Wildfire Research

Ignition Potential of Decks Subjected to an Ember Exposure

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Introduction

On average, the U.S. experiences over 73,000 wildfires annually (USFS, 2016). These wildfires burn millions of acres, destroy homes and, in some cases, cause injuries or fatalities of home owners and firefighting personnel. Wildfire occurrence and intensity is increasing worldwide, with major wildfires occurring outside the normal fire season (Short, 2015) and exhausting firefighting resources.

One challenge in combating wildfires is that they spread through three main scenarios:

1. Ember transport and deposition
2. Radiant heat
3. Flame impingement exposure

Ignition of a building can result from any of these scenarios. However, reports have indicated that ember exposure accounts for up to 90 percent of building ignitions (Potter and Leonard, 2010). Two of every three homes destroyed in the 2007 Witch Creek Fire in San Diego County, California, were attributed to ember ignitions (Maranghides and Mell, 2009). The risk of ignition from embers depends on several factors including:

- The number of embers and duration of exposure
- The amount of combustible debris or materials near the building
- Environmental conditions (such as temperature, relative humidity and wind)

In some cases, ember exposure has resulted in the ignition of a building 12 hours after the initial fire front had passed (Potter and Leonard, 2010). The delayed ignition can be explained by the continued production of embers after the fire front passed or smoldering combustion of a structural component that eventually transitioned to flaming combustion.

The 2012 Waldo Canyon Fire in Colorado Springs, Colorado, prompted post-fire damage investigations. Maranghides et al. (2015) reported that decks were commonly ignited by the accumulation of embers near the footers, on the top surface, or on the underside where combustible material had accumulated. Quarles et al. (2013) reported that deck ignitions and subsequent loss of homes resulted from flames from burning trees that impinged on the underside of the attached decks.

As a result of post-bushfire (wildfire) and laboratory studies in Australia, Dowling (1994) reported that the most common mode for ignition of timber bridges resulted from the accumulation of embers in gaps. Common accumulation locations included gaps between decking planks and against a *gravel beam* located at the edge of the timber deck surface that provided a vertical surface against which embers could accumulate.

Attached decks can be a vulnerable component of a building if they ignite and the resulting fire spreads to and into the occupied space. Spread into the building could occur if the building cladding was combustible (such as a wood or plastic siding product), or if the radiant heat was sufficient to break glass in a window or door. If the ignition occurred at the deck-to-wall intersection, spread into the building would be more likely. If ignition occurred at a location away from the building, flame spread to the building would have to occur, or fire growth would have to develop flame lengths or radiant heat exposure adequate to ignite combustible cladding or break glass.

Deck ignitions can potentially occur at locations on a deck where ember accumulation occurs. Experiments at the Insurance Institute for Business & Home Safety (IBHS) Research Center have demonstrated that wind-blown embers near a building do not accumulate uniformly when smooth surfaces are present. Observations have shown that natural accumulation areas will be at the base of the wall and a stagnation point away from the building (Figure 1). The location of the stagnation point is a function of the height of the building. Rough surfaces, such as mulch and most landscaping features, will stop embers, allowing them to accumulate wherever these features are present.

