Fire Containment in Wood Construction Doesn't Just Happen

Robert H. White and Kuma Sumathipala

Abstract

Regardless of the type of construction, structures capable of containing a fully developed fire do not just happen. Fire walls or area separation walls play an important role in the building codes in that they allow each portion of a building separated by such walls to be treated as a separate building. Attention to construction details is critical to maximizing the ability of a structure to contain a fire until its extinguishment. Unprotected joints, gaps, and penetrations can affect the fire resistance of an otherwise well-constructed assembly. In the case of fires originating in concealed spaces, firestopping and draft stopping can be important factors in preventing the spread of a fire within the concealed space. Spread of interior fires is typically controlled by compartmentalization. Within such compartments, rated assemblies and unrated assemblies may intersect. The construction detail of the intersection of a non-rated assembly and a fire-rated assembly can be critical in ensuring that the fire resistance of the rated assembly is maintained as intended. In the case of fires in the wildland-urban interface, failure to protect penetrations and other gaps in the protective membrane can allow burning brands to enter the interior and concealed spaces and thereby ignite combustibles not exposed to the outside.

White:
Research Wood Scientist, USDA Forest Service. Forest Products Laboratory, Madison, Wisconsin, USA
Sumathipala:
Senior Manager, Fire Research, American Forest & Paper Association, American Wood Council, Washington, DC, USA

Introduction

The various elements of a structure must serve many functions. Depending on the elements, they must provide structural stability, sound isolation, long-term permanence, and weather resistance. One function is to contain a fire to its area of origin. In the United States, a fire occurs in a structure at the rate of one every minute (Karter 2005). The estimated direct property loss in 2004 was $9,794,000,000 (Karter 2005). Wildfires have been responsible for total destruction of structures and major property losses. The 2003 direct property losses were 20 percent higher than the reported losses for 2004 due to the two southern California wildfires of 2003 that caused an estimated property loss of $2,040,000,000 (Karter 2005).

In the building codes, the question of fire containment by compartmentalization is addressed by specifying fire-rated walls, floors, doors, windows, and other structural elements or assemblies. Fire containment, however, involves more than just specifying a wall or floor assembly with a fire rating. Attention to construction details in design, specification, and construction is critical to maximizing the ability of a compartment to contain a fire for a limited time or until its extinguishment. Regardless of the type of construction, structures capable of containing a fully developed fire do not just happen; they must be designed, constructed, and maintained with the objective of containing an unintentional fire at any time.

Fire-Rated Walls and Ceilings

Construction of Fire-Resistance-Rated Assemblies

Fire-resistance-rated assemblies can be found in the *International Building Code (IBC)* (ICC 2003), directories of testing or listing organizations, International Evalua-

tion Services reports, and industry publications (AF&PA 2002, Gypsum Association 2003). Beyond the structural elements and the protective membranes, descriptions of the fire-rated assemblies should include the type and spacing of the fasteners for the protective membrane, the orientation of the membrane panels, and the presence, type, and installation details of any insulation. Each of these details can have an impact on the overall performance of the assembly during the standard fire exposure test, such as the ASTM E 119 (ASTM 2000) fire resistance test (Richardson 2001).

For assemblies containing gypsum board as protective membrane(s), the type of gypsum board required for the fire-resistance rated assembly needs to be specified. Types of fire-resistance rated gypsum board include Type X, Type C, and other proprietary gypsum board products. The joints between panels of gypsum wall board can be a weak link in the overall fire performance of the assembly with a gypsum board membrane (Richardson 2001). The performance of the joints has been addressed in the modeling of such assemblies (Takeda 2003).

Fire-resistance-rated firestopping materials should be used to ensure the integrity of utility penetrations of fire-resistance rated assemblies. Penetration firestopping includes through-penetration firestop and membrane-penetration firestop, and both are required to maintain the intended fire rating of the assembly (ICC 2003).

Types of Fire-Resistance-Rated Wall Assemblies

In the *IBC,* there are different types of fire-resistance-rated assemblies: fire walls, fire barriers. and fire partitions. Although their distinctions in common usage may be confusing, these terms refer to specific requirements in the *IBC.* The distinction is a general hierarchy of fire-resistance-rated assemblies that is easily recognized. "Fire partitions" are specified for situations such as walls separating dwelling units in the same building. A wall or similar barrier that is designed to contain fire within its area of origin and, therefore, establishes a fire area is a "fire barrier." Building codes limit the sizes of fire areas depending on type of construction and occupancy A fire barrier is supported by other assemblies such as a fire-resistance-rated floor/ceiling assembly. Fire barriers are required to protect corridors.

