PHENOL ADHESIVE BONDED MEDIUM-DENSITY FIBERBOARD FROM *QUERCUS RUBRA* L. BARK AND SAWDUST[1]

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ABSTRACT

Twelve-millimeter-thick medium density fiberboards made from double-disc, steam-pressure-refined red oak sawdust fibers at 6.5 and 9.0% phenol-formaldehyde levels for both, with and without the addition of sodium pentachlorophenate, meet most of the specifications required for exterior-grade, medium density, class 1 commercial particleboard and medium density hardboard. Panels made from red oak bark fibers showed inferior properties to panels made from red oak sawdust fibers. However, at a 9% resin level, untreated bark fiberboard exhibited acceptable modulus of elasticity in bending, internal bond, and face screw-holding values. The addition of the preservative to the adhesive had the effect of decreasing all of the strength properties and the linear expansion values of all untreated panels at three resin levels.

Three-layer type of panels made from red oak sawdust fiber faces and red oak bark fiber core had higher bending strength, stiffness, and face screw-holding values, but lower internal bond and tensile strength parallel to face values than a homogeneous type of panel made from a mixture of equal weight of sawdust and bark fibers. Three-layer panels also showed lower linear expansion values than the homogeneous type of panel. At a 6.5% resin level, both homogeneous and three-layer types of panels had acceptable strength properties except for the tensile strength parallel to face and linear expansion values.

Keywords: *Quercus rubra*, adhesives, phenol-formaldehyde, fiberboard, hardwood, sawdust, bark, pressure-refined, resin content, sodium pentachlorophenate, particleboard, bending test, tensile strength, modulus of rupture, modulus of elasticity, internal bond, screw-holding, thickness swelling, linear expansion.

INTRODUCTION

In recent years wood materials for use by the panel industry have become scarce and expensive in the United States as a result of competition with the pulp and paper industry for round wood and coarse residues. Panel producers are forced to seek resources that have been previously overlooked and considered undesirable. A recent survey indicates that in North American particleboard plants more than 75% of the raw material is softwood residues and mill wastes, but less than 7% is hardwood residues (Mottet 1975). Evidently, hardwood residues are not well utilized for board uses in America. There is a need to develop panel products from currently unused dense hardwood residues and bark because better utilization of presently available hardwood residue and bark supplies now wasted is a partial answer to meet the ever-increasing demand for wood. Previous laboratory study indicated that steam-pressure refining permits the use of red oak

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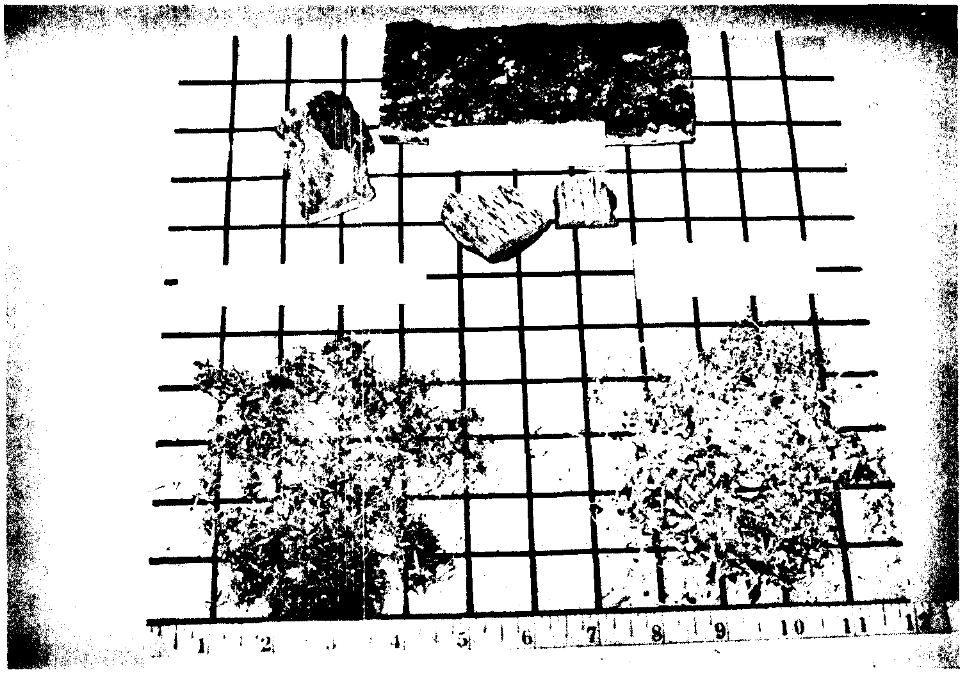

