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Thermal

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Characteristics of Thick Red Oak Flakeboard

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Abstract

As part of a cooperative project between Purdue University and the U.S. Forest Products Laboratory, 1-3/16-inch-thick red oak structural flakeboard was tested for fire penetration, flame spread, and thermal resistance. The small-scale testing indicated satisfactory thermal characteristics for a wood-based product. Fire penetration performance exceeded that of a 1-1/8-inch-thick plywood accepted as roof decking in heavy timber construction. Flame-spread performance met the class C criteria of 200 or less. Thermal resistance was consistent with suggested insulative design values for particleboard.

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FPL 407

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Thermal Characteristics of Thick Red Oak Flakeboard²

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Introduction

To make better use of our natural resources, efforts have been made to identify sizable and expanding markets for products that utilize small low-quality trees of the higher-density hardwood species.

A study of the potential use of hardwood-based materials for non-residential decking and flooring concluded that a substantial market exists for wood-based composite roof decking in the commercial-industrial sector of the building market (7).³ A subsequent study was undertaken to design, develop, and evaluate a hardwood structural flakeboard that satisfied the engineering requirements dictated by its intended

use as industrial-commercial roof decking (10). A red oak flakeboard has been designed—as part of a cooperative effort between Purdue University and the Forest Products Laboratory—to be competitive with the widely used ribbed steel materials abundant in the targeted market region of the East, North Central, and Northeastern states. As a continuation of the cooperative research, prototype full-size roof deck panels of red oak structural flakeboard were developed, manufactured, and performance tested (8).

This paper reports the results of performance testing of 1-3/16-inch-thick red oak structural flakeboard for fire penetration, flamespread, and thermal resistance. The thermal characteristics of an 1-1/8-inch-thick softwood plywood of the type normally used for roof decking were also determined.

Materials

The three-layer red oak structural flakeboard was designed to have a density of 40 lb/ft³ and a thickness

of 1.19 inches. The core was to be 58 percent of the weight and the faces 42 percent of the weight. The randomly oriented ring flakes of the core were 0.045 inch thick, random width, and 2 inches long. The 0.020-inch-thick, random-width, 3-inch-long disk flakes of the faces were to have a flake alignment of 70 percent. The flakes were bonded with a phenolformaldehyde resin. Specimens for the thermal tests were cut from 11 such panels made at the Forest Products Laboratory (FPL) for the cooperative study. The actual densities (oven-dry mass and volume) were 39.5 ± 3 lb/ft³.

Nine 4- by 8-foot sheets of 7-ply, 1-1/8-inch-thick plywood with exterior glue were purchased from a local lumberyard. There were no grademarks but the plywood appeared to have grade C-plugged face plies and grade D back plies. The plywood was made from western species such as aspen/cottonwood, white fir, white pines, yellow pines, hemlock, larch, spruce, and Douglas-fir, with the latter four as surface plies. Densities were 27.5 ± 3 lb/ft³.

¹ Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

² This study was part of a larger Purdue University-U.S. Forest Products Laboratory cooperative program that was conducted under the direction of Dr. Michael O. Hunt of Purdue University, West Lafayette, Ind.

³ Italicized numbers in parentheses refer to literature cited at end of report.

Methods

Fire Penetration

Building codes require building assemblies to have a minimum level of fire resistance. The fire resistance rating determined according to ANSI/ASTM E 119 (4) is for an entire assembly such as a wall, column, floor, roof, or beam. The fire resistance performance of a roof decking itself is not specified and would depend on the performance of the entire roof assembly. For the purpose of comparing materials, however, small-scale nonstandard fire penetration tests were conducted on the flakeboard and plywood. The panels were tested in the FPL 20- by 20-inch vertical panel furnace (fig. 1) using ANSI/ASTM E 119 (4) time-temperature fire exposure conditions.

The test panels were either a single panel or three panels glued together with phenol-resorcinol adhesive. Panels were conditioned at 80° F and 30 percent relative humidity to a moisture content (ovendry basis) of 7 percent for the plywood and 6 percent for the flakeboard. Three replicates of each specimen type were tested. Five 30-gage iron-constantan thermocouples were placed beneath asbestos pads on the unexposed side of the specimens, at the center of each quadrant and the center of the panel. For the three-panel specimens, five thermocouples were also placed between the inner and each of the two outer panels. Inside the furnace, a single iron-capped and four semiprotected thermocouples were located on a plane 2 inches from the exposed surface of the panel.