A wall that is continuous to the foundation and that has sufficient stability to allow the structure on either side of it to collapse without compromising the wall itself is a "fire wall." Fire walls create separate buildings for code purposes. The fire wall may have openings and other features incorporated into it. This is separate and distinct from any legal separations of the buildings such as lot or property lines. A fire wall co-located with the property line for joint service between buildings on dif-

ferent lots is a "party wall." A common example of a party wall is that which also serve as a lot line between row houses. Party walls are special condition fire walls that typically do not permit openings or other conditions that might compromise the integrity of the wall. In addition to these types of fire-resistance-rated walls, there are other specific fire-resistive requirements for exterior walls and building shaft enclosures, such as elevator shafts and stairwells.

As just discussed, fire walls are fire-resistance-rated assemblies that extend continuously from the foundation through the roof with sufficient structural stability and independence to allow collapse of the structure on either side of the wall without compromising the fire wall itself. The requirement that the fire wall must remain standing if there is collapse of the construction on either side of it mandates that consideration be given to the supporting structure of the fire wall. National Fire Protection Association (NFPA) 221-2006, *Standard for Fire Walls and Fire Barrier Walls,* describes three types of fire wall: cantilevered wall (freestanding), tied wall, and double wall. NFPA 221, Table 4-3, shows that "back-to-back" 1-hour fire-resistance-rated stud walls constitute a 2-hour fire wall assembly, and two 2-hour fire-resistance-rated stud walls may constitute a 3-hour fire-resistance-rated fire Wall.

Another option is an area separation wall that incorporates double stud walls for structural considerations and solid 25-mm- (1-in,-) thick Type X gypsum boards inserted in metal framing between the two stud walls for fire protection. This design for double stud walls, listed in the Gypsum Association's *Fire Resistance Design Manual* (Gypsum Association 2003), involves clips that fail when exposed to heat (Gypsum Association 1992, 2003). The collapse of the stud wall as a result of construction collapse within the building is not a factor because the stud wall is not part of the fire barrier. The "break away" aluminum clips that melt at elevated temperatures prevent the collapse of the stud wall from harming the solid gypsum fire barrier. Two 25-mm (1-in.) layers of the type X gypsum panels provide a 2-hour fire-resistance rating (Gypsum Association 1992, 2003).

For fire walls, there are requirements for extension of the fire wall beyond the exterior walls or roofs. Vertically these extensions are known as parapets. Furthermore, fire walls are required to be continuous across the building's width. from exterior wall to exterior wall and extend at least 457 mm (18 in.) beyond the surface of the exterior walls. Such extensions, vertically or horizontally, are intended to prevent re-entry of flames into the building, either over the roof or around the wall.

Construction details of the exterior wall bisected by the fire wall are an important consideration because they can be the basis for exceptions to the requirements for extension beyond the connecting exterior assemblies. Use

of certain construction materials in the exterior wall for a distance of 1.22 m (4 ft) to each side of the fire wall permits the omission of the wall extension by ensuring no flame re-entry due to the detail. Another of these exceptions for the requirement of a parapet for vertical continuity is the provision for construction that allows the fire wall to he terminated at the underside of combustible roof sheathing or decks if the roof sheathing is constructed of fire-retardant-treated wood for a distance of 1.22 m (4 ft) on both sides of the wall (ICC 2003). This provision of the *IBC* also requires that there be no openings in the roof within the 1.22 m (4 ft) of the fire wall and that the roof be covered with a minimum Class B roof covering. This exception is, however, not applicable to Types I and II construction that are required to be constructed of noncombustible materials.

Interconnection of One Assembly with Another Assembly

In providing this continuity of protection, a rated assembly may pass through another wall or floor assembly or a higher rated assembly may intersect with a lower rated assembly. Listings for fire-rated assemblies and the ASTM E 119 test standard itself are only for the wall and floor assemblies themselves. There is no standard way to test the intersection of the wall and floor/ceiling assemblies together. The wall and floor/ceiling tests do not address the joint details between walls and floor or roof assemblies.

Because fully developed fires typically bum in the central region of compartments, the center portions of the walls and ceilings will often receive the highest incident radiation flux. The elements in the comers (horizontal - between the wall and ceiling; and vertical –between the intersecting walls) generally receive less radiation and are less likely to be the first area breached by fire exposure. As such, field experiences with light-frame fire-rated assemblies have not driven a need to develop test criteria for these corners.

