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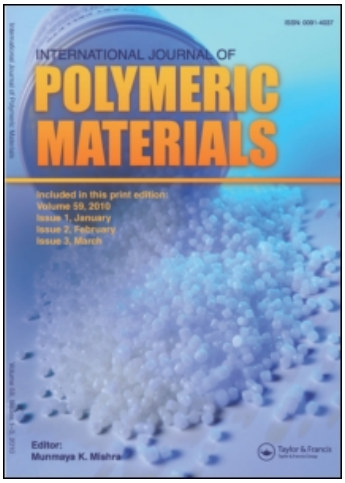

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Physical Properties of Particleboard Panels Manufactured from Phoenix Dactylifera-L (Date Palm) Mid-rib Chips using Ureaformaldehyde Binder

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

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F. I. Iskanderani
King Abdulaziz University, Faculty of Engineering, Department of Chemical and Materials Engineering, Saudi Arabia

Pertinent physical properties of experimental particleboard specimens produced from date palm (Phoenix dactylifera-L) branch mid-ribs chips impregnated with ureaformaldehyde (UF) polymer binder are investigated. The effect of process variables (press temperature, pressure, press cycle time and particle thickness) on thickness swelling, water absorption, equilibrium moisture content (EMC) and panel density are presented graphically and discussed in terms of process variables, internal structure of particles and UF-aqueous environment interactions. Scanning electron microscopy (SEM) data on the internal structure of date palm branch mid-ribs are also reported.

Keywords: date palm branch mid-ribs, natural fiber, particleboard, physical properties, SEM, ureaformaldehyde

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INTRODUCTION

Various physical properties of particleboard are not readily classified as either strength or hygroscopic characteristics but are nevertheless significant for many particleboard applications. Several of these characteristics such as density, vertical density profile across the particleboard thickness and springback exert an important influence on the overall strengths and hygroscopic characteristics of the particleboard. In addition, these properties are also partly determined by processing parameters, binder content and particle geometry.

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Address correspondence to F. I. Iskanderani, King Abdulaziz University, Faculty of Engineering, Department of Chemical and Materials Engineering, P.O. Box 80204, Jeddah - 21589, Saudi Arabia. E-mail: faisalii@kau.edu.sa

The most significant factors controlling the properties of the particleboard are the detailed internal microstructure of the wood material and the processing conditions such as the temperature, pressure and curing time. At a sufficiently high temperature and moisture content, wood becomes plasticized. Pressing under adequate pressure and temperature consolidates the mat to the required thickness and polymerizes the resinous binder network encapsulating individual chips. Thus, interparticle voids in the mat are largely eliminated, most of the water is evaporated and the hardened polymer network ensures retention of the compacted mat upon removal of the pressure. Generally a chipboard with a density lower than that of the employed wood furnish is unacceptably inferior [1].

The density of the raw wood material furnish is the most critical variable that determines the potential of a given species for chipboard production. Research in this realm indicates an improvement in binder efficiency when woods of lower specific gravities are used to manufacture chipboards of constant final specific gravity or when a constant wood specific gravity is used to make chipboard of higher final specific gravities [2]. These findings suggest that it is necessary to consolidate the wood chips to a higher specific gravity than the original wood in order to achieve sufficient interparticle contact and permit the use of a lower amount of adhesive.

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The vertical density gradient in a particleboard markedly influences several strength properties. The presence of the vertical density gradient enhances the bending strength most conspicuously, while the tensile strength perpendicular to the panel surface and interlaminar shear are deleteriously influenced by density distribution. Plath and Schnitzler [3] have shown a high correlation to hold between vertical density gradient and tensile strength perpendicular to the panel surface. Density and strength profiles across the panel thickness bear remarkable similarity in shape.

Chipboards typically comprise more than 90% ligno-cellulosic material on a dry weight basis. Accordingly, the properties of wood furnish exercise a determining influence on both the physical properties and production of the end product.

Several researchers have investigated the potential of incorporating other ligno-cellulosic materials into chipboard. Tests on three-layer redwood particleboards incorporating various amounts of redwood bark indicated that with increasing bark content the internal bond strength and dimensional stability decreases markedly at all resin contents [4]. However, the 24-hour water absorption decreased as bark content increased, indicating a lower hygroscopicity of the bark. Research on the effect of incorporating aspen bark in the furnish on

the physical properties of particleboard concluded that the linear stability deteriorated drastically when the butt log bark was included. On the other hand, several researchers [5–7] have reported acceptable to good properties observed in particleboards prepared with furnishes incorporating some favorable wood species.

Recently, published researches on *Phoenix dactylifera-L* have focused on the utilization of date palm fiber with both thermosets and thermoplastics [8–13]. The present paper reports some of the physical properties of chipboard panels manufactured from date palm branch mid-ribs, and attempts to correlate these properties with process variables and the internal structure of the ligno-cellulosic material.

