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Fire Resistance of Engineered Wood Rim Board Products

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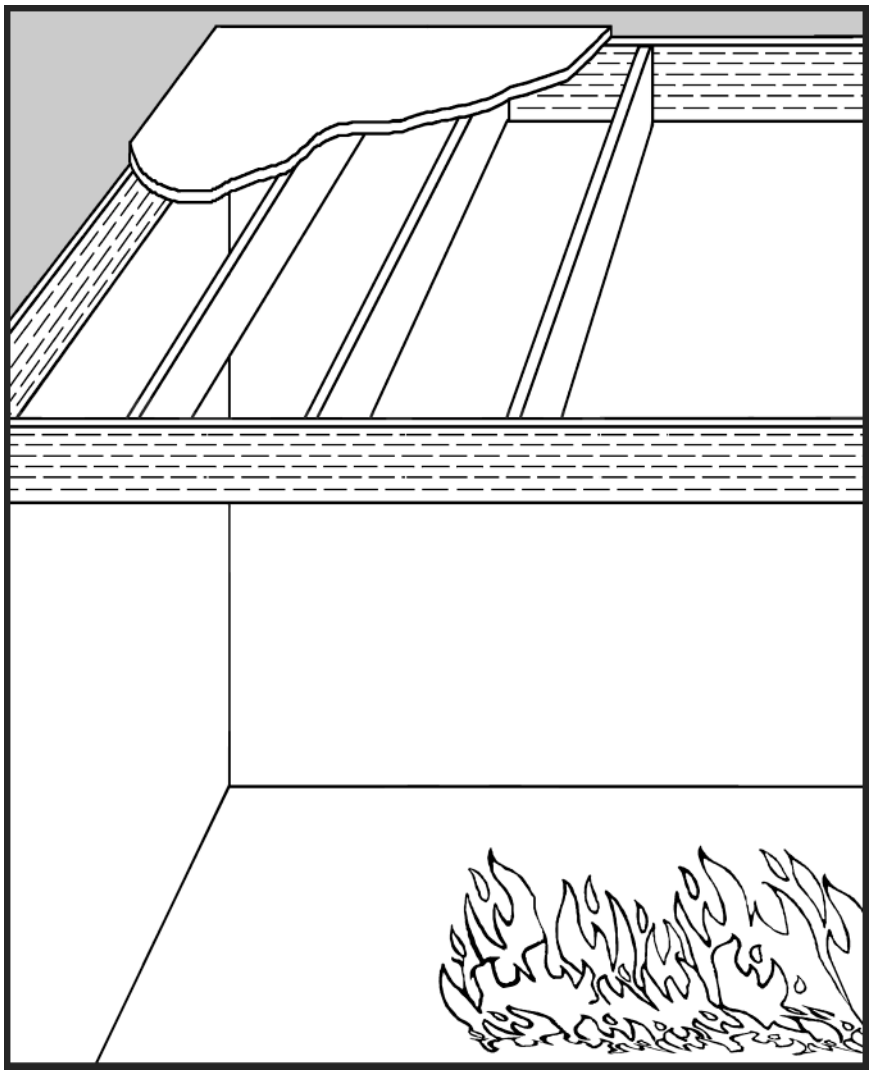

Abstract

Engineered wood products, such as oriented strandboard, laminated veneer lumber, and other composite wood products, are being used more often in construction. This includes use as rim boards, which are the components around the perimeter of a floor assembly. This situation has increased the need for information about the fire resistance of these products. In this study, we evaluated different engineered wood products for fire resistance using both the ASTM E119 standard for fire exposure and a modified time–temperature curve. We looked at unprotected, gypsum-board-protected, and double gypsum-board-protected rim boards. Using the data from this study, we evaluated possible construction options for achieving certain levels of fire resistance of engineered wood products in use as rim boards. We also developed a simple analysis method for evaluating the protection provided by the rim board.

Keywords: fire resistance, rim boards, composite wood products

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Fire Resistance of Engineered Wood Rim Board Products

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Introduction

As the use of engineered wood products has increased, the need for test data to support their use as fire barriers has also increased. This study evaluated various engineered wood products, in use as rim boards, for their resistance to fire penetration when exposed to the fire exposure specified in ASTM E119 (ASTM 2000).

Engineered wood products, such as oriented strandboard (OSB), are sometimes used as rim boards in floor assemblies. Rim boards are the structural components around the perimeter of a floor assembly, running both parallel and perpendicular to the floor joists. The ends of the floor joists are connected to the rim boards. In addition to providing lateral support to the floor joists, the rim boards must also be able to support the loads applied to the walls above. Fire-rated floor and wall assemblies are those tested and rated for fire resistance according to ASTM E119. Ratings are typically in the range of 45 to 120 min.

Due to their location in the assembly and the protection provided by the gypsum membrane in a fire-rated assembly, the rim boards in many applications may not be directly exposed to fire in ASTM E119. To investigate this condition, tests were also conducted using a modified time–temperature curve designed to simulate a rim board of a gypsum-protected assembly. In this study, wood products were tested both in direct exposure and with gypsum protection. The tests for this project were conducted without any load on the specimens.

Background

Rim Boards

Engineered wood products used as rim boards include plywood, OSB, glued-laminated timber, laminated veneer lumber (LVL), and I-joists. In addition to being the members perpendicular to the floor joists, rim boards are also used in the parallel direction as the starter joist.

Performance standards for engineered wood products used as rim boards have been developed by APA—The Engineered Wood Association (Tacoma, WA) (APA 2000b). In the APA performance standard (APA 2000b), the minimum nominal thickness is limited to either 25.4 mm (1 in.) for “APA EWS Rim Board” or 28 mm (1.125 in.) for “APA EWS Rim Board Plus” and the depth is not to exceed 610 mm (24 in.). As fire-blocking panels, “APA Performance Rated Rim Boards”, at minimum thickness of 25.4 mm, exceed the minimum requirement of 18 mm (0.7 in.) published in the model building codes (APA 2000a).

Past FPL Research

The tests of this study are similar to small vertical furnace tests conducted previously at the USDA Forest Service, Forest Products Laboratory (FPL). In Holmes and others (1979), four 13-mm- (0.5-in.-) thick structural flakeboards were tested in the small vertical furnace. Specimens were single panels or four plies of panels. Flame penetration times for the single layers ranged from 11.5 to 16.0 min. Char rates in the four-layer specimens ranged from 0.52 to 0.59 mm/min (0.020 to 0.023 in/min (1.92 to 1.69 min/mm)). Later, a 30-mm- (1.19-in.-) thick red oak structural flakeboard and 29-mm- (1.125-in.-) thick softwood plywood were tested (White and Schaffer 1981). These were tested as single layer and as three-layer specimens. Average flame penetration times for the single-panel specimens were 40.5 min for the flakeboard and 30.9 min for the plywood.

Various wood-based panel products were tested as thermal barriers for foam-plastic insulation (White 1982). Products included a particleboard, a hardboard, and various plywoods. In these tests, the panels were tested over a foam-plastic substrate. Fire penetration times depended on thickness, density, and moisture content. Options for improving the fire resistance with coatings have also been investigated (White 1986). Results for the charring rates of composite lumber products were reported at the Wood and Fire Safety Conference (White 2000). In these tests, thermocouples were placed at different depths to get the charring rates.

Materials

The manufacturers supplied the APA-trademarked composite rim boards to FPL in the form of 0.61- by 2.44-m (24- by 96-in.) panels. The thickness was from 25.4 to 31 mm (1 to 1.25 in.). Materials included three OSBs, a plywood, a Com-Ply, and an LVL product (Table 1). The Com-Ply product

Table 1—Wood products tested

Designation	Product type	Species	Thickness (mm)	Density (oven-dry) (kg/m^3)	Moisture content (%)
OSB-A	OSB	Mixed hardwoods	28	520	9
OSB-B	OSB	Southern Pine	29	630	8
OSB-C	OSB	Mixed hardwoods	29	580	8
PLYW	Plywood	Southern Pine	24	490	11
COMP	Com-ply	Douglas-fir	27	590	10
LVL	LVL	Douglas-fir	31	520	10

Table 2—Gypsum products tested

Designation	Product type[a]	Thickness (mm)	Area weights (kg/m^2)	Density (kg/m^3)
Gypsum H	Type X	13	10.5	800
Gypsum I	Regular	13	8.0	650
Gypsum J	Type X	16	11.0	680
Gypsum K	Type X	16	10.9	690

[a]Type X is fire rated.

had five layers including the two face veneers, two wood fiber layers, and a veneer center layer. The plywood consisted of seven layers, and the LVL had eleven layers of veneer. Specimens were conditioned at 23°C (73°F) and 50% relative humidity (RH). Moisture content ranged from 8% to 11%.

The gypsum wallboard products were 13- and 16-mm- (0.5- and 0.625-in.-) thick gypsum boards (Table 2). They were purchased from local building supply retail outlets. The 13-mm-thick gypsum boards included a fire-rated Type X and a regular (not fire-rated) gypsum board.

Methods

Tests were conducted in the FPL small vertical furnace and the FPL intermediate-scale horizontal furnace. The specimen sizes used in this test program were considerably smaller than that required by the ASTM E119 standard (ASTM 2000). The standard sizes are minimum 9 m^2 (100 ft^2) for a vertical specimen and 16 m^2 (180 ft^2) for a horizontal specimen.

Except for limited testing in the small vertical furnace using a modified time–temperature curve, the specimens were tested in a furnace using the time–temperature curve specified in ASTM E119.

Figure 1—Small vertical furnace at FPL with rim board test specimen.

The small vertical gas-fired furnace has a square opening for the test specimen (Fig. 1). The opening is 510 by 510 mm (20 by 20 in.). This concrete furnace has pipe outlets for discharging the natural gas into the furnace. A single furnace thermocouple in a capped metal pipe, opposite the center of the test specimen and 50 mm (2 in.) from the exposed surface, is used to control the furnace. The flow of natural gas is controlled so that the furnace temperature follows the desired time–temperature curve. Due to the placement of the pipe outlets, the furnace thermocouple is closer to the specimen surface than the 152 mm (6 in.) specified in ASTM E119. All air for combustion is admitted by natural draft through side vents near the bottom of the furnace.

The intermediate-scale horizontal furnace at FPL has overall dimensions of 2.1 by 1.3 m (83 by 51 in.) (Fig. 2). It can be used with a tension apparatus to obtain data on a member under simultaneous tensile load and fire exposure (White and others 1993). The interior dimensions are 1.68 by 0.96 m (66 by 38 in.). This mineral-fiber-lined furnace has eight diffusion-flame natural gas burners on the floor of the furnace. All air for combustion is admitted by natural draft through vents at the bottom and ends of the furnace. There are three furnace thermocouples in capped metal pipes along each of the two 2.1-m sides of the furnace. These thermocouples are approximately 305 mm (12 in.) from the exposed surface of the test specimen, the distance specified by ASTM E119 for horizontal specimens. As with the small vertical furnace, gas flow is controlled so the furnace temperature follows the desired time–temperature curve.