In a standard wood floor/ceiling assembly test, the fire exposure to the rim boards (the wood boards on the perimeter of the test assembly) is of a lower intensity than the exposure of the joists in the center of the assembly (Richardson 2001). The failure of the assembly in the test furnace is typically due to the failure of one or more structural members toward the middle of the assembly span.

To contain a fire in a room/compartment, one solution, involving a double stud wall, is to bypass the question of rim hoard design by inserting the solid gypsum fire barrier (Gypsum Association 1992, 2003). discussed earlier, between the two stud walls. In the absence of definitive test data to address the fire resistance of the fire-rated assembly in its entirety (from foundation to roof in the case of a wall), there are other options to con-

sider. A simple possibility is for all intersecting assemblies to have the same fire rating. For example. the *IBC* requires that all vertical assemblies holding up a horizontal fire-resistance-rated assembly to be rated to the same level as the horizontal assembly (ICC 2003, *IBC* Section 711.4).

Interestingly, however, a horizontal assembly bracing a fire-rated vertical assembly is not required to have the same rating as the rated vertical assembly An option to consider in such an instance, when an unrated horizontal assembly intersects a vertical fire-rated assembly, is to maintain a barrier within the interconnection space that will provide the required rating for the vertical assembly by using solid wood and/or gypsum board.

Another option is to maintain the continuity of the protective membrane of the rated vertical assembly, through the connection with the unrated horizontal assembly, by hanging the unrated Boor assembly on the outside of the rated wall assembly (such as balloon framing). In any option involving the interconnection between an unrated horizontal assembly (or an assembly of lower rating) and a fire-rated vertical assembly, the effect that failure of the unrated floor/ceiling assembly and its connections to the wall might have on the structural stability of the rated wall assembly needs to be taken into account.

As noted by Richardson (2001), the rim hoards and trimmers can be critical to the transfer of the gravity load from the roof and upper floors to the foundation of the building. As discussed in the previous section, a fire wall must also have sufficient structural stability under fire conditions to allow collapse of construction on either side without collapse of the fire wall itself.

Information on the solid gypsum area separation wall can be found in publications of the Gypsum Association (1992, 2003) and individual gypsum companies. Information for constructions involving trusses can be found in publications of the Wood Truss Council of America (WTC 2002). NFPA 221 provides information on other methodologies. Information on the use of wood and gypsum board to create a barrier within the interconnection space can be found in industry publications on the use of engineered wood products, including those of APA (2003), Trus Joist (2004), and Louisiana-Pacific (LP Building Products 2005). The construction details of Trus Joist and Louisiana Pacific publications are based on proprietary evaluations by Intertek Testing Services. These construction details mainly involve a structural composite lumber rim board of an unrated horizontal floor assembly and a fire-rated vertical wall assembly. The fire performance of structural composite lumber rim boards with and without gypsum board was investigated, and a procedure for the analysis was proposed by White (2006). In this FPL study, the fire tests involved only the rim board products themselves and not entire wall and floor/ ceiling assemblies.

In addition to considering the role of the unrated assembly in the structural stability of the rated assembly, one needs to consider the performance of any joints between the components of such construction details within the interconnection of the two assemblies that are in the potential path of the fire penetration. For the option that involves maintaining the barrier within the interconnection space, there are likely to be joints between the components. One way to minimize the effects of the joints is by designing the details to maximize the overlapping of the components of the construction. The addition of construction adhesives between the components may also help maintain the integrity of the barrier by sealing exposed joints of the wood components.

Some building officials prefer that the continuity of the protective membrane of the fire-rated wall assembly is maintained through an interconnection of another unrated assembly so it is consistent with the fire-rated assembly listing documentation (e.g., hanging an unrated floor/ceiling assembly on the outside of the rated wall assembly). This may, however, be a fallacy, depending on the construction details. An ASTM E 119 fire-resistance rating is obtained for the complete assembly, including the structural components. The structural components in the interconnection space would likely be different than those of the rated wall assembly. The role of the unrated assembly in the structural stability of the rated assembly needs to be considered. One advantage of making the rated wall continuous is the elimination or reduction in the number of joints in the fire barrier of the rated assembly. Without the penetration of the protective membrane of the rated assembly, the structural support of the structural components of the unrated assembly may need to be addressed with joist hangers or other design features.

