Suitability of Some Fast-Growing Trees and Date Palm Fronds for Particleboard Production

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Abstract

Three fast-growing trees, namely *Acacia saligna, Conocarpus erectus,* and *Melia azedarach,* as well as date palm (*Phoenix dactylifera*) midribs, were evaluated for their suitability for particleboard production. Panels were pressed at two target density levels of 750 and 650 kg/m^3 and a thickness of 13 mm using 10 percent urea-formaldehyde resin. Modulus of rupture (MOR) mean values for the manufactured boards ranged from 13.34 to 6.7 MPa for date palm boards pressed at high density (HD) and *C. erectus* boards pressed at low density (LD), respectively. Modulus of elasticity (MOE) mean values ranged from 2,674 to 1,149 MPa for *M. azedarach* boards at HD and *A. saligna* boards at LD, respectively. According to the American National Standards Institute, all boards pressed at HD passed the minimum requirements for both MOR and MOE, except for *A. saligna* boards. On the other hand, all boards pressed at LD did not pass the standard, except for *M. azedarach* boards. The internal bond mean values of all boards were higher than the standard requirements, but the boards did not satisfy the linear expansion requirements for general uses. Concerning thickness swelling, date palm boards compressed at LD were the only boards that passed the English National Standard requirements for both 2-hour and 24-hour immersions. In general, all the species under investigation can be used in the particleboard industry if they are pressed at a density level of 750 kg/m^3, while their dimensional stability properties might be improved by additional treatments, such as coating surfaces with melamine-impregnated papers or laminates in order to achieve a more stable product.

Successful development of particleboard production in the past four decades can be attributed to the fact that particleboards are a homogeneous material both for industrial production and for construction. This industry has the economic advantage of using low-cost wood, other lignocelluloses fibrous materials, and inexpensive processing with various types of binders. The demand for composite wood products has increased substantially throughout the world (Sellers 2000). Particleboard production forms about 57 percent of the total production of wood-based panels and is growing constantly at a rate of 2 to 5 percent annually (Drake 1997). Particleboard consumption significantly increases each year. According to the Food and Agriculture Organization of the United Nations (2010), the world consumption of particleboards in 1998 was 56.2×10^6 m^3 and in 2006 had risen to approximately 104×10^6 m^3. However, deforestation, forest degradation, and increasing demand for wood-based panels have led to a shortage of raw materials in the sector for a long time. The most effective ways to meet the growing demand for wood are the establishment of fast-growing tree plantations using the underutilized tree species and fibrous agricultural residues. These resources can play a key role in providing balance between supply and demand and decrease the demand on natural forests.

In developing countries such as Saudi Arabia and Egypt, where resources of wood for the production of particleboard are poor, fast-growing tree species can play a major role in providing good supply of woody raw material. For this reason, research has been carried out in the Forestry Research Unit, College of Food and Agricultural Sciences, King Saud University, Kingdom of Saudi Arabia, on a wide variety of fast-growing trees (Aref et al. 2003, Hegazy et al. 2008, Nasser et al. 2010). As a part of the unit's research, *Acacia saligna* (Labill.) H.L. Wendl., *Conocarpus erectus* L., and *Melia azedarach* L. trees were planted for biomass production as fast-growing tree species so that they can be used as supplement to the fuel wood and fibrous raw material.

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The average dry biomass yield of stems and branches for *A. saligna* (Labill.) H.L. Wendl. ranged between 65 to 80 tons/ha after 3 years of planting under the prevailing condition of the Riyadh region (not published). *A. saligna* wood is used as fuel and charcoal and for vine stakes and small agricultural implements, and it has been successfully processed into particleboard in Tunisia (El-Lakany 1987). On the other hand, the total dry woody biomass yield (stem and branches) of *C. erectus* L. (button mangrove) was about 67 tons/ha at the age of 3 years when trees were planted at close spacing of 0.7 by 0.7 m under the environmental conditions of the Riyadh region in Saudi Arabia (Hegazy et al. 2008). Wood of this species is hard and durable and has a high calorific value as fuel, but it is most widely used for high-grade charcoal (Morton 1981). Button mangrove is reported to tolerate diseases, insects, light frosts, pests, salinity, and waterlogging (National Academy of Sciences 1980, Little 1983).