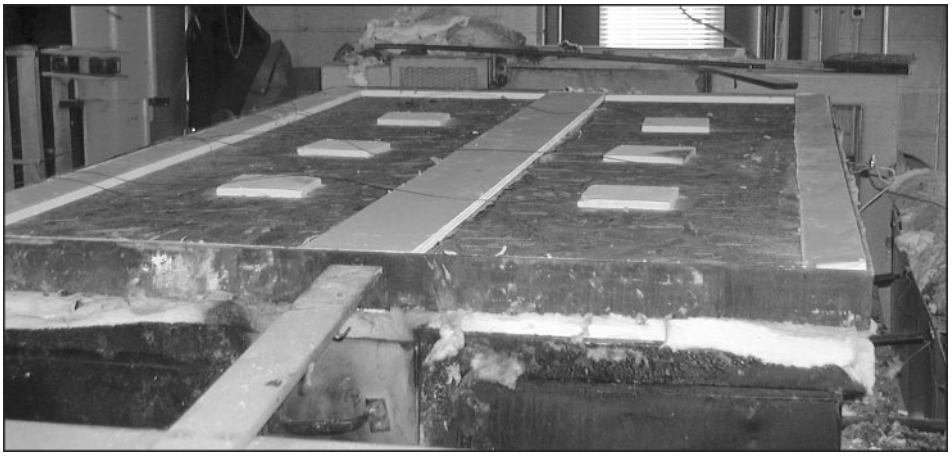

Figure 2—Rim board test specimen on top of the intermediate-scale horizontal furnace. The center 150-mm- (5.9-in.-) wide piece of gypsum board covers the butt joint of the two 590-mm- (23.2-in.-) wide pieces of rim board material.

Observations included the times for thermocouples to record temperature increases of 139°C average or 181°C maximum, an actual temperature of 300°C (572°F), and flame penetration to the unexposed surface. The 139°C/181°C and flame penetration criteria are specified in ASTM E119 and the 300°C criteria is generally accepted as the temperature at the base of the char layer for wood exposed to the ASTM E119 fire exposure. Thermocouples within or on the specimens were made from 0.25-mm- (0.01-in.-) diameter (30-gage) Chromel-Alumel (Type K) wires.

Small Vertical Furnace

ASTM E119 Temperature

Tests done in the small vertical furnace included single-layer, double-layer, and protected rim boards. Two replicates of each of the six rim boards (Table 1) were tested as single-layer specimens. On the unexposed surface, five thermocouples were placed beneath 50- by 50-mm dry, felted pads. These thermocouples were used to obtain the times for the 139°C/181°C and 300°C criteria. The pads were smaller than the 152- by 152-mm dimensions specified in ASTM E119. These thermocouples were placed in the overall center of the 510- by 510-mm panel and in the center of each quadrant of the panel (Fig. 1).

Double-layer panels of the composite rim board products were also tested. In addition to the five thermocouples on the unexposed surface, five thermocouples were placed between the two glued panels. A single replicate of each of these double-layer specimens was tested.

In a subsequent series of tests, selected composite rim board products were tested with the following protection configurations (the gypsum wallboard was attached to the fire-exposed side of the test specimen):

- **13-mm gypsum:** One layer of 13-mm-thick Type X or regular gypsum board directly fastened to the rim board
- **16-mm gypsum**: One layer of 16-mm-thick Type X gypsum board directly fastened to the rim board
- **16-mm gypsum, gap**: One layer of 16-mm-thick Type X gypsum board fastened to 19-mm- (0.75-in.-) thick, 25.4-mm-wide wood furring placed around the edges of the 510- by 510-mm panel leaving a 19-mm gap between the gypsum and the wood panel
- **Double 13-mm gypsum:** Two layers of 13-mm-thick Type X gypsum board directly fastened to the rim board
- **Double 16-mm gypsum**: Two layers of 16-mm-thick Type X gypsum board directly fastened to the rim board

For the tests with a single layer of gypsum board, 38-mm- (1.5-in.-) long Type W drywall screws were used. In the tests of double layers of gypsum board, the fasteners were 50-mm Type W drywall screws. The spacing of the screws was 230 mm (9 in.) on center around the edges of the 510- by 510-mm panel and 25.4 mm from the edges.

Modified Time–Temperature Curve

APA provided FPL with test data for three intermediate-scale fire tests of floor–ceiling assemblies. The assemblies tested contained four wood I-joists (241 mm high, 610 mm on center, with a 2.5-m span (9.5 in. high, 24 in. on center, with a 99-in. span)) with a ceiling of one layer of gypsum board (16 mm, Type C) attached to RC-1 resilient channels. In these tests, time–temperature data were recorded on the rim board and on the plenum (Fig. 3).

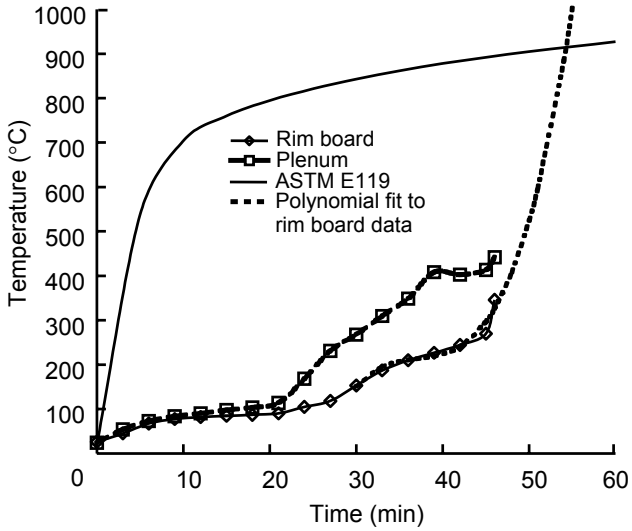

Figure 3—Time–temperature curves pertaining to modified time–temperature tests.

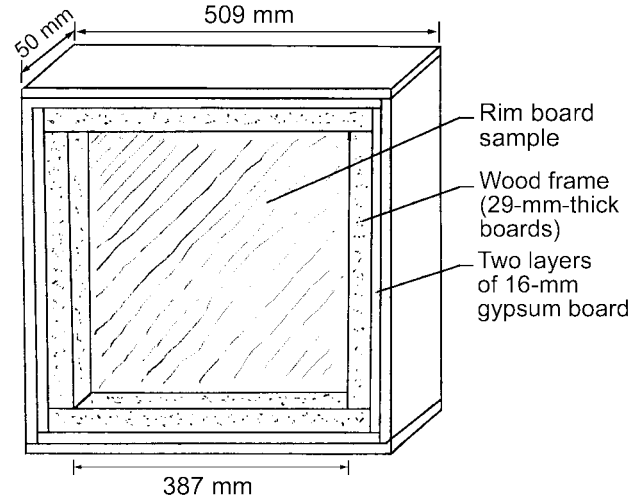

Figure 4—Specimen for tests in small vertical furnace using modified time–temperature curve. The test sample of the rim board, and gypsum in some tests, was attached to the back or nonfire-exposed side of the wood frame. Gypsum board was added to edges of the specimen to prevent failure through the sides of the wood frame.

The data for the uninsulated assembly were used to develop a modified time–temperature curve as a more realistic approach (Fig. 3). Since the test was terminated at 47 min, data beyond this amount of time were not available. To estimate the time–temperature curve beyond the 47 min, a third-order polynomial equation was fitted to the last portion of the test data and that equation was used to predict data for later times until the temperatures of ASTM E119 were reached. The ASTM E119 time–temperature curve was used thereafter.

To better simulate the interaction of the rim board and the floor joists, the rim board was placed on the back, open end of a 50-mm-deep wood frame that was placed in the opening of the furnace. The frame was built from 29-mm-thick rim boards and had outer dimensions of 445 by 445 mm (17.5 by 17.5 in.). The outer edges were covered with two layers of 16-mm Type X gypsum board to ensure that failure occurred out the back of the test specimen (Fig. 4).

In these tests, OSB-C rim board was tested unprotected and protected by a single layer of 16-mm Type X gypsum board. Two replicates of each type were tested. Initially, a bare thermocouple was placed on the rim board to control the furnace. Later, a bare thermocouple was wrapped around the metal pipe furnace thermocouple and that thermocouple was used to control the furnace. As will be noted later, we had considerable difficulty controlling the temperatures in the small vertical furnace to follow this modified time–temperature curve.

Intermediate-Scale Horizontal Furnace

Five tests were conducted using the 2.1- by 1.3-m horizontal furnace. Test configurations included

- Unprotected LVL
- Unprotected OSB-C
- 16-mm gypsum board protected OSB-C (one layer of 16-mm Type X gypsum board directly fastened to the fire-exposed (underside) of the rim board)
- 13-mm gypsum board protected OSB-C (one layer of 13-mm Type X gypsum board directly fastened to the fire-exposed (underside) of the rim board)
- Double 13-mm gypsum board protected OSB-C (two layers of 13-mm Type X gypsum board directly fastened to the fire-exposed (underside) of the rim board)

The rim board portion of the test specimen was constructed by placing two 590-mm-wide, 2.1-m-long panels side by side on top of the furnace (Fig. 2 and 4). To prevent failure from occurring along the edges of the panels, 75-mm (3-in.) strips of gypsum board were also placed along the outer edges of the test specimen. There was also a 150-mm-wide strip of gypsum glued over the 2.1-m-long butt joint of the two 509-mm- (23-in.-) wide panels. As a result, two areas of the test specimen were not covered with gypsum board on the top (Fig. 2). The interior dimensions of the furnace are 1.68 by 0.96 m. Thus, the two areas for potential flame penetration were approximately 1.68 by 0.4 m (66 by 16 in.). Each layer of the gypsum board protection was constructed using two 1.2- by 1.1-m (48- by 42-in.) panels. The 1.2-m-long joint between these two panels was taped. Fasteners of the gypsum board were placed 305 mm on center at the boundary and over the interior. Fasteners were 38-mm Type W drywall screws for the single-layer tests and 50-mm Type W drywall screws for the double-layer test.

Within each of the two areas not covered with gypsum board on the top surface, three thermocouples were placed on the top surface of the rim board. Thermocouples were at the center of the exposed area and 460 mm (18 in.) from each side of the center thermocouple. Dry, felted pads (150 by 150 mm) were placed over the thermocouples (Fig. 2).

Results

Small Vertical Furnace

ASTM E119 Temperature

Single layers of the different rim boards were tested in the initial series of tests. The rim boards were tested in the small vertical furnace using the standard time–temperature curve specified in ASTM E119 (ASTM 2000). Temperatures on the unexposed surface of the rim boards were recorded. All furnace exposures recorded by the controlling furnace thermocouple were within the accuracy limits for deviation from the standard time–temperature curve as specified by ASTM E119.

Results for these tests included the times for flame penetration, temperature of 300°C, and temperature increase of 139°C/181°C (Table 3). Flame penetration occurred beneath the felted pads due to the insulating effect of the pads.

Thus, the 300°C criteria normally preceded visual evidence of flame penetration. The times for the temperature criteria are based on data from the five thermocouples on the unexposed surface. The times listed for 300°C are the quickest times from one of the five thermocouples. The times for the 139°C/181°C criteria are either the times for the 139°C temperature increase based on averages of the data from the five thermocouples or the times for an individual thermocouple to increase by 181°C.

Charring rates in Table 3 were calculated assuming a simple linear model of times for 300°C divided by rim board thickness. This simple model is

$$t_{300°C} = m_1 x_b \tag{1}$$

where $t_{300°C}$ is time for 300°C (min), m_1 linear char rate parameter (min/mm), and x_b rim board thickness (mm).

The char rates in Table 3 were calculated using the corresponding time and thickness listed. The fastest linear char rates and times-to-failure were obtained in the tests of the 24-mm- (1-in.-) thick plywood rim board. The indicated faster linear char rate for plywood partially reflects the effect of a thinner specimen on the results due to nonlinear charring behavior (Eq. (2)). Of the three OSB rim boards, OSB-A had the fastest linear char rates and times-to-failure. The LVL rim board was tested three times due to warping of the specimens. Because of the warping, there was a loss of furnace temperature near the end of the tests and problems with surface flames around the edges of the specimen.