EXPERIMENTAL METHODS

Determination of Mass Density

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Density and moisture content determinations are required on each bending test specimen. The density is computed from the dimensions and weight of the bending specimen at the time of testing. The average density of the bending specimens is calculated after conditioning. Accordingly, the material for test in the dry state is conditioned to constant weight and moisture content in a conditioning chamber maintained at a relative humidity of 65 ± 1 percent and a temperature of $20 \pm 3^{\circ}C$.

The test piece for density determination is a 50×50 mm square having the thickness of the board to be investigated. Thickness measurements are taken at four different positions on the test piece. Every piece is weighed to an accuracy of ± 0.1 g. Thickness measurements and length measurements are carried out to an accuracy of 0.05 mm and 0.1 mm respectively. The volume of the test piece is calculated to the nearest $0.1\,cm^3$. The mass per unit volume is computed to the nearest $0.01\,g/cm^3$.

Water Absorption, Thickness Swelling and Equilibrium Moisture Content Tests

These tests are undertaken to determine the hygroscopic characteristics of building boards.

The test specimen is a $(25 \pm 0.1) \times (25 \pm 0.1)$ mm size with all four edges smoothly and squarely trimmed. The test specimens are conditioned as nearly as deemed practical to constant weight and moisture content in a conditioning chamber maintained at 65 ± 1 percent

relative humidity and a temperature of $20 \pm 3^{\circ}C$ for a period of 3–7 days (TS 642). The time lapse between the last two weighings must be at least 16 h. The constant weight is assumed to have been attained when the difference between the last two weighings does not exceed 0.1 percent.

After conditioning, the specimen is weighed to an accuracy of not less than ± 0.2 percent. Length and thickness are measured to an accuracy of no less than ± 0.3 percent. The volume of the specimen is computed from these measurements. The thickness is measured to an accuracy of ± 0.3 percent at four points midway along each side (ASTM D1037-78) or at the point of intersection of the diagonals of the square face (TS 180 UDK 675.815).

The specimens are submerged horizontally under 25 mm depth of distilled water maintained at a temperature of $20 \pm 1^{\circ}C$. After 2 h submersion, the specimens are suspended to drain for 10 min, at the end of which time the excess surface water is removed by means of a cloth. Subsequently, the specimen is weighed and its thickness is determined.

The percentage thickness swelling, q is calculated to 0.5 percent approximation using the formula

$$q = [(a - a_o)/a_o] \times 100$$

where

a_o is the thickness of the test piece before submersion, and

a is the swollen thickness after 2 h of submersion.

After submersion, the specimens are dried in an oven at $103 \pm 2^{\circ}C$ to constant weight. The weight is checked every 4 h. Constant weight is taken to have been attained when the weight difference between the last two readings does not exceed 0.1 percent. The dried specimen is cooled in a desiccator and subsequently weighed. The percentage moisture content (based on oven dry weight) M, is calculated from the initial (w_o) and final (w_f) weights after conditioning and after two-hour submersion using the formula

$$M = 100(w_o - w_f)/w_f.$$

Environmental Scanning Electron Microscopy

An XL30 ESEM model environmental scanning electron microscope developed by Philips was employed to study microstructural features in the mid-rib before and after compaction and after tensile tests. The electron micrographs are presented in Figures 1–4.

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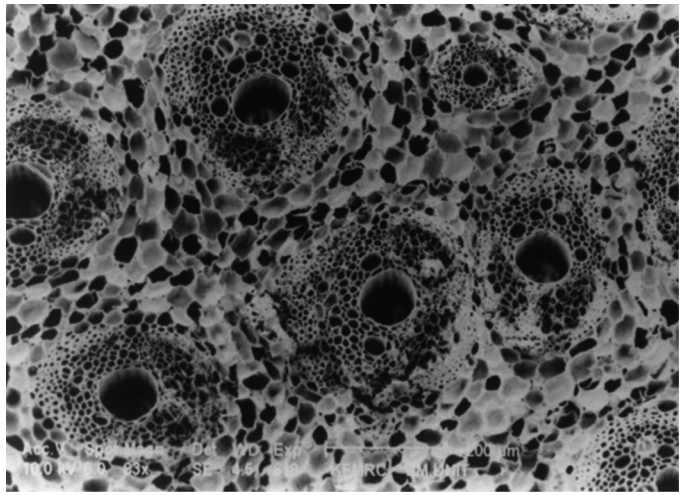

FIGURE 1 SEM micrograph of the cross-section of a date palm branch.

