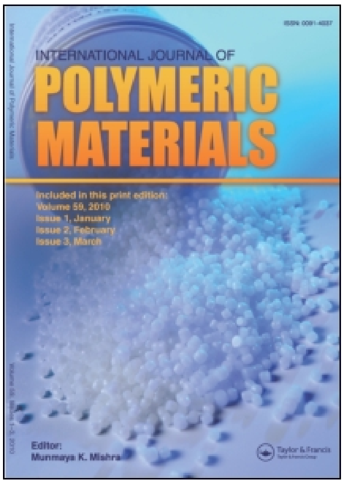

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Influence of Process Variables on the Bending Strength of Particleboard Produced from Arabian Date Palm Mid-Rib Chips

F. I. Iskanderani[a]
[a] Department of Chemical and Materials Engineering, King AbdulAziz University, Jeddah, Saudi Arabia

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Influence of Process Variables on the Bending Strength of Particleboard Produced from Arabian Date Palm Mid-Rib Chips

F. I. Iskanderani
King AbdulAziz University, Department of Chemical and Materials Engineering, Jeddah, Saudi Arabia

Feed produced from Arabian date palm (Phoenix dectylifera-L) biomass and impregnated with urea formaldehyde (UF) adhesive binder is subjected to hot compaction to yield particleboard panels of excellent bending strength. Process variables such as press temperature, press cycle time, compaction pressure and particle thickness are shown to exercise significant effects on the bending strength of the final product. The influence of chipping technique on particle integrity and surface quality is highlighted. Scanning electron microscopic (SEM) evidence is presented to illustrate microstructural damages caused by excessively high compaction pressure.

Keywords: bending strength, date palm, mid-ribs, urea formaldehyde

INTRODUCTION

Newly developed, economically attractive, and environmentally benign composite materials are being considered for various applications in the building, furniture, packaging and automotive industries. Mineral tillers and fibers have been used widely in the plastics industry to enhance certain properties and minimize the cost of the end product. Lingocellulosic fibers have received considerable attention for use with thermosets in high-volume mass production lower-cost applications.

Increasing annual wood product consumption to keep up with the fast-growing world population has made it imperative to cast a fresh look at existing raw material potential, consumption patterns and the future supply-demand strategies for the next few decades.

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Address correspondence to F. I. Iskanderani, Faculty of Engineering, King AbdulAziz University, P.O. Box 80204, Jeddah 21589, Saudi Arabia. E-mail: faisalisk@gmail.com

Projections indicate that by the year 2050, the global wood consumption, which stands at 3.425 billion m^3/year at present [1], will double. The huge gap that will develop progressively in the next half-century can be bridged by a strict "sustainable development" strategy of forestry wealth, recycling of wood-based lignocellulosic solid waste, and rational utilization of lignocellulosic biomass from seasonal plants and from seasonal pruning of trees.

In 1986 the USA generated nearly 158 million tons of solid waste, equivalent to half of the world's total [2]. According to projections, this total would have reached around 193 million tons by the year 2000 [3,4]. In 1986, only as little as 11% of the total solid waste was recycled [5]. Hence, a huge potential for the recycling of solid waste remains to be utilized.

As far as the utilization of biomass from annual crops is concerned, significant progress has already been recorded in many countries. Bagasse, which is obtained as the residue fiber from sugar cane processing, is probably the first utilized and most favored in the American continent. The first Bagasse composition panel production was accomplished in Louisiana (USA) as early as 1920 [6]. In Venezuela, bagasse fiberboards began to be produced in 1958 [7]. In Peru, prefabricated panelized construction was developed that utilized bamboo and wood [8] for earthquake-resistant structures. Bamboo as a building material has received wide attention in many countries including Japan [9] and Western Countries [10]. A Bulgarian study [11] cites a multitude of agricultural waste fibers including those from beech, hemp, vine, tobacco, cotton, raspberry, maize or sunflower stalks to be suitable for fiberboard production. Rice straw [12], sorghum stalks [13], reed [14] and cereal straw [15] have been utilized with success in reconstituted panel production. Research conducted by Chow [16] has shown that cornstalks and cobs can be used to produce chipboard or fiberboard. Kenaf utilization for panel manufacture holds great promise [17]. Kenaf is already a fiber crop grown commercially in the USA [18]. Research by Kalaycioglu has shown the particleboards manufactured from sunflower stalks to possess superior properties [19]. Recently, published researches on Phoenix dactylifera-L have focused on the utilization of date palm fiber with both thermoset and thermoplastic [20–27]. The present paper reports some of the physical properties of chipboard panels manufactured from date palm branch midribs, and attempts to correlate these properties with process variables and the internal structure of the lignocellulosic material.

