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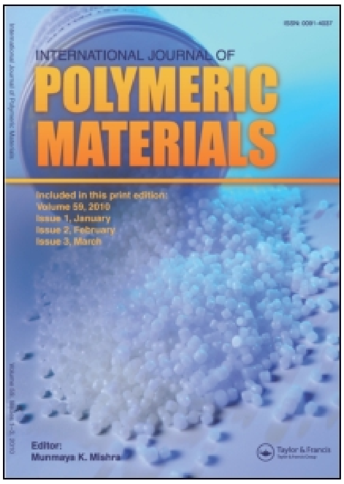

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Tensile Strength of Monolayer Particleboards Produced from Date Palm Midrib Chips Bonded with Urea Formaldehyde

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Systematic laboratory-scale experiments were carried out to study the technical feasibility of producing monolayer particleboards using midribs of Saudi Arabian date palm tree branches (Phoenix dactylifera-L) *as raw material. Chips produced from midrib and impregnated with a predetermined proportion of urea formaldyhde binder were hot-pressed under constant pressure (3.25 N/mm^2), temperature (180°C) and press cycle times of 5, 7, and 9 min. Experimental particleboard specimens subjected to mechanical tests exhibited satisfactory tensile strength levels. Strength was enhanced phenomenally by improving the particle quality and optimizing experimental variables. Electron microscopy and EDX data on the internal structure of the midribs are also reported.*

Keywords: date palm, midribs, particleboard, SEM, tensile strength, urea formaldehyde

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INTRODUCTION

According to a survey by Sutton [1], the annual wood consumption worldwide, on a per capita basis, is equivalent to 0.67 m^3. Considering the fact that the rate of consumption has been maintained for the last four decades [2], and that the estimated world population will double to reach 11 billion in the next 50 years, the present world demand for wood and wood products is expected to rise to 7 billion cubic meters by the year 2050. This prospect is significant enough to cause serious concern with far-reaching implications, particularly pertinent to global

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environmental issues. This situation has ushered in the concept of sustainable development, which is defined as the ability of a society or ecosystem to continue functioning into the indefinite future without being forced into decline through the exhaustion or overloading of key resources upon which that system depends [3].

Although the composite panel industry is experiencing massive growth in the tropical and subtropical geographic locations possessing vast forest wealth, many developing countries lack adequate forest reserves to meet the requirements for wood-based panels. Nevertheless, in many of these countries various lignocellulosic raw materials in the form of agricultural residues from annual crops are abundantly available. Certain of these residues, previously disposed of as waste, are currently being utilized profitably to manufacture chipboard, fiberboard and inorganic-bonded panels. A study on the worldwide utilization of agricultural fibers reports a total of 1039 citations selected from innumerable examples [4].

Bagasse, which is the residue fiber from sugar cane processing, appears to be the most preferred in the Americas [5]. A number of compositions including bamboo residues and red cypress shavings [6], bamboo and wood waste [7], wood and straw [8], sunflower stalk and hull [9], hardwood and coconut fiber [10,11], coconut coir and banana stalk, pineapple fiber and wood wastes [12] have been utilized to manufacture various composite panels. Rice straw boards with excellent bending strength and minimum water absorption have been reported [13]. Lignocellulosic materials from annual crops in the Middle East include cotton stalks, kenaf and hemp. One investigation has shown that hardboards produced from these materials are generally better than those made of rice straw [14]. Particleboards manufactured from mixtures of reed or cattail with wood, and conforming to specifications have been cited [15]. Cereal straw is the second most-used agricultural fiber, next to bagasse, in reconstituted panel production. The high silica content in cereal straws renders them fire-resistant and commendable thermal insulators. Straw panels 5 to 15 cm in thickness are currently being produced [16]. Their low density makes them resilient and resistant to earthquake. Up to 10% straw has been incorporated in the core layer of particleboard with no difficulties being encountered. Kenaf, which resembles hemp or jute in certain respects, has great potential for utilization in the manufacture of panels. The fibers in this plant constitute up to 20–25% of the dry weight [17]. Particleboards prepared with industrial tea wastes using 8% urea formaldehyde adhesive for the core and 10% adhesive for the surface layers have been found to possess adequate mechanical and physical properties to justify its use in furniture and internal building applications [18].

