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The Potential Use of Seaweed (*Posidonia oceanica*) as an Alternative Lignocellulosic Raw Material for Wood Composites Manufacture

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Abstract: A big challenge in the composites industry is the availability of cheap raw lignocellulosic materials, potential candidates to replace slow growing trees, in order to minimize the production cost. Therefore, a variety of plants were studied and tested worldwide in composites manufacturing. The objective of this study was to investigate the technical feasibility of manufacturing particleboards from seaweed leaves (*Possidonia oceanica*—PO). The use of such a material may benefit both socioeconomic and environmental development since these leaves settle on seashores and decay. The results showed that an incorporation of up to 10% PO leaves did not significantly affect the mechanical properties of the board. Internal bond strength was more severely affected than the other mechanical properties. The incorporation of PO leaves up to 25% did not significantly improve the dimensional stability of the boards. Markedly, boards made from 50% wood particles and 50% PO leaves showed the best thickness swelling values. It is suggested that higher resin dosage and an alternative resin system, such as isocyanates, may improve the panel properties.

Keywords: seaweeds; *Posidonia oceanica*; lignocellulosic materials; wood composite panels

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1. Introduction

Seaweeds or marine macroalgae are plant-like organisms which are in general live attached to rocks or other substrata in coastal territories. This aquatic flowering plant grows at the bottom of the sea and consists of about 60 species. A total of 42 countries worldwide are involved in the commercialization of seaweeds and it is reported that the entire area coverage of this plant approaches a value of about 177,000 km^2 [1]. Indonesia produces 800,000 tons/year dried seaweed, which corresponds to almost the half of the world's production, and approximately the 85% of that figure is exported [2]. Seaweed is widely used for industrial purposes such as in cosmetics, medicine, food and beverages, ink and paper [3,4]. Seaweed can also be manufactured artificially with different levels of viscosity and can be used as industrial adhesives, known as hydrocolloids [5]. Seaweeds are important habitats for various microorganisms living in the sea, however, they are considered to be a waste material, since many leaves break away after their growing season, settle on the sea shores and decay; furthermore, their appearance becomes an eyesore. It is reported that a moderately wide belt of *Possidonia oceanica* seagrass may deliver more than 125 kg of dry material per square meter of the coastline annually [6,7].

Possidonia oceanica is a lignocellulosic material that can be found on the shores of the Mediterranean Sea, covering approximately 40,000 km^2 of the seabed, and can be found in the form of seagrass balls and leaves [8]. The former has a fibrous form and comes from the rhizome of the plant and the latter comes from the living leaves. Seagrass has been investigated mainly because it was considered as a potential insulation material for buildings [6,7]. In addition, seagrass balls have been incorporated as a reinforcing agent in the manufacture of polyethylene composites [9,10]. Bettaieb et al. [11,12] examined the chemical and morphological characteristics of *Possidonia oceanica* leaves and concluded that they exhibited encouraging perspectives as nano-fillers for polymer matrices. Garcia et al. [13] studied the physical and mechanical properties of fiberboards made from *Possidonia oceanica* fibers and concluded that can be considered as an alternative to the conventional fiberboards. Similar observations were reported by Alamsjah et al. [14].

Although there is intense research into *Possidonia oceanica* fibers, the leaves have received far less attention. Saval et al. [15] manufactured cement-bonded particleboards from *Possidonia oceanica* leaves and outlined the possibility of their application in construction. Liew et al. [16] studied the physico-mechanical properties of particleboard made from seaweed adhesive and tapioca starch flour. They found that increasing the amount of tapioca starch flour in the seaweed adhesive resulted in improved mechanical properties. Kuqo et al. [17] made particleboards from *Possidonia oceanica* leaves and used isocyanate resin as a binder. They reported that seagrass leaves are propitious for application in construction and furniture industries.

A big challenge in composites industry is the availability of cheap raw lignocellulosic materials, potential candidates to replace slow growing trees, in order to minimize the production cost. A variety of plants were studied and tested worldwide in composites manufacturing, including vine stalks [18], topinambur stalks [19], cotton stalks [20,21], bamboo chips [22], canola straws [23], reed stem [24], date palms [25], oil palms and poppy husks [26], rice and wheat straw [27,28], stalks from cotton [29], camelthorn [30], and even chicken feathers [31,32]. This laboratory has extensive experience in the utilization of various lignocellulosic materials for composites manufacture, including vine prunings [33], castor stalks [34], bamboo and coconut chips [35,36], flax and banana chips [37,38] and cotton stalks [39]. As a consequence, the objective of this paper was to investigate the technical feasibility of manufacturing particleboards from seaweed leaves (*Possidonia oceanica).* The use of such materials may benefit both socioeconomic and environmental development since these leaves settle on the seashores and decay.

