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Potential of Jerusalem Artichoke *(Helianthus tuberosus* L.) stalks to produce cement-bonded particleboards

Matheus R. Cabral[a,b,*], Erika Y. Nakanishi[a], Gonzalo Mármol[a], Joahnn Palacios[b], Stéphane Godbout[b,c], Robert Lagacé[c], Holmer Savastano Junior[a], Juliano Fiorelli[a]

[a] Biosystems Engineering Dept., São Paulo University, Pirassununga, SP, Brazil
[b] Research and Development Institute for the Agri-environment, Quebec City, Canada
[c] Soil and Agricultural Engineering Dept., Laval University, Québec, Canada

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ABSTRACT

Jerusalem Artichoke (*Helianthus tuberosus* L.) stalk particles were studied as an alternative raw material for cement composites. Cement-bonded particleboards measuring 300 × 300 × 10 mm with nominal density of 1250 kg/m^3 were produced and assessed. Particleboards were subjected to two curing conditions: (1) – 48 h in a climatic chamber, followed by 25 days in an air saturated environment; and (2) – 48 h in a climatic chamber, and then in a dioxide carbon (15% concentration) environment (24 h), followed by 24 days in an air saturated environment. Physical and mechanical characterizations were carried out for both particleboard samples at 28 days. The particleboard tested in this study may be applied for industrial purposes, since cement-bonded Jerusalem Artichoke particleboards meet the mechanical requirements of the ISO 8335 Standard for building applications. Furthermore, thickness swelling and water absorption of the particleboards were lower than values reported in the literature and Standards requirements. In view of the results, Jerusalem Artichoke stalk particles are suitable to be used to produce cement-bonded particleboards for construction applications.

1. Introduction

The cement-bonded particleboards have been used in Austria since the 1920s and Germany since the 1940s. After World War II, there was an expansion of their use in North America and Asia. Nowadays, the acceptance of this product is reported as an appealing technology, because particleboards made of a polymer matrix are vulnerable to environmental weathering, heat and fungal attack, while the use of a Portland cement (PC) as a matrix, significantly provides the strength performance and structure durability (Wang et al., 2016).

However, currently wood is basically the most used raw material to produce cement-bonded particleboards, a fact which has been increasing the demand and consequently the wood price (International Energy Agency, 2016). On the other hand, this increase in demand and higher wood prices can stimulate the companies to look for new alternative raw materials.

Thinking of a solution for all the above-mentioned issues, the search for alternative lignocellulosic raw materials that can dampen the pressure on slow growing forests is crucial. As such, several vegetal materials could have great potential as alternative raw material for the cement-bonded particleboard production, showing acceptable chemical composition and morphological structures (Ayrilmis et al., 2017; Cabral et al., 2017; Cavdar et al., 2017; Dong et al., 2016).

In recent years, many studies have been conducted in order to apply stalks of vegetal materials to produce building elements, especially sunflower (Mati-Baouche et al., 2014; Nozahic and Amziane, 2012), eggplant (Guntekin and Beyhan, 2008) maize (Babatunde, 2011), cotton (Zhou et al., 2010) and achar (Aggarwal et al., 2008).

Jerusalem Artichoke (*Helianthus tuberosus* L.) is an herbaceous and tuberose vegetal of the *Asteraceae* family which has several advantages over other vegetal materials, such as high growth rates (over 6–8 t/ha), good frost and drought tolerance and growth in soils with minimal fertilizer requirements (Slimestad et al., 2010). The chemical composition of Jerusalem Artichoke (JA) stalks is similar to that of softwoods usually used to produce cement-bonded particleboards. The JA stalk presents an average content of 41% cellulose, 22% hemicellulose and 20% lignin (Wróblewska et al., 2009), while softwood presents a content of 45% cellulose, 20% hemicellulose and 25% lignin (Fengel and Wegener, 2003).

However, stalks from vegetal materials, when agglomerated with cement, have low durability due to the alkaline medium (pH ~ 12), as there is the mineralization of these vegetal materials by the

* Corresponding author at: Biosystems Engineering Dept., São Paulo University, Pirassununga, SP, Brazil.
E-mail address: matheusrc@usp.br (M.R. Cabral).

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precipitation process of the PC hydration products inside (lumen), and around these vegetal materials (Cabral et al., 2017). To provide a more durable cement-bonded particleboard, an alternative shown by Cabral et al. (2017) is the adoption of curing by accelerated carbonation, which provides cement-bonded particleboards with lower water absorption, thickness swelling and the preservation of the mechanical properties. Additionally, accelerated carbonation can provide a longer durability of the vegetal stalk material inside the PC due to the pH decreasing with consequently less chemical attack on the vegetal matter (Almeida et al., 2013; Santos et al., 2015).

Hitherto, there is a lack of information regarding the potential of JA stalk particles to produce PC composites. Therefore, the goal of this study was to evaluate the potential of JA stalks to produce cement-bonded Jerusalem Artichoke particleboard (CBJAP) cured by accelerated the carbonation process.

2. Materials and methods

This research was conducted in three steps: in the first step the collection and preparation of the raw material (JA stalks), physical, chemical and morphological characterization, as well the hydration test of JA in a PC matrix was conducted. In the second step, the manufacturing as well as the curing process of CBJAP was carried out. Finally, the products underwent analytical, thermal, physical and mechanical characterizations in order to determine the feasibility of producing CBJAP cured by accelerated carbonation process.

