

Physical and Mechanical Properties of Particleboard Produced from Some Timber Trees Irrigated with Treated Wastewater

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ABSTRACT

This study aimed to manufacture particleboards from *Casuarina cunninghamiana* (C), *Eucalyptus camaldulensis* (E), and *Pinus halepensis* (P) trees irrigated with treated wastewater and their mixtures (E-C, E-P, and C-P) with 50%:50% for each individual raw material. Two urea formaldehyde resin levels (9% and 13%) were used. Modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB) as mechanical properties and physical properties (water absorption and thickness swelling) were determined. The C-P panels with 9% and 13% resin levels showed the best mechanical and water resistant performance. All the 13% panels satisfy the minimum requirement of the European standard for the MOE, MOR, and IB except for the MOE of (P) panels, which was very close to the recommended value. The mixtures improved the water absorption and thickness swelling compared with the other produced panels especially for the 13% resin content panels. The (E-C) with 9% resin content showed the lowest mechanical properties and water resistance values. The three furnish types and their mixtures showed its suitability for particleboard production using the board processing conditions specified in this study.

Keywords: Modulus of elasticity, Treated wastewater, Internal bond strength, Water absorption.

INTRODUCTION

Egypt imports a large quantity of particleboard and oriented strand board (OSB). In 2018, the imported quantity of particleboard reached 47961 m³ versus 18016 m³ for production (FAO, 2020). This of course is due to the growing demands for wood-based panels. In general, the major problem that faces the particleboard production in Egypt is the lack of raw materials. Usually, low-density wood species are preferred in the particleboard industry where it provides high strength products due to the high compaction ratio (Xu *et al.*, 2004).

The commercial production of the particleboard in Egypt is based on *Eucalyptus* and *Casuarina* wood species, in addition to some agricultural residues such as, flax shives and bagasse fragments. The genus *Eucalyptus* is native to Australia, this genus contains

over 700 species (Doughty, 2000 and Hudson *et al.*, 2015). According to (Coppen, 2003), the genus of *Eucalyptus* is a fast-growing tree; several tree species of this genus can be utilized effectively for lumber production and paper production.

In Egypt, *Casuarina* species are utilized for windbreaks and shelterbelts and its wood can be utilized for pulp and paper production (Kandeel *et al.*, 1982). Aleppo pine (*Pinus halepensis* Mill.) is indigenous to the countries around the Mediterranean Sea (Gindel, 1944) and this species has the ability to withstand drought stress (Cortina *et al.*, 2011). Several adhesives can be used for particleboard production such as urea formaldehyde, melamine formaldehyde, and melamine urea formaldehyde. From these, urea formaldehyde adhesive is the most common resin type that it is widely used around the world due to the low production costs (Ansell, 2015; Wang *et al.*, 2018). It is worth mentioning that the particleboard industry is highly dependent on urea formaldehyde adhesives (Dinwoodie, 1978). In order to examine the quality of the produced particleboards some properties need to be determined, such as physical (density, water absorption and thickness swelling), mechanical (static bending properties (MOE and MOR) and internal bond strength), and chemical (volatile organic compounds and formaldehyde emissions) (Ansell, 2015).

Recently, there is a tendency to reuse treated wastewater efficiently instead of polluting the environment through its disposal. In Egypt, the awareness about reusing wastewater has been increased significantly during the last two decades through planting man-made forests with various tree species irrigated with treated wastewater.

In general, the major problem that faces the particleboard production in Egypt is the lack of the raw materials. The commercial production of the particleboard in Egypt is based on *Eucalyptus* and *Casuarina* wood species, in addition to some agricultural residues such as, flax shives and bagasse fragments. Regarding the shortage of raw materials used in particleboard production in Egypt, the fast growing tree

DOI: 10.21608/asejaiqsae.2020.77058

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Received February 9, 2020, Accepted March 10, 2020

species that irrigated with treated wastewater can play a major role in providing raw materials for the production of wood composites.