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RESULTS AND DISCUSSION

The Internal Structure of the Date Palm Branch

In general, the mechanical and physical properties of an engineering material are determined by the specific characteristics of its internal

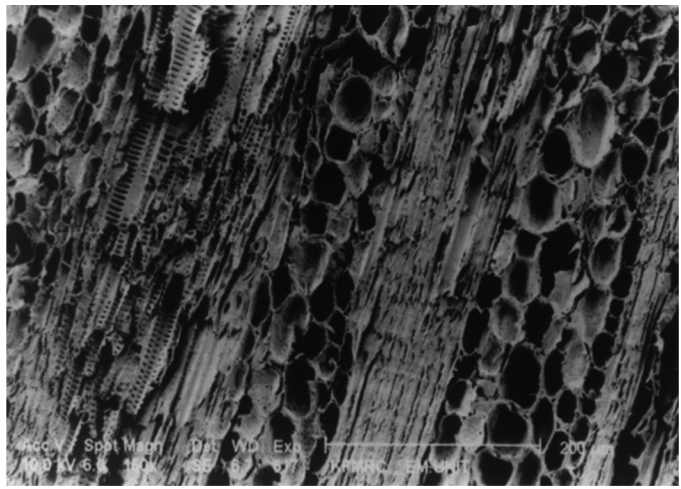

FIGURE 2 A vertical section of a date palm branch showing the xylem tube wall.

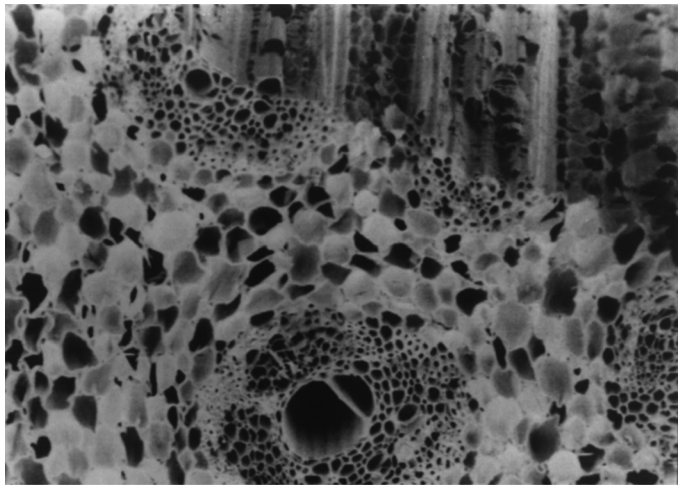

FIGURE 3 SEM micrograph shows the cylindrical form comprising the xylem and phloem surrounding it.

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structure and the specific properties of its microstructural constituents. Each of the various microstructural constituents of the material contributes in a particular manner to the overall behavior.

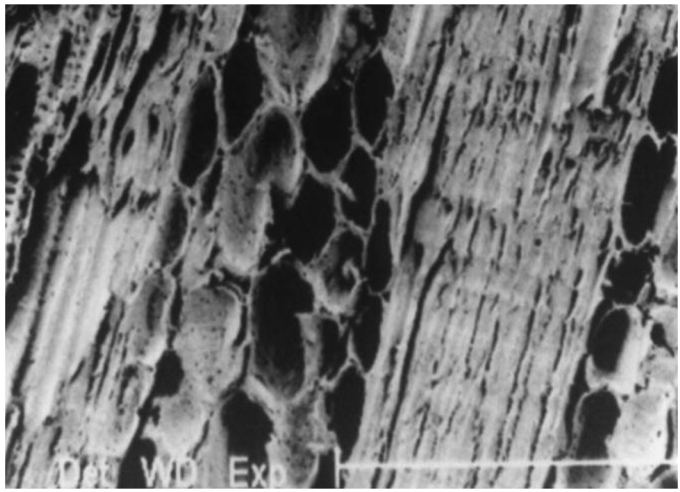

FIGURE 4 An array of parenchymatous cells in a vertical section of a date palm branch.

A close observation of the cross-section of a date palm branch under the scanning electron microscope reveals a number of distinct microstructural features. As shown in Figure 1, the structure of the branch essentially consists of numerous vascular bundles. The centers of these bundles are lined up and a certain order is observed. The vascular bundles are embedded in a matrix of ground tissue consisting of parenchymatous cells. In this particular specimen, a tubular hole about 80 micrometers in diameter rests in the middle of the vascular bundle and extends along the full length of the branch. In plant anatomy jargon, this tube is called meta-xylem [14]. It conveys water and soluble salts from the root of the tree to the leaves. The xylem tube wall is made of a strong and tough ligneous material and possesses a unique structure that resembles that of a ladder. Figure 2 depicts a vertical section of a date palm branch, which reveals this characteristic. A close inspection of the micrograph indicates the ladder-like structural wall of the xylem to be made of numerous tubular elements. The meta-xylem tube may have several smaller tubes around it called proto-xylem. This is engulfed by numerous tubes called phloem. The phloem tubes transport the prepared food from the leaves to the different parts of the plant. The cylindrical form comprising the xylem and phloem surrounding it is enveloped by fibers running parallel to the height of the cylinder, Figure 3.

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The matrix hosting these assemblies of vascular bundles consists of cells much larger than those encountered in phloem. These so-called parenchymatous cells serve to store starch and sugar produced by the plant [15]. Figure 4 illustrates an array of parenchymatous cells in a vertical section of a date palm branch. The parenchymatous cell walls are dotted with numerous micropores, which provide passage for fluid matter across cell walls.