FIG. 1. Upper center: Red oak bark. Lower left: Steam-pressure-refined red oak bark/fibers. Lower right: Hammermilled red oak sawdust.

(*Quercus rubra* L.) residues in the manufacture of acceptable medium-density fiberboard (MDF) using urea-formaldehyde resin (Chow 1976). However, there is little information available on converting fine northern red oak residues and bark to acceptable phenolic-bonded panel products for exterior applications.

OBJECTIVES

The objectives of this study were to (a) determine the suitability of using double-disc, pressure-refined red oak sawdust and bark as raw materials for phenolic-bonded medium density fiberboard manufacture, (b) determine the effect of three resin contents and the addition of a preservative on the properties of fiberboards made from red oak sawdust and bark, and (c) determine the properties of both a homogeneous type of panel made from equal mixtures of sawdust and bark fibers, and a three-layer type of panel made from red oak sawdust fiber faces and red oak bark fiber core.

EXPERIMENT

Materials

Red oak (*Quercus rubra* L.) sawdust and bark from a hardwood lumber mill in Illinois were collected. Each residue supply was defiberized in a commercial double-disc steam-pressurized attrition mill (Bauer 418) under conditions deemed best for each residue (Chow 1976). Red oak bark was first run through a hammermill with a 2.54-cm screen in order to reduce the size of the bark to a suitable