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Very recently, the prospect of utilizing wood sawdust waste in combination with limestone powder waste to produce a low-cost lightweight composite as building materials has been investigated by Turgut and Algin [19] and Turgut [20]. The authors conclude that this product possesses adequate mechanical and physical properties and provides an economical alternative to concrete blocks, ceiling panels and sound barrier panels. Cotton wastes and limestone powder waste composite produced by Algin and Turgut [21] are reported to satisfy the relevant international standards and offer a low-cost solution for walls, ceiling panels, and sound barrier panels.

Particleboard panels manufactured from Osage orange (*Maclure pomifera*) and red cedar (*Juniperus virginiuna L*) and tested in accordance with ASTM D-37 procedures have been shown to exhibit adequate mechanical strength and physical stability [22].

In the Kingdom of Saudi Arabia, huge quantities of date palm biomass results from seasonal pruning. Conservative estimates in the 1980s place the mass of date palm pruning residue at 500 thousand tons per annum [23,24]. A precursory study [25] on the possibility of producing chipboard from pruned palm fronds proved to be partially affirmative but inconclusive. Recently, published researches on *Phoenix dactylifera-L* have focused on the utilization of date palm fiber with both thermosets and thermoplastics [26–32]. The research undertaken by the author of the present paper thus investigates systematically the suitability of date palm midribs for particleboard manufacture and the board properties.

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EXPERIMENTAL METHODS AND MATERIALS

Preparation of Chips from Date Palm Midribs

Several tons of freshly pruned date palm branches from the Madinah al-Munawwara 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 (UF) using a rotary blender designed and manufactured by the Department of Chemical and Materials Engineering at King Abdulaziz University.

Hot Compaction

Mats of impregnated chips were formed in situ on the press platen. An automatic Bürkle 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, 150 and 160°C), 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.

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Tensile Strength Perpendicular to Parallel Faces

Tensile test specimens of square shape ($50\,mm \times 50\,mm \times 18\,mm$) were cut from sanded chipboard samples and stressed in uniaxial tension. The tensile force was applied continuously throughout the test at a uniform rate of motion (0.08 cm/cm of specimen thickness per min) of crosshead of the testing machine. The time lapse between application of the force and failure of the specimen was less than 30 sec. The tensile strength perpendicular to the surface, σ_P, was calculated from the formula:

$$\sigma_P = F/a^2$$

where F is the applied breaking tensile force and a is the side of the square specimen.

Environmental Scanning Electron Microscopy and EDX Analysis

An XL30 ESEM model environmental scanning electron microscope developed by Philips was employed to study microstructural features in the midrib before and after compaction and after tensile tests. The electron micrographs are presented in Figures 1–3.

Microanalysis was performed using the integrated EDAX analyzer (DX4i) and control software. The detector is a Si (Li)-type, equipped with a Super-UTW (sapphire series). The EDX program is operated

