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Evaluation of Particleboards Made from Giant Reed (*Arundo donax* L.) Bonded with Cement and Potato Starch

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Abstract: There is a general concern about the rationalization of resources and the management of waste. Plant residues can contribute to the development of new non-polluting construction materials. The objective of this study was to valorize a plant residue such as the giant reed and obtain a particleboard with cement using potato starch as a plasticizer in a manufacturing process involving compression and heat. The influence of cement and starch in different proportions and its stability over time were analyzed. Finally, their physical and mechanical properties were evaluated and compared to European Standards. High-quality sustainable particleboards (boards with high structural performance) were obtained and can be classified as P6 according to European Standards. Mechanical properties were improved by increasing the starch content and pressing time, whereas greater resistance to water was obtained by increasing the cement content. Giant reed particles seem to tolerate the alkalinity of the cement since there was no sign of degradation of its fibers. The use of these residues in the manufacture of construction materials offers a very attractive alternative in terms of price, technology and sustainability.

Keywords: composite; MOR; MOE; IB; panel

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1. Introduction

Environmental awareness is increasing in society and with it, public concern about the rationalization of resources and the management of waste. One way to collaborate in solving both problems is by increasing the use of construction materials composed of plant fibers, given these products are easily recyclable and are not aggressive with the environment. The recovery of this waste is also in agreement with European policies related to the environment [1–3]. The manufacturing of products from plant residues avoids their elimination through incineration, reducing greenhouse gas emissions by fixing carbon during their life cycle. This could help EU member states fulfill their agreements ensuring that accounted greenhouse gas emissions from land use, land use change or forestry (LULUCF) are balanced by at least an equivalent accounted removal of CO_2 from the atmosphere in the period 2021 to 2030 [4].

Cement-bonded wood composite panels are not a novel concept, having been on the market during the past century [5]. Cement traditionally has been used to strengthen wood composites improving their mechanical performance [6,7], fire retardance, water resistance and insulation [8]. These products are currently used by the construction industry in applications such as walls, roof sheathing and tiles, floor, fences and sound barriers [9–11]. However, due to a decreasing availability of wood, there has been a deterioration in the mechanical properties of these commercial composites.

Studies are currently oriented towards the production of new generation composite boards with lignocellulosic residues of agricultural origin. The development of bio-renewable materials mixed with cement provides added value for the agricultural waste market. The main advantages of using lignocellulosic materials as reinforcement in cement are their low density, low cost, biodegradability, availability of large varieties of fibers throughout the world and the promotion of a new agricultural economy [12,13].

A variety of investigations of plant fibers with cements have been studied: rattan [14], bamboo [15], rice husk [16], sisal [17–19], coconut [20–26], sugar cane bagasse [27–29], babaçu [30], banana [31,32], coconut and abaca [33], oil palm [34–36], canary palm [37], arhar [38], agave lecheguilla [39], date palm [40], hemp [41–45], kenaf [46], giant reed [47], hazelnut shell, wood and tea [48], cork [49], jute [50,51] and corn [52].

Composites made of natural fibers absorb a large amount of water causing cracking due to the swelling of the fibers. The initial curing process of cement compounds with plant biomass is problematic due to the loss of water absorbed by the fibers. However, later internal curing is favored by the release of part of the water that the biomass had captured. Natural fibers with cement composites are more susceptible to a lack, rather than an excess, of water. High amounts of water in the cement–fiber mix cause the segregation of the mixture, whereas small amounts of water make compaction of the mixture difficult and favors the presence of heterogeneities.

Another issue is that plant fibers suffer degradation when in contact with cement. Some investigations have focused on the modification of the surface of the fibers in order to prevent degradation [40,46,53–56]. The properties of these composites are limited by a combination of factors such as heterogeneity, wettability and chemical compatibility of the natural fibers with cement. Composites reinforced with lignocellulosic material present a great variability in their mechanical properties in cement boards due to the deterioration of their properties because of alkaline degradation (hydrolysis) and fiber mineralization [57]. These mechanisms produce changes in the chemical composition of the fibers that cause a reduction in strength and degradation of the polymeric matrix, of the fiber/polymer matrix interfacial bond [57] and also of plant fibers resulting in a delay in the cement hydration [31].

Various components of the biomass, such as soluble sugars or low molar mass hemicelluloses, have adverse effects on the preparation and performance of concrete [58]. Therefore, selecting biomass sources with a low content of these compounds would minimize these drawbacks. Research on starch-based lightweight concrete has investigated the effect of its polysaccharides on cement [59,60], the retardant properties of the starch for cement setting [61], the dispersion mechanism of sulfonated starch as a water-reducing agent for cement [62], jute–cement panels with different proportions of starch [63] and particles of palm tree with cement and starch [37].