In many buildings for which fire resistance is required, sound isolation is also likely to be a concern. Thus, details for the design of fire resistance may also need to take into account requirements for sound isolation. This is true for both the details of the fire-resistive assembly (Richardson et al. 2000) and use of fireblocking in the interconnections of wall and floor assemblies (Sultan 2000).

Fireblocking and Draftstopping

The need to provide fireblocking and draftstopping to contain a fire to its area of origin is addressed in building codes such as the *IBC*. Fireblocking and draftstopping are specified for concealed locations in combustible construction in both rated and unrated assemblies. As defined in the *IBC* (ICC 2003), fireblocking consists of "building materials installed to resist the free passage of flame to other areas of the building through concealed spaces." Locations requiring fireblocking include the hollow vertical spaces at each floor level within a fire bar-

rier wall. One advantage of platform construction over balloon construction is the integral fireblocking of platform construction.

Unlike through-penetration firestops and membrane-penetration firestops that are required to be fire rated to resist the standard fire exposure for prescribed periods of time, the requirements for fireblocking or draftstopping are prescriptive lists of materials. The specific materials to be used for fireblocking or draftstopping are prescribed in the building codes. Materials prescribed for fireblocking in the *IBC* (ICC 2003) include:

- 51-mm- (2-in.-) thick nominal lumber,
- two layers of 25-mm- (I-in:) thick nominal lumber with broken lap joints,
- one layer of 18.3-mm- (0.719-in.-) thick wood structural panel with joints backed by 18.3-mm- (0.719-in.-) thick wood structural panel,
- one layer of 19-mm- (0.75-in..) thick particleboard with joints backed by 19-mm- (0.75-in.-) thick particleboard, and
- gypsum board, cement fiber board, batts or blankets of mineral wool or glass fiber, or other approved materials installed in such a manner as to be securely retained in place.

Loose-fill insulation materials are not acceptable fireblocks unless suitable test data support its suitability for a specific application. Locations requiring fireblocking include concealed wall spaces at the ceiling and floor levels, interconnections between concealed vertical stud wall and concealed horizontal spaces of floors or other horizontal spaces, and stairways.

In tests of the interconnection of a wood joist floor and a double stud wall, Sultan (2000) found that semi-rigid glass or rock fiber insulation boards between the joist headers at the wall/floor joint prevented upward fire spread to the wall above. In these tests, upward flame spread was also prevented by placing 0.38-mm- (0.015-in.-) thick sheet steel or 13-mm- (0.5-in.-) thick OSB across the joist headers at the wall/floor joint. For wall /floor joints without fireblocking, the potential for vertical flame spread depended on the width of the air gap.

As defined in the *IBC,* a draftstop is "a material, device or construction installed to restrict the movement of air within open spaces of concealed areas of building components such as crawl spaces, floor/ceiling assemblies, roof/ceiling assemblies and attics" (ICC 2003). Draftstopping is required for floors and attics of combustible construction that exceed specified areas or involve specified multiple dwelling units. Materials prescribed for draftstopping include 12.7-mm- (0.5-in.-) thick gypsum board, 9.5-mm- (0.375-in.-) thick wood structural panel, 9.5-mm- (0.375-in.-) thick particleboard, or other approved materials. The draftstopping must be adequately supported to ensure that the integrity of the draftstop-

ping is maintained. Specific examples of fireblocking and draftstopping can be found in various publications (AF&PA 2001a, NFPA 1981, Schaffer et al. 1989, WTCA 2002).

Solid Wood Barriers

The charring rate of a solid wood barrier is well documented via numerous studies on charring rate of solid-sawn wood and other engineered wood products (ECS 1994, Schaffer 1967, White and Nordheim 1992, White 2002). To evaluate the fire resistance of a solid wood barrier, a charring rate of 0.635 mm/min (1.5 in./h) is generally assumed for wood (AF&PA 2003, White and Dietenberger 1999, White 2002). Thus, a nominal 2-in. (38-mm actual) piece of sawn lumber is sometimes assumed sufficient to provide 1-hour fire resistance. Because the nominal 2-in. dimension lumber is of finite thickness, fire penetration times are likely to be slightly faster than that indicated using the 0.635-mm/min (1.5-in./h) value, which is based on data for a semi-infinite slab. In tests of engineered wood rim board products, White (2003) found the penetration times for a finite slab to be 15 percent less than for the equivalent charring of a semi-infinite slab. Using this adjustment to the 38-mm (1.5-in.) char depth at 1 hour char rate, the sawn lumber slab of finite thickness would need to be 43 mm (1.69 in.) thick for 1-hour fire resistance for flame penetration.

