DIMENSIONAL STABILITY, DECAY RESISTANCE, AND MECHANICAL PROPERTIES OF VENEER-FACED LOW-DENSITY PARTICLEBOARDS MADE FROM ACETYLATED WOOD[1]

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ABSTRACT

Veneer-faced low-density particleboards were made using four combinations of control and acetylated veneers and particles. These boards were tested for dimensional stability in both liquid water and water vapor, for decay resistance in standard soil-block tests with *Tyromyces palustris* and *Trametes versicolor*, for strength losses during attack by *T. palustris*, and for mechanical strength in bending-creep and mechanical tests. Boards made from acetylated veneers and acetylated core particles showed excellent dimensional stability in both liquid water and humidity tests and were resistant to attack by both fungi in an 8-week soil-block test. During the 150-day bending-creep test, the totally acetylated boards showed no strength or weight loss during exposure to *T. palustris*. Modulus of elasticity and modulus of rupture were slightly reduced for totally acetylated boards compared to boards with control veneers and control particles, and internal bond strength was reduced by about 30%. Screw-holding capacity of the totally acetylated boards and boards with control veneers and particles was essentially the same.

Keywords: Dimensional stability, decay resistance, mechanical properties, particleboard, acetylation.

INTRODUCTION

Dimensional instability and susceptibility of wood to biological attack have restricted wood products from many potential markets. Dimensional instability, especially in the thickness direction, is a greater problem in wood composites such as flakeboards, particleboards, and fiberboards than in solid wood products. In wood composites, not only does normal, reversible swelling occur but also irreversible swelling caused by the release of residual compressive stresses imparted to the board during the pressing process. The greater surface area and porosity of wood composites compared to solid wood and the use of non-decay-

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resistant woods for composites may contribute to their greater susceptibility to biological attack. Other properties of reconstituted wood products that have restricted their use are loss of aesthetic appeal (loss of grain patterns) and greatly reduced screw-holding capacity as compared to solid wood and plywood.

Acetylation of both solid wood and wood composites has been shown to greatly improve dimensional stability and biological resistance (Rowell 1984). Thickness swelling in flakeboards and particleboards could be reduced 80% to 90% by acetylation of the furnish before board production (Rowell et al. 1986a, b). Flakeboards made from acetylated flakes were resistant to attack in fungal cellar tests against brown-, white-, and soft-rot fungi and tunneling bacteria (Rowell et al. 1987a).

In previous research, technology was developed to produce an acetylated low-density particleboard. Test boards showed excellent mechanical properties and dimensional stability (Yoshida et al. 1986), and decay and termite resistance (Imamura et al. 1986).

The purpose of our investigation was to produce an acetylated veneer-faced low-density particleboard that would be strong, aesthetically pleasing, able to hold screws, dimensionally stable, and resistant to decay attack.

MATERIALS AND METHODS

Materials, acetylation, and board formation

Particles of seraya (*Shorea* spp.) with a specific gravity of 0.4 were prepared with a drum chipper and then run through a knife-ring flaker. The general dimensions of the particles were 13 by 2 by 0.5 mm (length by width by thickness). The particles were oven-dried and then acetylated by impregnating with acetic anhydride and reacting at 130 C for 40 minutes. After reaction, the particles were rinsed with water and redried. Weight gain caused by acetylation was 20% based on the original oven-dry wood weight.

Douglas-fir (*Pseudotsuga menziesii*) veneers were prepared 3 mm thick, and then cut into 35- by 40-cm pieces. The veneers were oven-dried and then impregnated with aqueous sodium acetate as catalyst and redried. Retention was 2% based on the original oven-dry wood weight. The veneers were then impregnated with acetic anhydride and reacted at 120 C for 60 minutes. After reaction, the veneers were washed with water and redried. Weight gain caused by acetylation was 15% to 17% based on the original oven-dry wood weight.

Control and acetylated particles (800 g) were sprayed with a 20% solution of isocyanate resin (UL-4800 formulated by Gun-ei Kagaku Kogyo Co. Ltd.[3]) in acetone. Resin retention was 10% based on the oven-dry weight of the particles. The same isocyanate resin was applied with a roller to one face of control and acetylated veneers. Resin retention was 100 g/m^2.