The gas supply of the furnace was regulated so that the temperature of the iron-capped thermocouple followed the ANSI/ASTM E 119 time-temperature curve. The gas was turned off upon burnthrough or flaming along the edges of the unexposed face of the panel.

Flamespread

Comparative values for flamespread and smoke-developed were determined by the 25-foot tunnel furnace

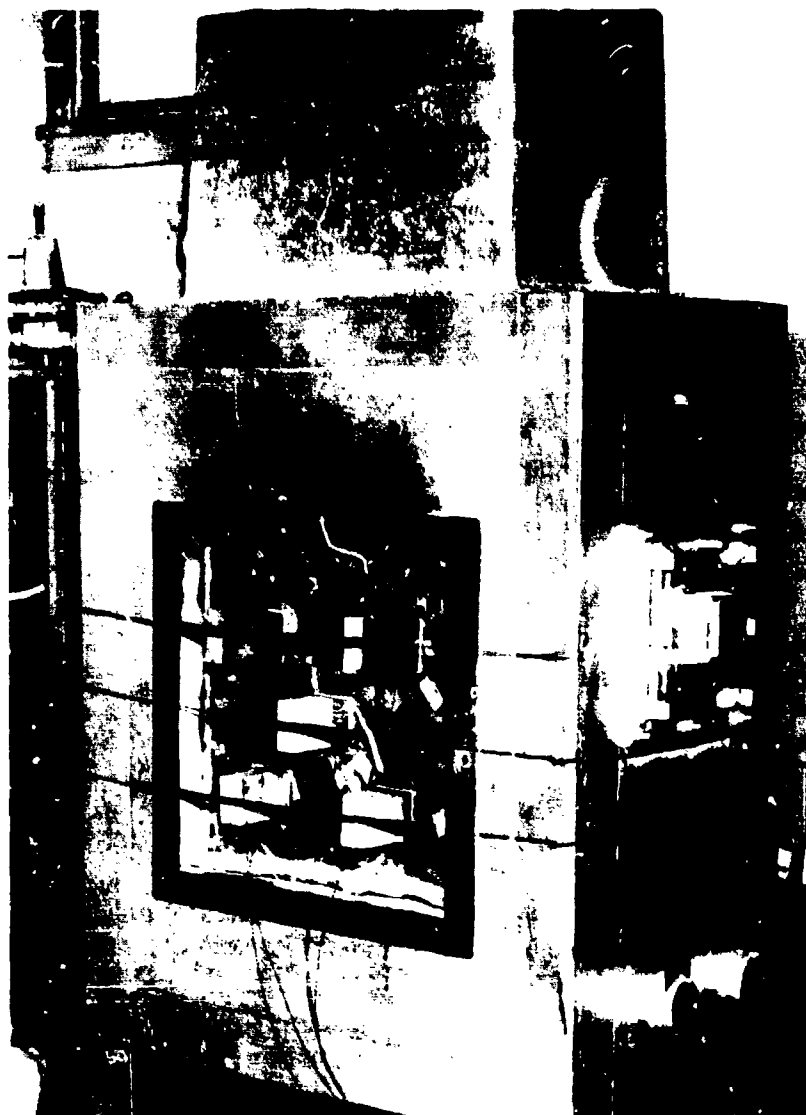


Figure 1.—Small nonstandard vertical furnace used to evaluate fire penetration performance of panel products.

(M 150 083-1)

tests of ANSI/ASTM E 84-79b (5) and the 8-foot tunnel furnace tests of ASTM E 286-69 (3). The 25-foot tunnel test, developed by the Underwriters Laboratories, is generally used by the building code writers to rate building materials for flamespread. The 8-foot tunnel test, developed by the FPL, is generally used for research and development.

For the 25-foot tunnel furnace tests, three specimens each of flakeboard and plywood were conditioned at 73° F, 50 percent relative humidity. ANSI/ASTM E 84 tests were conducted by the Hardwood Plywood Manufacturers Association at their

laboratory in Reston, Va. The ANSI/ASTM E 84 furnace (fig. 2) uses a 20-inch-wide, 24- or 25-foot-long specimen, placed on top of the tunnel so that the surface to be tested is facing downward. At the "fire end" of the chamber, two gas burners deliver flames upward against the surface of the specimen. Air movement is by an induced draft system. With Select-grade red oak flooring as the specimen, the flames travel the 19.5 foot from the end of the ignition fire to the end of the specimen in 5.5 minutes.