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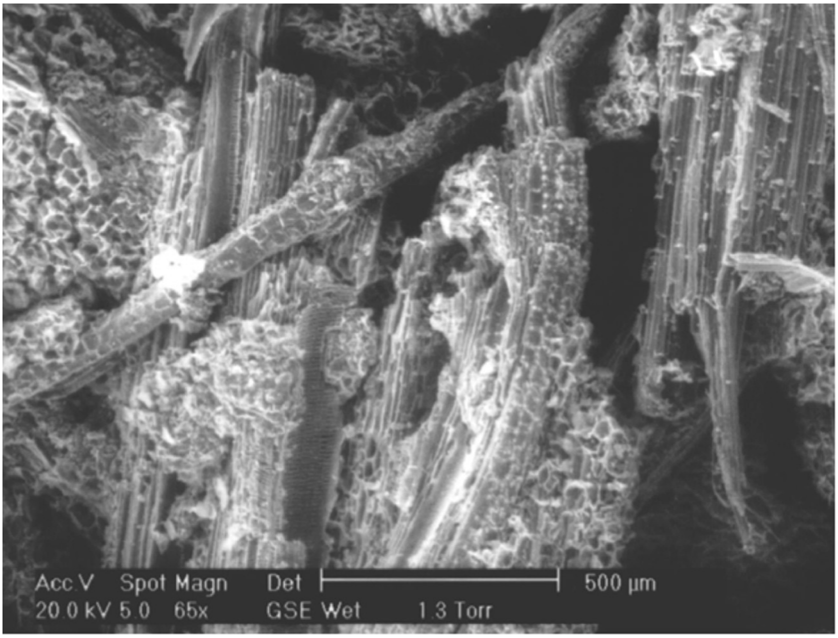

FIGURE 1 A typical fracture surface appearance of a tensile test specimen.

within a single window which contains all functionality, including microscope panel. Control of the basic beam and stage functions required for EDX analysis is therefore available directly from within the EDX program. The EDX program can be used qualitatively, semi-quantitatively and quantitatively. In the semi-quantitative mode the analytical results are calculated by use of a SEC table (standard-less element coefficient). A typical microanalysis of the lingocellulosic midrib material is presented in Figure 4.

RESULTS AND DISCUSSION

Effect of Temperature on Strength

It is generally observed that for a given particle thickness and fixed pressure and press cycle time, the tensile strength increases with increasing press temperature, reaches a maximum and then begins to decrease. It is interesting to note that a unique temperature for the maximum strength to develop exists around 180°C (Figure 5). The highest strength level attained at this temperature is obtained from monolayer chipboards prepared with

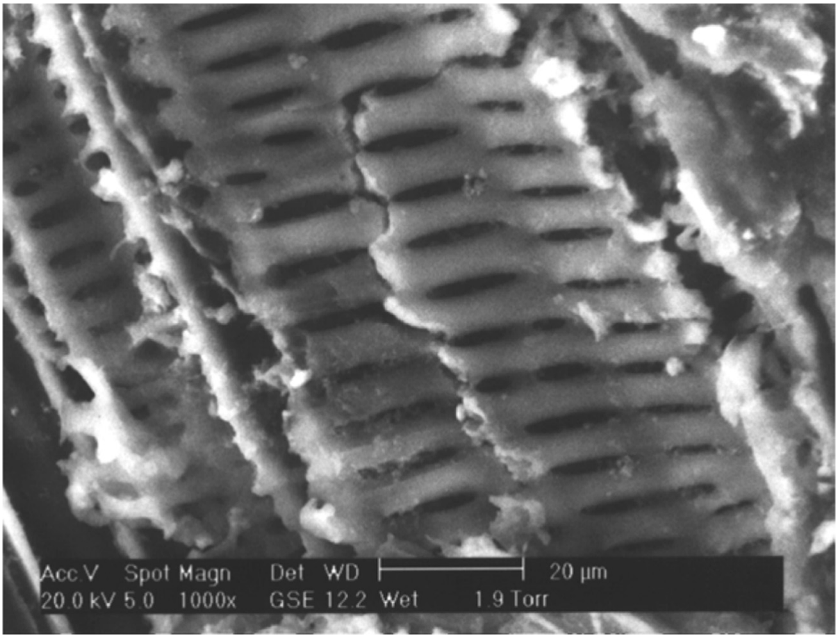

FIGURE 2 Rupture of a "raft-like" microstructural element in unglued chip subjected to an excessively high compressive pressure.

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coarse chips compacted to 19 mm thickness. The maximum strength of $0.23\,N/mm^2$ thus achieved compares very closely to the $0.26\,N/mm^2$ strength of the commercial reference three-layer sample of same thickness.