Lack of information on the performance of the particleboard produced using these raw materials with different production parameters limits the expansion in the commercial production of these panels with various characteristics. Therefore, this research aimed to investigate the feasibility of producing particleboards using three tree species irrigated with treated wastewater (*Eucalyptus camaldulensis* Dehn., *Casuarina cunninghamiana* Miq., and *Pinus halepensis* Mill.). In addition, the mechanical behavior (modulus of elasticity, modulus of rupture, and internal bond strength) and physical properties (water absorption and thickness swelling) were evaluated.

MATERIALS AND METHODS

In this study, three tree genera (*Casuarina cunninghamiana*, *Eucalyptus camaldulensis* and *Pinus halepensis*) were chosen randomly from the Egyptian / Chinese Friendship Forest, Sadat City, Monoufia Governorate, Egypt. The trees were irrigated with treated wastewater and the age ranged from 15 to 16 years old.

The density of raw materials was determined based on oven-dried mass and green volume. The extractives content of wood were determined according to the (ASTM D1105 – 96, 2000).

Six kinds of single-layer particleboards were produced: (1) panels with 100% *E. camaldulensis* wood particles denoted as (E), (2) panels with 100 % *C. cunninghamiana* denoted as (C), (3) panels with 100% *P. halepensis* wood particles denoted as (P), (4) panels with 50% *E. camaldulensis* and %50% *C. cunninghamiana* denoted as (E-C), (5) panels with 50% *E. camaldulensis* and %50% *P. halepensis* denoted as (E-P), and (6) panels with 50% *C. cunninghamiana* and 50% *P. halepensis* denoted as (C-P).

The particles size used for all board types was 20-40 mesh. Urea formaldehyde (50 % solid content) was used as a binder with two levels (9% and 13%) and 2% ammonium chloride (30% solid content) were added based on the oven-dried weight of particles. The target density of all the manufactured panels was 680 kg/m³ (corresponded to 10 mm thickness of finished boards). The pressure conditions were 2.5 N/mm² pressure and 160 °C for hot pressing temperature for 5 min pressing time.

In order to evaluate the quality of the produced panels, mechanical and physical tests were conducted. The mechanical performance of the produced panels was modulus of elasticity (MOE) modulus of rupture

(MOR) according to the European standard (EN 310, 1993), and internal bond strength (IB) according to (EN 319, 1993). The physical tests were water absorption and thickness swelling after 2h and 24h water immersion (EN 317, 1993)

The experimental design used for the present study was complete randomized design (CRD). All data were subjected to analysis of variance tests (ANOVA test at 95% confidence level) to determine the differences among the determined characteristics. In addition, Fisher's LSD method was used to compare all possible pairs of means.

RESULTS AND DISCUSSION

The basic density values of the three raw materials used for the particleboard manufacturing in this study were presented in (Figure 1). The mean values were found to be 0.58, 0.53, and 0.46 kg/m³ for *E. camaldulensis*, *C. cunninghamiana*, and *P. halepensis*, respectively. The mean comparisons using the Fisher's LSD method showed that the three density values were significantly different at 95 % probability level.

The mean values of total extractive content for the three raw materials are presented in (Figure 2). The values were found to be 9.26%, 4.32%, and 3.16% for *E. camaldulensis*, *C. cunninghamiana*, and *P. halepensis* respectively; it is clear that *E. camaldulensis* had the highest value. The Fisher's LSD test showed that the three density values were significantly different at 95 % confidence level.

The mean values of the modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB) for the produced panels are presented in (Table 1).

The analysis of variance (ANOVA) for all the mechanical properties tested in this study revealed that there were significant differences for the resin levels, furnish type and the interaction between resin levels and furnish type at 95% confidence level. Fisher's LSD test was applied to compare the differences among the means of resin levels and furnish types (Table 1). The European standard (EN 312, 2005) recommends a minimum MOR value of 12.5 N/mm² for the particleboards manufactured for general-purpose use in dry conditions. All particleboards produced with 9 % and 13 % UF glue level satisfied the minimum requirement indicated by the European standard except the (P) and (E-C) panels with 9 % resin content.

Upon the obtained results, the (C-P) panels with 13 % urea formaldehyde (UF) resin content gave the highest MOR values compared to the other produced panels. The lowest MOR values were observed in (E-C) panels with 9 % resin content.