Veneer-faced particle core boards were made by placing a mat of resin-coated particles on top of one resin-coated veneer and placing a second resin-coated veneer on top of the particle mat. This was placed in a hot press. A two-stage

pressing cycle was used as follows: 30 seconds at 160 C, 15 kg/cm², then 4.5 minutes at 160 C, 5 kg/cm². Four different types of board were made for the study: (1) control veneers, control particles; (2) acetylated veneers, control particles; (3) control veneers, acetylated particles; and (4) acetylated veneers, acetylated particles. Two boards of each type were made. The final veneer-faced particleboards were 35 by 40 cm with a thickness of 20 mm, and had a specific gravity of 0.5. Two centimeters were cut from each edge, and the remaining board was cut into specimens for testing.

Liquid water tests

Water-swelling-rate tests.—Oven-dry test specimens (5 by 5 by 2 cm) were placed in a 10- by 10-cm container, 5 cm deep. The container was placed on a flatbed micrometer for the thickness measurements. Water was added to the container, and specimen thickness was recorded as a function of time. Measurements were taken every 5 minutes for the first hour, every hour for the next 5 hours, and then once a day for 5 days. The percent swelling caused by water sorption was based on the original oven-dried thickness of the specimens.

Water-soaking tests.—Cyclic water-soaking tests were run on test specimens (5 by 5 by 2 cm) as previously described (Rowell and Ellis 1978). Each of six cycles consisted of water soaking for 5 days followed by oven-drying at 105 C for 2 days. Thickness swelling was calculated as a percentage of the original thickness of the oven-dry board. Weight increase caused by water sorption was determined after water soaking for 1, 10, and 31 days. The specimens were removed from the water, wiped of excess water, and weighed. The percent weight increase caused by water sorption was based on the original weight of the air-dried board. Duplicate specimens were run, and the values were averaged. Variation was less than ±5%.

Humidity tests

Oven-dried specimens (5 by 5 by 2 cm) were placed in constant humidity rooms at 30%, 65%, 80%, and 90% relative humidity (RH) and 27 C. After 21 days the specimens were weighed to determine the equilibrium moisture content (EMC). Previous work showed that EMC for control and acetylated boards was reached at 14 days (Rowell et al. 1986b).

Separate specimens were placed in a humidity room at 30% RH and 27 C. Thickness and weight were determined after 21 days. The specimens were then placed in a humidity room at 90% RH and 27 C for another 21 days, whereafter thickness was determined. This procedure was repeated for a total of four cycles of 30% to 90% RH. The specimens were then oven-dried, and thickness was measured. Changes in thickness were calculated as a percentage of the original thickness of the oven-dry board. Duplicate specimens were run, and the values were averaged. Variation was less than ±3%.

Soil-block tests

Decay tests were run according to Japan Wood Preserving Association (JWPA) Standard No. 3-1979 (Japan Wood Preserving Association 1979). Specimens (2.5 by 2.5 by 2.0 cm) were sterilized and placed in glass jars containing the brown-rot fungus *Tyromyces palustris* (Berk. et Curt.) Murr. or the white-rot fungus *Trametes versicolor* (L.:Fr.) Pilat. Specimens were removed after 8 weeks,
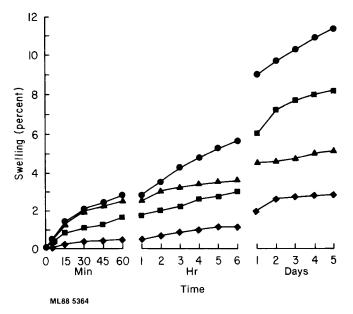
FIG. 1.   Rate of thickness swelling of veneer-faced low-density particleboards in liquid water. ●
control veneers, control particles; ■ acetylated veneers, control particles; ▲ control veneers, acetylated
particles; ◆ acetylated veneers, acetylated particles.

and extent of fungal attack was determined based on weight loss. Thickness swell-
ing of each specimen was also determined at the end of decay test. Six specimens
of each type were run, and the values were averaged.

Separate specimens (2.5 by 2.5 by 2.0 cm) were edge-coated on all sides with
an epoxy resin to prevent fungal invasion into the particle core. These specimens
were then placed in soil-block tests as described previously, and weight loss was
determined after 8 weeks of exposure. Thickness swelling after exposure was also
determined. Six specimens of each type were run, and the values were averaged.