2.1. Raw material and preparation

JA stalks collected and processed in Acton Vale, Quebec, Canada were dried in a forced ventilation oven (Model MA 035, Marconi, Brazil) at 60 °C for 72 h. After the drying process, JA stalks were ground using a knife mill (Model DPC-1, Cremasco, Brazil) and then separated on an automatic shaker (Model G, Produtest. São Paulo, Brazil) to obtain particles with an eight-mm length. Brazilian Portland cement type CPV-ARI (high early strength) was used in this experimental work, referring to previous studies on cement-based composites (Tonoli et al., 2009). This PC is equivalent to Type III ASTM C150 (2011).

2.2. Jerusalem Artichoke (JA) characterization

2.2.1. Chemical characterization

To perform the chemical characterization, JA particles were ground and sieved to reduce particle size to below 1 mm in a Wiley mill (Model 4, Thomas Scientific, USA). The cellulose, hemicellulose and lignin contents were analyzed according to the French Standards XPU 44–162 (AFNOR, 2005) using the Van Soest method. ASTM D1110 Standard (2007) was used to analyze the extractives content.

2.2.2. X-ray diffraction

JA particles were ground and sieved in a Wiley mill (Model 4, Thomas Scientific, USA) to reduce particle size below 1 mm, the particles were oven-dried (60 °C, 24 h), and subsequently characterized with the aid of AXS Analytical X-Ray Diffractometer (Model, AXS D5005, Siemens, Germany), operated at 1600 W of power: 40 kV x 40 mA. Cu-K alpha radiation, wavelength λ: 1.54056 Å inherent in the copper tube. Standardized test: 2θ angle range from 5° to 70° in reflection mode scanned at 2°/min.

The crystallinity index (CI) of JA particles was calculated according to the Buschle-Diller and Zeronian (1992) method. To compare the JA CI value, softwood XRD analysis was also carried out using the same conditions of the JA experimental analysis of this work. The CI is defined from Eq. (1):

$$CI = 1 - \frac{I1}{I2} \quad (1)$$

Where I1 is the intensity at the minimum 2θ value between 18° and 19° and I2 is the intensity associated with the crystalline region of cellulose (2θ values between 22° and 23°).

2.2.3. Morphological characterization

The morphological characterization of the JA particles (oven-dried at 60 °C, 24 h) without a metallic coating and without epoxy resin impregnation were evaluated in a Scanning Electron Microscope (SEM), model TM-3000, Hitachi, Japan. The particles were fixed to metallic holders ("stubs") and images were generated by the acquisition of backscattered electrons in different fields and magnifications (50, 100 and 500x) with a working distance of 6.60 mm. Therefore, the main cell types from the pith and bark of the JA particles were evaluated. Around 50 SEM images were obtained from twenty different samples for each magnification. However, just some of the representative images of each magnification were used in this manuscript.

2.3. Hydration test

Vegetal materials can mitigate the temperature increment that occurs during the PC setting process. To assess the compatibility of the JA particles within the PC matrix, a preliminary hydration test was conducted using a 500-mL stainless steel vessel insulated by a vacuum double wall. For each repetition (n = 5), 15 g of JA particles were mixed with 200 g of PC and a specific quantity of water for each sample was calculated using Eq. (2) (Hachmi et al., 1990).

$$W = C\left[JA\left(0.3 - \frac{MC}{100}\right)\right] \quad (2)$$

Where = W is the water volume (mL), C is the amount of PC (g), JA is the mass of JA (g) and MC is the moisture content (%) of JA particles.

PC-JA-water samples were mixed during 5 min and immediately dropped into plastic bags. A J Type Thermocouple (Omega, Stamford, Connecticut, USA) was inserted into each fresh mixture and connected to a data acquisition system (Brand Campbell Scientific Data 21 X) which ensured temperature data recording every minute for a period of 24 h. Additionally, a PC-water (control samples) were prepared without JA particles. Each sample was put into a 500-mL stainless steel vessel isolated by a vacuum double wall. All adiabatic systems were put into a 45.4 L thermal box (Coleman, Wichita, Kansas, USA) filled with fiberglass insulation (R-40 EcoTouch, Toledo, Ohio, USA) to avoid heat exchange. The thermal box was stored in a room kept at a temperature ranging from 23 to 29 °C. The hydration data were obtained and the inhibitory index was calculated according to the Okino et al. (2004) method.

2.4. Manufacturing and characterization of CBJAP

The CBJAP production parameters are shown in Table 1. CBJAP were manufactured with a target density of 1250 kg/m^3 (air-dry density), and a thickness of 10 mm. Initially, the JA particles were inserted in a planetary mixer, and subsequently the water was added using a spray nozzle. PC was added into the mixer and the mixture was homogenized for five min to prevent agglomeration.

After the homogenization, the mixture was manually placed in a

Table 1
Production parameters of CBJAP.

Particleboard dimensions		Particleboard constituents	
Length (mm)	300	Jerusalem Artichoke particle length (mm)	8
Width (mm)	300	Jerusalem Artichoke moisture (%)	8
Thickness (mm)	10	Jerusalem Artichoke ratio (g)	216
Target density (kg/m^3)	1250	PC ratio (g)	683
		Water (g)	360