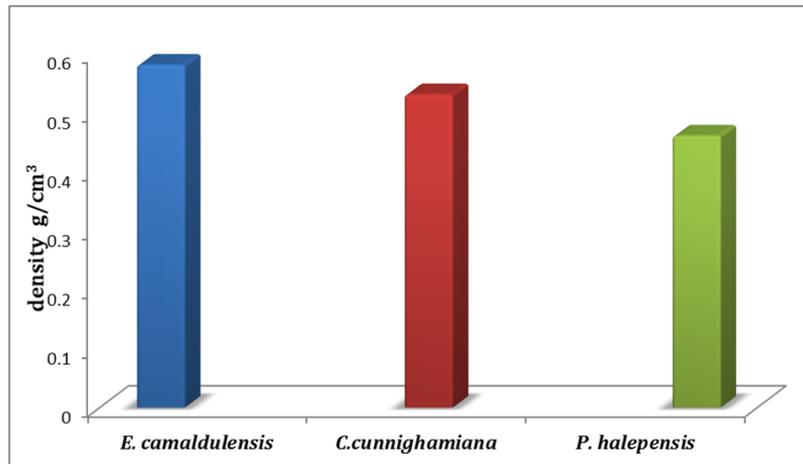


Fig. 1. The average values of density for the three wood species.

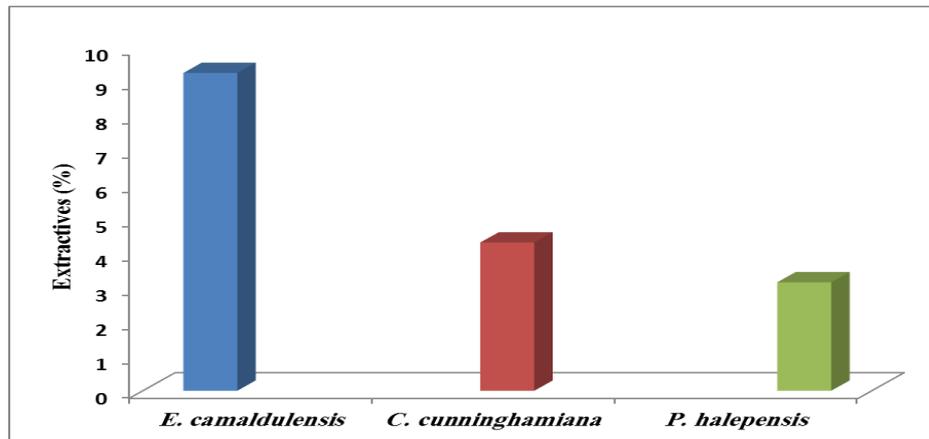


Fig. 2. The average values of total extractives content for the three wood species.

Table 1. Mean values of modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB) of the produced particleboards.

Items	MOR		MOE		IB	
	UF resin content (%)		UF resin content (%)		UF resin content (%)	
	9%	13%	9%	13%	9%	13%
<i>C. cunninghamiana</i> (C)	13.56 ^{ab} (1.1)	18.02 ^{bc} (1.74)	1376.3 ^{ab} (99.8)	2123.8 ^b (80.32)	0.94 ^a (0.11)	1.34 ^a (0.11)
<i>E. camaldulensis</i> (E)	12.98 ^{ab} (0.71)	19.38 ^{abc} (0.86)	1493.4 ^a (94.4)	2151.9 ^{ab} (116.5)	0.99 ^a (0.09)	1.37 ^a (0.05)
<i>P. halepensis</i> (P)	10.63 ^{cd} (0.47)	17.29 ^c (1.73)	1281.9 ^b (59)	1725.6 ^c (66.67)	0.68 ^b (0.12)	1.06 ^b (0.05)
E-C	9.46 ^d (0.71)	20.35 ^{ab} (1.76)	842.4 ^c (83.3)	2221.4 ^{ab} (77.98)	0.45 ^c (0.12)	1.40 ^a (0.1)
E-P	12.14 ^{bc} (1.45)	17.35 ^c (0.56)	1332.1 ^b (150.1)	1830.4 ^c (63.71)	0.93 ^a (0.07)	1.31 ^a (0.2)
C-P	14.23 ^a (1.11)	20.44 ^a (0.72)	1399.1 ^{ab} (91.2)	2282.5 ^a (36.11)	1.07 ^a (0.06)	1.45 ^a (0.09)

* Values in N/mm²; Means in the same column which do not share a common letter are significantly different at 95 % confidence level.