A non-linear time-char depth model has been proposed (White and Nordheim 1992). In the *National Design Specification® (NDS)* design procedure for exposed structural wood members (AF&PA 2001b), a nonlinear equation is used to adjust the 38-mm (1.5-in.) char depth at 1 hour value to other char depths at shorter or longer times. Assuming the 38 mm (1.5 in.) at 1 hour, the adjustment for finite slab thickness, and the nonlinear model, the estimated thickness needed for a 2-hour fire rating is 75 mm (2.9 in.), or two pieces of 2-in. nominal thickness sawn dimension lumber (76 mm actual thickness). If it is appropriate to use the 139°C/181°C (250°F/325°F) temperature rise criteria of ASTM E 119 for the unexposed surface, the times would be further reduced (White 2003).

A "solid" wood barrier, however, often has joints, gaps, and small penetrations that become the controlling factor in the fire resistance of the barrier. Joints can be a critical Factor in the fire resistance of a wood barrier. Section C3.1 on wood and wood-based panels of Eurocode 5 (ECS 1994) provides some guidance for joints in wood-based panels. Estimated failure times for panels with a butt joint, lap joint, single T&G joint, or double T&G joint are 20, 30, 40, and 60 percent, respectively, of the failure times For a solid wood barrier calculated using charring rates for wood. The values are valid when the gaps are limited to 1 mm (0.04 in.) or less, the lap joint is 30 mm

(1.2 in.) long, and the tongue and groove of the T&G joints are 15 mm (0.6 in.) long.

In the next two sections, test results are provided from two recent studies that illustrate the importance of addressing the presence of any joints or gaps in the solid wood barrier. These studies include tests of two wood decks (White 2004) and the development of an exterior fire-resistive fence to shield exits from a potential outdoor transformer fire.

Joints in Heavy Timber Deck

As part of a preliminary study on fire resistance of heavy timber decks, two decks were tested in the intermediate-scale furnace at FPL (White 2004). The nominal 3 by 6 laminated decking was an appearance-grade decking product consisting of three 18-mm- (0.7-in.-) thick laminates. This decking material was manufactured so the middle laminate of the decking provided the tongue and the other two laminates formed the groove. Total thickness of the decking was 55 mm (2.2 in.). Outer laminates were 131 mm (5.2 in.) wide. The 129-mm- (5.1-in.-) wide center laminate resulted in a 18-mm- (0.7-in.-) thick tongue and a 20-mm- (0.8-in.-) deep groove. The edges of the tongue and groove were beveled.

The second deck was constructed from the material with the tongue and groove removed so the deck consisted of butt edge joints. The decks were tested on top of the FPL tension furnace. Exposed surface area was 2.08 by 0.94 m (82 by 37 in.).

The biggest surprise in these tests was the greater time for the butt-joint deck compared with the T&G joint deck. Flame penetration at the joints occurred at 44.4 minutes for the T&G deck and at 64 minutes for the butt-joint deck. The average temperature for the unexposed surface and the internal temperatures obtained in the two tests were consistent.

Assuming a constant charring rate at 0.65 mm/min (1.53 in./h), the predicted bum-through time (unexposed surface to reach 300°C (572°F) for a 55-mm- (2.2-in.-) thick solid wood slab was 85 minutes. The shorter time duration for the 55-mm- (2.2-in.-) thick T&G deck was likely due to the gaps in the tongue-and-groove joints. The gap between the end of the tongue and the bottom of the groove was about 2 mm (0.1 in.). The product was of high quality, and the fit was sufficiently tight to provide its intended structural integrity along the edge. Smaller tolerance in the design would likely cause problems in installation when moisture content changes result in dimensional changes in the wood after manufacture. In contrast, the butt joint was a very tight joint along its entire 55-mm (2.2-in.) thickness.

Based on a series of tests of timber decks, Richardson and Batista (2001) concluded that the failure times for simple butt joints, single T&G joints, and double T&G boards were 10, 40, and 40 percent, respectively, of the

times for a solid wood member estimated using charring rates for wood. In the tests, the specification for the gaps between boards was 2 mm (0.08 in.) or less. The tests of Richardson and Batista (2001) illustrated the effect of increasing the thickness of gaps, particularly with butt joints.