In freshly pruned branches all of the tubular and cellular structural microconstituents are filled with various organic matters. Upon drying the volatile matter in these conduits and cellular vessels evaporate. The empty spaces generated as a result of drying provide suitable paths and recesses for the ingress of ureaformaldehyde liquid emulsion during impregnation.

Physical Properties of Monolayer Chipboard

Density

Increasing the temperature while maintaining a constant compaction pressure of $3.25\,N/mm^2$ increases the panel density (Figure 5).

As pointed out in the preceding sections, heating wood in the presence of moisture causes it to plasticize. Thus, chips containing

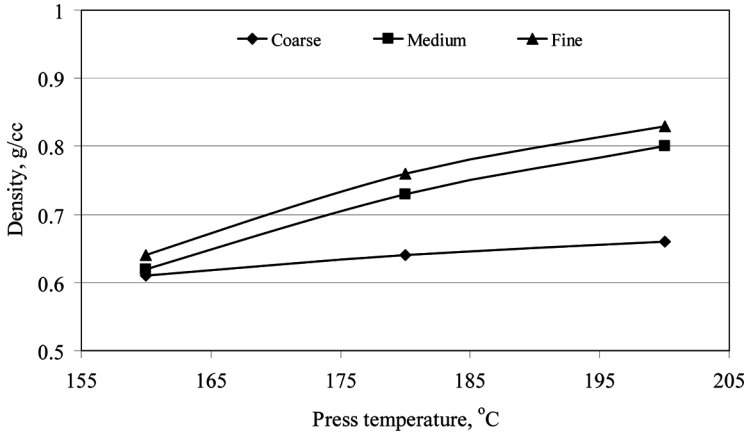

FIGURE 5 Density vs. press temperature. $P = 3.25\,N/mm^2$, $t = 5\,min$.

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moisture can undergo plastic deformation so that under a suitable compaction pressure interparticle porosity and surface irregularities become largely eliminated. This leads to densification.

The fact that the effect appears to be most pronounced in the specimens prepared from small-size chips is attributable to the high degree of plasticization and concomitant compressibility of chips. The smaller the size of chips the higher is the packing factor (volume of particles per volume of finished panel).

A second contribution to the density arises from the UF polymer. UF having a higher density than that of wood, the presence of 8–10% UF polymer in the composite panel would make a small but measurable difference in the density. The higher the percentage of UF the higher is the density of the particleboard. In industrial practice the UF content of the two surface layers which are composed of fine chips is around 12% compared to the 8% UF incorporated into the core layer which is made of coarse particles. Hence, the density of the particleboard would increase with increasing fraction of the fine chips in the finished product.

Increasing the pressure on a particulate mass of substance would normally result in consolidation and increased density. In particleboard manufacturing practice the density is usually predetermined for a given board thickness, and the amount of chips required is calculated on this basis. Then a quantity of chips impregnated with UF resin and equal to the calculated amount is pressed at a constant temperature under a progressively increasing pressure until the press opening between the upper and lower hot platens reaches the required

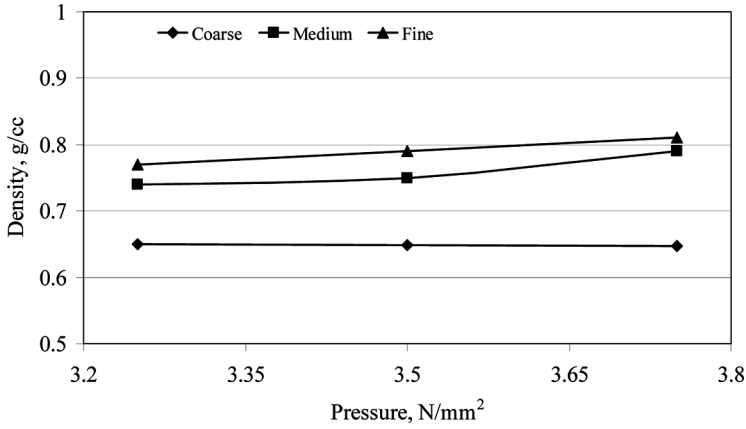

FIGURE 6 Density vs. compaction pressure. T = 180°C, t = 5 min.

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board thickness. Evidently, this necessitates a range of compaction pressures, with the optimum being that value of pressure which will consolidate the mat to the required thickness without causing damage to the internal structure in the form of cell wall disruption, or fiber rupture within each particle, or particle fragmentation. Within the limits set above, the contribution to the board density from increased pressure for a given particle thickness is meager. For example, increasing the compaction pressure on a mat from 3.25 N/mm^2 to 3.5 N/mm^2 and 3.75 N/mm^2 increased the density by 0.51% and 2.2% respectively (Figure 6). Pressure effects on the density of boards produced from medium-size and coarse chips are small.