In 1975 and earlier standards, the flamespread classification was



Figure 2.—The 25-foot tunnel furnace used to evaluate the flamespread characteristics of materials for regulatory purposes.

(M 149 215)

based either on the time in which the flame spread 19.5 feet or on the extreme flame-spread distance in a 10-minute test period. Calculations were based on Select-grade red oak flooring with a classification index of 100. In the 1979 standard, the flamespread classification is calculated from the total area under a flamespread time-distance curve, which ignores any flamefront recession. Using this method, the flamespread classification for red oak flooring is not necessarily 100. The smoke developed values are based on areas under the light absorption (pct)-time curves for the test material and the Select-grade red oak flooring and asbestos-cement board standards. The asbestos-cement board and the Select-grade red oak flooring have arbitrary smoke-developed values of 0 and 100, respectively.

For the 8-foot tunnel furnace tests, three specimens each of flakeboard and plywood were conditioned at 80° F, 30 percent relative humidity. These ASTM E 286 tests (fig. 3) use a 13.75-inch-wide, 8-foot-long specimen. The specimen is heated by a graduated level of radiation

from the stainless steel partition plate which divides the firebox and the specimen combustion chamber. The furnace, run under natural draft conditions, is adjusted so time for flames to travel the 87 inches of Select-grade red oak flooring is 19.0 ± 1.0 minutes.

Flamespread index calculations are based on the time to travel the 87 inches or the distance reached during standard test period. The duration of the standard test period is the average result obtained in the calibration with the red oak standard specimen. Smoke-developed value is computed from areas under the light obscuration-time curves for the test specimen and the red oak and asbestos millboard standard specimens. Both the flamespread index and smoke developed values are based on asbestos millboard and Select-grade red oak flooring having arbitrary indices of 0 and 100 respectively.

Thermal Resistance

The thermal resistances of the flakeboard and plywood were determined at three mean temperatures,

39°, 77°, and 113° F. The panels were tested in a thermal conductivity tester (fig. 4) which operates in accordance with the requirements of ASTM C 518-70 (2). The apparatus measures steady-state thermal transmission properties using a heat flow meter. Temperature gradients across the 12-inch-square oven-dry specimen were about 13° F and the heat flux was about 8 Btu/ft²-h.

Results and Discussion

Fire Penetration

In tests of single flakeboard panels, temperatures on the unexposed surface exceeded the ANSI/ASTM E 119 (4) temperature criteria of 250° F average temperature rise or 325° F maximum temperature rise in 34.3 to 35.5 minutes (table 1). The temperature criteria were exceeded in 26.5 to 27.5 minutes in the tests of single plywood panels. Assuming a charring temperature of 550° F, a char rate was computed from either the time an individual thermocouple recorded 550° F or the time of burn-through, whichever was shorter (table 1). On this basis, the flakeboard has an average apparent