2. Materials and Methods

2.1. Raw Material

Possidonia oceanica (PO) leaves were collected from the coastline of Volos, central Greece. Their size varied from 8 to 10 mm in width and 50 to 150 mm in length. The leaves were washed and rinsed with distilled water in order to eliminate sand and other contaminations. After that, they were dried at room temperature for about two months. In their dried form, they have a brown appearance (Figure 1). Their moisture content, absolute density and pH were 118%, 0.35 kg/m^3 and 8.2, respectively. The leaves were dried at 105 °C to 6.5–7% moisture content. Industrially produced wood chips comprising of predominantly mixed softwoods were supplied by a local plant. The wood chips were first screened through a mesh with 5 mm apertures to remove oversized particles, and they were then put through a mesh with 1 mm apertures to remove undersized (dust) particles.

After screening, the chips were dried to 6.5–7% moisture content. The boards were manufactured from particles dried to this moisture content.

2.2. Board Manufacture and Testing

A urea-formaldehyde resin (UF) (200–400 cP in viscosity, 47 s of gel time, and 1.277 kg/m^3 in density), 7% as a percentage of the oven dry weight of raw material, was applied for single layer board manufacture. Mattresses (50 × 50 cm^2) were hot pressed at 180 °C for 6 min. The specific pressure of the plates was 24 kg/cm^2 (with 200 kgf as the total nominal pressure). The target board thickness was 16 mm and the target density was 0.55 kg/m^3. A 2% aqueous solution of ammonium chloride (20% solids content), based on resin solids, was added to the UF as a hardener before spraying. No water-repelling agent was used in this study. Four types of panel were made, consisting of varying mixtures of wood chips and PO leaves (the percentages of wood to PO leaves were 90:10, 75:25 and 50:50, respectively) and control boards with no PO content were made. Three replicates were made for each board type. The flow diagram of the experimental procedure is depicted in Figure 2.

(**a**) (**b**)

Figure 1. *Possidonia oceanica* (PO) leaves as collected (**a**) and after drying (**b**).