For gap of ≤ 1 mm (≤ 0.04 in.), the tests suggested failure times for simple butt joints were 30 percent of those for solid-sawn lumber instead of the 10 percent for gaps of 2 mm (0.08 in.) or less. Adding wood flooring or panel products on top of the timber deck improved the failure times. Paneling on top of the decks provided the most benefits to the fire resistance of decks when the butt joints had 4-mm (0.16-in.) gaps compared with decks of T&G joints or narrow gaps. Given the limited ability to control gaps between deck boards over time, the best method to address the joint issue is to provide a multi-layer deck assembly by adding panel products or other floor topping, such as gypsum concrete, lightweight or normal concrete, on top of the heavy timber decks.

Fire-Resistive Barrier for Outdoor Residential Transformer

In a development in Wisconsin, houses were constructed without the required separation between the small residential transformers associated with underground electrical distribution systems and openings to the houses. Because the situation involved existing houses and existing transformers, it was desirable not to install a concrete barrier that required foundation footings the entire lengths of the barrier. A more suitable barrier was a fence with vertical fence posts away from the buried utilities. Esthetic considerations were also important. To assist a local fence company provide such a barrier, FPL conducted a series of small-scale fire resistance tests to quantify the fire-resistance rating of such a "fire-resistant" barrier.

A fence constructed of western redcedar horizontal boards was the preferred option. The charring rate of western redcedar when exposed to fire exposure specified in ASTM E 119 had previously been obtained (White and Nordheim 1992). In the case of a semi-infinite slab, the char depth (300°C [572°F]) would be 45 mm (1.77 in.) at 60 minutes. The tests of rim boards (White 2003) indicated that the thickness for a finite solid slab would need to be 18 percent greater than the char depth of a semi-infinite slab. Thus, a solid cedar barrier without joints would need to have a thickness of 53 mm (2.1 in.) to provide a I-hour fire-resistive barrier.

Given the dimensions of the barrier, the barrier would have joints between the horizontal cedar boards. These joints substantively reduce the fire resistance of the barrier because they allow flame penetration. Using the equations in the Eurocodes (ECS 1994), the estimates for the thickness of the barrier were 254 mm (10 in.) for a

butt joint, 170 mm (6.7 in.) for a lap joint, 127 mm (5 in.) for a single T&G joint, and 84 mm (3.3 in.) for a double T&G.

To reduce the total thickness required, a panel product was used as an inner core layer of the barrier. Various options were considered. For interior applications, gypsum board is the obvious choice due to its low cost and excellent fire-resistance properties. The exterior exposure eliminated gypsum board and other options such as OSB and other composite wood products. Preservative-treated plywood was one option. Fire-retardant-treated plywood was considered, but the treatment provides only limited benefits. Fire-retardant treatments are intended to reduce the flammability of the wood. Such treatments have mixed effects on the resistance of the treated wood to fire penetration. A cement board is durable in exterior applications but is not an insulative material. Since cement board was relatively inexpensive and readily available in local building supply outlets, wood barriers with cement board as the interior core were tested. For wider applications of such barriers, further investigation of non-combustible insulative products used as core materials in fire doors would be warranted. A more insulative core would increase the time before the wood layer on the unexposed side reaches temperatures at which it will degrade and ignite. The wood layers were constructed of tongue-and-groove western redcedar siding boards.

Given the intended application, the main failure criterion considered in these test was flame penetration. The specimens were tested in the FPL small vertical furnace using the time–temperature curve specified in ASTM E 119 (ASTM 2000). Specimens were prepared by the local fence company and supplied to FPL for testing. The layers were glued together with a mastic-like adhesive. The test specimen was conditioned at 23°C (73°F). 50 percent relative humidity (RH) prior to testing. Moisture content (MC) readings with a moisture meter were 10 to 14 percent.

In the two initial tests, the barrier consisted of the 12.5-mm- (0.5-in.-) thick cement board sandwiched with the cedar boards on each side. On the fire-exposed side, the western redcedar boards were nominal 1 by 8 T&G (V-grooved on two sides pattern) siding boards. The dressed dimensions of 1 by 8 cedar siding boards are 11/16in. (17.5mm) thick and 7-1/8in. (181 mm) long. For selected pieces measured, the average thickness was 16.7 mm (0.66 in.) and total width was 177 mm (7 in.). The tongue of the T&G was 6.3 mm (0.25 in.) thick. The non-fire-side boards were shiplap siding in the first test and the T&G boards for the second test. With these first two specimens, flame penetration at the joints of the exterior boards occurred in 40 to 45 minutes. Conduction of heat through the cement board caused the cedar boards on the exterior side to ignite. This was followed by flame

penetration through the horizontal joints between the boards.