The present research was undertaken to investigate the technological feasibility of manufacturing laboratory-scale particleboards from date-palm branch midribs pruned seasonally in the Kingdom of Saudi

Arabia. In view of the fact that the wooden composite panels used for various applications in the GCC States are totally imported [28], the local production of these panels in the member states would bring about import substitution and self-sufficiency.

EXPERIMENTAL METHODS AND MATERIALS

Preparation of Chips from Date Palm Mid-ribs

Several tons of freshly pruned date palm branches from the Madinah al-Munnawara and Bisha regions of Saudi Arabia were used in this investigation. Midribs from defoliated date palm branches were initially cut into suitable lengths and exposed in open air for natural drying to reduce the water content prior to mechanical processing. Fresh wood with high water content tends to clog the laboratory chipping machine. An additional benefit of predrying is to reduce the risk of fungal attack during storage. Depending on the atmospheric conditions the residual moisture content of the midribs is reduced to about 15% in 15–20 days.

Coarse chips were produced using a Vecoplan hacker type 20/6/2 + T. A Condux holtzschnitzler HS350 rotary knife chipper was employed to manufacture fine chips.

The chips were oven-dried at around 90°C until the residual moisture content was reduced to 3%, before sieving was carried out in an Allgaier-taumel siebmaschine type ATS600.

Dried chips were impregnated with urea formaldehyde using a rotary blender designed and manufactured locally.

Hot Compaction

Mats of impregnated chips were formed in situ on the press platen. An automatic Burkle hydraulic type 5140 hot press was used to produce experimental 57 × 77 cm chipboard samples of the desired thickness. Mats were pressed at three different temperatures (135°C, 150°C and 160°C) respectively, maintaining a constant compaction pressure of 2.4 N/mm^2 to achieve a board density of 0.65 g/cm^3. The press cycle time was 5, 6, or 7 min.

Bending Strength Tests

Bending test specimens were sectioned from sanded experimental chipboards. The bending test was conducted according to ASTM D1037-78 standard specifications. The bending strength, σ_b was

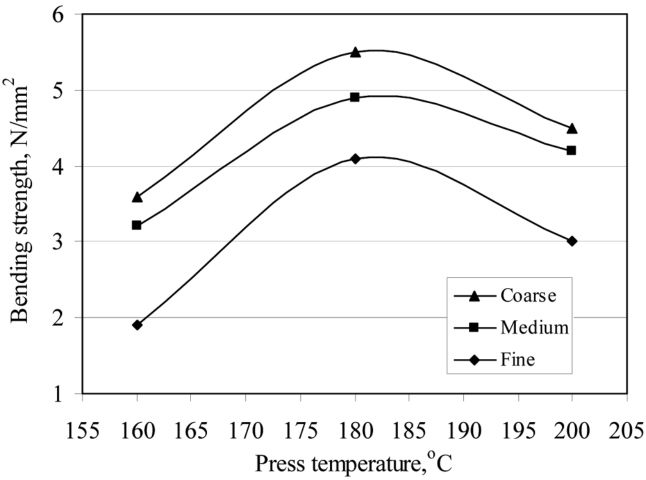

FIGURE 1 Bending strength vs. press temperature. $P = 3.25\,N/mm^2$, $t = 5$ minutes.

computed from the relation:

$$\sigma_b = 3PL/2bd^2$$

where P, L (200 mm), b (50 mm), and d (18 mm) denote the breaking load, the span between supports, the specimen width and thickness,