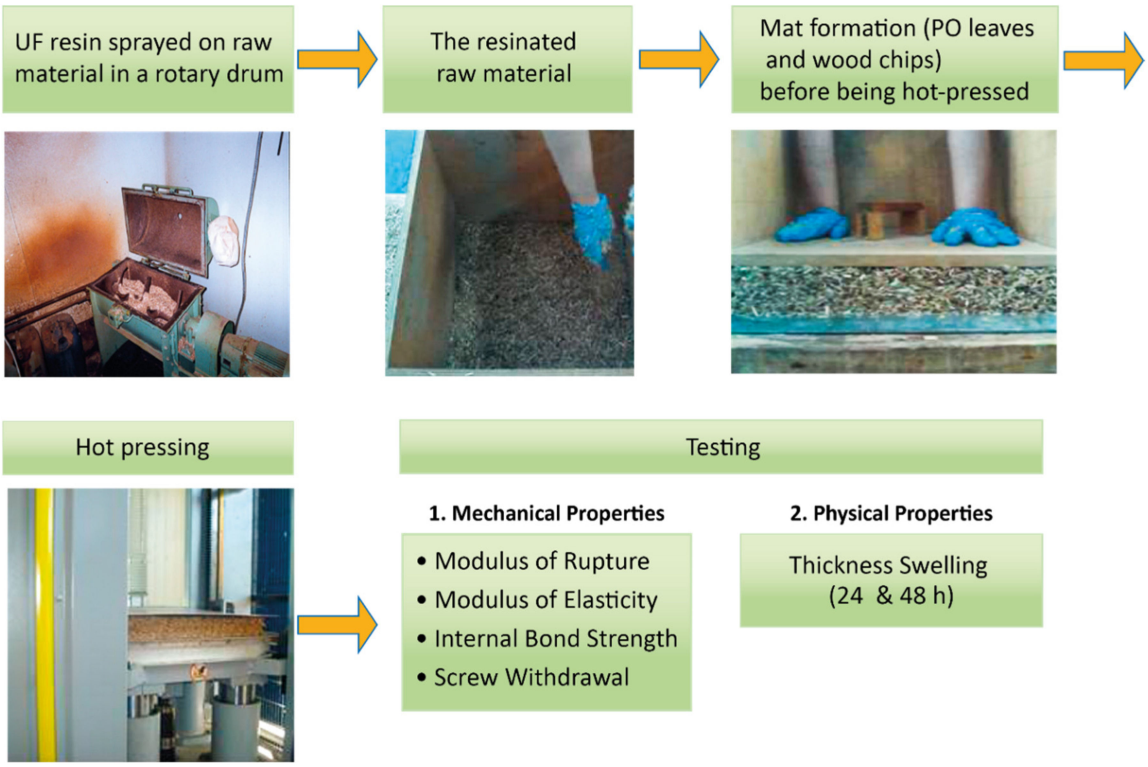

Figure 2. The flow diagram of the experimental procedure.

2.3. Board Testing

The boards were conditioned at 20 °C and 65% relative humidity prior to testing mechanical properties—internal bond strength (IBS), modulus of rupture (MOR) and modulus of elasticity (MOE), resistance to axial withdrawal of screws and physical properties—

thickness swelling after 24 h immersion in water [40–43]. In addition, thickness swelling was also determined after 48 h immersion in water.

2.3.1. Internal Bond Strength

The wide faces of the 50 by 50 mm samples were glued to slotted aluminum blocks that were then pulled apart on a universal Zwick-Roell Z020 universal testing machine (Zwick-Roell, Kennesaw, GA, USA) and the load required to achieve separation was recorded.

2.3.2. Flexural Tests

The 50 by 350 mm long beams were tested in third-point loading at a span of 320 mm at a loading rate of 3 mm per minute. The load and deflection were continuously recorded, and the resulting data were used to calculate modulus of rupture (MOR) and modulus of elasticity (MOE).

2.3.3. Screw Withdrawal Test

The screw withdrawal tests were performed on the faces and edges of 75 mm square sections using 4.25 mm diameter MDF screws at a withdrawal speed of 2.5 mm/min. The tests were conducted with a 10 kN capacity INSTRON-4486 test machine. A 2 mm pilot hole was drilled prior to inserting the screws to a depth of 17 mm in the panels, leaving 1 mm of the screw above the panel surface for testing. Six replicate specimens were tested for each panel type.

2.3.4. Thickness Swelling

Samples of 50 by 50 mm were weighed and their dimensions were measured with digital calipers (to the nearest 0.01 mm) before being immersed in distilled water. Differences in dimensions were measured after 24 and 48 h of immersion and changes were used to calculate % thickness swell.

2.4. Statistical Analysis

Statistical analysis was conducted using SPSS software program, version 24.0 (IBM, Armonk, NY, USA, 2018). One-way ANOVA was performed to identify significant differences at the 95% level of confidence, with Duncan's multiple range test grouping.

3. Results and Discussion

The mechanical properties of the single layer particleboards made from various wood/PO leaves combinations are shown in Table 1. It can be seen that using higher levels of PO leaves resulted in inferior board properties. An incorporation of up to 10% PO leaves did not significantly affect the mechanical properties of the board. In this regard, cluster analysis based on mechanical properties demonstrated close clustering of boards with only 10% PO with the control boards (that is, boards with no PO content) (Figure 3A). Internal bond strength (IBS) was more severely affected in comparison to the bending properties and the screw withdrawal resistance. Similar observations were also made by Grigoriou [44] with straw-based panels, by Papadopoulos and Hague [37] with flax-based panels, and by Hague et al. [45]. The significant reduction in IBS, especially in boards that contained 50% PO leaves, can be attributed to the fact that PO leaf chips are mainly comprised of relatively thin, short walled and weak cells [5]. Consequently, PO leaves are relatively weak and vulnerable to critical defects inside the panel structure, and therefore a rapid decrease in the IBS of the panel is observed as the PO leaves content increases. In addition, it must be pointed out that in boards made with 50% PO leaves, visible checks and cracks (internal blows) occurred in the core section of the mat, as clearly highlighted in Figure 4.

Table 1. The mechanical properties of various board types. Standard deviations are given in parentheses. The different letters show which values are statistically different at the 5% level.