Bending-creep test

Test boards (5 by 35 by 2 cm; grain of face veneer parallel to length) either
edge-sealed with an epoxy resin or not sealed were subjected to a bending-creep
test under progressive fungal attack in a decay chamber (Imamura and Nishimoto
1985). The chamber consisted of a metal wire frame covered with a polyethylene
bag and a porous plug of silicon rubber. The brown-rot fungus *T. palustris* was
used for decay attack. Mycelial fragments prepared from shake culture were spread
on the bottom tension surfaces of the sterilized particleboards. A tray filled with
sterilized water was set at the bottom of the chamber to keep the specimen in a
moist condition.

A load of 28 kg/cm² (approximately 10% of wet bending strength of sound
specimens) was applied at the center of each specimen outside of the decay cham-
ber. Deflection of the board at the center of the span length (300 mm) was measured
regularly with an electric dial gauge as a criterion to determine performance. The
bending-creep test was carried out until the particleboard broke under load or
150 days, whichever came first. The test apparatus was maintained in a condi-
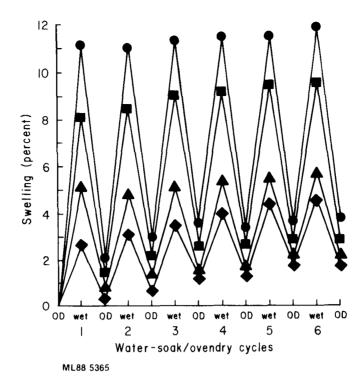
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Fig. 2. Changes in thickness of veneer-faced low-density particleboards in repeated water-soaking test. ● control veneers, control particles; ■ acetylated veneers, control particles; ▲ control veneers, acetylated particles; ◆ acetylated veneers, acetylated particles.

TABLE 1. *Weight increase caused by liquid water sorption of veneer-faced low-density particleboards.*

Specimen		Weight increase (%)		
Veneers	Particles	1 day	10 days	31 days
Control	Control	25.3	72.0	105.2
Acetylated	Control	23.1	70.0	98.2
Control	Acetylated	20.3	58.2	85.8
Acetylated	Acetylated	20.3	60.3	84.9

TABLE 2. *Equilibrium moisture content of veneer-faced low-density particleboards at various relative humidities (27 C).*

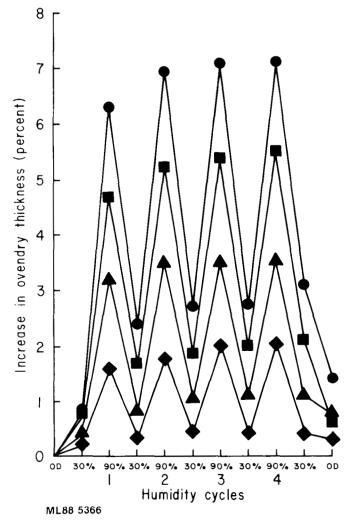| Specimen		Relative humidity (%)			
		30	65	80	90
Veneers	Particles	Equilibrium moisture content (%)			
Control	Control	4.2	8.6	12.6	15.1
Acetylated	Control	3.4	7.7	11.6	13.6
Control	Acetylated	2.5	5.1	7.6	9.0
Acetylated	Acetylated	1.6	4.3	6.6	8.3

FIG. 3.   Changes in thickness of veneer-faced low-density particleboards at 30% and 90% relative humidity. ● control veneers, control particles; ■ acetylated veneers, control particles; ▲ control veneers, acetylated particles; ◆ acetylated veneers, acetylated particles.

tioned room at 26 C, which was suitable for the incubation of the fungus. Three specimens of each type were run, and the values were averaged.

After failure or 150 days, oven-dry weight loss was determined for each specimen.

Mechanical tests

Static bending tests were conducted on boards (5 by 35 by 2 cm) according to Japan Industrial Standard (JIS) A5908-1983 (Japan Industrial Standard 1983). Modulus of elasticity (MOE) and modulus of rupture (MOR) were determined on water-soaked specimens as well as specimens equilibrated at 65% RH.