There were no significant differences between (C) and (E) particleboards in this study. Moreover, the MOR values for the mixtures except for the (E-C) panels with 9% resin level showed the ability to produce panels with acceptable ultimate breaking strength.

For modulus of elasticity (MOE), the (C-P) panels with 13 % UF resin content showed the highest value compared with the other produced panels. The lowest MOE value was observed in (E-C) panels with 9 % resin content. The European specifications (EN 312, 2005) recommends a minimum MOE value of 1800 N/mm² for particleboards for interior fitments (including furniture) for use in dry conditions. According to this study, all particleboards produced using 13 % UF glue satisfied the minimum conditions required by standards except for (P) panels which was very close to this value. On the other hand, almost particleboards produced with 9 % UF resin level does not satisfy the minimum requirement of the (EN 312, 2005). Generally, the boards having lower mechanical properties tested in this study can be used as insulating material in buildings, because such materials would not be subjected to any mechanical load.

The (C-P) panels with 13 % UF resin content gave the highest value for the internal bond strength (IB) in comparison with the other produced panels. The lowest IB value was observed in (E-C) panels with 9 % resin content. The (IB) strength of the (E) and (C) panels were better than those (P) panels. Generally, the (IB) strength increased with the increase in the level of urea formaldehyde resin. The European standard (EN 312, 2005) recommends a minimum (IB) value of 0.28 N/mm² for the particleboards manufactured for general-purpose use in dry conditions. Thus, all particleboards produced with 13 % and 9% UF resin achieved the minimum values recommended by the (EN 312, 2005) standard.

Extractives may play an important role in the properties of the panels especially the mixtures. According to (Foster, 1967), cold and hot water extractives, such as acetic and uronic acids, destroy the bond between the wood and resin during hot pressing. They decrease the pH of wood and cause early UF resin setting.

The obtained results were in agreement with (Zheng et al. (2006); Pan et al. (2007); Hassan, (2009)) since they found that with increasing UF resin levels the values of MOE and MOR of the panels were increased. Ashori and Nourbakhsh (2008), reported that the resin level was the main parameter affecting the static bending properties (MOE and MOR) and the (IB). In addition, Pan et al. (2007) and Saad and Kamal, (2012) concluded that boards with higher resin contents had

higher MOR, MOE, and IB values. In contrast to the majority of studies, Ayrlimis et al. (2012) investigated the effect of resin content on the mechanical properties of single-layer particleboards made from a mixture of wood particles (70 %) and rice husk particles (30%). Urea formaldehyde (UF) and phenol formaldehyde (PF) resin types with three different resin levels (8, 10, and 12 %) were used. Their results showed a slight improvement in the MOE and MOR when the UF and PF resin increased from 8 % to 10%, however, there were significant improvements for the 12 % resin content panels.

The mean values of water absorption and thickness swelling after 2 and 24 hours of water immersion for the produced panels are presented in (Table 2).

The mixtures improved the water absorption and thickness swelling after (2h. and 24h.) of water immersion for the panels with 9% UF resin content, except for the (E-C) panels. Moreover, both properties were improved when the resin content increased to 13%. The mixtures for the 13% UF resin content panels improved the water absorption and thickness swelling and even for the (E-C) panels. According to (Maloney, 1993), there are some factors that controls the water resistance of particleboards not only resin level or raw material density, such as different particle sizes, densities, pressing conditions (temperature, pressure, and press time, etc.)

The high values of water absorption and thickness swelling for the E-C panels with 9 % (UF) resin content may be attributed to the extractive content of the mixture which lower the bonding between the particles and adhesive. In contrast, when increasing the resin content with 13 % both properties in the (E-C) were improved, as the higher percentage of resin overcome this problem. To improve the characteristics of the 9% (E-C) panels in this study, pre-treatments to remove the extractives such as presoaking of particles in hot or cold water may be applied and this point needs to be investigated in further studies.