Board Type (Wood Particles: PO Leaves)	Density (Kg/m^3)	IBS (N/mm^2)	MOR (N/mm^2)	MOE (N/mm^2)	Screw Withdrawal Resistance * (N)	
					⊥	//
100:0	0.5 A (0.03)	0.12 A (0.04)	3.35 A (0.50)	648.11 A (70.35)	1652.25 A (267.27)	768.62 A (113.71)
90:10	0.55 A (0.05)	0.12 A (0.04)	2.83 A (0.29)	583.29 A (167.50)	1488.88 A (181.22)	669.57 A (69.58)
75:25	0.53 A (0.03)	0.07 B (0.04)	2.17 B (0.45)	461.37 B (105)	1148.01 B (187.68)	508.20 B (61.78)
50:50	0.53 A (0.03)	0.03 B (0.01)	1.26 C (0.29)	279.23 B (60.27)	802.49 C (68.11)	198.42 C (42.52)

*, ⊥ vertical to the surface, // parallel to the surface.

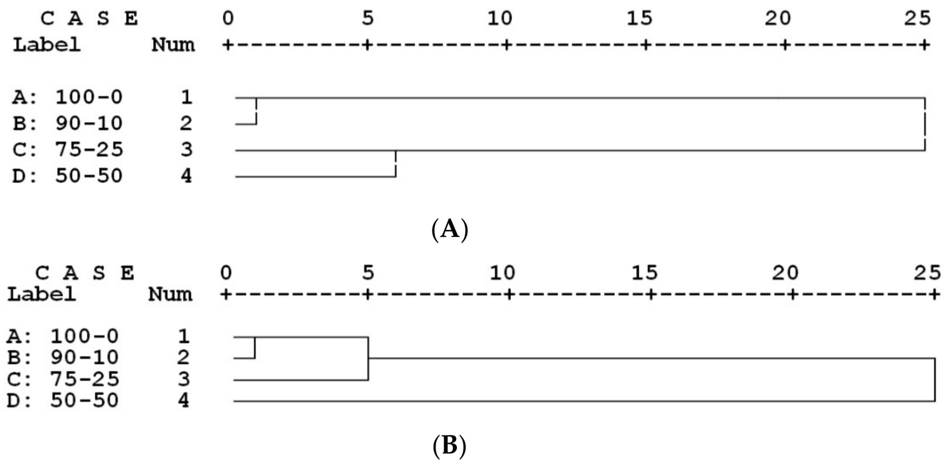

Figure 3. Cluster analyses of the four board types based on the mechanical properties (**A**), and based on all physical and mechanical properties (**B**).

Figure 4. Cracks (blows) in the core layer of boards made with 50% PO leaves, (**a**) after hot pressing; (**b**) after trimming.

Cluster analysis based on mechanical properties also illustrated distinct difference clustering of boards with higher PO contents (25% and 50%) with those containing lower PO contents (0% and 10%) (Figure 3A). The contour and surface plots demonstrated a close relationship between the mechanical properties, showing the nearly uniform effect of the increase in PO content on all properties studied here (Figure 5A,B).