Internal bond tests were conducted on boards (5 by 5 by 21 cm) cut from ends of specimens broken in static bending according to JIS A5908-1983.

TABLE 3. *Average weight loss in soil-block tests of unsealed and sealed veneer-faced low-density particleboards exposed for 8 weeks to either* Tyromyces palustris *or* Trametes versicolor.

| Specimen | | Average weight loss[a] (%) | | | |
| | | Unsealed[b] | | Sealed[b] | |
Veneers	Particles	TYP[c]	TRV[d]	TYP[c]	TRV[d]
Control	Control	28.5	26.2	18.2	5.7
Acetylated	Control	17.0	18.6	0.4	0
Control	Acetylated	15.7	2.6	5.8	1.2
Acetylated	Acetylated	0.4	0.5	0	0.3

[a] Average of six specimens.
[b] Specimen edges sealed or not sealed with epoxy resin.
[c] *Tyromyces palustris.*
[d] *Trametes versicolor.*

Wood screw-withdrawing force tests were conducted on boards cut from ends of specimens broken in static bending according to JIS A5908-1983. Screws 2.7 mm in diameter and 16 mm in length were withdrawn from both board edges and faces.

Six specimens of each type were used in the static bending, internal bond, and screw withdrawing tests. The values obtained were averaged.

RESULTS AND DISCUSSION

Liquid water tests

The rate and extent of swelling of veneer-faced particleboards in liquid water are shown in Fig. 1. During the first 60 minutes, all four types of boards swelled less than 3%. For the first 6 hours, both of the fastest swelling boards contained control veneers, which showed that initial swelling was controlled by the surface veneers. At 24 hours up to 5 days, both boards made with control particles swelled the most, showing that ultimate swelling was controlled by the core particles. During the 5-day test, boards with control veneers and control particles swelled over 11%, while the totally acetylated boards swelled less than 3%.

Thickness changes in the repeated water-soaking tests are shown in Fig. 2. Both boards with control particle cores swelled much more than boards with acetylated particle cores.

Increases in weight caused by liquid water sorption are shown in Table 1. All types of boards gained weight; boards with control veneers and particles gained

TABLE 4. *Average thickness swelling of unsealed and sealed veneer-faced low-density particleboards after exposure to fungal attack in soil-block tests.*

| Specimen | | Swelling[a] (%) | | | |
| | | Unsealed[b] | | Sealed[b] | |
Veneers	Particles	TYP[c]	TRV[d]	TYP[c]	TRV[d]
Control	Control	9.4	10.9	9.3	9.6
Acetylated	Control	6.3	7.0	5.9	6.0
Control	Acetylated	3.3	4.0	3.3	4.3
Acetylated	Acetylated	2.0	2.0	1.3	2.0

[a] Average of six specimens.
[b] Specimen edges sealed or not sealed with epoxy resin.
[c] *Tyromyces palustris.*
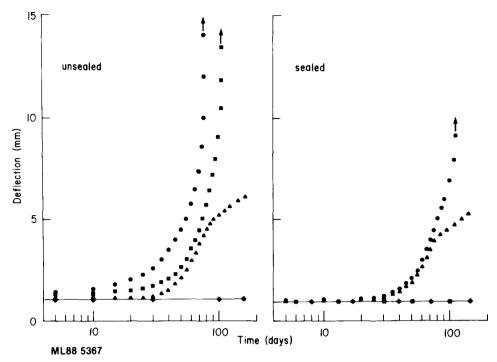[d] *Trametes versicolor.*

FIG. 4. Deflection time curves of unsealed and sealed veneer-faced low-density particleboards under progressive fungal attack by *T. palustris* on bending-creep test. ● control veneers, control particles; ■ acetylated veneers, control particles; ▲ control veneers, acetylated particles; ◆ acetylated veneers, acetylated particles.

the most weight. Most of the water was probably in the interstitial voids in the particle core.

Humidity tests

Table 2 shows the EMC at each RH tested in the 21-day humidity test. The EMC was reduced about 50% in totally acetylated boards as compared to boards with control veneers and particles at each RH.