One factor of great significance contributing to the strength is thought to arise from the surface roughness of the chip caused by the specific method of chip production. Low interparticle contact area associated with chips of high surface roughness produced by the "vibrating cup mill" method evidently results in inhomogeneous distribution of the urea formaldehyde adhesive over the surface of adjacent particles and limits their intimate contact. This gives rise to inferior bonding.

Furthermore, it is recognized that the above method of producing chips has an even greater disadvantage, as chips are split from the larger lumps under impact loading and rapidly undergo a series of compressive strokes between the vibrating steel rings throughout the duration of the chipping operation. This is believed to cause considerable damage in the internal structure of the material. Consequently, collapsed cells and disrupted fibers weaken the chips and the boards made from such a product. Thus, there appears to be great

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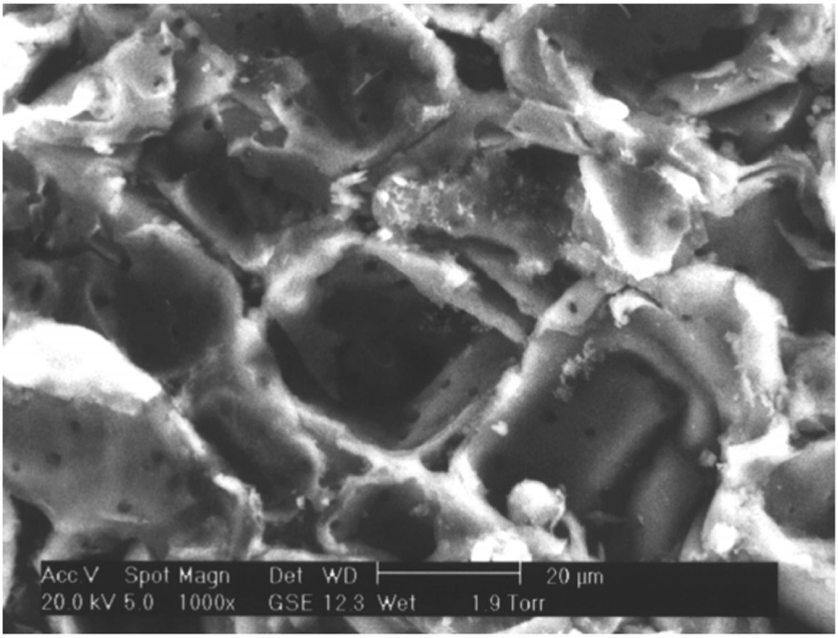

FIGURE 3 Disturbed cells in unglued chip subjected to an excessively high compressive pressure.

potential for further enhancements in the mechanical performance of boards in employing knive-chippers whereby damage-free chips with fiber integrity and high strength are produced.

The importance of pressing temperature cannot be overemphasized. As the polymerization of UF adhesive is sensitively dependent upon the processing temperature, the process temperature plays a critical part in developing strength in the finished board. During hot compaction, moist wood chips impregnated with the UF resin become plasticized and undergo change of shape and volume to produce a highly densified panel. Simultaneously, UF polymerization proceeds to generate intermolecular bonds, which result in the formation of a highly branched, crosslinked hardened three-dimensional polymer network. Thus, individual wood particles rigidly encapsulated within this thermoset polymer network and bonded together to adjacent particles give rise to a hard, strong and dimensionally stable panel.

At relatively low press temperatures (e.g.,160°C or lower) for short press cycle times limited to 5 min. UF polymerization appears to be incomplete. Thus the full strengthening potential is not completely exploited. On the other hand, at higher temperatures