Table 3—Small vertical tests of single layers (ASTM E119 exposure)

Test no.	Specimen type	Thickness (mm)	Times (min) for 139°C /181°C	Times (min) for 300°C	Times (min) for Flame penetration	Linear char rate (m_1, Eq. (1)) (min/mm)
1695	OSB-A	28	29	33	35	1.19
1696	OSB-A	28	28	32	33	1.15
1697	OSB-B	29	31	36	39	1.24
1698	OSB-B	29	30	35	35	1.20
1688	OSB-C	29	32	36	36	1.24
1689	OSB-C	30	33	38	37	1.27
1686	PLY	24	21	23	25	0.97
1687	PLY	24	21	23	25	0.94
1690	COMP	28	30	34	37	1.22
1691	COMP	27	30	34	37	1.27
1692	LVL	32	36	40	40	1.26
1693	LVL	31	37	42	41	1.35
1694	LVL	31	35	41	43	1.31

Double-layer specimens of the rim boards were tested in the second series of small vertical furnace tests using the ASTM E119 time–temperature curve. In addition to the five thermocouples on the unexposed surface, five thermocouples were placed between the two rim boards, which had been glued together with a phenol-resorcinol adhesive. The results recorded were the flame-penetration times and times to reach 300°C on the unexposed surface of the specimen and between the two layers (Table 4). For the data in Table 4, the times for 300°C are the quickest times indicated by the five thermocouples on the unexposed surface of the first and second layers. Linear char rates (m_1 from Eq. (1)) (Table 5) were calculated from the corresponding time and thickness given in Table 4. The char rate for the second layer is based on additional time for the second layer beyond the time for the first layer (Table 5). As with the single-layer tests, the 24-mm-thick southern pine plywood rim board had both the quickest failure times and linear char rates. Of the three OSBs, the 28-mm-thick OSB-A had the quickest failure times and linear char rates.

A nonlinear model for times to 300°C ($t_{300°C}$) and the char depth (x_c) was developed by White and Nordheim (1992):

$$t_{300°C} = m_2 \, x_c^{\,1.23} \tag{2}$$

where m_2 is nonlinear char rate parameter (min/mm$^{1.23}$).

Table 4—Thicknesses and times for small vertical tests of double rim boards (ASTM E119 exposure)

		Thickness (mm)			Times for unexposed surface (min)		
						Both layers	
Test no.	Specimen type	1st layer	2nd layer	Both layers	1st layer to 300°C	139°C/181°C	300°C
1702	OSB-A	28	28	56	40	75	81
1704	OSB-B	29	29	59	42	78	83
1700	OSB-C	29	29	58	43	85	88
1699	PLYW	24	24	49	31	56	60
1703	COMP	27	26	53	38	73	80
1701	LVL	31	31	63	45	87	90
1705	LVL	31	31	63	46	87	89

Table 5—Char rates (m_1 and m_2) for small vertical tests of double rim boards (ASTM E119 exposure)

		Linear char rates (m_1, Eq. (1)) from Table 4 data[a] (min/mm)			Char rates from regression of data for all five thermocouples on unexposed surface of first layer	
Test no.	Specimen type	1st layer	2nd layer[b]	Both layers	Linear char rate (m_1, Eq. (1)) (min/mm)	Nonlinear char rate (m_2, Eq. (2)) (min/mm$^{1.23}$)
1702	OSB-A	1.42	1.48	1.45	1.45	0.677
1704	OSB-B	1.42	1.40	1.40	1.46	0.670
1700	OSB-C	1.47	1.58	1.52	1.52	0.701
1699	PLYW	1.27	1.19	1.23	1.31	0.629
1703	COMP	1.44	1.58	1.50	1.50	0.704
1701	LVL	1.43	1.42	1.42	1.52	0.687
1705	LVL	1.48	1.38	1.41	1.52	0.689

[a]Table 4 data are for the thermocouple on a given surface with the quickest times.
[b]Char rate = $(t_2 - t_1)/(x_2)$ where t_2 is time for 2nd layer, t_1 is time for 1st layer, and x_2 is thickness of second layer.

Also in Table 5, we list the linear (m_1) and nonlinear (m_2) char rate parameters calculated using linear regression analysis of the 300°C times for all five thermocouples between the two layers and the thickness of the rim board. A form of this nonlinear model (Eq. (2)) is used in the predictive model described in AF&PA (1999) for determining the fire endurance of wood members.

Protected rim boards were tested in the final series of small vertical furnace tests with the ASTM E119 fire exposure. Different types of rim board were tested with the following protection configurations:

- 13-mm gypsum board directly applied
- 16-mm gypsum board directly applied
- 16-mm gypsum board applied to wood furring strip for air gap
- Double 13-mm gypsum board directly applied
- Double 16-mm gypsum board directly applied

The 13-mm gypsum boards for the single-layer tests included both regular and fire-rated Type X gypsum board (Table 2). Two different Type X, fire-rated 16-mm gypsum boards (Table 2) were tested as single-layer protection directly applied. In some tests, there were thermocouples placed between the layers. The protection provided by the gypsum board substantially improved the fire endurance times (Table 6).

Modified Time–Temperature Curve

Unprotected and protected OSB-C rim board samples were tested in a limited series of tests using a modified time–temperature curve representing the exposure of the rim board within a fire-rated floor–ceiling assembly. We had considerable difficulty in keeping the furnace exposure consistent with the modified time–temperature curve. In particular, we were not able to increase the furnace temperature to the levels of the ASTM E119 time–temperature curve after keeping it at the very low levels for the initial segments of the modified time–temperature curve. We terminated these

Table 6—Small vertical furnace tests of rim boards with gypsum protection (ASTM E119 exposure)

		Times (min) for				
		139°C/181°C rise in temperature		300°C		
Test no.	Gypsum protection (Table 2)	Wood–gypsum interface	Unexposed surface of rim board	Wood–gypsum interface	Unexposed surface of rim board	Gain over unprotected rim board[a]
			OSB-C			
1718	13-mm H	14	63	18	65	28
1736	13-mm I (Reg.)	14	62	18	66	29
1735	16-mm K[b]	27	81	30	89	44
1706	16-mm J	—	71	—	76	39
1709	16-mm J with gap	—	67	—	70	33
1719	Double 13-mm H	17/ 47[c]	112	55	125	88
1710	Double 16-mm J	—	126	—	134	97
			Plywood			
1707	16-mm J	—	58	—	65	42
1708	16-mm J with gap	—	60	—	65	42
1711	Double 16-mm J	—	111	—	117	94
			OSB-A			
1720	13-mm H	17	55	22	57	25
1722	16-mm J	18	64	22	66	34
1721	Double 13-mm H	15/ 48[c]	111	58	117	85

[a]The times for 300°C in the tests of the unprotected rim boards were 37, 23, and 32 min for OSB-C, plywood, and OSB-A, respectively (Table 3).
[b]This 16-mm gypsum board was used in horizontal furnace tests.
[c]Results for gypsum board–gypsum board interface of first layer and gypsum board–wood interface of the second layer of gypsum board.

tests at 60 min. Char depths and maximum temperatures on the unexposed surface were recorded (Table 7). The time zero of fire exposure initiation was shifted to improve the agreement of the recorded time–temperature curves with the specified time–temperature curves. In the tests of the OSB-C protected with 16-mm gypsum board J, there was no charring of the rim board at the conclusion of the 60-min test.

Intermediate-Scale Horizontal Furnace

The results for 300°C in the horizontal furnace (Table 8) were generally consistent with that obtained in the small vertical furnace tests (Tables 3 and 6). In the test of OSB-C protected with a single 13-mm fire-rated gypsum board H (Test No. 2130), the temperature rise of 139°C/181°C occurred on the backside of the gypsum board at 21 min. Failure of the gypsum board was heard at about 71 min. In the test of OSB-C protected with two layers of 13-mm fire-rated gypsum board H, the temperature rise of 139°C/181°C occurred on the backside of the first layer of gypsum board at 15 min and the backside of the second layer at 40 min. Failure of the gypsum board was heard at 76 min and at 120 min. Visual observation inside the furnace was not possible.

Analysis and Discussion

Unprotected Rim Board

The data for the unprotected rim boards include times for the back, unexposed surface of the rim board (single- and double-layer specimens) to reach 300°C and data for the back surface of the first layer in the double-layer specimen to reach 300°C (Fig. 4). With Equation (2) applied to the combined data, the equation for the times to reach 300°C ($t_{300°C}$, min) on the back surface of a rim board of thickness x_b (mm) is (Fig. 4)

$$t_{300°C} = 0.5611\, x_b^{1.23} \quad (3)$$

This corresponds to a failure time of 34 min for a 28-mm-thick rim board. For the 139°C/181°C temperature criteria, the value of the m_2 parameter is 0.5227.

Table 7—Test results for OSB-C tested with modified time–temperature curve in the small vertical furnace

Test no.	Protection	Duration of exposure[a] (min)	Char depth (mm)	Max. temp. on unexposed surface (°C)
1712	None	54	16	120
1713	None	54	17	166
1714	16-mm gypsum J	53	0	43
1715	16-mm gypsum J	55	0	42

[a]Actual duration of test was 60 min. The time zero was shifted to reduce differences between recorded temperatures and the specified time-temperature curve.

Table 8—Results for horizontal furnace tests (ASTM E119 exposure)

		Times (min) for unexposed surface				
				300°C		
Test no.	Protection	139°C /181°C rise in temperature	Flame penetration	Test sample	Improvement over unprotected sample	Small vertical results[a]
			OSB-C			
2128	Unprotected	24	33	29	—	36, 38
2130	13-mm gypsum H	73	83	76	47	65
2129	16-mm gypsum K	77	86	80	51	89
2131	Double 13-mm gypsum H	116	122	118	89	125
			LVL			
2127	Unprotected	36	44	40	—	40–42

[a]From Tables 3 and 6.

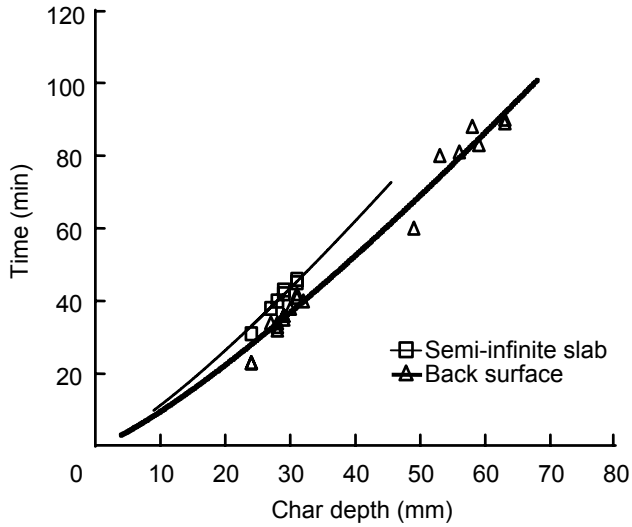

Figure 5—Plot of times to 300°C in single-layer and double-layer tests of unprotected rim boards. First-layer data from double-layer tests is identified as a semi-infinite slab. Regression of data using the nonlinear time–char depth model (Eq. (2)).

The data for the first layer of the double-layer specimen are valid for charring of a semi-infinite slab. The equation for the times to reach 300°C ($t_{300°C}$, min) at a depth x_c (mm) in a rim board (Fig. 5) is

$$t_{300°C} = 0.6637\, x_c^{1.23} \qquad (4)$$

The estimated time for a semi-infinite slab reflects the conduction of heat into the wood beyond the char base. The nonlinear nature of the charring reflects the insulative effect of the char layer on further charring. As the back surface increases in temperature, the insulative boundary condition of the back surface reduces heat transfer out the back and the char rate increases.