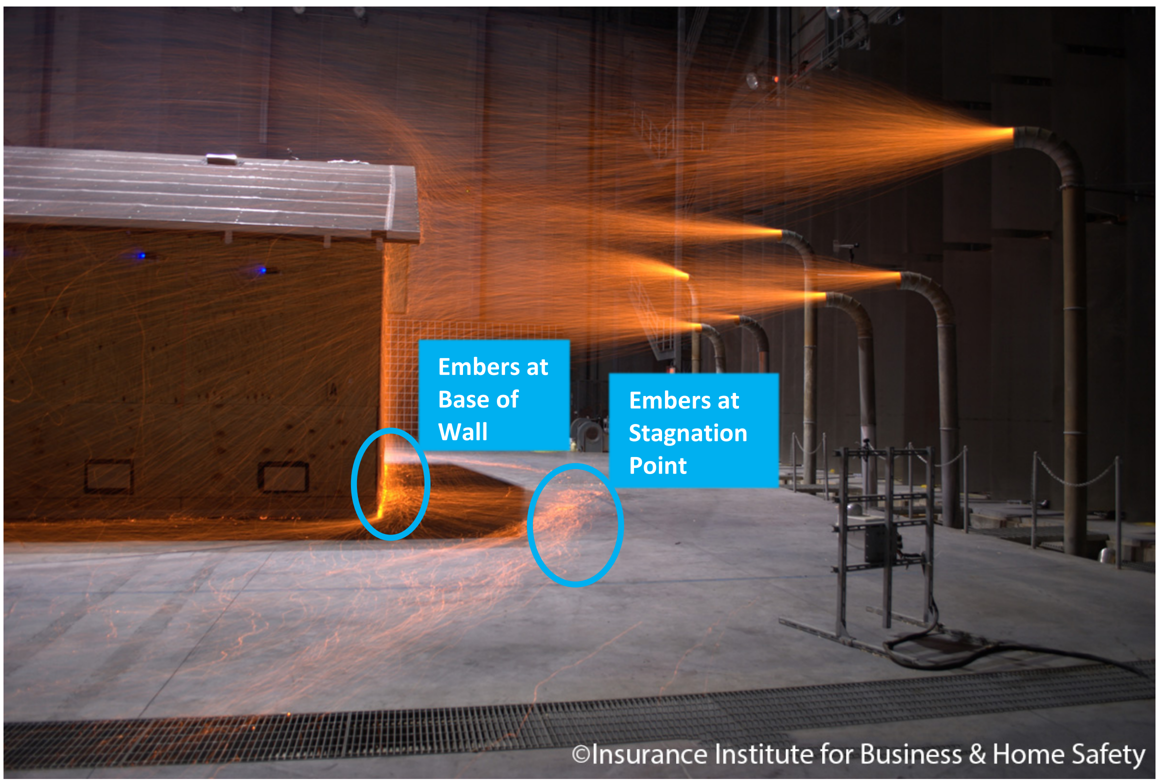

Figure 1. Wind-blown embers accumulated at the base of a wall and a stagnation point (function of building height) some distance from a building inside the large test chamber at the IBHS Research Center.

Deck-to-wall connection details that result in a gap can allow for debris to accumulate. Debris can also accumulate in gaps between deck boards (refer to Figure 2). These gaps are intended to allow for expansion and contraction of deck boards and minimize the occurrence of unwanted buckling. When a building is threatened by wildfire, the deck will experience and must be able to resist an ember exposure. Ember accumulation in gaps could result in ignition of the debris and deck boards. Deck-to-wall design features, such as use of flashing, could minimize debris accumulation in this area. Routine maintenance minimizes the accumulation of debris in gaps between deck boards. So, the remaining question is how vulnerable decks are to an ember exposure when accumulated debris has been removed or has not accumulated and cannot contribute to a fire.

Figure 2. Typical debris accumulation points at deck-to-wall connection (top) and gap between deck boards (bottom).

Building codes and standards provide requirements and guidance on products and construction details that can reduce the vulnerability of buildings to wildfire. Options include the International Code Council's *International Wildland-Urban Interface Code* (IWUIC), National Fire Protection Association (NFPA) 1144: *Standard for Reducing Structure Ignition Hazards from Wildland Fire*, and California Building Code Chapter 7A – "Materials and Construction Methods for Exterior Wildfire Exposure." Each of these documents provides information on construction, including materials and design features, and vegetation management on the property.

The selection, placement and maintenance of vegetation, and other combustible items (for example, firewood piles and storage sheds) on the property is typically referred to as *defensible space*. Combined, these elements provide a coupled approach to reducing the vulnerability of the building to wildfire exposure. If an effective defensible space is created and maintained, the potential for an underdeck flame impingement exposure is reduced. Given the typical size of residential and most commercial properties, it would not be possible to reduce the ember exposure to an attached deck with even the most effective defensible space on an individual property. Therefore, understanding the threat of an ember exposure to a deck is critical to understanding its vulnerability to wildfire and potential exposure to the building.

Fire-related performance requirements for decks are usually limited to the walking surface, thereby limiting requirements that affect the structural support system (columns, beams and joists). The NFPA and IWUIC documents limit common dimension decking (1- to 2-in.-thick material) to material that meets the requirements for being noncombustible, fire-retardant-treated (FRT) lumber or an ignition-resistant material. An ignition-resistant material is defined in the NFPA standard and IWUIC building code, and based on the American Society of Testing and Materials (ASTM) Standard ASTM E84.

Non-fire-retardant-treated (non-FRT) lumber and commercially available plastic composite products currently available are not allowed by the IWUIC and are not recommended by NFPA 1144. Chapter 7A of the California Building Code provides a performance-based method by which these nominally combustible products can be approved for use in wildfire-prone areas. The standard test method (*State Fire Marshal Standard SFM 12-7A-4*) includes an underdeck flame exposure test that simulates combustibles beneath a deck and a burning brand exposure test that simulates combustibles on the upper surface.