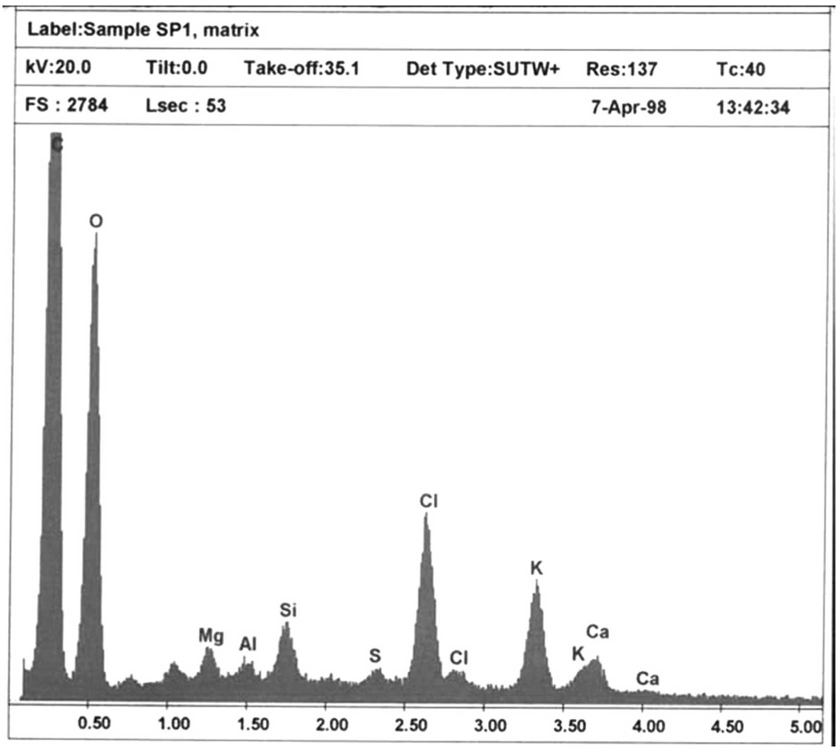

FIGURE 4 A typical microanalysis of the lingocellulosic midrib material.

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(e.g., 200°C), thermal degradation of the polymer sets in and supersedes polymerization. Consequential deterioration of strength occurs due to bond scission, resulting from thermo-oxidative degradation of the adhesive.

Effect of Press Cycle Time on Strength

The influence of press cycle time at 180°C and a compaction pressure of 3.25 N/mm^2 on the strength is illustrated in Figure 6. The highest strength values are attained with a press cycle time of 5 min. Extending the time beyond 5 min brings about a progressive decrease in the strength level. This is interpreted in terms of the deleterious effect of prolonged heating at 180°C on the stability of UF polymer. Based on experimental observations, it is assumed that polymerization is complete after 5 min at 180°C. Accordingly, extending heating under the stated conditions would result in the deterioration of mechanical

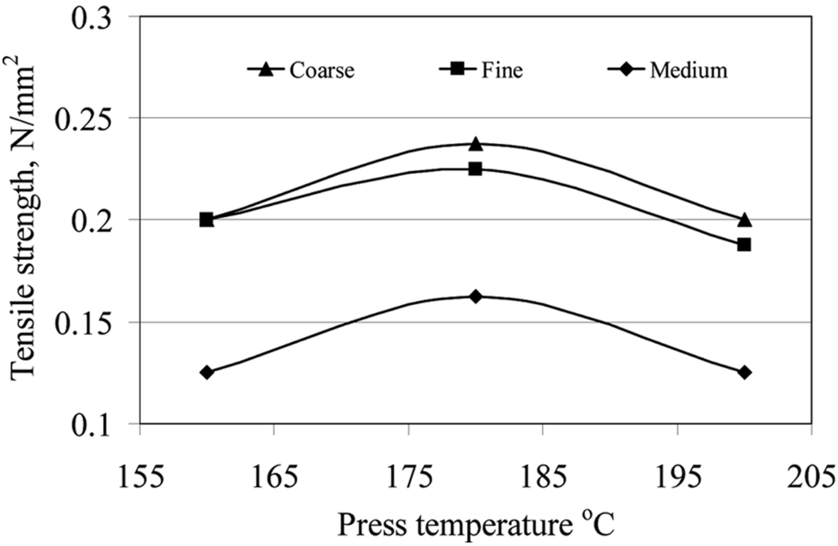

FIGURE 5 Tensile strength vs. press temperature. Compaction pressure $P = 3.25\,N/mm^2$, press cycle time $t = 5\,min$.