Data from the humidity-cycle tests show that boards with control core particles swelled much more in 30% to 90% RH cycles than did boards with acetylated core particles (Fig. 3). Boards made from acetylated veneers and core particles

TABLE 5. *Duration of test until creep fracture and weight loss of specimens.*

Specimen		Unsealed[a]		Sealed[a]	
Veneers	Particles	Time to fracture (days)	Weight loss (%)	Time to fracture (days)	Weight loss (%)
Control	Control	78	21.3[b]	111	16.7[b]
Acetylated	Control	108	22.8[b]	(—)[c]	0[d]
Control	Acetylated	(—)[c]	15.3[d]	(—)[c]	14.4[d]
Acetylated	Acetylated	(—)[c]	0.7[d]	(—)[c]	0[d]

[a] Specimen edges sealed or not sealed with epoxy resin.
[b] Percent weight loss at time of specimen failure.
[c] No fracture for more than 150 days.
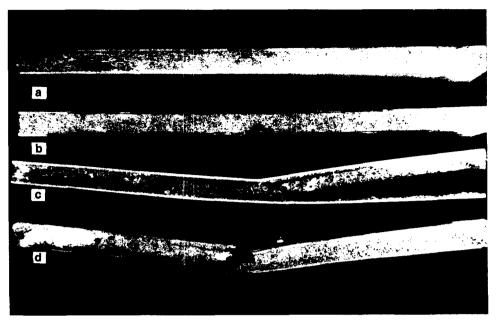[d] Percent weight loss after total test period of 150 days.

FIG. 5. Unsealed specimens after bending-creep test. (a) acetylated veneers, acetylated particles; (b) control veneers, acetylated particles; (c) acetylated veneers, control particles; (d) control veneers, control particles.

swelled about 2% on the final 30% to 90% cycle, while boards made with control veneers and core particles swelled over 7% on the same cycle.
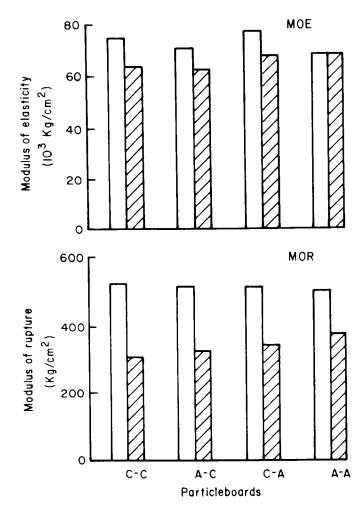
Soil-block tests

Weight loss after 8 weeks' exposure to a brown-rot or white-rot fungus is shown in Table 3. In the unsealed boards with control veneers and particles, both *T. palustris* and *T. versicolor* caused 26% to 29% weight loss. Weight loss was reduced by about 10% when the board core particles were acetylated. When veneers and core particles were both acetylated, attack by both organisms was stopped.

When the board edges were sealed with an epoxy resin, neither organism could attack when the board had acetylated veneers regardless of whether the core was acetylated or not.

Thickness swelling, which occurred during both of the 8-week soil-block tests, is shown in Table 4. About 10% swelling occurred with both fungi in unsealed and sealed boards with control veneers and particles. Swelling was reduced to about 2% under the same conditions in totally acetylated boards.

Bending-creep test

Deflection time curves for the brown-rot fungi are shown in Fig. 4 for unsealed and sealed boards. Unsealed boards made with control veneers and particles failed in an average of 78 days, whereas boards with control core particles and acetylated veneers failed in 108 days (Table 5). Although the boards with control veneers and acetylated core particles increased in deflection after 30 days, they did not
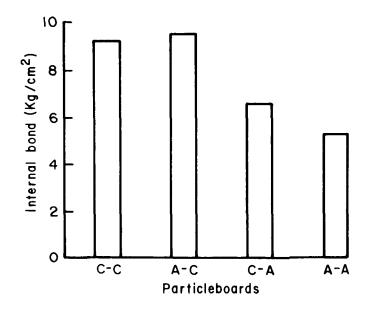
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FIG. 6.   Dry ☐ and wet ▨ modulus of elasticity (MOE) and modulus of rupture (MOR) of veneer-faced low-density particleboards. C-C, control veneers, control particles; A-C, acetylated veneers, control particles; C-A, control veneers, acetylated particles; A-A, acetylated veneers, acetylated particles.

fracture in the 150-day test. The totally acetylated boards showed very little deflection during the 150 days.