M. azedarach L., also known as Chinaberry, is a fast-growing deciduous tree. It has a medium-density hardwood and is considered a promising species because of its considerable tolerance to climate and adaptation to poor soils and seasonally dry conditions (Harrison et al. 2003).

Date palm (*Phoenix dactylifera* L.) is a perennial species with an average life of 150 years. There are approximately 62 million trees in the Middle East and North Africa and 100 million worldwide (Al-Sulaimann 2003). Each year, the trees are pruned to remove old, dead, or broken leaves. This produces approximately 100,000 tons of date palm fronds and 15,000 tons of date palm leaves in Saudi Arabia alone. Worldwide, an estimated 1,130,000 tons of date palm fronds are produced annually (Al-Jurf et al. 1988). However, researchers used date palm midrib residues in particleboard manufacture and tried to use the best manufacturing conditions to get acceptable quality requirements from such raw material (El-Mously et al. 1993, Nemli et al. 2001, Ashori and Nourbakhsh 2008, Iskanderani 2008). Results have proven that the products from palm midribs carry physical and mechanical properties satisfying the international standards.

In the present investigation, wooden particles of *A. saligna, C. erectus,* and *M. azedarach,* as well as the lignocelluloses material from date palm (*P. dactylifera*) midribs, were used as alternative raw materials for particleboard production. The initial objective of this study was to explore the potential suitability of these resources for particleboard manufacturing. In addition, it aimed to analyze the influence of two different levels of board density on the physical and mechanical properties of particleboards manufactured from these underutilized low-quality materials (Cai et al. 2004, Ayrilmis 2007) and to determine if such fiber resources could be used to produce particleboards with acceptable properties.

Materials and Methods

Raw materials

The wood raw material used in this experiment was taken from trees grown in the University Experimental Station near Dirab, Riyadh, Saudi Arabia (24°24′33″N, 46°39′40″E). Characteristics of these tree species and their descriptions are listed in Table 1. Trees were felled and cut into approximately 1-m logs using a chainsaw. Logs were left to air dry and later reduced to 0.5- to 1.0-cm thin disks using a disk saw and then oven dried. Disks were further reduced to smaller chips and then milled twice with a laboratory-scale hammer mill having circular sieve opening sizes of 12 mm and 5.5 mm, respectively. The resulting particles were then sieved with an automatic sieve shaker and group of serial sieves (American Society for Testing and Materials [ASTM] E-11 specification). The sieves had openings of 8, 20, 40, and 60 mesh, which are equal to opening sizes of 2.4, 0.85, 0.43, and 0.25 mm, respectively. Particle sizes of 8 to 20 mesh and 20 to 40 mesh were used in this experiment in a mixture of 80 and 20 percent, respectively, by weight. Particle descriptions of length, width (or thickness), and slenderness ratio for both sizes are listed in Table 2. The wood particles were stored in a chamber to maintain a constant 10 percent moisture content (MC) at 22 percent relative humidity (RH) and 21°C ± 1°C until they were used.

Panel manufacturing

Particles were oven dried at 90°C for 40 to 48 hours until the MC of particles reached and equilibrated to 3 percent MC (by taking regular MC samples every 2 h). Particles

Table 1.—Tree measurements and average specific gravity (SG) values of the raw material used in panel production.

Species	No.	Age (y)	Height (m)	Diameter (cm)	Average SG	Remarks
A. saligna	6	3	3.5–5	4–9	0.42	Complete stem and branches with bark (14%–19%) by volume
C. eructus	8	4	5–5.5	5–8	0.60	Complete stem and branches with bark (12%–18%) by volume
M. azedarach	3	9	10–11	18–19	0.43	Logs up to 1.4 m without bark
P. dactylifera	50	—	—	—	0.25	Midrib or fronds without leaves

Table 2.—Screen analysis and slenderness ratio (L/D) of the particles used in panel manufacturing.[a]

	Particles 8–20 mesh			Particles 20–40 mesh		
Species	Length (mm)	Width (mm)	L/D ratio	Length (mm)	Width (mm)	L/D ratio
A. saligna	5.32 (2.13)	1.30 (0.46)	4.09	3.33 (2.1)	0.51 (0.21)	6.61
C. erectus	4.11 (1.72)	0.91 (0.55)	4.52	4.0 (2.0)	0.52 (0.22)	7.59
M. azedarach	4.83 (1.99)	1.30 (0.53)	3.71	3.0 (1.6)	0.51 (0.43)	5.88
P. dactylifera	5.51 (1.60)	1.17 (0.59)	4.70	4.2 (1.8)	0.47 (0.22)	9.08