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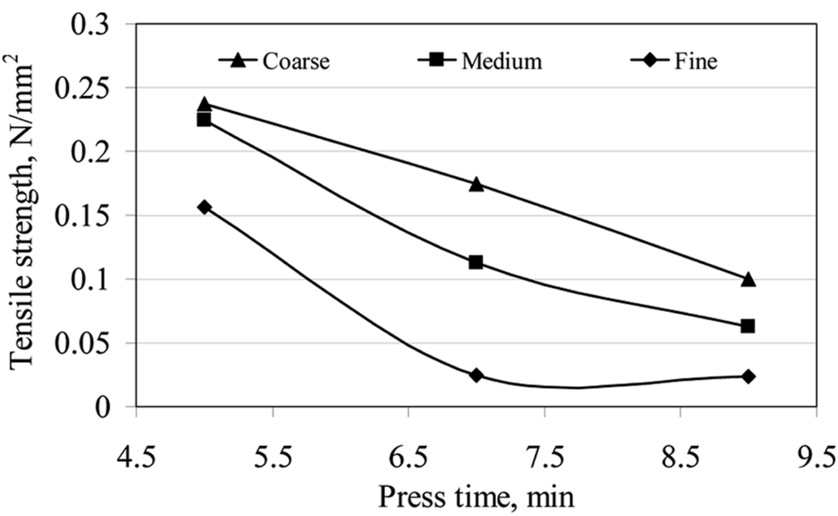

FIGURE 6 Tensile strength vs. press cycle time. Press temperature $T = 180^{\circ}C$, $P = 3.25\,N/mm^2$.

strength due to bond scission prompted by thermal as well as thermo-oxidative degradation of the UF polymer.

Effect of Pressure on Strength

The effect of compaction pressure on the strength is shown in Figure 7. At a relatively low compaction pressure of 3.25 N/mm^2, maximum strength is observed. Increasing the pressure above this value brings about a steep decline in strength. This may be explained in terms of damage, which is likely to occur in the internal structure of individual wood particles. In the industrial practice of chipboard production mat spreading is automated such that chips are spread with a sufficiently small angle between the longitudinal axis of the chips and the horizontal conveyor surface. When the mat is pressed, wood particles should be reoriented without any constraint until their respective axes become parallel to the horizontal, i.e., parallel to the flat face of the board. However, when the said angle is large, the shear and compressive stresses set up in the chips during pressing damage the particles by causing internal cell wall collapse, fiber disruption and breaking of chips. This can cause considerable reduction in the strength. In the present research spreading was invariably carried out manually such that irrespective of all the care exercised, this negative factor could not be completely eliminated.

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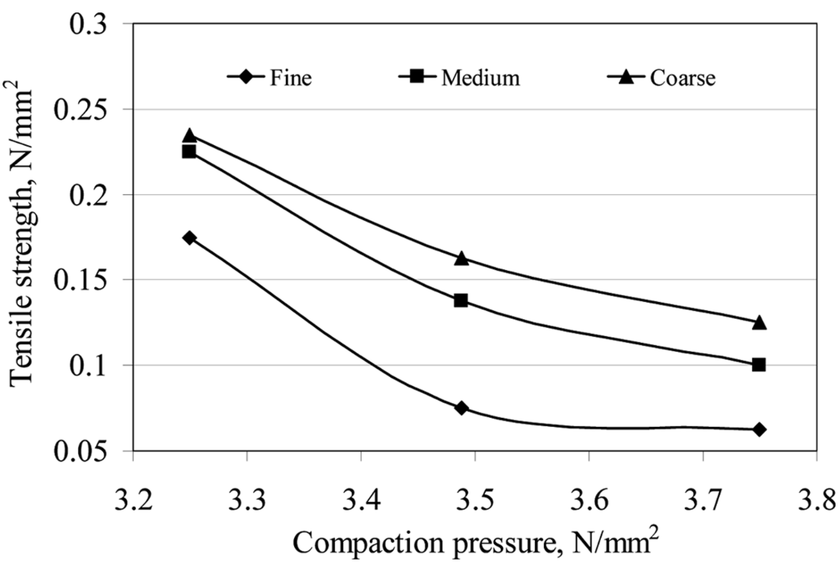

FIGURE 7 Tensile strength vs. compaction pressure T = 180°C, t = 5 min.