Sealed boards with control veneers and particles failed in an average of 111 days, whereas sealed boards with control veneers and acetylated core particles increased in deflection after 30 days but did not fail in the 150-day test. However, the boards with acetylated veneers and control core particles and the totally acetylated boards showed little deflection throughout the test. These results showed that as long as the surface of the board was acetylated, the attacking fungal mycelium could not invade the untreated core.

Because wood specimens subjected to the same load creep at different rates

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Fig. 7. Internal bond strength of veneer-faced low-density particleboards. C-C, control veneers, control particles; A-C, acetylated veneers, control particles; C-A, control veneers, acetylated particles; A-A, acetylated veneers, acetylated particles.
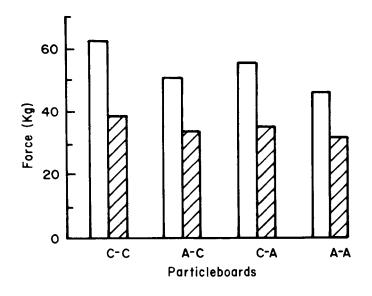
depending upon their moisture content, it is important to determine the creep caused by the moisture present in the wood separately from the creep caused by strength losses associated with decay. In developing the standard test procedure, two sets of control specimens were used. One set had aqueous inoculum applied to the bottom tension surface of the test specimens, and the second set had an equal amount of sterile water applied to the bottom side. The wet sterile controls showed less than 5-mm deflection during the 150-day test, while the controls with decay fungus failed within the 150-day test. This showed that only a small part of the deflection observed was associated with creep caused by moisture.

Unsealed boards with control veneers and core particles failed at the end of the bending-creep test (Fig. 5). In boards with control core particles and acetylated veneers, only the core failed. In boards with acetylated core particles and control veneers, only the veneers failed. No failures occurred in the totally acetylated boards.

Weight loss associated with strength loss determined after the bending-creep test is shown in Table 5. In unsealed boards, about 20% weight loss occurred when the core was untreated, 15% when the core was acetylated and control veneers were used, and less than 1% when both core and veneer were acetylated. Edge sealing eliminated weight loss in all boards with acetylated veneers.

Mechanical tests

The dry MOE values for all boards were between 73 and 82 $\times$ 10^3 kg/cm^2 whereas water-soaked MOE values ranged from 58 to 60 $\times$ 10^3 kg/cm^2 (Fig. 6).

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Fig. 8.   Force required for screw withdrawal from faces □ and edges ▨ of veneer-faced low-density particleboards. C-C, control veneers, control particles; A-C, acetylated veneers, control particles; C-A, control veneers, acetylated particles; A-A, acetylated veneers, acetylated particles.

In the totally acetylated boards, the water-soaked and dry MOE values were the same, whereas the other three types of boards had lower wet values than dry.

Dry MOR values ranged from 480 to 550 kg/cm² for boards whereas wet MOR values ranged from 280 to 390 kg/cm² (Fig. 6). In all boards, wet MOR was lower than dry MOR. The reduction was greater in the boards with control veneers and particles.

Internal bond values for the totally acetylated boards were about 35% lower than those of boards with control veneers and particles (Fig. 7). This was probably due to the hydrophobic nature of the acetylated wood, causing poor wetting of wood. Internal bond values were the lowest in boards with acetylated core particles where adhesion was most critical.

The force required to pull a screw out of the face of the board was highest in boards with control veneers and particles, somewhat reduced in boards with control veneers and acetylated core particles, and lowest in boards with acetylated veneers (Fig. 8). The force required to pull the screw out from the edge was about the same for all boards and was about 30% lower than values from veneer-covered boards.

CONCLUSION

This research showed that a veneer-faced low-density particleboard can be produced from veneers and particles that have been acetylated before board formation. Dimensional stability and biological resistance were greatly improved over control boards, though mechanical properties of dry specimens were somewhat reduced. Since no significant strength losses occur as a result of the acetylation

process (Rowell and Banks 1987), mechanical properties should improve once an adhesive is developed that will adhere hydrophobic surfaces together (Rowell et al, 1987a, b). The thick surface veneer greatly improves the screw-holding ability of veneer-faced particleboard as compared to nonveneered particleboard.

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