Different manufacture parameters of panels made of cement with lignocellulosic materials have been analyzed, concluding that cemented panels are high-strength construction materials. However, their industrial production requires a high investment and further research is needed to reduce cost manufacturing [64] and to evaluate the effects of fiber pretreatment methods and alternative curing methods for the long-term performance of these composites [12,65].

Giant reed (*Arundo donax* L.) is one of the largest species of grass growing in Mediterranean regions. It is a wild perennial plant to which no genetic improvement or genotype selection has been made. It grows annually, with average heights of 4 m and a mean thickness of 4 cm. Reed has traditionally been used in many Mediterranean countries. In the southeast of Spain, it was used in construction as part of the roof and floor up to the beginning of the 20th century. However, it is now in disuse and has become an environmental problem since it forms dense reed beds along river banks. When the water level rises, the reeds are uprooted and carried away on the current, forming large masses that block watercourses, causing flooding and sweeping away any structure that gets in their way. In the Segura River in Spain, the authorities are forced to make significant economic investments in order to keep reeds controlled, hence they are cleaned and processed in authorized landfills [66].

Several authors used giant reed biomass to obtain particle-boards with different adhesives. A study on multilayer panels of oriented particles [67] found that these boards have good mechanical behavior and were therefore suitable for use in load-bearing structures according to European Standards [68]. With urea formaldehyde (UF), Garcia Ortuño et al. [69] obtained panels with good properties of modulus of rupture (17.67 N/mm^2), modulus of elasticity (3025.90 N/mm^2) and internal bounding strength (1.31 N/mm^2) that could be commercialized. Giant reed particleboards have also been manufactured with unmodified starches [70] and presented good mechanical properties (modulus of rupture of 16.20 N/mm^2, modulus of elasticity of 2520.97 N/mm^2 and internal bounding strength of 0.39 N/mm^2) through a cyclical process of humidification, heat and pressure. The best properties were found when potato starch was used as an adhesive. In other tests of giant reed with cement mortars, Shon [71] observed that the thermal conductivity and density of the concrete decreased.

Plant residues can contribute to the developing of new non-polluting construction materials. The objective of this research was to valorize a plant residue such as the giant reed and obtain a particleboard, adding a very small amount of cement in comparison with the wood–cement composites and using potato starch as a plasticizer in a manufacturing process involving compression and heat. The influence of cement and starch in different proportions and its stability over time were analyzed. Finally, the particleboard's physical and mechanical properties were evaluated and compared to European Standards [68] in order to verify whether it could be used as a building material.

2. Materials and Methods

2.1. Materials

The materials used were residues of giant reed (*Arundo donax* L.) and different proportions of CEM II/B-LL 32.5 N Portland cement, potato starch (*Solanum tuberosum*) and water.

The giant reed biomass (Figure 1) was obtained from clearing the banks of the Segura River in southeast Spain. The reeds were laid out in a vertical position to dry outdoors for 12 months until their relative humidity was 8.2 ± 0.4%. They were then cut and shredded in a blade mill. The particles were collected in a vibrating sieve and only those that passed through the 0.25 mm sieve were selected.

Figure 1. Giant reed used in the manufacturing of the panels.

Potato starch from the food industry, with 90% purity, was used as a plasticizer. Chemically, starch is a mixture of two similar polysaccharides: amylose and amylopectin.

Potato starch typically contains large oval granules and gels at a temperature of 58–65 °C. Water was taken directly from the mains water supply, with an average temperature of 20 °C.

2.2. Manufacturing Process

The manufacturing process consisted of combining dry reed particles with cement in different proportions in weight (0, 10 and 20%) and starch (0, 5 and 10%). Then, 10% water was sprayed onto the mixture before stirring it for 15 min in a blender (LGB100, Imal s.r.l., Modena, Italy) until homogenized.

The mat, formed in a mold of dimensions 600 mm × 400 mm, was then placed in a hot press with a force of 2.6 MPa, a temperature of 100 ºC and four different times (1, 2, 3 and 4 h). Subsequently, the boards were cooled to room temperature. A total of 132 panels were made, comprising seven types with four different classes (the 28 different configurations are shown in Tables 1 and 2).

Table 1. Types of panels manufactured.