The burning brand specified in the California Office of the State Fire Marshal–approved test is much larger than typical wind-blown embers and is the same as that specified in an ASTM test used to evaluate the fire performance of roof coverings (ASTM E108). Wind-blown embers are also typically glowing, not flaming. Therefore, the burning brand test is more reflective of a top-of-deck flame impingement test rather than a wind-blown ember exposure. In addition, the language in Chapter 7A only requires decking products to meet the provisions of the underdeck flame impingement test to comply.

Objectives

The objectives of this study were to evaluate:

- The ability of an ember exposure to directly ignite combustible wood and plastic composite decking without the contribution of accumulated debris at ember accumulation points
- The effectiveness of the standard underdeck flame-impingement exposure test to predict the performance of decking to an ember exposure
- Fire propagation and growth on ignited decks

Although there is the possibility of a flame-impingement exposure for an attached deck during a wildfire, an ember exposure is almost certain. A key question in this study is whether the current SFM and ASTM standard test methods are adequate to predict performance during an ember exposure, or whether a separate standard test method is needed.

Additional experiments that investigated the potential for a fire that ignites on an attached deck to spread to the building are reported in the Appendix: Fire Spread and Growth.

Experimental Procedures

Test Facility

The IBHS Research Center large test chamber can hold a full-scale, one- or two-story residential or small commercial building. The test chamber includes a wind tunnel, powered by a 105-fan array that can simulate the flow characteristics of the atmospheric boundary layer (ABL) at speeds greater than 100 mph (71.5 m/s). See Standohar-Alfano et al. (2017) for more information about the wind flow characteristics in the IBHS test chamber.

Wind flows in the ABL are typically characterized by the variation in mean ($\bar{V}$) wind speed and the along-wind turbulence intensity (Iu) which is a measure of gustiness of the wind as it varies with height. Due to the gustiness of the wind and the fact that it changes with height above the ground, design wind speeds in building codes in the U.S. are reported as a 3-second gust at 33 ft (10 m) above the ground (V3s, 33 ft). For these experiments, wind time histories simulating an open-country terrain were scaled to two different wind speeds. In this report, the slower time history will be referred to as *medium*, while the faster time history will be referred to as *high*.

Table 1 provides the flow characteristics for each of the time histories at the mean roof height of the building and the code equivalent wind speed at 33 ft (10 m). Figure 3 shows the time-varying nature of the wind speeds for both the medium and high records at mean roof height of the building, 12.6 ft (3.8 m). The 3-second gust velocities at mean roof height and 33 ft (10 m) for each time history are also shown in Figure 3. A nominal wind speed that did not change with height and was constant over time was also used. The wind speed of this nominal condition ranged between 10 mph and 12 mph (4.5 m/s and 5.4 m/s). The wind tunnel also has a turntable with a diameter of 55 ft that can rotate 360 degrees, allowing for the evaluation of wind speed and direction on the deposition and ignition potential from an ember exposure.

Table 1: Flow characteristics for the two wind time histories used in the current investigation.

Time History	At Mean Roof Height (12.6 ft)			$V_{3s,33\ ft}$ (mph)
	$\overline{V}$ (mph)	*Iu* (%)	V_{3s} (mph)	
Medium	17.6	14.3	26.9	30.4
High	29.9	16.8	47.7	51.7