Thermocouples were placed on the unexposed surface beneath 50-mm- (2-in.-) square ceramic pads on the unexposed surface. These pads are smaller than the 152-mm- (6-in.-) square size specified in ASTM E 119 for its much larger specimens. Besides flame penetration and structural collapse for load-hearing structural assemblies, ASTM E 119 also has unexposed surface temperature increase failure criteria. Criteria for failure are temperature increases of 139°C (250°F) average or 181°C (325°F) maximum. The criteria address the potential ignition of combustible materials placed on or against the non-fire surface. Thermocouples on cool surface recorded temperatures exceeding the 181°C (325°F) maximum temperature rise at 42 minutes in the first test and at 47 minutes in the second test.

For the third specimen, two layers of the cedar boards were placed on the fire-exposed side of the cement board. No wood boards were on the non-fire-side of the cement board. The exposed boards were oriented horizontally. For the interior layer of cedar boards, the orientation of the boards was perpendicular to the fire-exposed boards (i.e., vertical). In the third test (double layers of cedar boards on fire-exposed side of cement board), the temperatures on the back surface of the cement board exceeded the 181°C (325°F) maximum temperature rise at 64 minutes. Test was terminated at 2 hours with the cement hoard intact.

The fourth specimen was identical to the third specimen except a layer of cedar hoards was on the non-fire-side of the cement board. This last test was terminated at 60 minutes without any flame penetration to the unexposed surface of the specimen. Temperature on the unexposed surface of the specimen was 72°C (162°F) at the time of test termination. Specimen was removed and examined. The cedar boards on the fire side of the cement board were charred. The cement board was intact. There was only surface charring of the fire-exposed surface of the cedar hoards on the cool side of the cement board.

The cement boards were effective barriers for the joints when placed on the unexposed side of the wood hoards. Due to their high thermal conductivity, cement boards benefit from having the insulative wood between the board and the fire exposure. When the cement board was the middle layer, the joints of the cedar boards contributed to the earlier failure. The last two tests showed that by placing two layers of the 17.5-mm- (0.7-in.-) thick cedar T&G boards on the fire-exposed surface of the 13-mm (0.5-in,) cement board, the resulting composite assemble – 48 mm (1.9 in.) thick or 66 mm (2.6 in.) thick with decorative wood layer on non-fire side – can satisfy the 1-hour standard fire exposure performance criteria of a fire-resistive barrier.

Protection from Exterior Fires

The ability of a structure to contain a fire is particularly important in exterior fire exposures such as those associated with fires in the wildland-urban interface. The number of structures potentially subjected to a wildland fire and the need to contain the wildland fire itself often strain the ability of the fire services to provide the individual attention normally associated with an interior house fire. Unlike interior structures fires, total destruction of homes is a characteristic of wildland-urban interface fires.

After a wildland-urban fire, some homes can survive even among widespread destruction of surrounding homes. As noted by Cohen (2000). the characteristics of the home and its immediate surroundings will greatly influence its survival. If there is vegetation within proximity of the structure or firebrands are present during a wildland fire exposure, the survivability of a structure is improved by either preventing any ignition of the combustible components of the structure (Cohen 2000) or preventing the fire penetration of the exterior shell of the structure (Jennings et al. 2000).

Homeowners must take the principal responsibility for ensuring adequately low ignitability of their homes (Cohen 2000, IBHS 2001). In addition to construction details and appropriate landscaping to create a defensible space around the home, constant maintenance to remove combustible debris (such as leaves, pine needles) on and around the home reduces the available fuel loads and improves survivability (IBHS 2001). Additional information on what homeowners and local communities can do is available on various websites, such as Firewise program (www.firewise.org) and the Southern Center for Wildland-Urban Interface Research and Information (www. interfacesouth.org). Both of these websites are supported by the USDA Forest Service.

In addition to flames from combustible items and vegetation in the immediate vicinity of the structure and radiation exposures from the burning vegetation and/or adjacent structures, a hazard of wildland-urban interface fires that distinguishes them from interior fires is the likely presence of airborne firebrands. Experiments have shown that a single glowing firebrand can ignite shredded paper beds (Manzello et al. 2006). In contrast, research has shown that wildland flame fronts will not ignite exposed wood surfaces if the flame-to-structure distance is greater than 10 to 40 m (33 to 130 ft) (Cohen 2000, Cohen and Butler 1996).