Thickness Swelling

Ingress of water molecules through the surface of particleboard specimens and permeation into the cellular structure of wood is assisted by the porous nature of both the particleboard texture and the lignocellulosic substance of wood. Water molecules enter through interparticle pores, cell membranes, wood/UF polymer interfaces and through cracks and orifices in the polymer film binding the wood particles together. Thus, water absorption, facilitated by capillary action and molecular diffusion, causes swelling which is measured as percentage increase in thickness as a result of immersing test pieces in water under the standard set of conditions specified earlier.

The effect of temperature on swelling is manifested very clearly in Figure 7. The increase in swelling with increasing press temperature, especially in the 180–200°C range, is conspicuous. An increment of

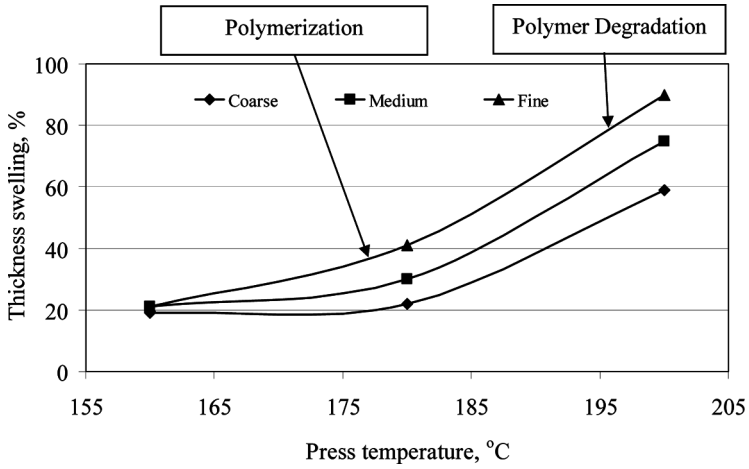

FIGURE 7 Percentage thickness swelling vs. press temperature. P = 3.25 N/mm^2, t = 5 min.

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20°C, from 160 to 180°C, doubles the percentage thickness swelling. The highest swelling occurs in panels pressed at 200°C. At this temperature, substantial thermal degradation of the UF polymer appears to take place within the press cycle time. Cracks and crazes, which develop in the UF polymer film, provide, in addition to the existing pores and interstices, passages for water permeation. As expected, panels prepared with the particles of the smallest size manifest the highest percentage of swelling. This is attributed to increased total surface area of wood particles per unit volume.

Increasing the compaction pressure causes a significant reduction in thickness swelling. This effect is vividly displayed in Figure 8. While panels prepared from fine, medium-size and coarse particles exhibit thickness swelling values of 42, 30 and 23% respectively, increasing the compaction pressure to 3.75 N/mm^2 diminishes the thickness swelling of the same panels to remarkably low levels of 14, 13 and 11%, respectively. The positive effect of pressure increase arises from the consideration that higher pressures lead to reduction of macroscopic porosity, which provides primarily the ports for water entry into the interior across the section of the specimens.

The influence of varying the press cycle time at 180°C and a compaction of 3.25 N/mm^2 is shown in Figure 9. The fall in the thickness swelling with increasing pressing time could be anticipated when extended heating would lead to efficient formation of polymer network reducing porosity. Prolonging the press cycle time to 9 min causes a

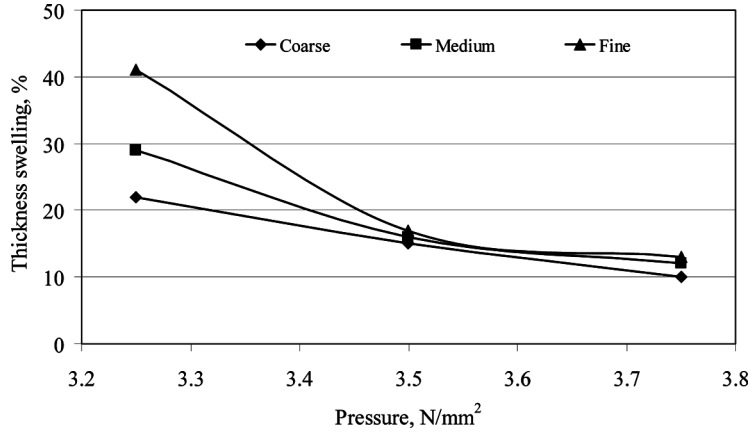

FIGURE 8 Percentage thickness swelling vs. compaction pressure. T = 180°C, t = 5 min.

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marked rise in thickness swelling. This rise is thought to be associated with polymer degradation which causes the UF polymer film to rupture and disintegrate as a result of residual stress build up and thermo-oxidative deterioration in the polymer film.