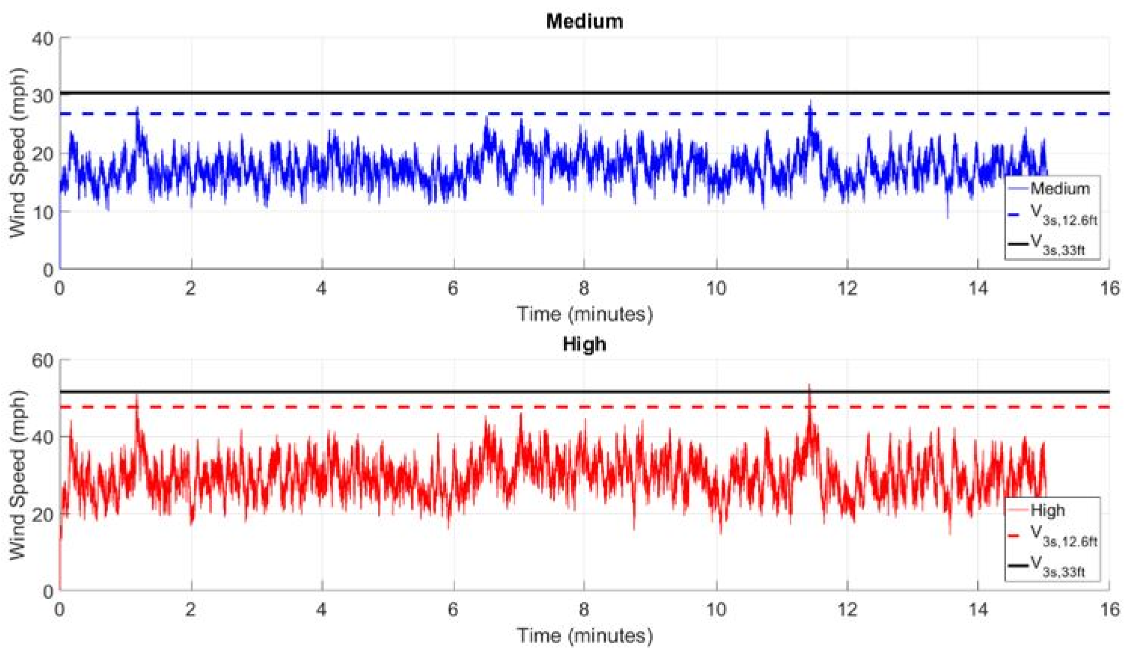

Figure 3. Medium- and high-wind speed records used in wildfire experiments (1 mph = 0.45 m/s); peak 3-second gust wind speeds are indicated by the dashed horizontal lines and the code-equivalent 3-second gust speeds at 33 ft (10 m) are shown by the black lines.

Auger System

These experiments used a custom-made system to generate embers. The raw material consisted of a mixture of Southern Yellow Pine wood chips and wooden dowels processed from hardwood species sourced in the Midwestern U.S. The nominal chip-to-dowel ratio was 80:20. All raw material was dried to a moisture content less than 10 percent by conditioning in a heated container. Moisture content was determined by oven-drying hand-grab samples taken from the material drying in the storage container.

Figure 4 is a diagram of the custom-made generators used to burn fuel and create embers. The fuel was delivered into the generator by a pneumatic feed line (A). The fuel dropped on top of a metal grate immediately above a gas burner (not shown). A vertically oriented fan (B) under the burner pushed embers up and out of the exhaust duct (C). Eight generators were placed at equally spaced intervals in front of the fan array.

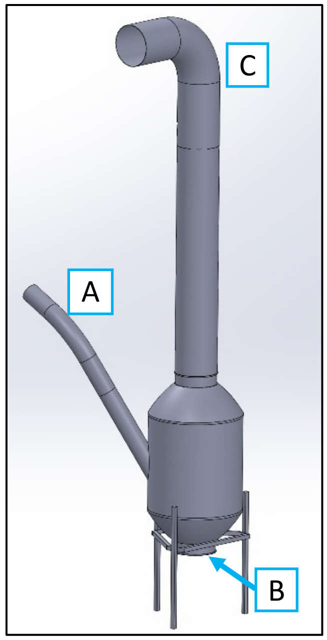

Figure 4. Diagram of an ember generator used in wildfire experiments, showing the pneumatic feed line (A) for feeding fuel to the generator; vertically oriented fan (B); and exhaust duct (C).

Figure 5 shows an overview of the feed system, ember generators, and test building. Prior to testing, fuel was placed in hoppers (A). Five augers (not shown) dropped fuel into the pneumatic feed lines. The feed rate was controlled by powering the augers on and off at defined intervals. The desired feed rate was obtained when individual augers were turned on for a predetermined length of time between 3 and 5 seconds, and then off for 10 to 20 seconds. The on/off times for each individual auger were determined by visual inspection of ember output and evidence of elevated temperatures inside the ember generators (red color of the metal burn chambers). The goal of the intermittent fuel delivery method was to ensure a consistent output of embers by all generators without damage to the generators from excessive heat.