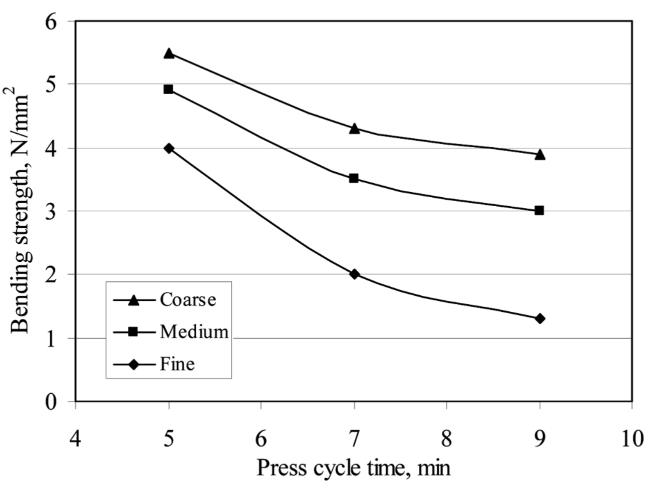

FIGURE 2 Bending strength vs. press cycle time. $P = 3.25\,N/mm^2$, $T = 180^{\circ}$.

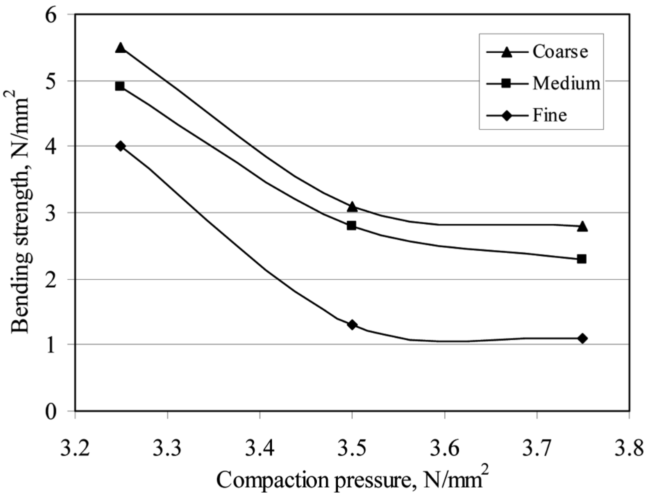

FIGURE 3 Bending strength vs. compaction pressure. T = 180°C, t = minutes.

respectively. No less than twelve bending tests were carried out for each chipboard produced. The standard deviation calculated for the bending strength of chipboards produced under various processing conditions fell in the range ±1.708. Bending test results are presented in Figures 1–5.

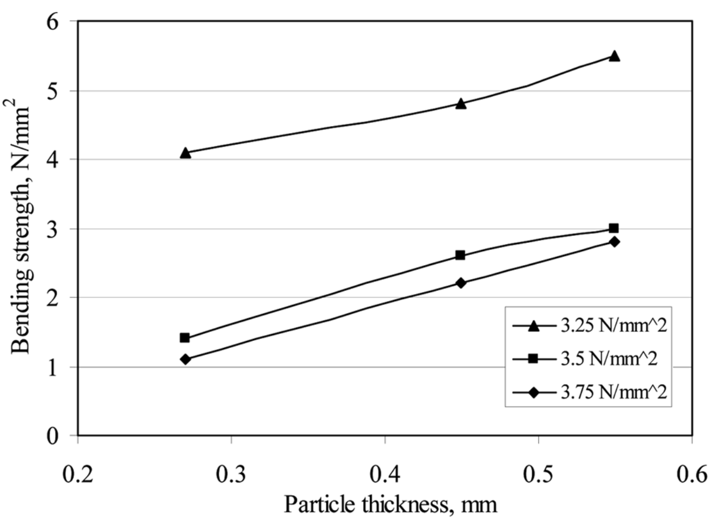

FIGURE 4 Bending strength vs. particle thinckness. T = 180°C, t = 5 minutes.