[a] Each value is an average of 150 measured particles. Values in parentheses are standard deviations.

were then blended with urea-formaldehyde (UF) resin using a pneumatic spray gun and mixing shaker for 10 minutes at room temperature (20°C to 22°C). Based on the ovendry particle weight, a 10 percent UF resin (50% solid content) and 1 percent wax (50% emulsion) were applied for all boards. As a hardener, ammonium chloride (NH_4Cl, 1%, based on the resin weight) was applied to the UF solution. The resinated particles were placed in a molding box prepared with aluminum foil. The furnishes were manually formed, sprayed with 25 ml of water on both faces, and prepressed into 30 by 30-cm mats inside the foil. The adhesive-coated mats were then compressed on steel cauls in a manual hot press (Carver Laboratory Press) at a temperature of 160°C (except for date palm boards, where the temperature was 120°C) using a pressure of 30 kg/cm^2 without using press stops. Total pressing cycle was 8 minutes, including 2 minutes of closing time. Two target densities of 750 and 650 kg/m^3 (based on the calculated weight of particles in a specified target volume) at a target thickness of 13 mm were used for all the board species. After pressing, the panels were trimmed to a final size of 27 by 27 cm to avoid edge effects. Five panels were made for each treatment. Particleboards were conditioned for 2 weeks in a special chamber cabinet modified to maintain an RH of 65 percent and temperature of 20°C. The conditioned panels were cut later into various sizes for property evaluations.

Particleboard property evaluation

Mechanical properties, including modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB), as well as the physical properties, including linear expansion (LE), thickness swelling (TS), and water absorption (WA), are the most important specifications required for particleboard evaluation. They were measured for each finished panel, and data analysis was performed using the SAS software package (SAS Institute Inc. 2000). The significance of different treatments was determined with analysis of variance and a least significant difference test ($\alpha = 0.05$). The specific methods used for evaluation of various properties are described below.

Mechanical properties

Finished particleboards were cut into various specimens following the methods of ASTM Standard D1037-99 (ASTM 1999) with some modification. Two rectangular (5.1 by 27-cm) pieces were used for three-point flex measurement of MOR and MOE, and two 5.1-cm square pieces were used for IB measurement. The mechanical properties were determined using an Instron testing machine (Model 1122; Instron Corporation, Canton, Massachusetts). Each reported value is an average of 10 measurements.

Physical properties

For the LE test, two rectangular 5.1 by 15-cm pieces from each panel were used for determining LE according to ASTM Standard D1037-99. All the samples assigned for the test were conditioned for 2 weeks at an RH of 50 percent and a temperature of 20°C ± 3°C. Measurements of the samples length were recorded to the nearest 0.02 mm with a digital caliper. Samples were conditioned again for 2 weeks at an RH of 90% ± 5% and a temperature of 20°C ± 3°C and measured again at the same previous position. The difference between the two measurements was used to calculate LE as percentages of the first conditioning values. Each reported value is an average of 10 measurements.

For the TS and WA test, one square 11 by 11-cm piece from each panel was used for determining TS and WA according to ASTM Standard ASTM D1037-99. Samples were soaked in water at room temperature (20°C to 22°C) for 2 and 24 hours to determine the short- and long-term properties. The weight and thickness of the samples were measured before and immediately after soaking and used to calculate WA and TS, which are reported as percentages of the values before soaking. Each reported value is an average of five measurements.

Results

The average values of specific gravity for the raw material used in panel manufacturing are listed in Table 1. According to wood density classification (Panshin and de Zeeuw 1980), the midrib of *P. dactylifera* is considered a low-density (LD) material, while *A. saligna* and *M. azedarach* are considered medium-density wood and *C. erectus* a high-density (HD) wood. Screen analysis for the particles revealed that the particle geometry of 8 to 20 mesh size had a length range of 4.1 to 5.5 mm, width range of 0.9 to 1.3 mm, and slenderness ratio between 3.7 and 4.7. On the other hand, for particles of 20 to 40 mesh sizes, these range dimensions were 3.0 to 4.2 mm, 0.47 to 0.52 mm, and 5.9 to 9.1 mm for length, width, and slenderness ratio, respectively.

