the remaining mass was centrifuged (C2A05BBANA). Subsequently, the particles were placed in a ventilated oven (MA035), at 60 °C, until the remaining moisture reached 8%. After drying the particles, they were transferred to a vibrating screen (Produtest) and particles retained on the 8 mm screen were selected.

2.2. Production panel

The particles and polyurethane bicomponent resin based on castor oil at 12 and 15%, by dry mass of the particles, were placed in a planetary mixer (MT120) for 3 min in order to homogenize the distribution of the adhesive on the particles. After mixing, the material was placed into a mold for casting a 40 cm × 40 cm × 1 cm mattress and cold pressing. Subsequently, the material was pressed in a hydraulic press with pressure of 5 MPa and temperature of 100 °C for 10 min. Then, the produced panels were kept at 20 °C and 65% RH to achieve approximately 12% moisture before cutting the panel to the final dimensions of 38 cm × 38 cm × 1 cm. 5 panels were produced for each combination of density (0.4, 0.5 and 0.6 g cm^{-3}) and resin (12–15%), totalizing 30 experimental panels.

2.3. Mechanical properties

In order to determine the mechanical properties of the panels, bending tests were conducted on a universal testing machine (EMIC DL 30,000) for modulus of rupture (MOR) and Modulus of Elasticity (MOE) determination. In this test, samples with nominal size of 25 × 5 × 1 cm were used. To perform the physical–mechanical tests, ABNT NBR 14810-1: 2006 standard [20] was adopted by the similarity with the product produced.

2.4. Physical properties

To determine the physical properties of the experimental panels, water absorption (WA) and thickness swelling (TS) tests were applied after 4, 8, 12, 16, 20 and 24 h. To quantify these properties, specimens with nominal size of 2.5 × 2.5 × 1 cm were used. They were submerged in distilled water at 20 °C. To perform these tests, the same standard document used for mechanical properties determination was adopted.

2.5. Thermal properties

To determine the thermal conductivity (TC) and thermal resistance (TH), cylindrical specimens with dimensions of 5 cm of diameter and 1 cm of thickness were obtained. Subsequently, the samples were placed into a DTC-300 Model 2022 equipment. These properties were determined following the recommendations of ASTM Standard E1530-11 [21].

2.6. Data analysis

To evaluate the mechanical and thermal properties, completely randomized design (CRD) experiments were carried out. The treatments were arranged in a 3 × 2 factorial arrangement, where the factors corresponded to density and resin. The density factor has three levels (0.4, 0.5 and 0.6 g cm^{-3}), while the resin factor has two levels (12 and 15%), totaling six treatments for each property. As for the physical properties, experiments were arranged in a completely randomized design (CRD), in which the treatments were arranged in a 3 × 2 × 6 factorial, where the studied factors corresponded to density, resin and hours. The density factor consisted of three levels (0.4, 0.5 and 0.6 g cm^{-3}), the resin factor of two levels (12 and 15%) and the hours factor in six levels (4, 8, 12, 16, 20, 24), totaling 36 treatments. The density and hours factor, by the fact of being quantitative, were analyzed by linear regression ($p < 0.05$) when the factors were significant in the ANOVA. For the resin factor, by the fact of being qualitative, was analyzed by Tukey test ($p < 0.05$) when the factors were significant in the ANOVA. The assumption for ANOVA was determined using the Shapiro-Wilk test (normal errors) and the Bartlett test (homogeneity of variance), both with $p < 0.05$. The software used for data interpretation was R version 3.0.0.

R version 3.0 software (free) is a tool for data analysis and manipulation, as it presents several tools such as parametric tests, linear and nonlinear modeling, time series analysis, survival analysis and spatial statistical simulation. It is also a tool to create different types of graphs [40].

The statistical models used to evaluate the above properties were:

$Y_{ijk} = \mu + a_i + h_j + (ah)_{ij} + e_{ijk}$
Y_{ijk} = k-th observation of the variable MOR, MOE, TC and TR at the jth level of the density factor and the i-th level of the resin factor
μ = overall average
a_i = i-th level of resin factor, i = 12 e 15
h_j = j-th level of the density factor, j = 0.4, 0.5 e 0.6
$(ah)_{ij}$ = effect of interaction between the ith level of resin factor with the j-th level of density factor
e_{ijk} = residual effect
$Y_{ijnk} = \mu + a_i + h_j + c_n + (ah)_{ij} + (ac)_{in} + (hc)_{jn} + (ahc)_{ijn} + e_{ijnk}$
Y_{ijnk} = k-th observationof the variable WA and TS in the jth level of factor density, in the i-th level of the resin factor and c-th level of the factor hours
μ = overall average
a_i = i-th level of resin factor, i = 12 e 15
h_j = j-th level of the density factor, j = 0.4, 0.5 e 0.6
c_n = n-th level of hours factor, n = 4, 8, 12, 16, 20 e 24
$(ah)_{ij}$ = effect of interaction between the i-th level of resin factor with the j-th level of density factor
$(ac)_{in}$ = effect of interaction between the i-th level of factor resin with n-th level of factor hours
$(hc)_{jn}$ = effect of the interaction between the j-th level of density factor with c-th level of hours factor
$(ahc)_{ijn}$ = effect of interaction between the ith level of resin factor with the j-th level of density factor and c-th level of factor hours
e_{ijnk} = residual effect

Cross-classification experiments are those in which two or more factors are studied simultaneously, each with two or more levels. The factorial scheme is one of the ways to organize treatments and not one type of design. In fact, the factorial experiments are assembled according to a type of experimental design, such as Completely Randomized Design or Randomized Block Design. In factorial experiments, treatments are obtained as a combination of factor levels. In a complete factorial experiment, each level of one factor matches all levels of the other factors. Factorial experiments are applicable to all fields of science. It is mainly applied assess the influence of the effect of several factors in the studied variable, as well as the relationship between them. Therefore, these were the reasons to adopt the statistical models mentioned above [41,42].