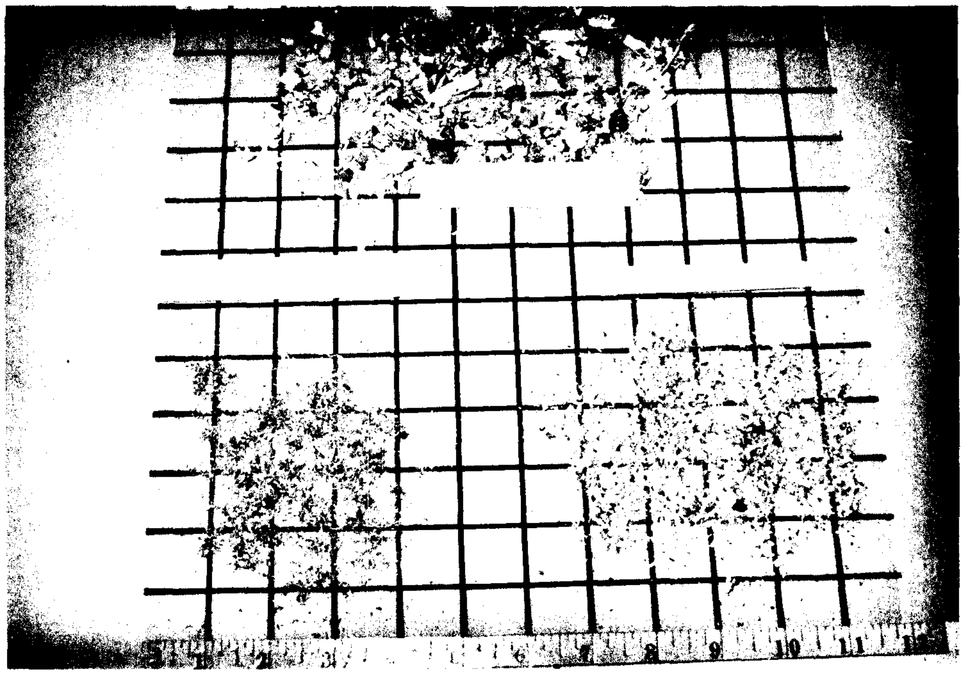

FIG. 2. Upper center: Red oak sawdust. Lower left: Steam-pressure-refined red oak sawdust fibers. Lower right: Hammermilled red oak sawdust.

feed material for the pressure-refining system. The moisture content of each material was between 8 and 10% at the time it was refined (Figs. 1 and 2).

Experimental design

Two boards were made for each combination of independent variables. A dry-process was chosen for the board production. A commercial phenol-formaldehyde adhesive was used as a binder in the experiment. Conventional techniques for board production were employed. A total of 36 boards (a replication of 2) 46 cm × 51 cm × 12 mm were made.

Experimental factors held at constant levels were:

1. Nominal panel density: 0.70 grams per cubic centimeter based on oven-dry weight and volume at test.
2. Adhesive and wax: phenol-formaldehyde and 1% wax emulsion.
3. Press time and temperature: 180 C and 9 min.

The experiments were divided into two series, as follows:

Series I: Panels made from red oak sawdust and bark fibers.

The independent variables included in this series were:

1. Furnish types: Red oak sawdust fibers and bark fibers.
2. Resin content: 4.0, 6.5, and 9.0% phenol-formaldehyde based on oven-dry weight of the furnish.

3. Preservative treatment: Untreated and treated panels. For preservative-treated panels, a commercial grade of sodium pentachlorophenate was added to the phenolic resin and was incorporated into the panel based on oven-dry weight of the furnish at a level of 1.0%.

Series II: Panels made from mixtures of equal weights of red oak sawdust and bark fibers.

The independent variables included in this series were:

1. Panel structures: Homogeneous type and three-layer type (sawdust fiber faces and bark fiber core).
2. Resin content: 4.0, 6.5, and 9.0% phenol-formaldehyde based on oven-dry weight of the furnish.

Testing and dependent variables

All panels were trimmed to 43 cm × 48 cm and cut to various sizes to produce specimens for subjection to tests of (a) modulus of rupture (MOR) in bending; (b) modulus of elasticity (MOE) in bending; (c) tensile stress perpendicular to face or internal bond (IB); (d) tensile stress parallel to face (TS); (e) face screw-holding (FS); (f) thickness swelling; and (g) linear expansion (LE) between 50 and 90% relative humidity at 21 C condition exposure. In all there were a total of seven dependent variables. All test procedures followed those outlined in American Society of Testing and Materials (ASTM) except that the conditioning of the specimens was at 50% relative humidity (ASTM 1978). Accelerated aging test was not conducted in this study.

Data were statistically analyzed. A special computer program was used to compute the treatment means and overall analysis of variance table for data from replicated factorial experiments with various independent factors.

RESULTS AND DISCUSSION

It was found that the processing of red oak bark required shorter retention time and consumed less steam pressure and horsepower than red oak sawdust during the refining process. However, both materials produced panels with tight edges and uniform density throughout the thickness.

The results of analysis of variance for this experiment indicate that residue type, phenolic resin content, sodium pentachlorophenate, panel structure, and their interactions apparently influenced all strength properties and linear expansion values of the panels at a significant level of less than 1% probability in both series of the study.

Panels made from red oak sawdust and bark fibers

Table 1 shows the average test results of 12-mm-thick medium density fiberboard panels made from red oak sawdust and bark fibers. All strength values were adjusted to a density of 0.7 grams per cubic centimeter based on oven-dry weight and volume at test, because all strength properties are found to be linearly related to panel density. Each value of MOR and MOE in bending is an average of six tests. Each value for IB, tensile strength parallel to face, screw-holding, thickness swelling, and linear expansion is an average of eight, four, eight, four, and four tests, respectively.