Regarding the target density levels intended for the panel manufacture, they were 750 and 650 kg/m^3 for high and low levels, respectively, at a board thickness of 13 mm. However, using a manual hydraulic press without using the stops in pressing boards made it difficult to reach and control the intended target density. *A. saligna* particles were hard to press, while date palm particles were easy to press. Accordingly, the actual density was slightly higher or lower than the target density, as shown in Table 3. In this case, density was excluded from the factorial design, and each board combination of species and density was considered an individual treatment. However, statistical analysis revealed that the difference between the eight board treatments (4 species × 2 densities) were highly significant for all the measured mechanical and physical properties.

Mechanical properties

The average values of MOR, MOE, IB, LE, TS, and WA of the experimental panels are presented in Table 3. As shown in this table, MOR mean values for the manufactured boards ranged from 13.34 to 6.78 MPa for date palm boards pressed at HD and *C. erectus* boards pressed at LD, respectively. For the MOE property, the maximum mean value of 2,674 MPa was attained by *M. azedarach* boards at HD, while the minimum value of 1,149 MPa was attained by *A. saligna* boards at LD.

According to US standards (A208.1 for particleboard; American National Standards Institute [ANSI] 1999), the minimum values for MOR and MOE requirements for Type 1-M-1 particleboard for commercial use are 11 and 1,725 MPa, respectively. Based on these standards, all the species boards pressed at the high level of density passed the minimum requirements for both properties, except for *A. saligna* boards, which recorded 9.57 MPa for the MOR

Table 3.—Average values of the mechanical and physical properties of experimental boards.[a]

Species	Actual density (g/cm^3)	Bending properties (MPa) MOR	MOE	Internal bond (MPa)	Linear expansion (%)	Thickness swelling (%) 2 h	24 h	Water absorption (%) 2 h	24 h
A. saligna	0.70	9.57 D (1.39)	1,868 C (389)	0.54 CDE (0.09)	1.15 A (0.15)	34.4 A (0.91)	40.3 A (1.2)	67.2 A (2.1)	82.3 AB (2.3)
C. erectus	0.75	11.25 BC (2.33)	2,326 B (410)	1.02 A (0.16)	0.84 B (0.10)	20.1 C (3.7)	29.0 B (2.1)	46.0 D (80.)	63.3 C (4.4)
M. azedarach	0.71	12.01 AB (0.48)	2,674 A (130)	0.66 BCD (0.07)	0.75 B (0.06)	25.2 B (1.4)	30.3 B (1.9)	54.9 BC (0.7)	65.9 C (0.1)
P. dactylifera	0.79	13.34 A (1.80)	2,018 C (258)	0.53 DE (0.9)	0.62 CD (0.04)	11.9 E (1.0)	21.7 D (0.3)	31.7 E (4.5)	38.4 E (3.2)
A. saligna	0.61	7.34 E (0.57)	1,149 D (198)	0.53 DE (0.04)	0.75 B (0.05)	22.0 C (2.1)	29.8 B (1.71)	72.7 A (1.6)	87.0 A (1.8)
C. erectus	0.66	6.78 E (1.62)	1,319 D (326)	0.72 B (0.11)	0.72 BC (0.12)	14.9 D (2.1)	23.2 D (1.3)	27.1 E (4.0)	51.5 D (1.7)
M. azedarach	0.65	9.80 DC (1.15)	2,013 C (181)	0.65 BCD (0.04)	0.62 CD (0.04)	22.2 C (1.1)	26.4 C (1.2)	51.0 CD (2.3)	67.6 C (3.4)
P. dactylifera	0.67	9.04 D (1.65)	1,443 D (241)	0.43 E (0.02)	0.56 D (0.02)	6.3 F (1.2)	13.7 E (2.5)	59.8 B (3.9)	79.5 B (2.6)
ANSI standard		11.0	1,725	0.40	0.35	—	—	—	—
EN standard		11.5	1,600	0.35	—	8	15	—	—

[a] Each value is an average of five samples. Values in parentheses are standard deviations. MOR = modulus of rupture; MOE = modulus of elasticity; ANSI = American National Standards Institute.

property. On the other hand, all the boards pressed at the low level of density did not pass the prescribed standard, except for *M. azedarach* boards, which recorded 2,013 MPa for the MOE property.