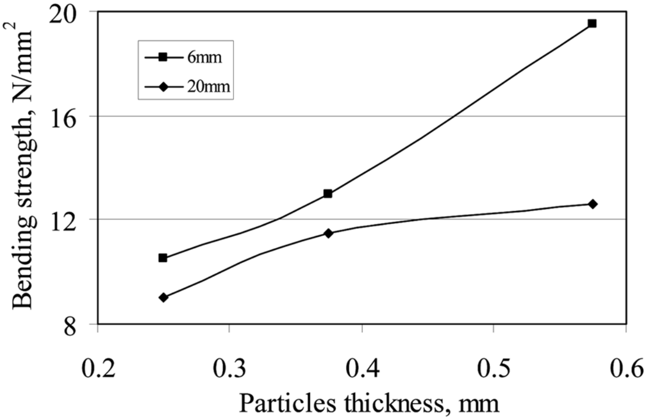

FIGURE 5 Bending strength vs. particle size for monolayer panels produced from rotary knifechips. T = 160°C, P = 2.4 N/mm^2, t = 5 minutes.

Environmental Scanning Electron Microscopy and EDX.

An XL30 ESEM model environmental scanning electron microscope developed by Philips was employed to study microstructural features in the midrib before and after compaction. The electron micrographs are presented in Figures 6–9.

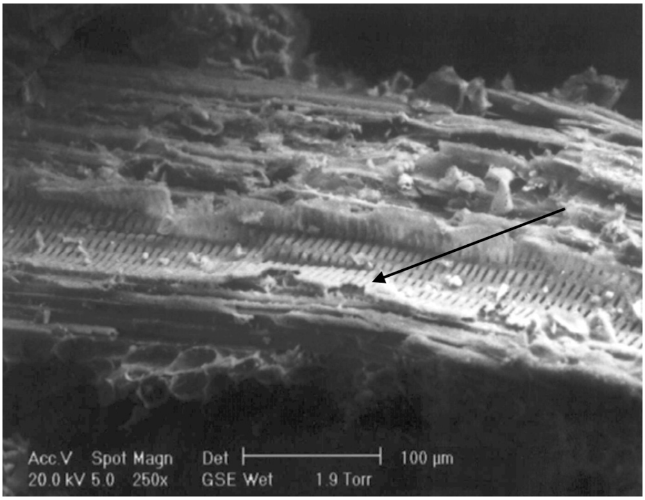

FIGURE 6 Cell wall rapture (arrowed) arising from excessive compaction pressure.

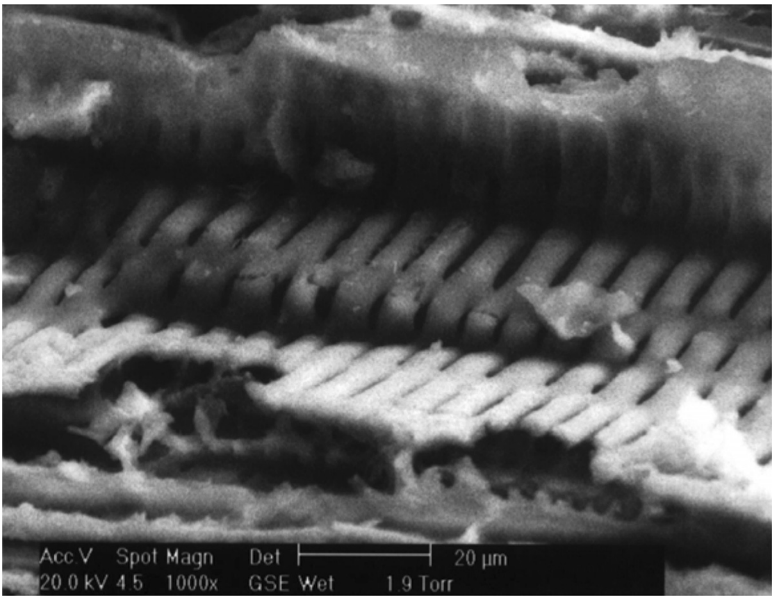

FIGURE 7 A magnified view of cell wall rupture shown in Figure 4.