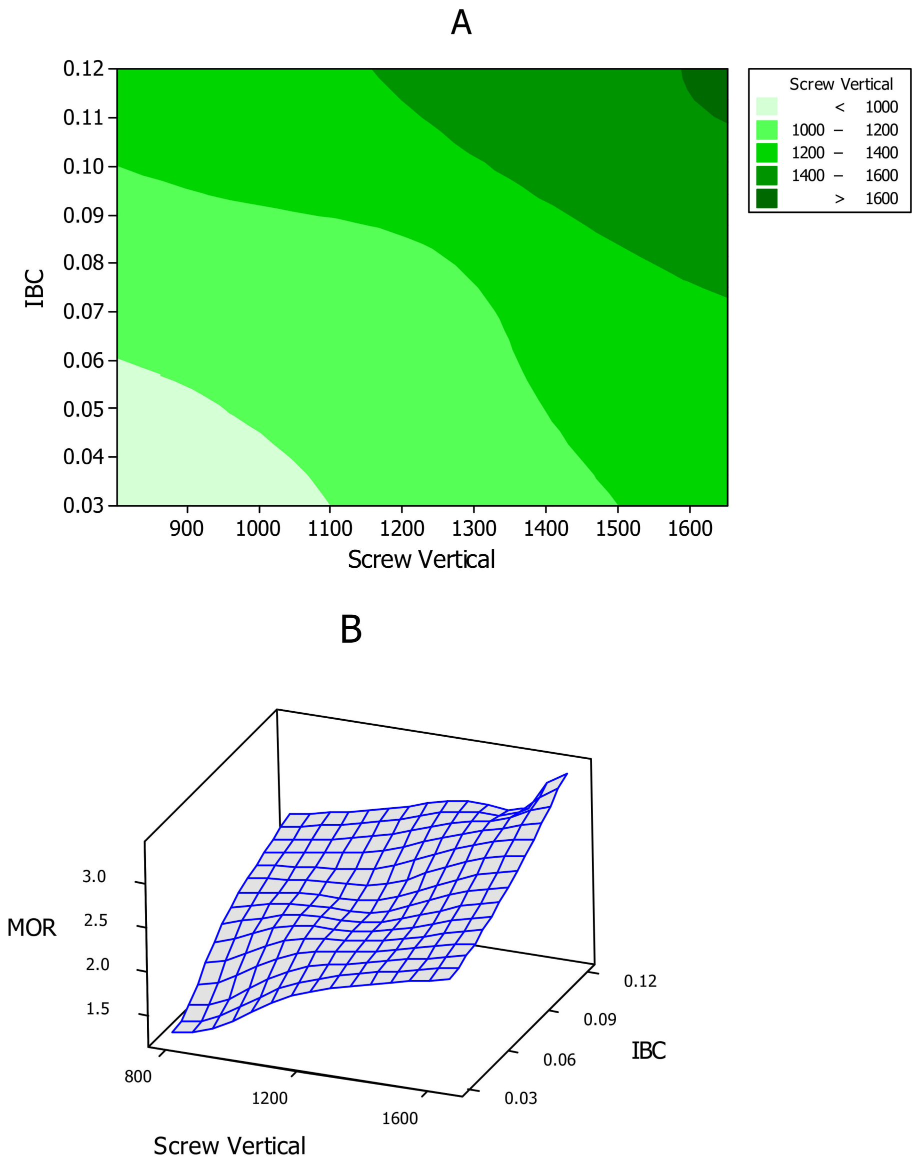

Figure 5. Contour (**A**) and surface (**B**) plots, based on mechanical properties of the four board types.

The thickness swell values after 24 h immersion in water are summarised in Table 2. The results showed that the incorporation of PO leaves up to 25% did not significantly affect the dimensional stability of the boards. It is to be mentioned that no water-repelling agent was used in this study. What can be deducted from the data presented in Table 2 is that boards made from 50% wood particles and 50% PO leaves showed the best thickness swelling values. In fact, this value is significantly different from the corresponding value of boards made from pure wood chips. This tendency remained the same after 48 h immersion in water. Cluster analysis clearly demonstrated distinct different clustering of boards containing 50% PO with the other three board types, indicating the significant effect of the increase in PO content on the overall properties of the boards (Figure 3B). Two possible explanations can be offered for this behaviour; firstly, the great resistance to water that PO leaves have as an aquatic plant contributed in a decrease in thickness swelling, and secondly, their flat shape served as a coating layer, which in turn protected the internal part of the board.

Table 2. The physical properties of various board types. Standard deviations are given in parentheses. The different letters show which values are statistically different at the 5% level.

Board Type (Wood Particles: PO Leaves)	Moisture Content (%)	Thickness Swelling (%)	
		24 h	**48 h**
100:0	9.90 A (0.21)	63.31 A (5.75)	66.77 A (7.80)
90:10	9.93 A (0.31)	64.99 A (6.25)	66.70 A (7.01)
75:25	10.31 A (0.11)	66.44 A (6.67)	69.21 A (5.68)
50:50	11.41 A (0.20)	56.07 B (9.45)	57.42 B (9.44)

4. Conclusions

This study made an approach to investigate the technical feasibility of manufacturing particleboards from seaweed leaves (*Possidonia oceanica*—PO). The use of such a material may benefit both socioeconomic and environmental development since these leaves settle on seashores and decay, and therefore they are generally considered to be a waste material of no industrial value. An incorporation of up to 10% PO leaves did not significantly affect the mechanical properties of the board. Internal bond strength was more severely affected than the other mechanical properties. The results showed that the incorporation of PO leaves up to 25% did not significantly improve the dimensional stability of the boards. Markedly, boards made from 50% wood particles and 50% PO leaves showed the best thickness swelling values. It is suggested that a higher resin dosage and an alternative resin system, such as isocyanates, may improve the panel's properties and could allow a higher content of PO leaves to be incorporated in the panel. Such strategies have been successfully employed in the commercial manufacture of panels from cereal straws.

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