Particle size appears to be one of the paramount factors governing thickness swelling. Figure 10 shows the sensitivity of thickness

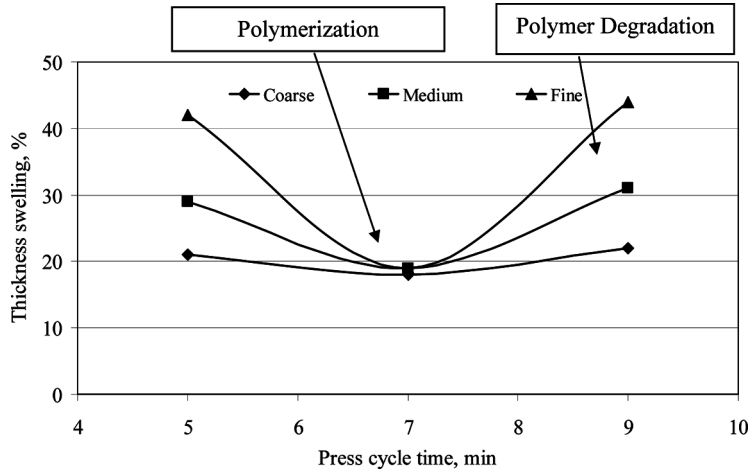

FIGURE 9 Percentage thickness swelling vs. press cycle time. T = 180°C, P = 3.25 N/mm^2.

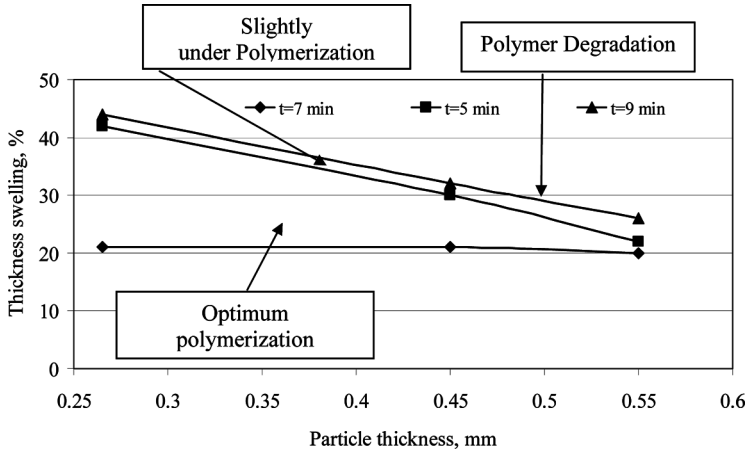

FIGURE 10 Percentage panel thickness swelling vs. particle thickness. $T = 180^{\circ}C$, $P = 3.25\,N/mm^2$.

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swelling to particle size for a pressing temperature of 180°C and a compaction pressure of $3.25\,N/mm^2$. Isochronal plots of thickness swelling vs. particle size indicate a consistent decrease with increasing size. As already discussed, increasing the particle size decreases interparticle porosity, thus mitigating water entry.

Water Absorption

Press temperature plays a major role in determining the extent of water absorption (Figure 11). Particleboards pressed at 160°C for 5 min under a pressure of $3.25\,N/mm^2$ exhibit 96 to 101% water absorption for the coarse and medium chip panels respectively. At 180°C these figures experience a small fall to 92.6 and 94.3% respectively. At 200°C water absorption of fine, coarse and medium-size chips registers significant increase. The generally lower absorption exhibited at 180°C may be ascribed to the fact that full polymerization occurring at this temperature minimizes water ingress into the specimens. At 200°C polymer degradation is thought to be responsible for increased water absorption through damaged sites in the polymer film.

Initially, increasing the compaction pressure (from $3.25\,N/mm^2$ to $3.5\,N/mm^2$) has a beneficial effect on reducing water absorption. This is expected, since efficient compaction would reduce interparticle porosity resulting in decreased water entry into the specimens. However, further increase of pressure promotes absorption due to

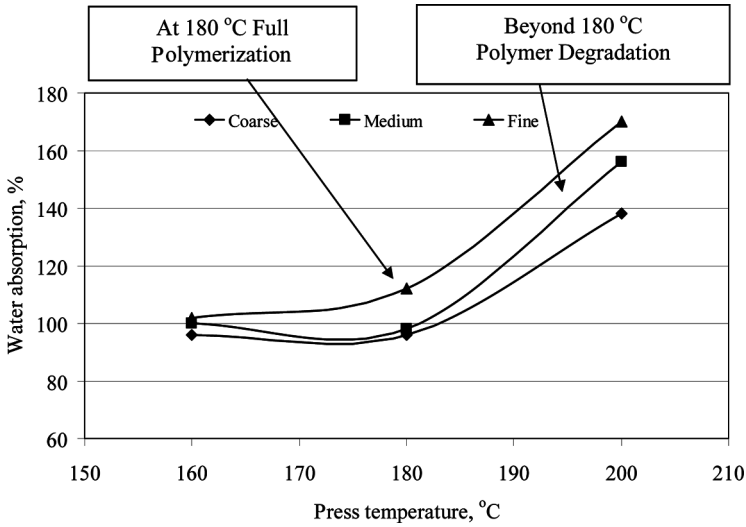

FIGURE 11 Percentage water absorption vs. pressing temperature. P = 3.25 N/mm^2, t = 5 min.

increased permanent damage induced in individual particles through which water absorption is facilitated (Figure 12).