Comparison With Data for Wood Products

A linear charring rate of 1.6 min/mm (0.6 mm/min, 38 mm/h, 1.5 in/h) is generally assumed for charring of a semi-infinite slab of solid wood or glued-laminated lumber. Except for plywood (1.31 min/mm (0.76 mm/min, 1.8 in/h)), the linear char rates for the composite rim boards ranged from 1.45 to 1.52 min/mm (0.7 to 0.66 mm/min, 1.65 to 1.56 in/h), or slightly faster than the 1.6 min/mm charring rate for solid wood. The linear char rate obtained by regression of all first-layer data (Table 5) of the double-layer specimens is 1.36 min/mm (0.74 mm/min, 1.75 in/h). A nonlinear parameter (m_2) of 0.6839 corresponds to a char depth of 38 mm at 1 h. Equation (4) for the combined data set corresponds to a char depth of 39 mm (1.53 in.) at 60 min.

In the 1980s, FPL tested a 30-mm-thick red oak flakeboard (density of 633 kg/m^3 (39.5 lb/ft^3)) and a 29-mm-thick plywood (density of 440 kg/m^3 (27.5 lb/ft^3)) (White and Schaffer 1981). The individual veneers of the plywood were a mixture of western species. Failure times (288°C (550°F)) in the single-layer tests averaged 32 min (1.2 min/mm (0.83 mm/min, 1.96 in/h)) for the western species plywood. In this study, the 24-mm-thick southern pine plywood (density of 489 kg/m^3 (30.5 lb/ft^3)) failed in 23 min (0.96 min/mm (1.04 mm/min, 2.45 in/h)). In White and Schaffer (1981), failure times (288°C) in the single-layer red oak flakeboard tests averaged 38 min (1.3 min/mm). In this study, the three 29-mm-thick OSBs (densities of 516 to 628 kg/m^3 (32.2 to 39.2 lb/ft^3)) failed in 32 to 38 min (1.14 to 1.27 min/mm (0.88 to 0.79 mm/min, 2.08 to 1.87 in/h)) in the single-layer tests.

Charring rate for the initial layer of the multilayer plywood specimen was 1.33 min/mm (0.75 mm/min, 1.77 in/h) in White and Schaffer (1981) compared with 1.27 min/mm in this study. Charring rate for the initial layer of the three-layer flakeboard specimen was 1.53 min/mm in White and Schaffer (1981) compared with an average 1.46 min/mm for the initial layer of the multilayer OSB specimen in this study. In the 1970s, we tested samples consisting of four layers of 13-mm flakeboard (Holmes and others 1979). For the four types of flakeboard tested, the char rates for the initial 13-mm layer averaged 1.37 min/mm.

Fire penetration times for the finitely thick panels, as determined by thermocouples under an insulative pad, were faster than that expected from data for the charring of semi-infinite slabs (Fig. 5). In this study, the six rim boards had charring rates of 0.94 to 1.35 min/mm in the single-layer tests. As just noted, char rates for the initial 13-mm layer averaged 1.37 min/mm in Holmes and others' (1979) tests of multilayer flakeboard samples. In the tests of the 13-mm flakeboards as single layers, the corresponding char rates averaged 1.09 min/mm (0.92 mm/min, 2.2 in/h). In White and Schaffer's (1981) tests of a 27-mm- (1.06-in.-) thick plywood and 30-mm-thick flakeboard, the char rates for the initial layer averaged 1.43 min/mm compared with the corresponding average char rate of 1.18 min/mm in the single-layer tests.

The nonlinear charring parameter for the composite rim products (densities of 489 to 628 kg/m^3) ranged from 0.63 to 0.70 min/mm$^{1.23}$ (Table 5). The estimate for the combined data was 0.6637 (Eq. (4)). In a study of solid wood (White and Nordheim 1992), the nonlinear charring parameter (Eq. (2)) ranged from 0.50 min/mm$^{1.23}$ for basswood (density of 399 kg/m^3 (24.9 lb/ft^3)) to 0.75 min/mm$^{1.23}$ for red oak (density of 747 kg/m^3 (46.6 lb/ft^3)). The parameter result was 0.55 min/mm$^{1.23}$ for southern pine samples (density of 509 kg/m^3 (31.8 lb/ft^3)).

In a study of composite timber products (White 2000), the nonlinear charring rate parameter was determined for three

Douglas-fir LVLs. The parameter values were 0.648, 0.688, and 0.683 min/mm$^{1.23}$ for densities of 529, 535, and 552 kg/m^3 (33.0, 33.4, and 34.5 lb/ft^3), respectively. This is comparable with the 0.687 and 0.689 min/mm$^{1.23}$ for the first layer of the double-layer tests of the Douglas-fir LVL (density of 518 kg/m^3 (32.3 lb/ft^3)) obtained in this study (Table 5). These tests of composite lumber products also included samples of laminated strand lumber and parallel strand lumber made from yellow poplar. The parameter values for these two products were 0.663 and 0.667 min/mm$^{1.23}$ for densities of 678 and 536 kg/m^3 (42.3 and 33.5 lb/ft^3). In this study, the OSB of mixed hardwoods had parameter values of 0.677 min/mm$^{1.23}$ (density of 520 kg/m^3) and 0.701 min/mm$^{1.23}$ (density of 580 kg/m^3).

288°C or 300°C

In earlier wood charring studies, we used a temperature of 550°F as the criteria for the base of the char layer. As we shifted to the SI system of units, which include Celsius for reporting data, we initially used 288°C, which is the more precise conversion of 550°F. Since that implied a greater precision in the criteria than is justified, we later used the criteria of 290°C and 300°C. Data for the small vertical tests of single and double layers of the rim boards were collected for both 288°C and 300°C. The average times for 300°C are less than 1% greater than the times for 288°C (multipliers of 1.008 for the single-layer tests and 1.006 for the double-layer tests).

Small Vertical Compared With Intermediate Horizontal Furnace

Given the differences in furnace construction and specimen orientation and size, differences in test results for the two furnaces would be reasonable. The individual test results for the 300°C criteria are shown in Table 8. A linear regression of the five pairs of results (zero intercept) produced a multiplier of $m = 0.96$ [horizontal furnace = $m \times$ vertical furnace] and R^2 of 0.95. Linear regression of the 139°C/181°C data produced a multiplier of 1.02 and R^2 of 0.96. While there were some differences between individual pairs, there was not a consistent bias between the two furnaces in this limited set of five pairs of results.

Protection of Rim Board

Fire Penetration Times

Fire penetration times can be significantly improved by protecting the rim board with gypsum board (Tables 6 and 8). The averaged improvements at 300°C on the unexposed side of the unprotected rim boards in the small vertical tests were 26 min for the fire-rated 13-mm, 40 min for the fire-rated 16-mm, 86 min for the double fire-rated 13-mm, and 96 min for the double fire-rated 16-mm protection alternatives (Table 6).

The improvement provided by the regular 13-mm gypsum board was consistent with that of fire-rated gypsum board. Even greater improvements were observed in the horizontal furnace tests (Table 8). An air gap between the gypsum and the wood panel products did not improve the times in these small vertical furnace tests. This is consistent with other data for air gaps involving combustible panels (Schaffer and others 1989).

An interior finish on a wall, floor, or roof assembly provides thermal protection to the rest of the assembly. The amount of protection provided is generally expressed in minutes as the "finish rating", which is defined as the time for the surface of the element being protected to reach an average temperature rise of 139°C or maximum temperature rise of 181°C. In the standard fire test, the finish ratings are obtained using thermocouples on the interface between the wood element and the protective gypsum board membrane.

In contrast to a gypsum board membrane attached to studs in a wall assembly, the gypsum boards in these tests were tested across a continuous wood surface.

In terms of the finish ratings for the gypsum products, the times we obtained in the tests were consistent with available published data for finish ratings in wood-stud wall tests. In listings of wood-stud wall assemblies (UL 2000), the fire-rated 13-mm gypsum board H had a finish rating of 15 min (Design No. U317) and the fire-rated 16-mm gypsum board K had a finish rating of 26 min (Design No. U305).

In the small vertical tests (Table 6), the corresponding finish rating test results (times for 139°C/181°C on the unexposed surface of the gypsum board) were 14 and 17 min for the 13-mm fire-rated gypsum board H and 27 min for the 16-mm gypsum board K. In the horizontal furnace tests, the time for 139°C/181°C on the unexposed surface of the gypsum board (finish rating) was 21 min for the single layer of 13-mm fire-rated gypsum board H.

In intermediate-scale tests on wood and steel studs, Zicherman and Eliahu (1998) found that standard, 13-mm gypsum board from five different manufacturers all had finish ratings of 15 min or more. In our test, the finish rating for the 13-mm regular, or standard, gypsum board was 14 min.

Charring of Protected Rim Boards

The times for 300°C at the wood–gypsum interface and at the unexposed back surface of the rim board (Table 6) can be used in the following equation to estimate the char depth of rim board protected with gypsum board (Table 9):

$$t_{300°C} = m_5 x_b + b_0 \quad (5)$$

where $t_{300°C}$ is time to reach 300°C (min), x_b rim board thickness (mm), m_5, char rate parameter (min/mm), and b_0 a constant (min) determined for specified protection.

Table 9—Linear charring (Eq. (5)) of rim boards protected with gypsum board (Fig. 5)

	Estimates of constants for Eq. (5)			
	For $t_{+139°C/181°C}$		For $t_{300°C}$	
Configuration	m_5 (min/mm)	b_0 (min)	m_5 (min/mm)	b_0 (min)
Rim board with no protection	1.653	–17.0	1.656	–12.95
Single layer of 13-mm gypsum	1.573	14.9	1.515	19.28
Single layer of 16-mm gypsum	1.772	20.0	1.833	23.80
Double layer of 13-mm gypsum	2.245	47.5	2.267	56.45
Double layer of 16-mm gypsum	1.999	65.8	2.043	71.68

We also use Equation (5) to estimate the char depth (x_c) within a rim board that is protected with gypsum board. By combining the data for each of the different protection configurations, we obtained estimates for the constants in Equation (5) (Fig. 6) for the five protection configurations (Table 9). The same was done, using Equation (5), for the times to temperature rise of 139°C average or 181°C maximum (Table 9).

Since we did not determine the times for the wood–gypsum interface temperature in the tests of double 16-mm gypsum board, we assumed 66 min for 139°C/181°C and 72 min for 300°C. The 66 min is from Underwriters Laboratories (UL) Design U301. The 72 min was estimated based on the 66-min data for the other protection configurations as well as previous tests of double 16-mm gypsum board on solid wood substrates. In those tests, the times to 288°C (550°F) at the gypsum–wood interface ranged from 71 to 80 min. The calculation of char depth is important in estimating the residual load capacity of the rim board after a specified fire exposure. Since a linear interpolation is assumed, estimates for situations exceeding the experimental failure times (Fig. 6) may introduce sizable errors.