TABLE 1. *Effects of phenolic resin contents and preservative on average properties of panels made from pressure-refined red oak bark and sawdust fibers (density = 0.7 g/cm³).*

Properties		Bark			Sawdust			Req. for Commercial Pt. bd.[c]
		Phenolic Resin (%)			Phenolic Resin (%)			
		4.0	6.5	9.0	4.0	6.5	9.0	
Modulus of Rupture (kp/cm²)	UT[a]	78 (1,110)[d]	92 (1,308)	99 (1,408)	127 (1,800)	169 (2,403)	197 (2,802)	127 (1,800)
	T[b]	55 (782)	75 (1,067)	95 (1,351)	117 (1,664)	139 (1,977)	189 (2,688)	
Modulus Elasticity (kp/cm²) × 100	UT	180 (256,000)	204 (290,155)	208 (295,845)	243 (345,626)	289 (411,054)	338 (480,748)	176 (250,000)
	T	151 (214,772)	162 (230,418)	198 (281,621)	260 (369,806)	283 (402,519)	331 (470,791)	
Internal Bond (kp/cm²)	UT	3.2 (46)	4.9 (70)	6.5 (93)	3.5 (50)	5.3 (75)	8.0 (114)	4.6 (65)
	T	1.8 (26)	2.8 (40)	4.1 (58)	2.3 (33)	5.6 (80)	8.2 (117)	
Tensile Strength Parallel to Plane (kp/cm²)	UT	33 (469)	37 (526)	44 (626)	52 (740)	71 (1,010)	81 (1,152)	70[e] (1,000)
	T	30 (427)	31 (441)	28 (398)	34 (484)	67 (953)	73 (1,038)	
Face Screw-Holding (kg)	UT	71 (157)	77 (170)	100 (220)	114 (251)	132 (291)	155 (342)	102 (225)
	T	38 (84)	59 (130)	76 (168)	134 (295)	136 (300)	138 (304)	
From 50%–90% R.H. Linear Expansion (%)	UT	0.656	0.595	0.540	0.510	0.450	0.430	0.350
	T	0.550	0.560	0.455	0.459	0.408	0.359	
Thickness Swelling (%)	UT	4.5	4.8	4.0	4.8	4.5	5.7	—
	T	4.0	4.5	3.5	4.0	3.5	4.5	

[a] Unpreserved or untreated.
[b] 1% sodium pentachlorophenate was added to the resin, treated.
[c] U.S. Commercial Standard 236–66, Type 2, Class 1, medium density phenolic-bonded particleboard.
[d] Numbers in parentheses are lb/in.² except the face screw-holding values (in pounds).
[e] According to U.S. Voluntary Products Standard PS 58–73 for medium density hardboard.

TABLE 2. *Test results on phenolic-bonded panels made from equal mixtures of pressure-refined red oak sawdust and bark (density = 0.7 g/cm³).*

P-F resin content (%)	Structure of panel	Bending strength: MOR (kp/cm²)	Bending strength: MOE (kp/cm²) × 100	Tensile strength: Perpendicular to face (IB) (kp/cm²)	Tensile strength: Parallel to face (TS) (kp/cm²)	Face screw-holding (kg)	50% R. H. to 90% R. H. (21 days): Thickness swelling (%)	50% R. H. to 90% R. H. (21 days): Linear expansion (%)
4.0	3-Layer (Bark Core)	127 (1,800)[a]	218 (310,068)	2.8 (40)	38.7 (550)	86 (190)	3.4	0.491
	Homogeneous (Sawdust & Bark)	99 (1,408)	204 (290,155)	3.2 (46)	44.4 (632)	82 (181)	5.1	0.527
6.5	3-Layer (Bark Core)	162 (2,304)	261 (371,228)	4.6 (65)	49.3 (701)	123 (271)	3.2	0.477
	Homogenous (Sawdust & Bark)	120 (1,707)	247 (351,316)	4.9 (70)	52.8 (751)	114 (251)	3.8	0.513
9.0	3-Layer (Bark Core)	169 (2,404)	271 (385,451)	6.0 (85)	56.3 (800)	132 (291)	3.0	0.562
	Homogenous (Sawdust & Bark)	134 (1,906)	250 (355,583)	6.7 (95)	60.0 (853)	127 (280)	3.0	0.626
Requirement for Commercial Exterior Board		127 (1,800)	176 (250,000)	4.6 (65)	70.0 (1,000)	102 (225)	—	0.350