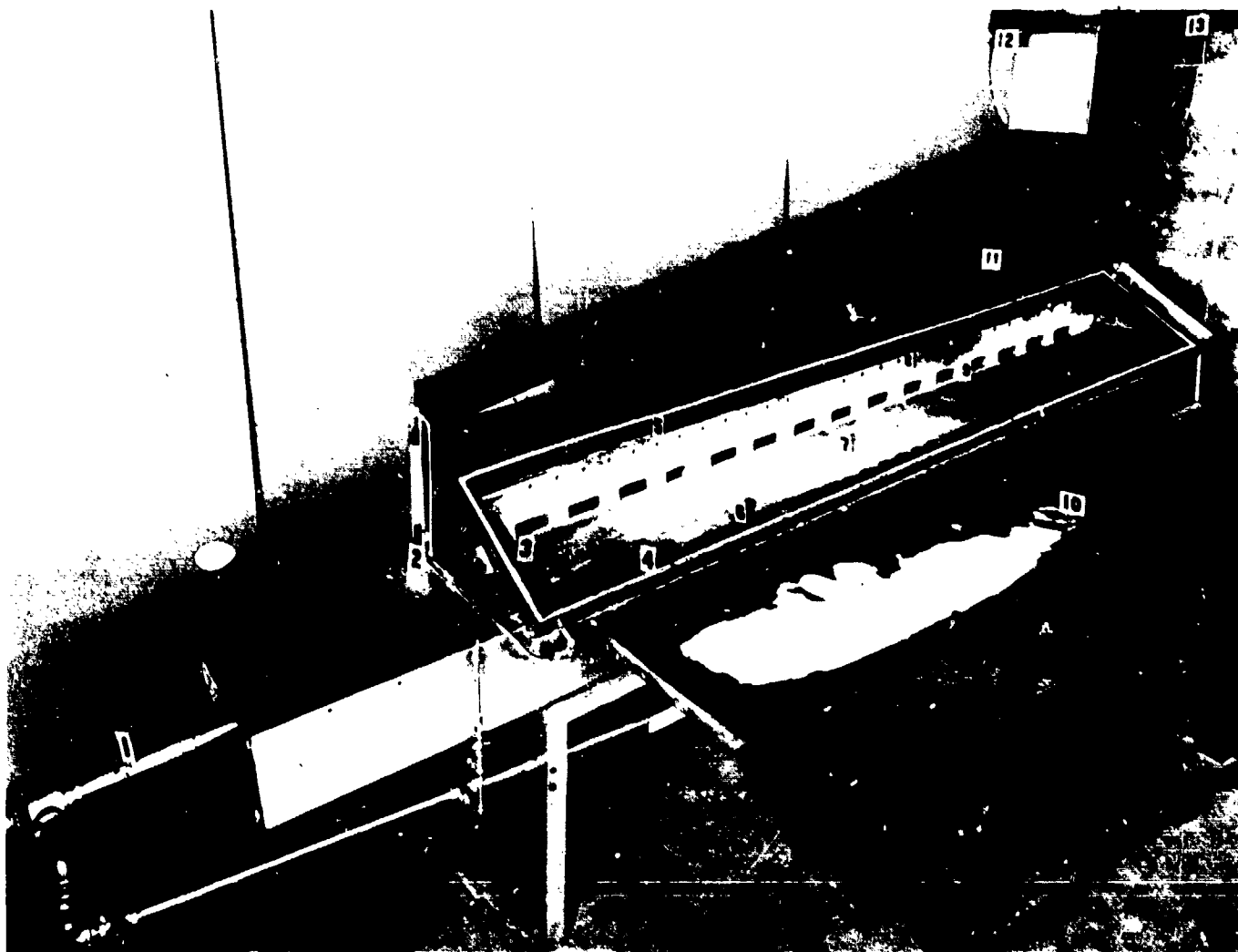


Figure 3.—The 8-foot tunnel furnace used to evaluate the flamespread characteristics of materials for research and development purposes.

(M 119 375)

char rate of 1.9 inches/hour compared with 2.1 inches/hour for the plywood.

For the first panel in the three-panel flakeboard specimens, the apparent char rate based on time at which five thermocouples averaged 550° F was an average 1.5 inches/hour (table 2). Apparent char rates based on the time at which the first of the five thermocouples reached 550° F were an average 1.6 inches/hour. The lower apparent char rate for the first panel in the three-panel specimen compared with the single-panel specimens is due to heat being conducted to the rest of the specimen instead of accumulating and increasing the temperature. The initial char rates were higher than

the steady-state char rates based on the center panel in the three-panel specimens (table 2). The production of a char layer reduces the char rate until a steady rate is obtained. The average steady-state char rate for the flakeboard was 1.2 inches/hour compared with 1.4 inches/hour for the plywood. In similar tests of four types of 1/2-inch-thick structural flakeboard, the steady-state char rates ranged from 0.99 to 1.26 inches/hour (9).

The effect of panel type *per se* (e.g., plywood vs. flakeboard) on char rates is unclear because the char rate for wood-based materials decreases with increases in the density or with increases in the moisture content of the panels (22).