IB data as shown in Table 3 ranged from 0.43 MPa (date palm at LD) to 1.02 MPa (*C. erectus*). The minimal requirements of IB for general-purpose particleboard in both standards—ANSI A208.1 and EN 312-2 (European Committee for Standardization [CEN] 1996a)—are 0.40 and 0.24 MPa, respectively. According to these standards, all the IB mean values of the particleboards produced in this experiment were higher than requirements.

Physical properties

The mean values of linear expansion ranged from 0.56 to 1.15 percent for date palm LD and *A. saligna* HD, respectively (Table 3). According to the ANSI standard, particleboards should have a maximum LE value of 0.35 percent, which means that all the manufactured panels did not satisfy the LE requirement for general uses.

Based on the CEN standards (EN 312-4; CEN 1996b), particleboard should have a maximum TS requirement value of 8 and 15 percent for 2-hour and 24-hour immersions, respectively. However, the average TS of the tested specimens after 2-hour immersion exceeded this level, except for date palm boards compressed at the LD level, which attained an average TS value of 6.3 percent. Similarly, the average TS of the tested specimens after 24-hour immersion also exceeded the requirement, except for date palm boards compressed at the LD level, which attained an average TS value of 13.7 percent. These results revealed that date palm boards compressed at the LD level were the only boards that passed the TS requirements of the CEN standard for both 2- and 24-hour immersions.

Discussion

Board density is a measure of the compactness of individual particles in a board and is dependent mainly on the wood density and the pressure applied during pressing (Vital et al. 1974). An increase in board density is accomplished essentially by either increasing the weight of the wood in the mat or compressing the mat, which results in an increase in wood volume available to distribute stresses and also an increase in contact between the particles and resin efficiency by additional and improved glue bonds (Gatchell et al. 1966). This conclusion obviously applies to our experiment, where increasing board density resulted in an increase in all the mechanical properties for all the species. An increase of 13 percent in the density of *C. erectus* boards (660 to 750 kg/m^3) resulted in an increase of MOR, MOE, and IB values of 66, 76, and 42 percent, respectively. Similarly, an increase of 18 percent in date palm boards (670 to 790 kg/m^3) resulted in an increase of 47, 40, and 23 percent for the same properties, respectively. However, Maloney (1993) stated that a compaction ratio of 1.3 (board density/wood density) is a good estimate of the degree of compaction needed to consistently make well-bonded boards. The effect of the density profile on the bending properties has long been of interest where most researchers have explored a higher bending strength but lower IB with increasing board density (Kelly 1977, Kawai and Sasaki 1986, Humphrey 1991, Shuo and Bowyer 1994, Schulte and Fruhwald 1996).

Comparing properties of the species under investigation with other published research data revealed that only date palm properties were available in the literature. El-Mously et al. (1993), using a board density of 650 kg/m^3, obtained MOR, MOE, and IB values of 10.5, 18,512, and 0.43 MPa, respectively, while Nemli et al. (2001) obtained MOR values in the range of 15.3 to 18.9 MPa and IB values in the range of 0.35 to 0.83 MPa for the same density. On the other hand, Ashori and Nourbakhsh (2008), using a board density of 750 kg/m^3 and resin content between 9 and 11 percent, attained MOR, MOE, and IB range values of 10 to 16.6 MPa, 1,333 to 1,861 MPa, and 0.38 to 0.63 MPa, respectively. However, the values obtained for date palm MOR in this experiment were similar or slightly lower than the published values if the board density was considered, where MOE and IB values were higher for boards pressed at an HD level.