Type	Number of Panels	Weight Dosage (%)	
		Starch	Cement
A	20	10	20
B	20	5	20
C	20	10	10
D	20	-	10
E	20	-	20
F	16	5	-
G	16	10	-

Table 2. Division of panels in classes according to their pressing time.

Pressing Time (h)	Class	Number of Panels
1	1	4
2	2	8 [1]
3	3	4
4	4	4

[1] Only for types A to E. For types F and G, the number of panels was four.

Twenty-eight days after manufacture, four specimens of each type (A to G) and class (1 to 4) were cut to the appropriate dimensions as indicated in European Standards [72] in order to carry out the tests needed to characterize the mechanical, physical and thermal properties of each of the boards being studied (Figure 2). Three hundred and sixty-five days after manufacture, four boards of class 2 from types A to E were cut and also tested.

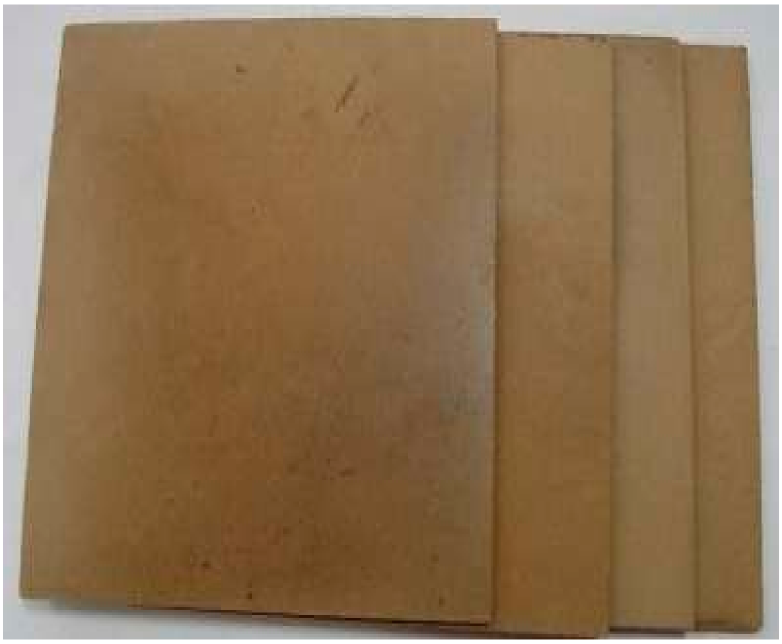

Figure 2. Giant reed–cement–starch panels.

2.3. Methods

The method followed was experimental. The tests were conducted in the Materials Strength Laboratory of the Higher Technical College of Orihuela at Universidad Miguel Hernández, Elche. The values were determined according to European Standards established for wood particleboards [73].

After they were manufactured and cut, density [74], thickness swelling (TS) and water absorption (WA) after 2 and 24 h immersed in water [75], internal bonding strength (IB) [76], modulus of elasticity (MOE) and modulus of rupture (MOR) [77] were measured (Table 3). Later, the boards were evaluated according to European Standards [68]. In order to assess the resistance of the reed particles to the alkalinity of the cement, MOR and MOE tests were performed after 365 days on four class 2 panels of types A to E.

Table 3. Characteristics of the tests performed.

Test	N of Replicates (Per Panel)	N of Replicates (Total)	Size of the Specimens	Equipment Used
Relative Humidity	3	396	20 g	Model UM2000, Imal s.r.l.
Density	6	792	50 cm × 50 cm	Model IB700, Imal s.r.l.
Thickness Swelling (TS)	3	396	50 cm × 50 cm	Model 76-B0066/B Water Bath, Controls S.A. Model UM2000, Imal s.r.l.
Water Absorption (WA)	3	396	50 cm × 50 cm	Model 76-B0066/B Water Bath, Controls S.A. Model UM2000, Imal s.r.l.
Modulus of Rupture (MOR)	6	792	150 cm × 50 cm	Model UM2000, Imal s.r.l.
Modulus of Elasticity (MOE)	6	792	150 cm × 50 cm	Model UM2000, Imal s.r.l.
Internal Bonding Strength (IB)	3	396	50 cm × 50 cm	Model UM2000, Imal s.r.l.

The morphology of the inside of the experimental panels was examined using a scanning electron microscope (SEM) (Hitachi model S3000N, Hitachi, Ltd., Tokyo, Japan) equipped with an X-ray detector (Bruker XFlash 3001, Billerica, MA, USA). For the observations, images of fractured 5 mm × 5 mm cross-sections of the panels were taken.