The reason for decreasing the thickness swelling with increasing resin content to the greater area of particles is covered with adhesive. When voids are filled with resin that also indicates that particles are more bonded together, consequently, less water can enter between particles (Kelly, 1977; Schneider et al., 1996).

This study was in agreement with other studies on different wood species as raw materials. For example, Taş and Sevinçli (2015), reported that the values of thickness swelling after 24h soaking in water of *Pinus brutia* were, 57.18, 47.16, and 36.14 for 6 %, 10%, and 12% resin content, respectively.

Table 2. Mean values of water absorption and thickness swelling after 2h and 24 h water immersion.

Items	Water absorption				Thickness swelling			
	UF resin content (%)				UF resin content (%)			
	9%		13%		9%		13%	
	2h	24h	2h	24h	2h	24h	2h	24h
<i>C. cunninghamiana</i> (C)	56.29 ^c (2.53)	67.23 ^c (0.79)	40.69 ^b (0.94)	52.61 ^b (1.35)	16.04 ^{cd} (0.69)	24.17 ^{cd} (0.56)	13.5 ^{a,b} (0.28)	21.97 ^b (0.59)
<i>E. camaldulensis</i> (E)	56.80 ^c (0.34)	68.01 ^c (1.86)	42.25 ^b (2.02)	52.95 ^b (2.98)	16.68 ^c (0.68)	24.67 ^c (1.27)	13.54 ^b (0.50)	21.63 ^{bc} (0.40)
<i>P. halepensis</i> (P)	78.42 ^b (0.68)	88.36 ^b (1.12)	63.80 ^a (4.01)	74.08 ^a (1.99)	18.65 ^b (1.1)	26.80 ^b (0.17)	14.46 ^a (0.36)	24.55 ^a (0.69)
E-C	87.97 ^a (2.74)	98.49 ^a (5.02)	34.86 ^d (1.08)	45.62 ^d (1.03)	22.35 ^a (0.42)	28.99 ^a (0.46)	9.32 ^d (0.32)	15.91 ^d (0.34)
E-P	54.81 ^c (2.24)	62.07 ^d (1.02)	37.62 ^c (0.97)	48.76 ^c (0.54)	14.75 ^d (0.52)	22.61 ^d (0.87)	12.14 ^c (0.14)	19.94 ^c (1.64)
C-P	46.52 ^d (2.50)	56.35 ^e (3.01)	30.72 ^e (1.29)	41.76 ^e (0.67)	13.11 ^e (0.31)	20.82 ^e (0.49)	8.82 ^d (0.35)	14.49 ^d (0.44)

* Values in percentage; Means in the same column which do not share a common letter are significantly different at 95 % confidence level.

In this study, wax was not added to improve the water resistance of the panels. Therefore, the addition of paraffin wax will improve the physical properties. There are other additives that may improve the performance such as use of phenolic resins, coating of the particleboard surfaces and acetylating of particles can improve the water repellency of the panels (Rowell and Norimoto, 1988; Nemli *et al.*, 2005; Guntekin *et al.*, 2008 and Ayrilmis *et al.*, 2009).

Based on the findings of this research, there is a need to expand in tree plantations establishment especially fast-growing trees irrigated with treated wastewater and this is important to provide continuous raw materials for manufacturing wood-based panels such as particleboard.

CONCLUSIONS

Single layer particleboards were manufactured using *Eucalyptus camaldulensis* (E), *Pinus halepensis* (P), and *Casuarina cunninghamiana* (C) wood particles from trees irrigated with treated wastewater and their mixtures among the three genera (E-C, E-P, and C-P) with two levels (9% and 13%) of urea formaldehyde (UF) adhesive. The result of this study showed that all particleboards produced with 9 % and 13 % UF glue level satisfied the minimum requirement indicated by the European standard for MOR except the (P) and (E-C) panels with 9 % resin content. The mechanical properties of the 13 % resin content panels were above the minimum requirement of the European standard (EN 312, 2005) for general-purpose boards for use in dry conditions. Almost particleboards produced with 9 %