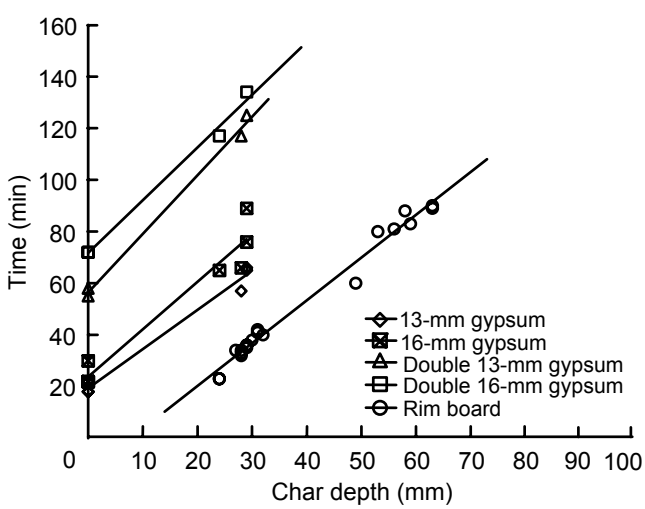

Figure 6—Plot of all data for tests with rim boards protected with different gypsum board configurations. Lines from linear regression of data for each protection configuration (Table 9).

There was insufficient data to investigate possible nonlinear models. For unprotected wood, the char layer reduces the char rate as it gets thicker. In the case of gypsum protection, the continued degradation of the gypsum board would probably result in increased charring rates as the duration of fire exposure increases.

Comparison With Data for Gypsum-Protected Wood

Thick Slabs

In unpublished 1986 FPL tests of double-layer 16-mm Type X gypsum board protection of 91-mm- (3.6-in.-) thick glued-laminated slabs, the result (168 min to reach 288°C at 25-mm penetration) was considerably greater than the 113 min calculated for 300°C using Equation (5) and the constants from Table 9 for double 16-mm gypsum board protection. The ratio of the slope in Equation (3) to the slope in Equation (4) (0.5611/0.6637 = 0.845) is an option to adjust for the distinction between penetration of panel and charring of a semi-infinite slab. With this ratio, the 168 min becomes 141 min, which is still greater than the 113 min. In similar 1986 tests of double 16-mm gypsum board protection of plywood with foam plastic on the back, the data (96 min to 288°C on the back of the 16-mm plywood) is only slightly greater than the 93 min calculated using the constants from Table 9 for double 16-mm gypsum board protection. Data from the 1986 FPL tests indicated that the charring rate of the gypsum-protected wood does increase with time.

The gypsum board improved the fire resistance by both delaying the initial charring of the wood surface and by reducing the char rate once the charring of the wood began (Table 9). In 2-h tests of unloaded glued-laminated beams

(nominal 1.4 m long, 270 mm high, and 150 mm wide (4.6 ft long, 10.6 in. high, and 5.9 in. wide)) made from eight Australian species, Gardner and Syme (1991) found that a 13-mm gypsum board reduced the char depth by approximately 40%. Of the 40%, 17% was credited to the delay in the initial charring. For the 13-mm gypsum protected wood beam, Gardner and Syme (1991) developed the following equation:

$$x_c = (234\ t\ /\ \rho) - 5.8 \qquad (6)$$

where x_c is char depth (mm), t time (min), and ρ air-dried density of wood (kg/m^3).

Applying Equation (6) to the tests of OSB-A and OSB-C protected with 13-mm gypsum board resulted in estimates of 82 and 94 min, respectively. Applying the 0.845 ratio to these estimates reduces the estimates to 69 and 79 min, respectively. In the tests of the protected OSBs, the temperature criterion of 300°C occurred at 57 and 65 min, respectively.

Richardson and Batista (2001) tested decks with and without gypsum board protection. The deck boards were 38 mm thick. The decks were constructed with butt joints resulting in 2-mm (0.08-in.) spacing between the deck boards. Flames on the unexposed surface of the decking occurred at 44 min with the 16-mm Type X gypsum board protection compared with only 4.5 min without the gypsum board. Since the decking had 2-mm spacing between the boards, the charring necessary for flames to emerge on the unexposed surface was less than that expected for the full 38-mm thickness of the deck.

With Eq. (2) (m_2 = 0.6839, 38 mm at 1 h) and the 4.5-min failure time for the joints between boards without gypsum board protection, the corresponding calculated char depth at the time that flame penetration occurred is 4.6 mm (0.18 in.). The calculated time to a 4.6-mm char depth using Equation (5) and the constants from Table 9 (assuming16-mm gypsum board) is 32 min. The actual failure time for the protected deck was 44 min.

The fire performance of gypsum board depends on the calcination of the gypsum board and is adversely affected by its shrinkage. This affects the integrity of the gypsum board itself and its attachment to the substrate with fasteners. Although the regular gypsum board's thermal performance was the same as the fire-rated board in our tests, fire-rated boards should be specified. This is particularly the case when the gypsum board is intended to provide prolonged protection.

The additives in fire-rated gypsum board are intended to improve the integrity of the calcined gypsum. Richardson and Batista (2001) noted that cracks and detachment from fasteners occurred sooner when the gypsum board was attached to the bottom of solid wood decks compared with its performance when attached to the underside of a wood-joist floor assembly.

They concluded that the low thermal conductivity of the wood limits heat flow out of the gypsum board, thus the calcination of the gypsum board is accelerated (Richardson and Batista 2001). In their tests, physical failure of the gypsum board attached to the bottom of the wood decks occurred in less than 45 to 50 min. Their data suggested that the 16-mm Type X gypsum board provided 18 to 20 min of thermal protection to the exposed surface of the deck.

Cone Calorimeter Tests

In tests using the cone calorimeter to heat exposed and protected wood samples to a heat flux of 50 kW/m^2 (32.3 W/in^2), Tsantaridis and others (1999) also found that gypsum board, irrespective of type, increases the time to reach the charring temperature of 300°C on the surface of the wood member and decreases the charring rate of the wood member. The 50-kW/m^2 heat flux was used since it corresponds to the standard time–temperature curve of the ASTM E119 test during the first 30 to 40 min. The wood samples were 100 mm (3.9 in.) thick (45 mm (1.8 in.) wide). Without gypsum protection, 300°C at 42-mm (1.7-in.) depth occurred at approximately 45 min.

In the tests involving U.S. or Canadian gypsum products, the mean times for 300°C at 42-mm depth ranged from 120 to 205 min in four tests of 13-mm gypsum boards (two fire-rated Type X, one fire-rated Type C, and one regular), 135 to 221 min for four 16-mm gypsum boards (all Type X), and 205 min for a 24.9-mm- (0.98-in.-) thick board (Type X).

Although all these times for gypsum-protected wood are major improvements compared with the 45 min for 42-mm char depth of the unprotected wood, there was considerable scatter in the times for the different gypsum products. The range of times to reach 300°C at the wood surface was considerably narrowed: 19.9 to 23.9 min for the 13-mm gypsum boards and 29.1 to 33 min for the 16-mm gypsum boards.

Although there was a correlation between the times for the wood surface to reach 300°C and the thickness of the gypsum board, the data did not indicate a similar correlation between the char rate of the wood, once the surface had reached 300°C, and the thickness of the gypsum board.

Variations in the properties of the wood samples and increased variability of gypsum board behavior as it undergoes calcination may account for this lack of correlation. The specimen size in the cone calorimeter test is relatively small, which probably increased variability in the testing of gypsum board. The times for 300°C at the 42-mm wood depth were 82% to 198% greater than that calculated by adding the time for the surface to reach 300°C to the time for the unprotected wood sample to char to a depth of 42 mm. In contrast, the 300°C times for the protected rim boards (Table 6) in our tests were 5% to 36% greater than the sum of the times for 300°C at the surface plus the 300°C times for the unprotected OSB rim boards. The 100- by 100-mm specimen was

horizontal with the exposure from the top in the cone calorimeter. Thus, the physical movement of the gypsum board pulling away from the wood substrate that happens in most actual applications does not occur in a cone calorimeter test (Tsantaridis and Ostman 1998).

Wall Tests

In a series of full-scale wood-stud wall tests, Richardson and Batista (1997) provided data for 160°C (320°F) and 290°C (554°F) at the gypsum–wood interface and physical failure of the membrane for various gypsum board membranes. The times for the 12.7-mm (0.5-in.) Type X gypsum board were 15, 19, and 36 min for 160°C, 290°C, and physical failure, respectively. The times for the 15.9-mm (0.63-in.) Type X gypsum boards were 20, 23, and 42 min for 160°C, 290°C, and physical failure, respectively. The times for the double 12.7-mm Type X gypsum boards were 42, 48, and 71 to 74 min for 160°C, 290°C, and physical failure, respectively.

In our tests of 13-mm fire-rated gypsum boards in the small vertical furnace (Table 6), the times for 139°C/181°C temperature rise (that is, 160°C) and for 300°C were similar to the results of Richardson and Batista (1997). We obtained somewhat greater times with the 16-mm fire-rated gypsum board K. In our tests of the double-layer 13-mm fire-rated gypsum board H, the times were slightly greater than the results of Richardson and Batista (1997).

These differences may be due to increased thermal–structural interactions in the full-scale tests and differences between gypsum board products of the same thickness. Physical failure is important to keep in mind when applying Table 9 constants to other applications.

Application of Finish Ratings

Protected Rim Boards

For protected wood, one approach that is sometimes used when data is lacking is to assume that the fire endurance is the sum of the finish rating of the protection piece and the endurance time of the wood member in direct E119 fire exposure without protection. This is based on the actual temperature, keeping within the 139°C/181°C temperature rise criterion (~160°C), being less than the charring temperature of wood (300°C). In this approach, the gypsum board is assumed to disappear once the finish rating temperature is achieved.

In Table 10, the recorded finish ratings (139°C/181°C rise in temperature at the gypsum–rim board interface) (Table 6) are added to the times for the unprotected rim boards (Table 3) to obtain the estimates for the protected rim board. Comparison of the estimates with the experimental data for protected rim boards (Table 10) illustrates the conservative nature of this approach when gypsum board is attached to the fire-exposed side of wood rim board members.

Finish ratings for different membranes can be obtained from tests of the membrane protection in wood-frame assemblies (walls and floors). They are included in some listings of fire-rated assemblies. As noted earlier, the 13-mm gypsum

Table 10—Estimates for fire endurance times (300°C) for protected rim boards using finish rating method applied to these FPL tests (ASTM E119 exposure)

			Times to 300°C (min)		
Protection	Rim board	Finish rating[a] (1)	Unprotected[b] rim board (2)	Estimate: sum of (1) and (2)	Actual protected rim board[a]
13-mm gypsum H	OSB-C	14	37	51	65
13-mm gypsum H	OSB-A	17	32	49	57
13-mm gypsum I (Reg.)	OSB-C	14	37	51	66
16-mm gypsum J	OSB-A	18	32	50	66
16-mm gypsum K	OSB-C	27	37	64	89
16-mm gypsum J	OSB-C	18[c]	37	55	76
16-mm gypsum J	PLYW	18[c]	23	41	65
Double 13-mm gypsum H	OSB-C	47.2	37	84	125
Double 13-mm gypsum H	OSB-A	47.8	32	80	117

[a]From Table 6.
[b]From Table 3
[c]From test on OSB-A.

board H had a finish rating of 15 min and the 16-mm gypsum board K had a finish rating of 26 min in listings for wood-stud wall assemblies in the UL Fire Resistance Directory (UL 2000).

The finish ratings for different fire-rated 16-mm gypsum boards in the UL Listing Design No. U305 for a wood-stud wall assembly ranged from 20 to 26 min. Even using the 26 min for the finish rating resulted in conservative estimates (by 8 to 16 min) for the three tests of the 16-mm fire-rated gypsum board J. When the 15 min was used for the 13-mm fire-rated gypsum board H, the estimates were also conservative by 10 to 13 min compared with the small vertical furnace test results and 14 min compared with the horizontal furnace test results.