Flamespread

Flamespread values from ASTM E 84 are used by building code officials to specify the flamespread requirements for interior finish materials. The A (0 to 25), B (26 to 75), and C (76 to 200) classification system of the National Fire Protection Association is typical (1). In the 25-foot tunnel furnace, the average flamespread values for three tests were 110 for flakeboard and 55 for plywood (table 3). These were calculated using the modified George-Williams-Leir (G.W.L.) method of ASTM E 84-79b and were rounded to the nearest multiple of five. Based on these results, the red oak structural flakeboard met the class C flamespread criteria of 200 or less and the thick plywood met

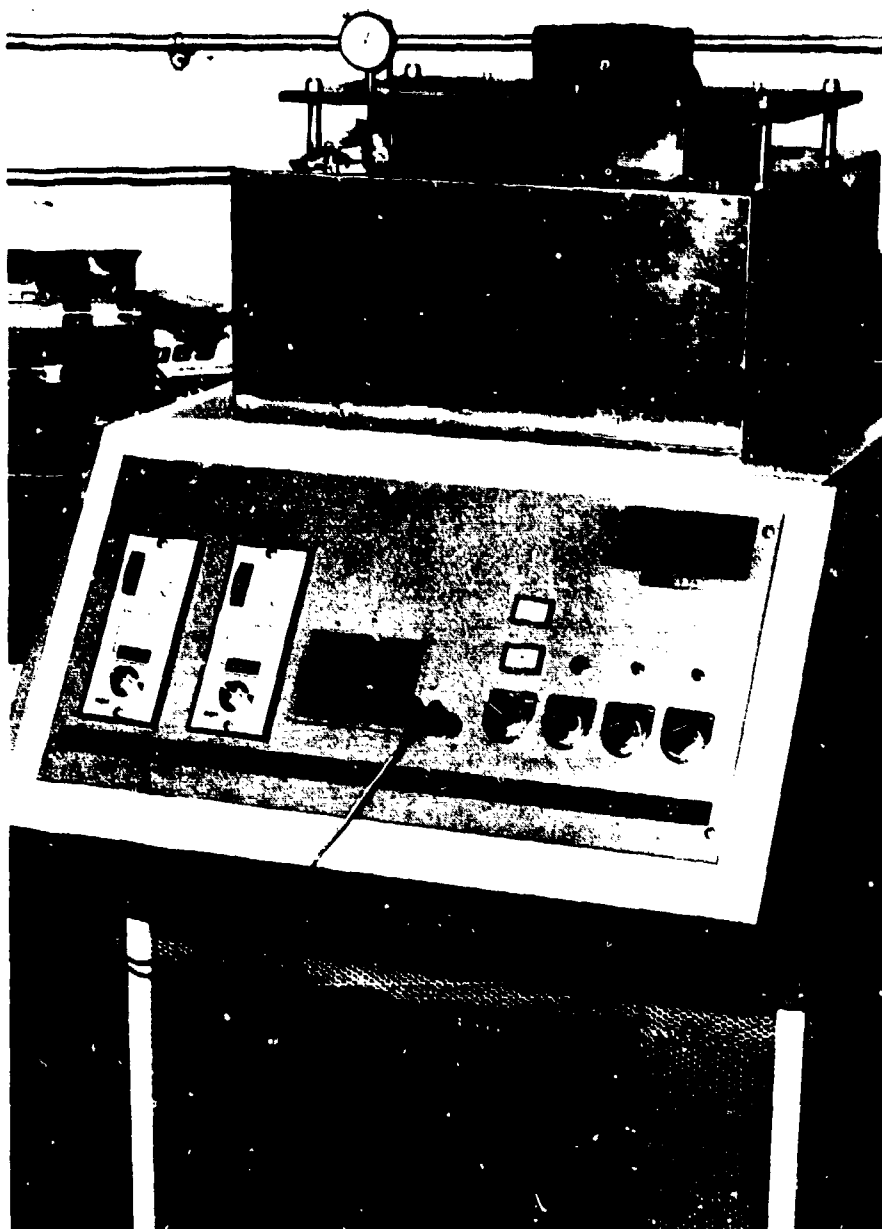


Figure 4.—The thermal conductivity tester measures the steady-state thermal transmission properties using a heat flow meter.
(M 150 084-4)

class B criteria of 75 or less. Fire-retardant-treated wood products are capable of meeting the class A criteria of 25 or less.

Computed according to ASTM E 84-75 or earlier standards, as most published flamespread values have been, the average flame-spread values were 122 and 74 for the flakeboard and plywood, respectively. The low flamespread values for the plywood were consistent with UL flamespread values (19) for

nominal 1-inch solid lumber, which indicate that Douglas-fir, hemlock, and spruce have flamespread classifications of 60 to 100. PS-1 construction plywood has a flamespread rating of 75 to 200 (1). The variation in rating depends on glue type, thickness, and species. Plywood with exterior adhesive performs better than that with interior; thick panels better than thin; and low-density species better than heavier species (1). In previous tests of four types of 1/2-inch structural

flakeboards, the average flame-spread values ranged from 71 to 189 (9).