UF resin level does not satisfy the minimum requirement of the European standard for MOE. All particleboards produced with 13 % and 9% UF resin achieved the minimum values recommended by the European standard for IB. Based on the result of this study the 13% UF resin level panels had lower values of water absorption and thickness swelling than those observed in the 9% UF resin. panels. It was clear that the mixture improved the physical properties (water absorption and thickness swelling). The obtained data showed that the (E-C) with 9% UF resin level panels had the highest values of water absorption and thickness swelling. The (C-P) panels had the best mechanical and physical properties compared with the other produced panels. The particleboards with low mechanical properties could be used for insulation purposes. The results showed the suitability of the three species and their mixtures which irrigated with treated wastewater as raw material for particleboard industry in Egypt.

ACKNOWLEDGEMENTS

Deep appreciation is expressed to Prof. Dr. Mohamed El-Rouby, professor of Agronomy, Faculty of Agriculture, Alexandria University, for his great advice and assistance through the phase of the statistical analysis. Also, our deep appreciation goes to Prof. Dr. Mohamed El-Raey, Institute of Graduate Studies and Research, Alexandria University for his valuable suggestion and comments.

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الملخص العربي

الخواص الفيزيائية والميكانيكية للخشب الحبيبي المصنع من بعض الأشجار الخشبية المروية بمياه الصرف الصحي المعالجة

خالد طه سليمان حسن، إبراهيم السيد خيرالله، أحمد عامر الستاوي، هبة محمود عبد الله

غراء يوريا فورمالدهيد قد أعطت الحد الأدنى الذي نصت عليه المواصفة القياسية الأوروبية لكل من معامل المرونة ومعامل الكسر وقوة الرابطة الداخلية باستثناء معامل المرونة لتلك الألواح المصنعة من أشجار الصنوبر والتي كانت قريبة جداً من القيمة الموصي بها. ومن الجدير بالذكر ان خلط المواد الخام للألواح الشجرية المستخدمة مع بعضها في صورة توليفات قد حسنت من الخواص الفيزيائية وهي مقاومة الألواح لامتصاص الماء والانتفاخ في السمك مقارنة بالألواح الأخرى المنتجة من كل نوع على حدي وخاصة عند استخدام مستوى ١٣% من الغراء. وقد كانت الخواص الميكانيكية وخواص مقاومة الألواح للماء أقل ما يمكن في الألواح المنتجة من توليفات من الكافور والكاروارينا معاً عند استخدام مستوى غراء ٩%. وقد أظهرت الأنواع الشجرية محل الدراسة صلاحيتها لإنتاج الواح الخشب الحبيبي وذلك باستخدام ظروف التصنيع المحددة في تلك الدراسة.

تهدف هذه الدراسة الى تصنيع ألواح الخشب الحبيبي من أشجار الكافور والكاروارينا والصنوبر النامية في مصر والمروية بمياه الصرف الصحي من غابة الصداقة المصرية الصينية وهي احدى أهم الغابات الصناعية في جمهورية مصر العربية وفي هذه الدراسة تم تصنيع ألواح من الأنواع الشجرية محل الدراسة وكذلك تم تصنيع ألواح من الخشب الحبيبي بتوليفات من تلك الأنواع وبعضها بنسبة ٥٠% لكل مادة خام وتم استخدام مستويين من غراء اليوريا فورمالدهيد هما ٩% و ١٣% وتم تقييم جوده الألواح الناتجة عن طريق اجراء اختبارات ميكانيكية على الألواح المصنعة تمثلت في تقدير معامل المرونة ومعامل الكسر وقوة الرابطة الداخلية وكذلك تم اجراء اختبارات فيزيائية وهي الانتفاخ في السمك ومقاومة الألواح لامتصاص الماء بعد التصنيع. أظهرت نتائج تلك الدراسة ان الألواح المصنعة بتوليفات من الكاروارينا والصنوبر معاً بمستوى غراء ٩% و ١٣% أعطت أفضل خواص ميكانيكية وأعلى مقاومة لامتصاص الماء ومن النتائج المتحصل عليها في تلك الدراسة ان جميع الألواح المصنعة باستخدام مستوي ١٣%