To address the unique aspects of wildland-urban fires, several new test methodologies were developed at the University of California Forest Products Laboratory (now closed) (Jennings et al. 2000). More recently, ASTM International Committee E-5 established a new subcommittee (ASTM E5.14) to specifically consider the standardization of test methods to evaluate building materi-

als and assemblies for structures constructed in the wildland-urban interface. In addition to maintaining and revising the existing ASTM E 108 standard test method for roof coverings, the subcommittee is considering proposals for the testing of decking materials, vents, exterior walls, and landscape vegetation.

The need to address construction details is not eliminated by the use of noncombustible materials. A clay tile roof may not provide protection from firebrands if the ends are not capped. The use of "bird stops" to close up the cement tile roof at the eave end not only prevents birds from creating a nest but also closes off this avenue for penetration of firebrands. If the fire exposure is severe enough, a surface layer of a noncombustible material may be too thin or too conductive to prevent the ignition of a combustible substrate. It is not just joints and gaps in the exterior finish that are important. As seen in the test results for the "fire resistive" transformer barrier, joints in the substrate can also be a factor in the fire resistance of the exterior shell.

Construction features aimed at improving permanence of the structure can adversely affect the ability of a structure to withstand the fire exposure of a wildland fire. Soffit vents and other vents needed to provide the ventilation to prevent biological decay of the structure also provide the means for firebrands or flames to penetrate into the attic or other concealed spaces. The penetration can be via direct flame penetration or firebrands. Wide overhangs likely increase the available combustible materials beneath them to provide the fire load needed to cause fire penetration into the attic.

Closing Comments

A recent fire illustrates how successes and failures in fire containment are influence by construction details. It was reported that a chair or love seat was on the balcony at the time of the fire. There was little evidence of the chair after the fire. The intensity of the fire upon the exterior balcony of the apartment was sufficient for the fire to spread into the attic above via the thin aluminum soffits outside the balcony. The gypsum board and plywood ceiling of the exterior balcony, however, withstood the fire and prevented a more direct route to the attic. The closed patio door was able to provide sufficient fire resistance during the initial intense fire exposure to limit the damage to the interior of the apartment to that due to heat and smoke rather than flames. For closets and rooms with closed interior doors, damage was even less. Within the attic, a vertical sheet of plywood installed to confine loose-fill insulation shielded the rest of the attic from direct radiation of the flames that penetrated the soffits. Venting of the heated air through the attic vents and holes created by fire fighters likely prevented flashover conditions in the attic. Even if flashover had occurred in the at-

tic, the draftstopping of the attic would have hindered the spread of the fire within the attic space.

This paper has concentrated on construction details that may impact the ability of a building to contain a fire until extinguishment. Beyond construction details, factors such as combustible contents, presence of sprinklers, and overall architectural design of the building have an impact on the potential spread of a fire within a building and the severity of a fire. The severity of a given fire will depend on the available combustible fuel and the corresponding availability of ventilation.

Structures capable of containing a fully developed fire do not just happen. Even with excellent design and engineering, the ability of a building to contain a fire can be undermined by inadequate quality control during construction or subsequent renovations that defeat the original purpose. Proper design and construction of structures involves finding compatible solutions that address all the requirements placed on a building, whether it be sound isolation, fire protection, permanence, weather resistance, or protection from burglars or terrorists. We need to ensure that solutions to one set of requirements that are developed in isolation do not adversely impact the other requirements. Through research, education, and active code enforcement, we can insure that wood products continue to provide an economical, environmentally sound, and safe means of building construction.

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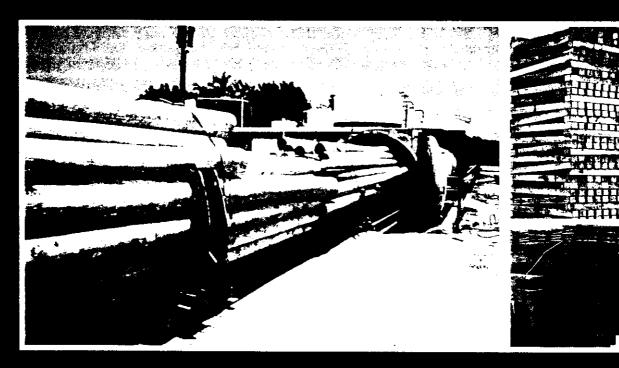
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Edited by H. Michael Barnes
Professor, Department of Forest Products,
Mississippi State University, Mississippi, USA