In a UL listing for a wall assembly with double 16-mm fire-rated gypsum board (Design No. U301), the finish rating is 66 min (UL 2000). Thus, the estimates for double 16-mm fire-rated gypsum board would be 103 min on OSB-C (66 + 37) and 89 min on the plywood (66 + 23). In the test of double 13-mm fire-rated gypsum board H, we obtained 125 min on OSB-C in the horizontal furnace test, 134 min on OSB-C in the small vertical furnace test, and 117 min on plywood in the small vertical furnace test. The finish rating method does not take into account the reduced charring rate resulting from protection provided to the wood from the gypsum board remaining on the wood beyond the duration of the finish rating.

Protected Floor Assemblies

When a floor assembly has a fire-rated ceiling, the rim board is not immediately subjected to the exposure represented by ASTM E119 time–temperature curve. The tests using the modified temperature curves were designed to provide data for such situations.

In the case of the I-joist assembly used to develop the modified time–temperature curve, the membrane was 16-mm Type C gypsum board attached to resilient channels (RC-1). Using the modified temperature curve, we tested unprotected OSB-C and OSB-C with 16-mm gypsum board protection. With the modified temperature curve, the charring of an unprotected rim board was only 17 mm at 54 min. With direct protection of 16-mm gypsum board, there was no charring of the rim board. These times reflect the protection to the rim board provided by the adjacent floor assembly membrane.

As in the discussion of the protected rim board, one approach for extending the application of the data is to use the finish rating of the floor assembly's protective membrane in conjunction with direct E119 exposure data for the rim boards. In the floor–ceiling assembly test, after which the modified test was modeled, the temperatures on the bottom chord intersection of the ceiling reached the 139°C/181°C temperature criteria at 31.3 min. Using the E119 direct exposure char rate (Tables 3 and 9) for the remaining exposure time in the modified temperature tests, we obtained estimates for the char depth at the end of the test. The estimates were in agreement with the experimental data (Table 11).

Table 11—Estimates for fire endurance times (300°C) for rim board OSB-C of floor assembly with protected membrane using finish rating of floor–ceiling membrane

Protection	Duration of exposure (min)	Estimated char depth[a] (mm)	Experimental char depth[b] (mm)
None	54	18	16
None	54	18	17
16-mm gypsum	53	0	0
16-mm gypsum	55	0	0

[a]From (duration of exposure minus ceiling finish rating) and char rate from E119 direct exposure tests (Tables 3 and 9).
[b]From Table 7.

Loaded Rim Board

All the tests conducted for this study were conducted without any load being applied to the specimen. The experimental data addresses the question of thermal protection, that is, protection against flame penetration or excessive temperature rise.

In addition to flame penetration and excessive temperature rise, a third failure criterion is structural integrity. American Forest & Paper Association (AF&PA 1999) provides a general methodology for such an evaluation. The methodology involves an effective charring rate and normal room temperature structural analysis of the residual cross section using ultimate strength values.

A form of the nonlinear model (Eq. (2)) is used in the predictive model. In AF&PA (1999), an effective linear char rate, [β_{eff}, mm/min (in/h)] is calculated from what is described as a nominal linear char rate value [β_n, char depth, mm (in.) at 1 h] using a nonlinear relationship. The effective char rate at the fire exposure time, t [min (h)] is

$$\beta_{eff} = 1.2\ \beta_n / t^{0.187} \tag{7}$$

The effective char rate, which includes a 20% factor to account for rounding at the corners and reduction of strength and stiffness of the heated portion of the member, is used in AF&PA (1999) to calculate the residual cross section of exposed wood members. Each surface of the cross section exposed to the fire is reduced by this effective char depth, x_{eff} [mm (in.)].

$$x_{eff} = \beta_{eff}\, t \tag{8}$$

Compression Failure

In AF&PA (1999), the load capacity during the standard fire test is calculated based on the residual cross section and the ratio of the allowable stresses to the actual ultimate stresses. In the case of the rim board, we assume charring in one direction and only on one side. In general, lateral support of the rim board will prevent buckling failure. (Buckling failure is discussed later.) Thus, we will assume the mode of failure is compression failure. With this assumption, the design load ratio, R_s, at failure due to fire in AF&PA (1999) methodology becomes

$$R_s = K\, A_{y\text{-}f} / A_{y\text{-}s} = K\,(d - x_{eff}) / (d) \qquad (9)$$

where K is allowable design stress to average ultimate strength adjustment factor, $A_{y\text{-}f}$ area based on reduced cross section due to fire (mm^2), $A_{y\text{-}s}$ area based on full cross-sectional dimensions (mm^2), d original thickness of rim board (mm), x_{eff} effective char depth (mm).

In the standard ASTM E119 test, the specimen is loaded to its full allowable design load. Thus, the design load ratio, R_s, has a value of 1. For vertical loads, the allowable design stress to average ultimate strength adjustment factor for APA rim boards is 3.0 (APA 2000b). For lumber, the allowable design stress to average ultimate strength adjustment factor for compression strength is 2.58 (AF&PA 1999).

With K assumed to be 3 and with an original thickness of 28.5 mm (1.125 in.) in Eq. (9), failure of a fully loaded rim board (R_s of 1) is predicted at an effective char depth of 19 mm. For lower loads relative to full allowable load, the char depth needed for failure will increase. In a double stud wall assembly in which the load of the exposed stud wall and rim board is transferred to the second stud wall and rim board, the design load ratio (R_s) would have a value of 2. The predicted effective char depth of the second rim board for failure in this case is 9.5 mm (0.37 in.).

The fire exposure needed for the reduction of the cross section can be computed from Equations (7) and (8). For calculations when the rim board is directly exposed to ASTM E119 exposure, the double-layer tests of this project (Table 5 and Fig. 5) support the use of a nominal char rate (β_n) of 38 mm at 1 h or 39 mm at 1 h.

For the predicted effective char depth of 19 mm, the corresponding fire endurance time is 20 min (Eq. (7) and (8)). For lower loads relative to full allowable load, the times-to-failure will increase. For R_s of 2, the predicted effective char depth is 9.5 mm (Eq. (9)). The corresponding fire endurance time is 8 min (Eq. (7) and (8)) using the 38 mm in 1 h char rate.

In AF&PA (1999), the effective char depth includes a 20% increase to account for the effect of elevated temperatures on the mechanical properties of the wood layer beneath the base of the actual char layer. For wood directly exposed to fire, this layer is fairly narrow (Janssens and White 1994).

For wood protected with gypsum board, the more gradual increase in temperature of the wood interior results in a thicker layer of wood being subjected to elevated temperatures for a longer time. We are assuming the 1.2 factor is still valid for wood protected with gypsum board. In Eurocode 5 (European Committee for Standardization 1994), the simplified effective cross section method adds a constant depth of 7 mm (0.28 in.) to the actual char depth of wood directly exposed to the fire for greater than 20 min. The 7 mm is also used for surfaces protected by gypsum board when charring of the wood member continues 10 min or more past the initial charring of the wood.

Buckling Failure

If there is no lateral support, buckling failure may need to be considered. Based on observations of lateral deflection away from the fire in fire tests of wall assemblies, one can assume that the direction of buckling failure is parallel to the direction of charring, which is across the thickness of the rim board. If buckling failure is the controlling failure mode, the design load ratio, R_s, at failure due to fire in the AF&PA (1999) methodology becomes

$$R_s = K\, I_{y\text{-}f} / I_{y\text{-}s} = K\,(x - a)^3 / (x)^3 \qquad (10)$$

where K is ratio of allowable design stress to average ultimate strength adjustment factor, $I_{y\text{-}f}$ moment of inertia based on reduced cross section due to fire (mm^4), $I_{y\text{-}s}$ moment of inertia based on full cross-sectional dimensions (mm^4), x original thickness of rim board (mm), and a effective char depth (mm).

Application of Methodology

The primary intended application of this data is the evaluation of the fire resistance that the rim board can provide in specific assemblies. Based on the data in this report, we provide a procedure for evaluating possible construction options. Figure 7 illustrates construction with a double stud wall–rim board wall separation system. The rim board needs to provide protection consistent with the fire-rated wall assembly below the floor–ceiling assembly. Typically, this requires either a 1- or 2-h rating.

In this analysis, we are calculating the fire rating for a rim board system as the sum of the finish rating of the floor–ceiling assembly, the fire resistance of the first rim board, and the fire resistance of the second rim board (if double-wall construction). As discussed previously, the finish ratings of the protective membranes can be found in directories of fire-rated assemblies such as the UL Fire Resistance Directory (UL 2000).

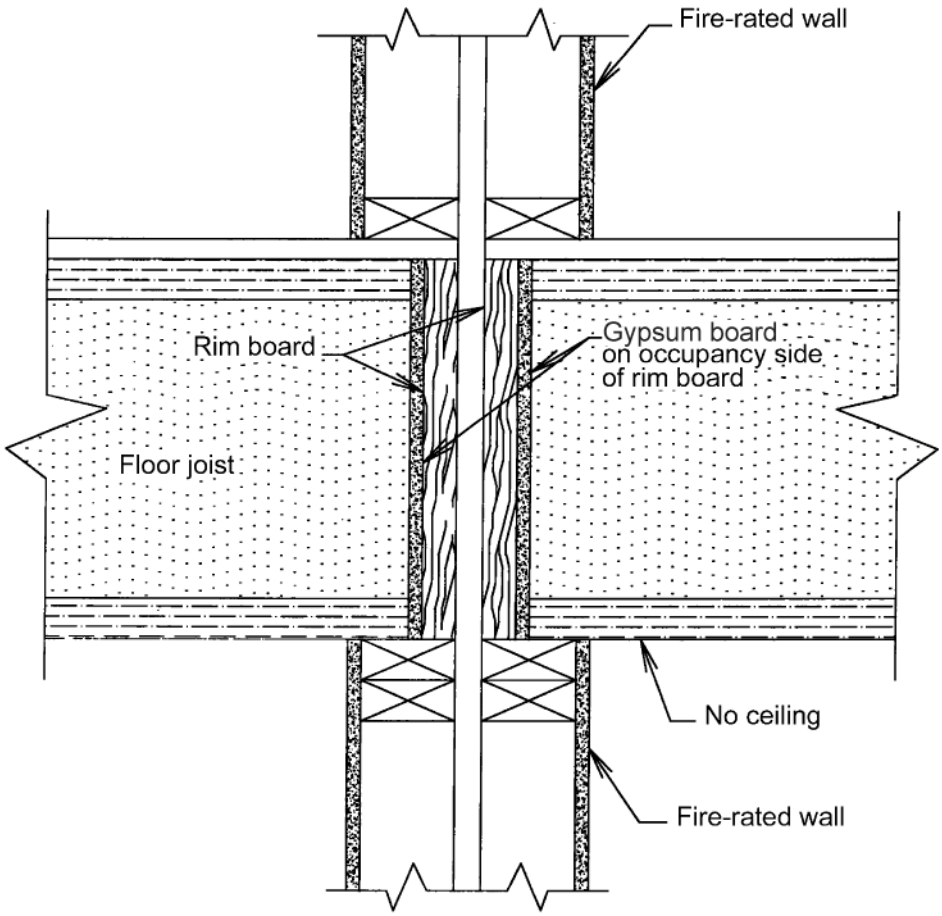

Figure 7—Example of double-wall construction with rim boards between two fire-rated wall assemblies. This example illustrates gypsum board applied to the fire-exposed surface of the rim board and no ceiling membrane on the floor assembly.