Press cycle time influences water absorption via compaction and UF polymerization effects. Initially, at a constant temperature of 180°C,

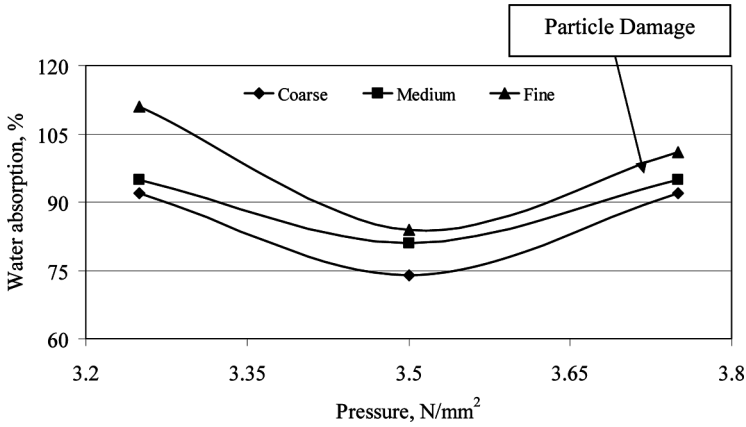

FIGURE 12 Percentage water absorption vs. compaction pressure. T = 180°C, t = 5 min.

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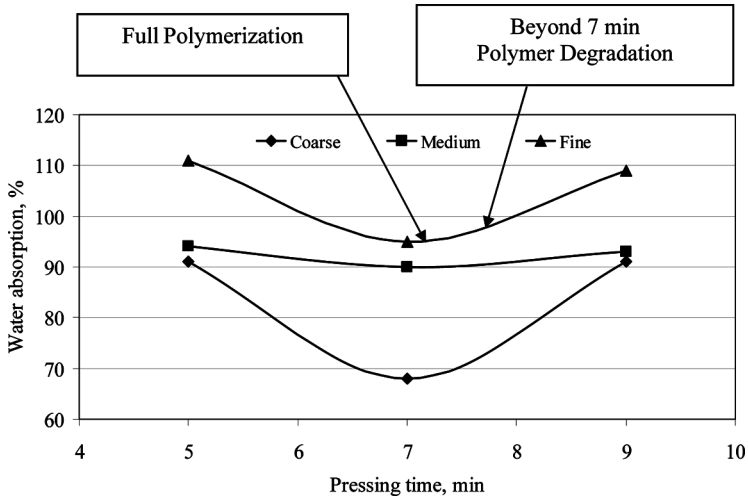

FIGURE 13 Percentage water absorption vs. pressing time. $T = 180°C$, $P = 3.25\,N/mm^2$.

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increasing the pressing time from 5 min to 7 min decreases absorption. This is interpreted in terms of reduced porosity resulting from efficient compaction accruing from effective plasticization of wood chips and full polymerization. Increasing press cycle time to 9 min, as expected, causes marked UF degradation as a result of which cracks and crazes generated in the UF film readily admit water into the composite board. Figure 13 indicates this deleterious effect to be most pronounced in panels composed of fine chips. This is associated unambiguously with the high fraction of interparticle contact area where damages are most likely to exist. Also, as the surface area of particles per unit volume is increased, the fraction of particles starved with respect to UF is correspondingly increased. Chips fully or partially unimpregnated with the adhesive readily absorb water into the composite panel. The performance of panels produced with relatively coarse chips is much more favorable than that of boards made from fine chips. The minimum water absorption of coarse chips (67%) compares satisfactorily with that of commercial three-layer particleboards of the same thickness.

Equilibrium Moisture Content

Variation of the equilibrium moisture content (EMC) as a function of press temperature for press cycle time of 5 min is presented in Figure 14. The minimum EMC occurs at 180°C, which is taken to be the optimum temperature for UF polymerization under the conditions

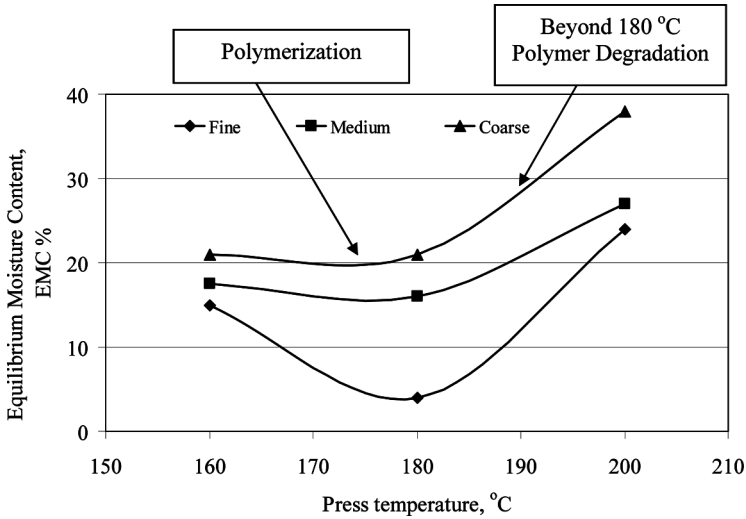

FIGURE 14 Percentage EMC vs. press temperature. $P = 3.25\,N/mm^2$, $t = 5\,min$.