In contrast to the 25-foot tunnel values, the flakeboard had a lower 8-foot tunnel furnace flamespread index than did the plywood (table 3). The average ASTM E 286 flame-spread indices were 98 and 112 for the flakeboard and plywood, respectively. The individual sheets of plywood were of varied species compositions and densities. Most of the plywood panels used in the 25-foot tunnel tests were from different sheets than the plywood used in the 8-foot tunnel tests. Also, fundamental differences in the construction and operation of the two furnaces result in the materials being subjected to different fire exposures not based simply on time and surface area. Relative performances of materials in fire tests depend not only on the materials but also the test method. A regression analysis of published ASTM E 84 flame-spread values (6, 19) and ASTM E 286 flamespread values (20, 21) for 13 different species of untreated lumber indicated no correlation between the two sets of values or their ranking of the different species. The data indicated that species with low ASTM E 84 flamespread (60 to 85) have higher flamespread values (102 to 134) in the ASTM E 286 and species with high ASTM E 84 flamespread values (120 to 230) have lower ASTM E 286 flamespread values (94 to 134). The relationship between the ASTM E 84 and ASTM E 286 values for the flakeboard and plywood were consistent with this pattern.

In both the ASTM E 84 and ASTM E 286 tests, a smoke-developed factor was determined (table 3). Based on test results for other untreated wood products, all of the values were acceptably low and the value of 40 in the ASTM E 84 tests of the plywood was exceptionally low. In ASTM E 84 tests of four 1/2-inch-thick structural flakeboards (9), the average smoke-developed factors ranged from 123 to 189.

Thermal Resistance

Due to confounding factors, differences between the average ther-

mal resistance for the three mean temperatures were not significant at the 5 percent level. Based on the combined data for the three mean temperatures of 39°, 77°, and 113° F (a total of nine tests per panel type), average thermal resistances were computed for the flakeboard and plywood panels (table 4).

Assuming an interior surface resistance⁴ of 0.61 and exterior surface resistance of 0.17 (18), the thermal transmittance,⁴ "U," of the flakeboard decking is 0.42. To obtain a "U" factor of 0.07 (7), insulation with a thermal resistance of 12 would have to be added to either the flakeboard or the plywood.

Assuming the material is homogeneous (not layered), an average apparent thermal conductivity⁴ of the specimen can be computed (table 4). The results are consistent with values in the literature. Because the glue in plywood has no important effect on conductivity (16), plywood is considered to be similar in thermal conductivity to solid wood perpendicular to grain. Based on curves of Kollmann and Malmquist (12) (see also 11, 13), the thermal conductivity perpendicular to grain is approximately 0.70 for 40-lb/ft³ flakeboard and 0.74 for 27-lb/ft³ solid wood. For a medium-density particleboard of 40 lb/ft³, Lewis (15) suggests an insulative design value of 0.76 as a conservative estimate of thermal conductivity. Flakeboard has a thermal conductivity nearly one-third lower than does solid wood across the grain, at the same density (13). The thermal conductivity of the red oak flakeboard is close to the value for the plywood because of the higher density of that flakeboard.

Thermal conductivity of flakeboard also increases with moisture content and with temperature. Regression analysis of the red oak flakeboard data indicated that the mean temperature had some effect on thermal conductivity but quantification of the effect was not possible. In Lewis's (15) tests of

Table 1.—Fire penetration of single-panel specimens

Test	Thickness	Time average temperature reached 250°F above ambient ¹	Time at individual thermocouple reached		Time of burn-through	Char rate ²
			325°F above ambient ¹	550°F ¹		
	In.	Min	Min	Min	Min	In./hr
FLAKEBOARD						
1	1.18	35.5	37.5	40.4	41.7	1.75
2	1.18	35.1	34.6	37.2	39.7	1.91
3	1.24	34.3	34.5	36.7	40.0	2.03
Average	1.20	35.0	35.5	38.1	40.5	1.90
Standard deviation	.03	0.6	1.7	2.0	1.1	0.14
PLYWOOD						
1	1.08	27.5	28.4	32.3	32.0	2.03
2	1.08	27.1	28.4	31.6	31.0	2.10
3	1.07	27.1	26.5	31.9	29.8	2.17
Average	1.08	27.2	27.8	31.9	30.9	2.10
Standard deviation	.01	0.2	1.1	0.4	1.1	0.07

¹ Based on 5 thermocouples under asbestos pads on the unexposed surface of the panel. A thermocouple was located in the center of the panel and the center of each quadrant.