Examples are Design No. L506 (assembly rating 45 min) with 13-mm Type X gypsum board directly attached to 38- by 235-mm (nominal 2- by 10-in.) joists (finish rating 15 to 20 min); Design No. L501 (assembly rating 60 min) with 16-mm Type X gypsum board directly attached to 38- by 235-mm joists (finish rating 30 min); and Design No. L532 (assembly rating 90 min) with two layers of 16-mm Type X gypsum board attached to 38- by 235-mm joists with furring channels (finish rating 63 min).

To analyze the structural performance of the rim board, we need to consider the applied loads. For structural loads, there are three possibilities in the double-wall system. These are (1) no load; (2) the load on the studs of the fire-exposed wall are transferred to the other wall upon failure of the wall; and (3) the load on the studs of the fire-exposed wall is not transferred to the other wall upon failure (Fig. 7). If fire protection is needed from a fire on either side of the wall, the analysis must be repeated for the other direction and the appropriate gypsum board included.

In the case of no load, we are only concerned with thermal protection and the full thickness of both rim boards can be considered. For the second (adjacent) rim board, the times for 139°C/181°C would be the controlling criterion. Since there are no joints in the rim board, this temperature criterion would probably precede any flame penetration of the second rim board.

For the load-bearing rim board, structural failure of the rim board is assumed to be the controlling criterion. For full allowable load, the estimated effective char depth for failure of the fire-exposed rim board is 19 mm (original rim board thickness of 28.5 mm) as discussed previously. In the AF&PA (1999) calculation procedure, as applied here, the effective char depth is 20% greater than the experimental char depths. The allowable char depth would be greater if the applied load is less than the full allowable load.

When the full load of the first stud wall is transferred to the second wall in a double-wall system, the fire-exposed rim board can be assumed to remain in place and its failure only

occurs when the full thickness of the rim board has charred. Because of the extra load on the rim board on the unexposed side, the estimated effective char depth for failure of the second rim board is 9.5 mm for the case of full allowable load on the 28.5-mm-thick rim boards. Structural failure of the second rim board is assumed to be the controlling criterion.

If the load is not transferred, the estimated effective char depth for the fire-exposed rim board is 19 mm for a 28.5-mm-thick rim board. The second rim board would also collapse when its effective char depth is 19 mm. We are assuming the first rim board completely fails resulting in the second rim board being fully exposed to the fire. It is also assumed that failure of the first rim board does not otherwise affect the integrity of the second rim board.

The applicable test data are summarized as design fire resistance times for rim boards of 25.4- and 28.5-mm thickness (Table 12). The times are for effective char depth associated with compression failure of rim board loaded to double full allowable design load due to load transfer, effective char depth associated with compression failure of rim board loaded to full allowable design load, 139°C/181° C temperature criteria on the unexposed surface, and 300°C on the unexposed surface, respectively. Values in Table 12 are based on Equations (3) through (5), Equations (7) through (9), and Table 9. The effective char depths of 9.5 and 19 mm correspond to nominal char depths of 7.9 and 15.8 mm (0.31 and 0.62 in.) for the 28.5-mm-thick rim board. The design fire resistance times and the effective char depths for structural failure would need to be adjusted for rim boards of other thickness and for other load levels. All references to gypsum board assume fire-rated Type X gypsum board.

In the following examples, the data from Table 12 were applied to various wall configurations. These configurations were designated with a D for double walls and S for a single wall and then numbered within each group. Rim boards were assumed to be 28.5 mm thick. A similar analysis can be done for a wall constructed with 25.4-mm-thick rim boards. Designs D1, D6, D8, and S2 do not have calculated fire resistance times of 60 min or greater if the rim board is only 25.4 mm thick.

If fire protection is needed from a fire on either side of the wall, the analysis must be repeated for the other direction and appropriate gypsum board included.

Table 12—Design fire resistance times for 25.4-mm-thick and 28.5-mm-thick rim boards with different combinations of gypsum board protection

	Design fire resistance times[b] (min)							
	25.4-mm-thick rim board				28.5-mm-thick rim board			
Protection[a]	8.5-mm char depth[c]	17-mm char depth[c]	139°C/181°C on back side	300°C on back side	9.5-mm char depth[c]	19-mm char depth[c]	139°C/181°C on back side	300°C on back side
Single rim board only	7	17	28	30	8	20	32	35
Two rim boards	7	17	65	70	8	20	75	79
Rim board + 13-mm gypsum	30	41	55	58	31	43	60	62
Rim board + 16-mm gypsum	37	50	65	70	38	53	70	76
Rim board + two 13-mm gypsum	72	89	104	114	74	92	111	121
Rim board + two 16-mm gypsum	86	101	117	124	88	104	123	130

[a]Wood composite rim board of thickness listed and ovendried density greater than 510 kg/m^3 (31.8 lb/ft^3). Gypsum board is fire-rated Type X.
[b]From Table 9 for protected rim boards, Equation (3) for 300°C on back side of unprotected rim board, Equation (3) with m_2 parameter equal to 0.5227 for 139°C/181°C on back side of unprotected rim board, and Equation (4) for char depths of unprotected rim board. Also assumes full allowable design load, compression failure only, and a ratio of ultimate strength to allowable stress of 3.
[c]Values listed are effective char depths. Nominal char depths are 7.1 and 14.2 mm for the 25.4-mm rim board and 7.9 and 15.8 mm for the 28.5-mm rim board.

While no differences between fire-rated and unrated 13-mm gypsum boards were shown in this study, a rated product is recommended because of the known fire performance. This is particularly the case for applications where the design effective char depth is greater than 9 mm (0.35 in.). Such applications require that the gypsum board maintain its integrity for sustained fire exposure.

These analyses only address the failure of the rim boards. Other failure scenarios are not considered. In the case of double-wall construction, there is the failure scenario of the fire-exposed rim board followed by failure through the wall assembly of the floor above. For most of the systems discussed in the following examples, the time credited to the second rim board is 20 min or less. In the component additive method (White 2002), the time assigned to the contribution of the wood-stud wall assembly to the fire resistance rating is 20 min when directly exposed to ASTM E119 fire exposure. Thus, this scenario is not likely for systems where the time credited to the second rim board is 20 min or less.

Failure through adjacent wood components is also not specifically considered. Based on the standard char rate of 0.6 mm/min (1.5 in/h), examination of failure through adjacent unprotected wood components showed that this was unlikely. This potential scenario should be re-examined when two layers of gypsum board protection are used on the rim board.

Double-Wall, Two 28-mm Rim Board Construction

Using Table 12 to examine various options, we start with the double-wall construction (Fig. 7) consisting of two rim boards without any protection.

D1. Unprotected, one hour, no load: If there is no load, the calculated fire resistance is 67 min (35 min for the fire-exposed rim board, 300°C, plus 32 min for the unexposed rim board, 139°C/181°C). The conservative nature of these calculations is indicated by comparing this 67 min with the 75 min assigned to 139°C/181°C on the back of the two rim boards (Table 12), based on two rim boards tested without a gap between them. If it is necessary to reduce the time credited to the second or unexposed rim board from 32 to 20 min or less to address scenarios involving the unprotected wall above, a rated or unrated gypsum board ceiling membrane could be added to the floor–ceiling assembly over the room of fire origin.

D2. Unprotected, one hour, load transferred to adjacent rim board: If the unprotected rim boards are fully loaded and the load of the fire-exposed rim board is transferred to the unexposed rim board, the calculated fire resistance is 43 min (35 min for the back of the fire-exposed rim board to reach 300°C plus 8 min for unexposed rim board to char to a depth of 9.5 mm). A floor–ceiling assembly with a 17-min finish rating over the room of fire origin would bring the estimated failure time to 1 h.

An alternative analysis for the unprotected rim boards with load transfer is to treat the two rim boards as one and use Equations (4) and (7) through (9) to calculate the time for structural failure of a 57-mm- (2.2-in.-) thick rim board. For R_s of 1 and K of 3, the calculated time for such a rim board is 46 min (38-mm effective char depth). This nonlinear char rate model makes this alternative approach less conservative than the additive approach of Table 12.

D3. Unprotected, one hour, load not transferred to adjacent rim board: If the unprotected rim boards are fully loaded and the load of the fire-exposed rim board is not transferred to the unexposed rim board, the calculated fire resistance is 40 min (20 min for the back of the fire-exposed rim board to char to a depth of 19 mm plus 20 min for unexposed rim board to char to a depth of 19 mm). A floor–ceiling assembly with a 20-min finish rating over the room of fire origin would bring the estimated failure time to 1 h.

Again, an alternative analysis is to treat the two rim boards as one and use Equations (4) and (7) through (9) to calculate the time for structural failure of a 57-mm-thick rim board. In this case, R_s is 0.5 (half of the load is not transferred to residual cross section). The calculated time for such a rim board is 61 min (47-mm (1.9-in.) effective char depth). This alternative approach is less conservative in this particular case since it assumes the first rim board continues to protect the second rim board past the time for its own structural collapse [47-mm effective char depth compared with 38 mm (2 by 19 mm)]. For an effective char depth of 38 mm using Equations (4) and (7) through (9), the estimated fire exposure time-to-failure is 46 min.

D4. Protected, one hour, no load: By adding 13-mm gypsum board to the fire-exposed rim board, just the fire-exposed rim board provides 1 h (62 min) of protection if there is no load (300°C, Table 12).

D5. Protected, one hour, load transferred to adjacent rim board: For loaded double-wall construction with the fire-exposed rim board protected with 13-mm-thick gypsum board and with the unexposed rim board unprotected, the calculated fire resistance is 70 min if there is load transfer. This assumes 62 min for the back of the protected fire-exposed rim board to reach 300°C plus 8 min for unprotected unexposed rim board to char to a depth of 9.5 mm.

D6. Protected, one hour, load not transferred to adjacent rim board: If the rim boards are fully loaded, the fire-exposed rim board is protected with 13-mm gypsum board, and the load on the fire-exposed rim board is not transferred to the unexposed rim board, the calculated fire resistance is 63 min. This assumes 43 min for the fire-exposed rim board to char to a depth of 19 mm plus 20 min for the unexposed rim board to char to a depth of 19 mm.

In each of these protected cases (D5 and D6), no ceiling membrane on the adjacent floor–ceiling is needed for a 1-h system with 13-mm gypsum on the fire-exposed surface of the rim board on the occupancy side (double-wall system).

D7. Adjacent rim board protected, one hour, load transferred to adjacent rim board: Another option is to have the fire-exposed rim board unprotected but add 13-mm gypsum protection to the fire side of the second (adjacent) rim board. Such a system would provide 66 min of protection if there were load transfer. This assumes 35 min for fire-exposed rim board to reach 300°C and 31 min for unexposed rim board to char to a depth of 9.5 mm.

For this configuration, a 1-h system requires no adjacent-floor–ceiling membrane on the fire-exposed side to prevent failure that involves both rim boards. To address the scenario of failure through the wood studs of the wall assembly above the second or unexposed rim board, one can use a rated or unrated gypsum board ceiling on the floor–ceiling assembly over the room of fire origin to reduce the time credited to the second or unexposed rim board from 31 to 20 min or less.

D8. Adjacent rim board protected, one hour, load not transferred to adjacent rim board: The preceding alternate system (D7) provides 66 min if there is load transfer. This same configuration provides 63 min of protection if there is no load transfer. This assumes 20 min for the back of the fire-exposed rim board to char to 19 mm plus 43 min for the unexposed rim board to char to 19 mm. To address failure through the two rim boards, no ceiling membrane is needed on the adjacent floor–ceiling for the 1-h configuration.