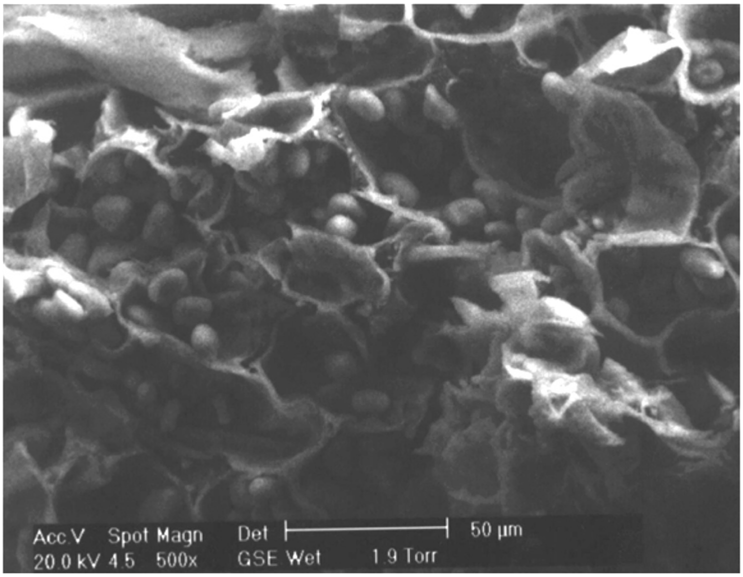

FIGURE 8 Cell wall collapse indicated by disfiguration of individual cell membrances.

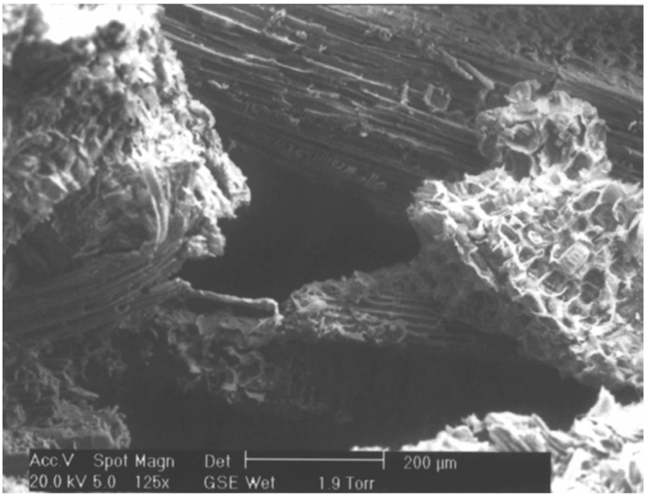

FIGURE 9 Particle breaking and fragmentation as a result of excessive compaction pressure.

DISCUSSION AND RESULTS

Effect of Temperature on the Bending Strength

The bending strength was observed to increase phenomenally by increasing the pressing temperature from 160°C to 180°C in all cases under consideration (Figure 1). For instance, while the bending strength for panels manufactured from coarse, medium and fine chips using a press temperature of 160°C under a compaction pressure of $3.25\,N/mm^2$ for 5 min is $3.62\,N/mm^2$, $3.17\,N/mm^2$ and $1.86\,N/mm^2$, respectively, increasing the pressing temperature to 180°C increases the strength to $5.5\,N/mm^2$, $4.82\,N/mm^2$ and $4.08\,N/mm^2$, respectively. All other things being equal, further increasing the press temperature to 200°C causes the bending strength of the boards cited above to fall to $4.43\,N/mm^2$, $4.23\,N/mm^2$ and $2.98\,N/mm^2$, respectively. The relatively low bending strength of panels produced at the comparatively low temperature of 160°C is attributed to incomplete polymerization of the UF resin, while, processing at the higher temperature of 200°C under identical conditions results in polymer degradation and consequential loss of strength. It is well-established that lengthy exposure of polymers at high temperatures inevitably leads to the severing of intermolecular bonds and concomitant deterioration of strength. As in the case of tensile strength, the maximum bending strength is observed to develop at 180°C. This is taken to be the optimum temperature for the palm midrib furnish/UF binder system, under the stated conditions.