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stated. Elevating the temperature to 200°C causes polymer degradation. During exposure to aqueous environment, interaction of water with the degradation by-products gives rise to increased water retention (i.e., EMC) of the composite board. EMC of boards made from fine particles seem to be relatively low. This may be attributed to the larger proportion of available diffusion paths for the polycondensation reaction water to be lost to the atmosphere. Due to the relatively smaller interparticle area resulting from their size, large particles provide limited effective diffusion paths for the by-product water molecules to escape into the atmosphere. Consequently, a larger proportion of residual moisture remains within the particleboard.

Increasing the compaction pressure increases the EMC in general (Figure 15). Permanently damaged sites, emanating from high compaction pressure, in cell walls are likely to accommodate additional water molecules such that the residual water content of the composite is enhanced.

Prolonged press cycle time too, raises the EMC (Figure 16). Increased amount of degradation products resulting from extended press cycle time being hydrolyzed with water may be an additional factor for increased water retention in the composite.

High moisture content in the chips during pressing and high EMC in the finished panel would lower the strength by hydrolyzing the

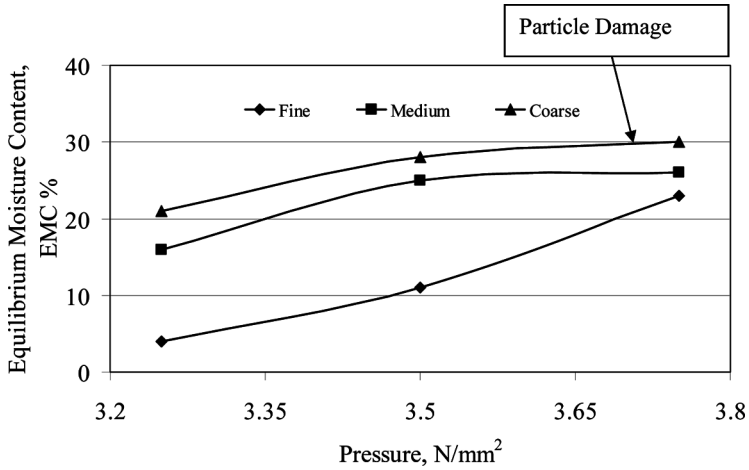

FIGURE 15 Percentage EMC vs. compaction pressure. T = 180°C, t = 5 min.

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polymer. However, about 6% moisture content in wood, during pressing, is beneficial for it improves heat transfer and aids polymerization in the mat core so that adequate strength develops. When the hot platens contact the mat, moisture in the surface evaporates and diffuses to the core of the mat. This, the heat transfer to the core is accelerated.

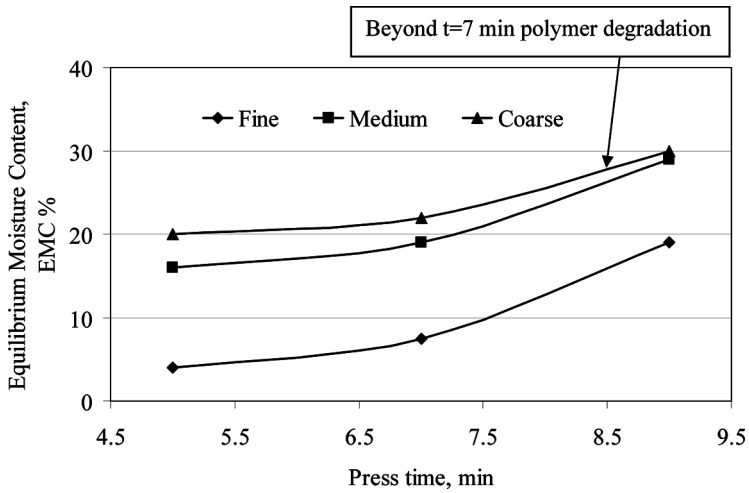

FIGURE 16 Percentage EMC vs press cycle time. T = 180°C, P = 3.25 N/mm^2.

This causes the adhesive in the core layer to polymerize more quickly than if the heat transfer occurred by conduction only through the wooden material and air spaces. However, excessive moisture imposes the requirement of excessively long press cycles to allow final removal of moisture through the edges in order to prevent delamination of the panel upon pressure release. Unduly long press cycles can lower the strength further due to polymer degradation.

CONCLUSIONS

1. The present work has shown conclusively that monolayer chipboard panels of excellent physical properties can be manufactured from date palm branch mid-ribs.
2. The properties of the chipboard can be engineered as required by carefully controlling the processing parameters.

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