Since this configuration D8 results in early failure of the fire-exposed rim board and assigns 42 min to the second or unexposed rim board, it is not recommended unless the scenarios of the fire spreading within the cavity between the walls is specifically addressed. The long time assigned to the second rim board increases the likelihood of failure via an unprotected wall assembly above or below the unexposed rim board prior to 1 h. As mentioned with configurations D1 and D7, one option is an adjacent floor–ceiling membrane that will increase the cumulative time at which the fire-exposed rim board fails and thereby reduce the remaining time for a 1 h rating to 20 min or less. Other options are adding protection to the fire-exposed side of the studs above and below the second or unexposed rim board or fire-stopping the cavity to address this scenario.

D9. Protected, two hour, no load: Two-hour double-wall systems can be obtained by using double layers of gypsum board to protect the rim board. With two layers of 13-mm Type X gypsum board added to the fire-exposed rim board, a single rim board of a double-wall system provides 2 h by itself (121 min) if there is no load (300°C on back side; Table 12).

D10. Protected, two hour, load transferred to adjacent rim board: For loaded double-wall construction with the unexposed (adjacent) rim board unprotected, the calculated fire resistance for double 13-mm fire-rated gypsum board on the fire-exposed rim board is 129 min if there is load transfer (121 min for the fire-exposed rim board to reach 300°C plus 8 min for the unexposed rim board to char to a depth of 9.5 mm).

D11. Protected, two hour, load not transferred to adjacent rim board: If the rim boards are fully loaded and the load on the fire-exposed rim board is not transferred to the unexposed rim board, the calculated fire resistance is less than 2 h, that is, 112 min (92 min for fire-exposed rim board to char to a depth of 19 mm plus 20 min for unexposed rim board to char to a depth of 19 mm).

By using double layers of fire-rated 16-mm gypsum board, the calculated fire resistance can be increased to 124 min (104 min for the fire-exposed rim board to char to 19 mm plus 20 min for the unexposed rim board to char to 19 mm) when there is no load transfer. No ceiling membrane is needed on the adjacent floor–ceiling for the 2-h configurations.

Single-Wall, 28-mm Rim Board Construction

In these examples, we examined the case of the rim board alone in conjunction with a 1-h-rated floor–ceiling system. In the modified temperature tests, 17 mm of the 28-mm-thick rim board charred in 54 min (Table 7). In the proposed analysis, this corresponds to the 16-mm actual char depth [19-mm effective char depth reduced by 20% per AF&PA (1999)] at 50 min [30-min finish rating for 1-h floor–ceiling assembly plus 20 min for 19-mm char depth of unprotected rim board (Table 12)].

S1. Unprotected, one hour, no load: For a single, nonload-bearing wall system, 1-h protection can be achieved by doubling the rim board. Table 12 shows that such a system will endure 75 min (139°C/181°C on back side).

S2. Protected, one hour, no load: For a single, nonload-bearing wall system, 1-h protection can be achieved by protecting the rim board with a single layer of 13-mm gypsum board. Table 12 shows that such a system will endure 60 min (139°C/181°C on back side).

S3. Protected with abutting one-hour floor–ceiling assembly, one hour, no load: For a single, nonload-bearing wall system, 1-h protection can be achieved if the rim board itself is protected only by a floor–ceiling system with a finish rating of 28 min. This assumes 32 min (139°C/181°C on back side) for the rim board (Table 12) plus 28 min for the ceiling membrane.

S4. Protected with abutting one-hour floor–ceiling assembly, one hour, loaded: For a single, load-bearing wall system, the adjacent floor–ceiling would need a minimum of a 17-min finish rating to obtain a 1-h system when the rim board on the fire-exposed side is protected with 13-mm gypsum board (43 min for the fire-exposed rim board to char to a depth of 19 mm).

S5. Protected, two hour, no load: A rim board on an unloaded single wall system with double 13-mm Type X gypsum has close to 2 h of endurance (111 min, 139°C/181°C on back side) while a rim board with double layers of 16-mm Type X gypsum exceeds 2 h (123 min, 139°C/181°C on back side).

S6. Protected with abutting one-hour floor–ceiling assembly, two hour, loaded: For a single-wall system, two layers of 13-mm Type X gypsum board on the rim board in a load-bearing system have a calculated rating of 92 min. An adjacent floor–ceiling with a 28-min finish rating would provide a 2-h system with this configuration.

Limitations of Methodology and Data

In Table 12, we are calculating the fire resistance of the whole by adding the performance of the components. In Harmathy's (1965) rules for fire endurance, rule one states "the insulative fire endurance of a construction consisting of a number of parallel layers is greater than the sum of the insulative fire endurance characteristics of the individual layers when exposed separately to fire."

The additive procedure of Table 12 is based on the thermal performance of the different components in the fire tests. The structural behavior of the rim board is derived from its thermal performance (charring rate). The load-bearing capacity is derived from the uncharred depth at 300°C. Data from the calculated results in Table 12 were compared with other alternative approaches. These comparisons indicated that the values obtained from the additive methodology of Table 12 were conservative.

The modified temperature test results showed that adding the ASTM E119 times for the floor–ceiling assembly to the times for the rim boards is a suitable approach. In addition, the tests of the protected rim boards showed that adding the finish rating for a membrane to the times of an unprotected rim board is a conservative approach.

Some care needs to be taken when using finish ratings. In any given test, the behavior of the protective membrane can be significantly influenced by the physical behavior of the structural components of the assembly. As noted by Richardson and others (2000), the substrate influences the fire performance of gypsum board.

A general rule of fire endurance is that fire resistance ratings are for an assembly; that is, the protective ceiling membrane does not have a rating, only the whole assembly. Physical behavior of the materials due to the fire exposure can influence the performance of other components of the assembly.

In the approach presented in this paper, we assumed the collapse of the initial, fire-exposed rim board does not adversely affect the integrity of the second rim board. Construction details that would make this assumption invalid would likewise affect the validity of the calculations. In all likelihood, compression failure of the rim board does not prevent the residual cross section from continuing to provide some protection to the rim board of the adjacent wall.

In the component-additive method (Canadian Wood Council 1991, Richardson and Batista 1997), the fire resistance rating of the assembly is taken as the sum of the time for the membrane and the time for the framing. The times assigned to the membranes and the framing in the component-additive method, however, were derived from full-scale testing of assemblies not tests of the components. While similar in values, the membrane times in the component-additive method are not the finish ratings of the membranes (International Code Council 2000). Finish ratings are based on the temperature criteria specified in ASTM E119 (ASTM 2000) and are reported for specific assemblies in listings of fire-rated assemblies such as the UL Fire Resistance Directory (UL 2000).

The data presented in this paper are based on small-scale fire resistance tests. Some tests were conducted using an intermediate-scale furnace. The small-scale nature of the test data needs to be considered in any application of the methodology.

The standard test method (ASTM 2000) requires a significantly larger test specimen. Large specimens are particularly important to determine thermal–structural–physical interactions on the performance of the protective membrane.

For the application of these results, however, the size of the test specimen was comparable with the intended field of application, that is, rim boards around the edges of a floor assembly. Items not considered included joints in the gypsum board membrane and spacing between the edges of the gypsum board and adjacent wood components.

Deflection of load-bearing assemblies usually results in the gypsum board failing sooner than from nonloaded walls (Richardson and Batista 1997). Larger specimens are also needed to better evaluate the effects of joints in the protective membrane and other dimensional limitations in actual applications.

The size of the test specimen can be specifically relevant in the evaluation of gypsum board since its fire resistance behavior of forming cracks is consistent with the weakest links theory of material strength. The probability of so-called weak link failure is significantly lower in smaller pieces of gypsum board since chemical constituents and physical properties are not uniform (Richardson 2001).

Equation (3) (Table 9) should not be extrapolated to obtain endurance times exceeding those shown in Figure 6.

Since rim boards are supported along their length, rim boards are assumed not to carry a bending load. Thus, deflection along the length of the rim boards would not normally be a factor.

As noted by Tsantaridis and others (1999), mechanical properties of the board and the fasteners are important since any reduction of the charring rate is relevant only as long as the gypsum board remains attached.

The type and spacing of the fasteners can be critical to the performance of gypsum board (Richardson and others 2000). In the experiments, 38- and 50-mm Type W drywall screws were used. In the small-scale tests, the spacing was 230 mm on center along the edges of the 510- by 510-mm rim board specimens. In the intermediate-scale tests, the fasteners were 38- and 50-mm box nails and the spacing was 305 mm on center at the boundary and over the interior. The specimens were 1.2 by 2.1 m. Application of the data to situations involving larger areas or horizontal orientation of the gypsum board will probably increase the importance of the fasteners to the overall performance of the protective membrane.

Conclusions

Using the ASTM E119 fire exposure, we conducted a series of small-scale fire resistance tests of unprotected wood composite rim boards and rim boards protected with gypsum board. The results were consistent with previous tests of wood products, including glued-laminated timber. Initial charring of the unprotected samples was consistent with the general rule that the base of the char layer of a wood member exposed to the ASTM E119 fire exposure is at 38 mm in 1 h. Deviations from the 38 mm in 1 h conclusion were similar to those found in tests of lumber samples of different species and densities. Based on the nonlinear model for time and char depth used previously, the average for the six rim boards was a 39-mm char depth in 1 h. A limited number of tests in an intermediate-scale horizontal furnace produced results consistent with the tests in the small vertical furnace.

Flame penetration or 300°C on the back surface of the unprotected rim board occurred earlier than that predicted by the 0.6 mm/min (1.4 in/h) char rate. The times for 300°C on the backside of the rim board corresponded to 45 mm in 1 h. The data for 300°C on the back surface were consistent with the nonlinear model for time and char depth.

Times for temperatures in the specimens to reach 300°C were less than 1% greater than the times recorded using a temperature criterion of 288°C, which is the precise SI conversion of 550°F that we previously used as the temperature criterion for the base of the char layer. In a limited series of tests using a modified temperature curve, we simulated the case of rim boards with a floor–ceiling assembly with a 1-h rating.

With the data and various assumptions, a simple analysis method was proposed for evaluating the protection provided by the rim board in specific assemblies. We identified and evaluated various specific construction options using this methodology.

For a composite rim board (28-mm-thick and ovendried density greater than 510 kg/m^3), options in 1- and 2-h-rated loaded and unloaded wall assemblies were evaluated. The evaluations of double stud walls included assumptions about whether the construction allowed transfer of the load to the second or unexposed wall when the fire-exposed rim board failed. Applications of the data to other situations need to take into account potential thermal–physical interactions that can adversely affect the performance of any protective membrane.

For loaded double stud walls with double 28-mm-thick rim board construction (Fig. 7), the fire test data and analysis identified the following configurations as options for 1-h construction:

a. Unprotected rim board if the adjacent floor–ceiling assembly has a finish rating of at least 20 min

b. Fire-exposed rim board protected with 13-mm Type X gypsum board

c. Rim board on the fire-exposed side unprotected but 13-mm Type X gypsum board on the fire side surface of the second rim board

Option c is recommended only if there is load transfer to the adjacent wall and the floor–ceiling assembly over the room of fire origin has a rated or unrated ceiling membrane.

Protection for 2 h is possible with the rim board protected with double layers of 13-mm Type X gypsum board if there is load transfer. Double layers of 16-mm gypsum board are needed if there is no load transfer.

For single-wall, single 28-mm-thick rim board construction with 1-h protection, one option for the rim board is protection with 13-mm Type X gypsum board if the adjacent floor–ceiling assembly has a finish rating of at least 20 min. If double 13-mm Type X or Type C gypsum board protection is provided, the adjacent floor–ceiling does not need a protective membrane for a 1-h system.

Two-hour protection is possible in a single-wall, single rim board construction with double 13-mm Type X gypsum protected rim board if the adjacent floor–ceiling assembly has a finish rating of at least 20 min.

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