In general, the slightly lower MOR and MOE values for all the species attained in this experiment and the higher IB values may be attributed to the interaction effect of several defining factors but not to a single factor. First, the geometry or configuration of the particles obtained in this trial was smaller or lower in quality than that produced by other researchers because these particles were produced using a hammer mill available in our laboratory (Table 2), whereas others had used a laboratory ring flaker, which can produce particles of high quality. Particles produced by such flakers might have dimensions of 16, 3.5, and 0.35 mm for length, width, and thickness, respectively, which can attain a high slenderness ratio (length/thickness) of 45 (Nourbakhsh 2010). Zheng et al. (2006) mentioned that high-quality particleboards of high strength and smooth surface can be obtained by using a homogeneous material with a high degree of slenderness (long, thin particles) but without oversized particles, splinters, and dust. On the other hand, low-slenderness particles in the core layer gave high IB values (Ntalos and Grigoriou 2002). Another reason could be that some boards incorporate up to 12 to 19 percent bark particles, as shown in Table 1. However, it is clear in this trial that the two species manufactured without bark (*M. azedarach* and date palm) had higher strength properties than the other two species (Table 3). The deleterious influence of bark content on board properties has been mentioned in similar, earlier works (Moslemi 1935, Semple et al. 2002, Zheng et al. 2006). Moreover, the presence of bark in the particles may slightly increase pH and/or lower absolute acid buffering capacity of wood particles, which may extend the gel time and inhibit the curing of UF resin (Mo et al. 2003, Zhang et al. 2003).

Another reason might be the use of a manual hydraulic press, where closing time was 2 minutes to reach the maximum load of 30 kg/cm^2 and was followed later by a sudden and uncontrolled release for the pressure at the end of the press cycle. Nemli and Demirel (2007) studied the effects of the entrance and exit pressure levels on the technological properties of the panels and found that a decrease in the entrance pressure and an increase in the exit pressure significantly decreased the MOR and MOE because of the decrease in surface layer density and improved the IB strength and TS because of the increase in core layer density.

Concerning the dimensional stability properties of this trial, all the mean values of LE, TS, and WA increased with increasing board density as they were subjected to mild accelerated aging conditioning (2-h soaking), but the difference grew wider after exposure to more severe conditioning (90% RH, or 24-h soaking). This difference is due to the release of greater compression stress in HD boards at a later stage compared with the LD boards (Wong et al. 1998). Ayrilmis (2007) mentioned that when wood-based panel products are exposed to humid conditions or soaked in water, spring-back of the densified material is released and dimensional changes take place. Therefore, LE and TS were attributed to the release of compressive stresses, hygroscopic swelling of wood particles, and the deterioration of the interparticle bonding. In general, the reasons for high values of dimension instability (compared with both CEN and ANSI standards) may be due to the small particles produced in this experiment and the longer press closing time, as mentioned earlier. Miyamoto et al. (2002a) mentioned that LE of particleboard decreased with increasing particle length and size, while it increased with increasing press closing time when this factor exceeded 100 seconds (Miyamoto et al. 2002b). In comparing the sizes of different particles, Viswanathan and Kailappan (2000) made it clear that WA and TS were least for the board made from the largest particles. They explained that the higher WA values attained by the boards made from smaller particles would be because of the larger surface area, which absorbs more water. However, the panels may require additional treatments, such as increasing resin level, coating particleboard surfaces with melamine-impregnated papers or laminates (Xu et al. 2005), using high press temperature and time of postheat treatments, or using the acetylation method (Zhang et al. 1997) in order to achieve a more stable product from such species.

Summary and Conclusion

The mechanical and dimensional performance of particleboards made from *A. saligna, C. erectus,* and *M. azedarach,* as well as date palm (*P. dactylifera*) midribs, was investigated in this study. With 10 percent UF usage and a board density of 650 kg/m^3, the studied species did not meet the bending stiffness and dimensional stability requirements for Type 1-M-1 panels (panels using UF resin and compressed at a medium-density range between 640 and 800 kg/m^3), which are usually used for shelving, general uses, and home furniture. However, increasing board density up to 750 kg/m^3 was found to be an effective method for attaining acceptable mechanical properties for both MOR and MOE. TS and LE of these panels were attributed to the release of compressive stresses, hygroscopic swelling of wood, and the deterioration of interparticle bonding. On the other hand, the values of IB for all species and both density levels passed the minimum requirement. In general, we can recommend that all the species under investigation can be used in the particleboard industry if they are pressed at a density level of 750 kg/m^3 or higher using a compaction ratio of at least 1.3 for high wood species density. The dimensional stability properties might be improved by additional treatments, such as coating surfaces with melamine-impregnated papers or laminates, in order to achieve a more stable product.

Acknowledgments

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