Additionally, increasing the applied pressure also increased the extent of the damage. Excessively high pressure causes splitting and fragmentation of individual chips as well as wall collapse and rupture. This would lead to the creation of a fresh particle surface devoid of any UF adhesive and consequently lowering the strength. Figure 1 illustrates a typical fracture surface after a tensile test, as observed through a Philips XLSEM environmental scanning electron microscope. Chip splitting and some fragmentation are evident. Figure 2 indicates clearly the fracture of a "raft-like" structural element caused by excessively high compressive loading of unglued chips in loose cold mats. Figure 3 exhibits the collapse of cellular structure in certain chips.

A pressure of $3\,N/mm^2$ and below has been tried with no positive results. Pressure lower than $3.25\,N/mm^2$ applied to several mats using chips from the vibrating cup mill results in poor compaction and low strength. This is ascribed to the highly irregular shape, non-uniform thickness and very rough surfaces of individual chips. All these factor add up to reduce effective interparticle contact. Under such conditions adequate strength cannot develop.

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Effect of Particle Size on Strength

Figure 8 depicts the variation of the strength with particle thickness, for various compaction pressures, at constant press temperature (180°C)

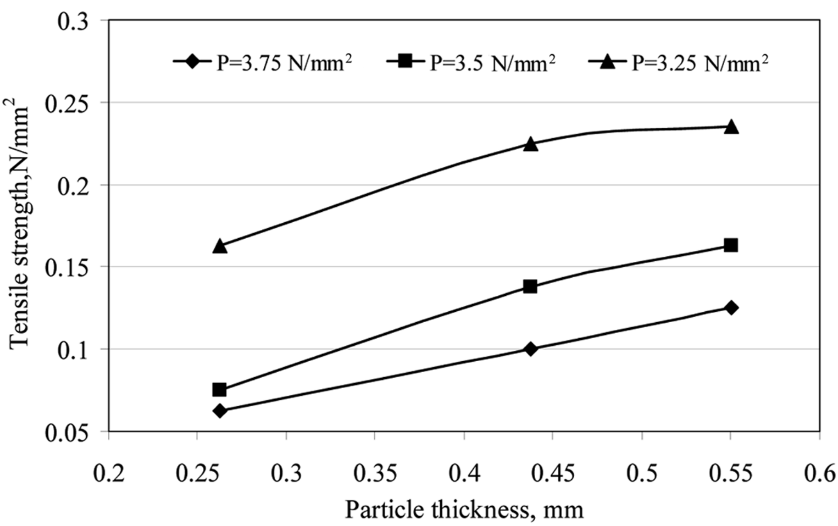

FIGURE 8 Tensile strength vs. particle thickness. T = 180°C, t = 5 min.

and constant press time (5 min). For all levels of pressure applied, the strength is observed to register continuous rise with increasing wood particle dimension (thickness and length). For instance, under the stated process variables, at compaction pressure of 3.25 N/mm^2 the strength increases from about 0.16 N/mm^2 for the fine chips (0.27 mm thick and 17 mm long), to 0.22 N/mm^2 for the medium size (0.445 mm thick and 18.5 mm long), and to 0.23 N/mm^2 for the coarse chips (0.551 mm thick and 21.5 mm long), representing an increase of 39.3 present and 43.2 present, respectively. Although, for the reasons already stated in the previous section, considerably lower strength levels are obtained with increased compaction pressure, the general trend of increasing strength with increasing particle size is maintained.