The highest strength obtained with the monolayer board is 5.5 N/mm^2. Improvements in the quality of chips and more accurate control of the compaction pressure has been shown to bring about considerable enhancement of strength.

Effect of Press Cycle Time on the Bending Strength

Figure 2 demonstrates the manner in which the bending strength is affected by the variations in the press cycle time at 180°C and under a compaction pressure of 3.25 N/mm^2.

The highest strength levels are achieved for a press cycle time of 5 min. Increasing the press cycle time triggers a progressive fall in the bending strength. Thus, press cycle times of 7 and 9 min reduce the strength by 21% and 32%, respectively. This significant reduction in strength is ascribed to the well-documented thermal and thermo-oxidative degradation of the UF polymer by bond scission.

Effect of Pressure on the Bending Strength

The variation in the bending strength with compaction pressure is indicated in Figure 3. The highest strength levels are attained invariably under the moderate pressure of 3.25 N/mm^2 at 180°C for a press cycle time of 5 min. Under these conditions, and in the presence of moisture, wood chips become plasticized such that adequate compaction occurs. Plasticization smoothens rough surfaces so that interparticle contact is greatly enhanced. Concurrently, polymerization of the UF adhesive proceeds to form a hardened network of UF polymer which confers strength and dimensional stability upon the composite panel.

The marked decrease observed in the bending strength as the compaction pressure is increased, is put down to the damage induced in the internal structure of individual chips, first during chip production using the vibrating cup method and, at a later stage, under high compaction pressure (Figures 6 and 7). Material damage in the form of cell wall collapse (Figure 8) and particle fragmentation (Figure 9) occurs which results significantly in inferior strength characteristics.

Additionally, anomalous chip orientation emanating from manual mat spreading causes further damage associated with shear and compressive stresses set up in particles with large angles of inclination to the horizontal press platens. The outcome of these stresses is the effective shortening of the length of misoriented chips due to breaking and fragmentation, which impair the panel properties.

Effect of Particle Size on the Bending Strength

Figure 4 illustrates the effect of particle size on the bending strength. All of the three isobar graphs show, for a constant temperature (180°C) and press cycle time (5 min), the bending strength rises with increasing particle size. The possible causes for this observation have already been expounded in some detail. Increasing the particle size decreases the interparticle surface area per unit volume, which in turn reduces the number density of defects in the UF polymer film. These defects act as fracture initiation sites. The smaller the number density of such sites in a given panel volume, the higher is the strength.

Effect of Chip Refinement on the Strength of the Monolayer Particleboard

In recognition of the fact that chips produced by the vibrating cup mill both lacked surface smoothness and a substantial fraction of them suffered internal structural damage, attempts were made to improve the quality of chips. Accordingly, a rotary knife chipper was employed to replace the vibrating cup mill. Investigations into the strength of particleboards prepared with the chips produced in the knife chipper showed a phenomenal increase in the strength.

The chips produced using the rotary knife chipper were classified into three different sizes designated as fine, medium, and coarse. Specimens machined from monolayer panels manufactured from these chips and subjected to static three-point bending tests yield excellent results (Figure 5). Thus, with enhanced feed quality it was possible to produce superior panels using a relatively lower pressing temperature (160°C) and a reduced compaction pressure ($2.4\,N/mm^2$) which, in turn, mitigated the risk of thermal degradation of the UF binder and permanent damage to the internal structure of wood, respectively. Chips with visibly smooth and flat surfaces free from cracks and structural defects permitted higher packing efficiency and interparticle contact, which in turn greatly increased the heat transfer rate across panel thickness. It is thus shown that, through improved heat transfer rate, effective polymerization was achieved at a substantially lower temperature within the same press cycle time. Likewise, better interparticle contact results in stronger adhesion.

CONCLUSIONS

1. Date palm branch midribs have been shown to respond favorably to the mechanical, thermal and blending procedures for the manufacture of chipboard panels.
2. The experimental chipboard samples subjected to standard bending tests possessed superior properties and outperformed the control specimens.

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