² Computed from the time a thermocouple reached 550° F or time of burnthrough of the panel, whichever resulted in the higher char rate.

Table 2.—Fire penetration of three-panel specimens

Test	Char rate	
	Initial ¹	Steady-state ²
	<u>ln./hr</u>	
FLAKEBOARD		
1	1.50	1.15
2	1.58	1.21
3	1.55	1.15
Average	1.54	1.17
Standard deviation	.04	.04
PLYWOOD		
1	1.74	1.42
2	1.83	1.42
3	1.75	1.38
Average	1.77	1.41
Standard deviation	.05	.02

¹ Calculated from time for the thermocouples located about 1.2 in. from the fire-exposed surface to reach an average temperature of 550° F.

² Calculated from difference between times for thermocouples located about 1.2 in. and thermocouples located about 2.4 in. from fire-exposed surface to reach an average temperature of 550° F.

⁴ Units of resistance are { h·ft²·°F/BTU }, of transmittance are { BTU/h·ft²·°F }, and of conductivity are { BTU-in./h·ft²·°F }.

Table 3.—Fire performance of panels in 25- and 8-foot tunnel furnaces

Test	25-foot furnace (ASTM E 84) ¹			8-foot furnace (ASTM E 286)		
	Moisture content	Flamespread classification ²	Smoke developed	Moisture content	Flamespread index	Smoke developed
	Pct			Pct		
FLAKEBOARD						
1	8.0	107 (122)	114	5.3	93	106
2	8.4	110 (125)	154	5.5	98	133
3	7.5	106 (120)	142	5.7	102	139
Average	8.0	108 (122)	137	5.5	98	126
Standard deviation	.4	2 (2)	20	.2	4	18
PLYWOOD						
1	8.7	56 (79)	22	6.6	99	156
2	10.3	53 (69)	41	6.5	112	103
3	9.9	56 (73)	52	6.8	124	110
Average	9.6	56 (74)	38	6.6	112	123
Standard deviation	.8	2 (5)	15	0.2	12	29

¹ Current practice is to round the average results to the nearest multiple of 5. Thus, the flakeboard had a flamespread of 110 and smoke developed of 135 and the plywood had a flamespread of 55 and smoke developed of 40.

² Flamespread classification calculated in accordance with ASTM E 84-79b (in parentheses, according to E 84-75).

Table 4.—Thermal resistance

Panel	Density	Thermal resistance		Apparent thermal conductivity	
		Value	Coefficient of variation	Value	Coefficient of variation
	Lb/ft ³	h·ft ² ·°F/BTU	Pct	BTU-in./h·ft ² ·°F	Pct
Flakeboard	39.5	1.58	6.2	0.74	6.4
Plywood	27.5	1.66	4.4	0.66	4.8

ovendry particleboards, the increase in thermal conductivity with mean temperatures was 0.00093 units per °F. Based on curves of Kuhlmann (14) (see also 13), the increases with mean temperature were about 0.0004 units per °F for ovendry particleboard and 0.003 units per °F for particleboard at 20 percent moisture content. Kuhlmann's (14) curves also indicated that thermal conductivity increased about 0.005 per unit increase in percent moisture content for a temperature of -4° F and 0.026 per unit increase in percent moisture content for a temperature of 176° F.

Conclusions

Small-scale performance testing of the red oak structural flakeboard indicated that it has satisfactory thermal characteristics for a wood-base product. The fire penetration performance of the flakeboard exceeded the performance of 1-1/8-inch-thick plywood roof decking. Based on three ASTM E 84 tests, the flakeboard met the class C criteria of 200 or less for flamespread. The thermal resistance of the thick flakeboard was consistent with suggested insulative design values for particleboard with a 40-lb/ft³ density.

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As part of a cooperative project between Purdue University and FPL, 1-3/16-inch-thick structural flakeboard was small-scale tested for fire penetration, flamespread, and thermal resistance. Performance was satisfactory for a wood-base product: Fire penetration resistance exceeded that of plywood accepted as roof decking; flamespread performance met class C criteria; thermal resistance was consistent with suggested insulative design values.