[a] Numbers in parentheses are lb./in.² except the face screw-holding values (in pounds).

According to Table 1, all panels made from red oak sawdust fibers obtained better average values of all strength properties and lower average linear expansion values than those for panels made from red oak bark fibers on both preservative-treated and untreated conditions at all three resin levels. This may be attributed to the fact that particle shape and texture of bark fibers were more granular in form and similar to dustlike materials whereas the sawdust fibers were more bulky and fine fibrous materials. For this reason, bark panels exhibited the poorest properties in both modulus of rupture and tensile strength parallel to face at low resin levels.

In all cases, panels with higher resin content were stronger, stiffer, had better fiber to fiber bonding strength, higher screw-holding values at the panel surface, and lower average linear expansion values; but increasing the resin from 6.5% to 9% in unpreserved red oak bark panels did not result in noteworthy increases in MOR and MOE values. This represents a reduction in resin efficiency at the 9% resin level. However, this was not the case in red oak sawdust panels.

Test results also show that the addition of 1% sodium pentachlorophenate preservative to the phenolic resin had adverse effects on most of the strength properties of the panels. This agrees with the MOR test results of a study reported by Brown and Alden (1960), but disagrees with the results of a study reported by Huber (1958). However, treated panels were somewhat more dimensionally stable than untreated panels in this study.

When compared to commercial standards, all panels made from red oak sawdust fibers at 6.5% and 9.0% resin levels meet or exceed the minimum average

MOR, MOE properties requirement of exterior type, medium density, class 1 (Type 2-B-1) commercial particleboard (U.S. Department of Commerce 1966); and the minimum tensile strength requirement for medium density hardboard according to the commercial standard PS58-73 for hardboard products (U.S. Department of Commerce 1973). Both treated and untreated panels exceeded the maximum limit of the linear expansion for commercial board.

In terms of MOE or stiffness, and fiber to fiber bond properties, bark panels at 6.5% and 9.0% resin contents meet the requirement for exterior-type commercial particleboard. They are suitable for certain applications in areas where high bending strength, MOR and tensile strength are not required.

Panels made from a mixture of red oak sawdust and bark fibers

Table 2 shows test results on exterior-type panels at three resin levels made from mixtures of equal weights of red oak sawdust and bark fibers. In general, higher average MOR, MOE, and screw-holding values and lower average thickness swelling and linear expansion values were obtained from the sawdust fibers face-bark core, three-layer type of panels than those of the homogeneous type of panels at all resin levels. However, the latter exhibited better internal bond and tensile strength parallel to face properties than those of the former. Table 2 also indicates that resin content was important in influencing all properties except linear expansion values. As much as 6.5 or 9.0% phenolic resin was needed for both the three-layer and homogeneous types of panels made from a mixture of sawdust and bark fibers in order to achieve the minimum MOR, MOE, IB, and face screw-holding requirements for commercial exterior-type particleboard in accordance with commercial standard CS236-66 for mat-formed particleboard (U.S. Department of Commerce 1973). As far as the property of linear expansion is concerned, none of the boards met the requirements of Commercial Standard CS235-66 for mat-formed particleboard.

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