A close inspection of the fracture surface reveals the fracture to have occurred predominately by the debonding of particles along the interparticle surface. In other words, fracture initiation sites seem to be prevalent in the UF polymer film that binds adjacent particles together. Evidently, as the surface area of the film (i.e., the surface area of the chips) increases, the probability of having crack initiation sites in the polymer film greatly increases. Since the total interparticle contact area decreases with increasing particle size, it follows that the number of crack initiation sites decreases with increasing chip dimension.

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Strength of Monolayer Particleboards Manufactured from Rotary-Knife Chip

Figure 9 illustrates the variation of the tensile strength with particle size. The superior strength accomplished by improved quality chips is evidently clear. These results greatly exceed the corresponding values obtained from panels manufactured using the vibrating cup mill chips and compare very favorably with the minimum acceptable strength levels for corresponding panel thickness specified by international standards. The seeming disparity between the strength value corresponding to the 20 mm and 6 mm thick panel is thought to result from the difference in the rates of heat transfer from the parallel face towards the center of the mat during pressing.

The rate of heat transfer, across the thickness, to the center plane of the thicker (20 mm) specimens is predictably slower than that for the thinner (6 mm) specimens. Hence, due to the greater time lag between the attainment of the press temperature on the surface and in the center of thicker specimens, the degree of polymerization in the thicker specimens is lower than that for the thin samples. Thus, under-polymerization in the thicker panel is expected to give rise to relatively lower strength.

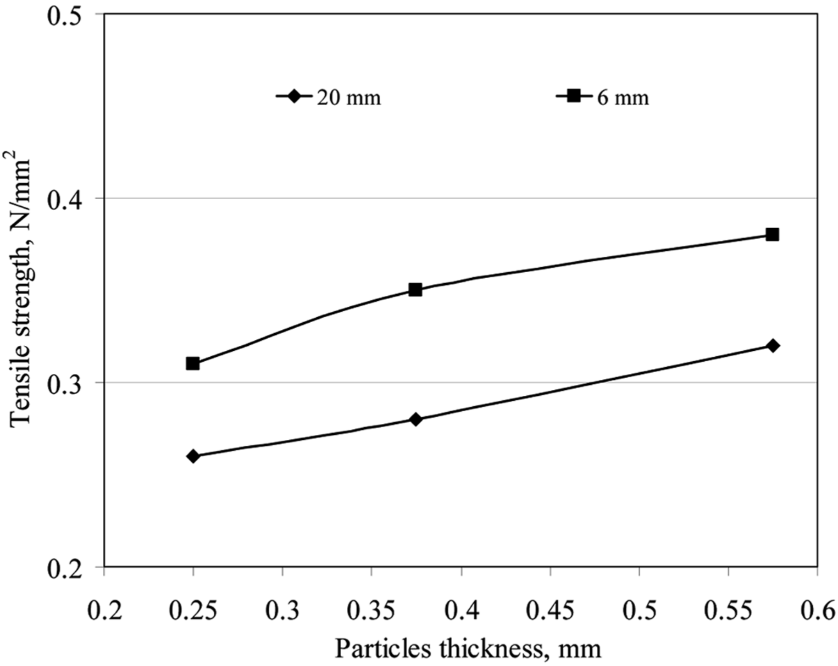

FIGURE 9 Tensile strength perpendicular to parallel faces vs. particle size for monolayer panels produced from rotary knife-chips.

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The apparent difference observed between the strength of panels produced from chips of different size is accounted for by the fact that, while the percentage of the UF binder in all cases is fixed (10%), the amount of binder per unit area of particle surface is different for different particle size. As the total surface area of particles in a given mat increases with decreasing particle size, so does the amount of UF binder per unit area. This would certainly result in a comparatively weaker internal bond.

CONCLUSIONS

Extensive research carried out on date palm biomass from various regions of Saudi Arabia has shown conclusively that monolayer particleboards of excellent tensile strength and aesthetic appearance can be produced from date palm midribs by following conventional procedures employed in manufacturing particleboards of commercial grade.

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