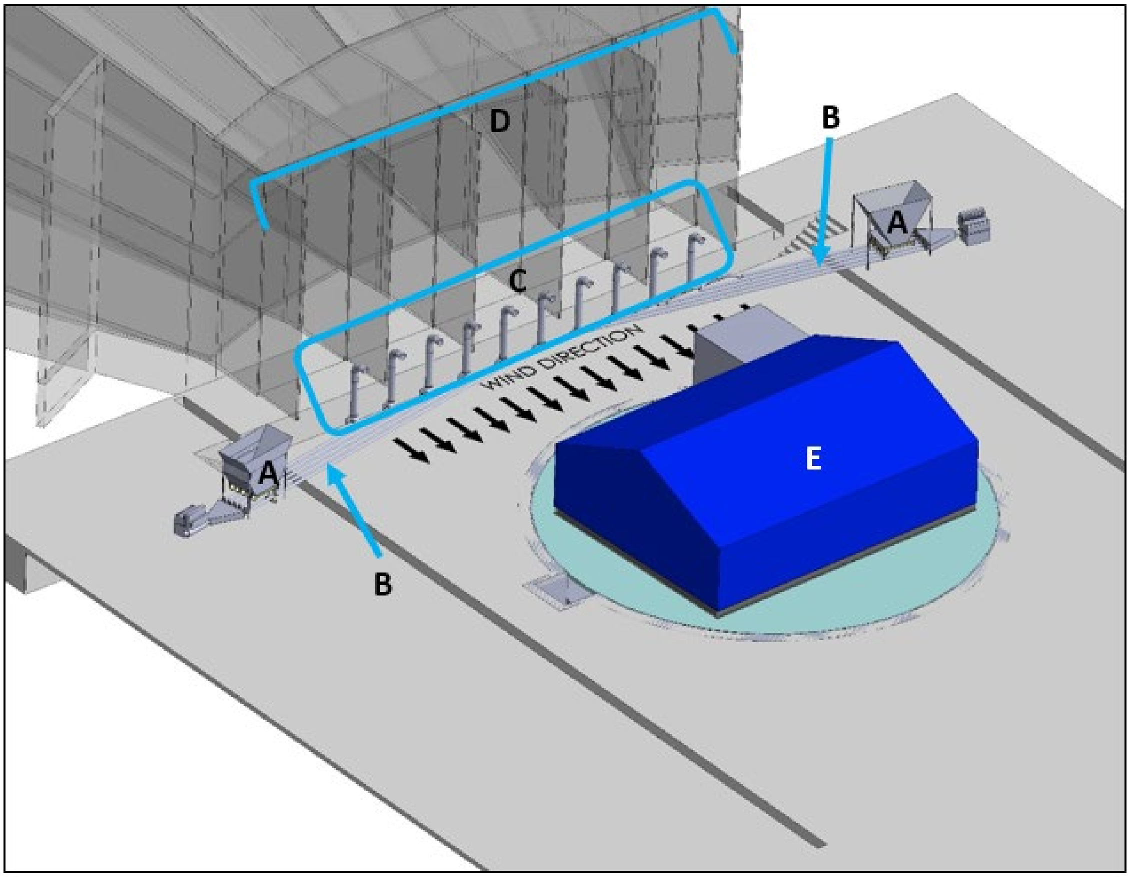

Figure 5. Auger feed and ember generation system, including left and right hoppers (A); auger feed lines (B) for delivery of fuel to generators (C); fan array (D); and test building (E).

The augers delivered fuel to the pneumatic feed lines (B). These feed lines delivered the fuel to the ember generators (C). As described previously, the ember generators burned the fuel and a fan pushed embers through the vertical exhaust duct. The fan array (D) created the wind flow in the test chamber using the wind traces shown in Figure 3. The test building (E) was then subjected to an ember exposure. Figure 6 shows the ember-generating system in use during an experiment.

Figure 6. *Test deck exposed to embers from ember generators.*

Deck Construction

Decking products were purchased from various vendors. Prior to testing, the deck assembly was conditioned to a moisture content between 6 and 10 percent (oven dry basis) in a dehumidification lumber dry kiln. All test material decks were 5 ft x 5 ft with a nominal ⅛-in. gap between deck boards. The decking products were either a nominal 2 in. or a nominal 1 in. thickness, where actual thicknesses ranged from ¾ in. to 1½ in. Decks consisted of nominal 6-in.-wide deck boards supported by 2 x 6 joists spaced 16 in. on center. Joists were in the Spruce-Pine-Fir species group and obtained from a local building supply store.

Eight different deck board products were evaluated. A summary of these products is shown in Table 2. Material types included wood, both FRT and non-FRT, and plastic composite (PC) products composed specifically of wood fiber and either polyvinyl chloride (PVC) or polyethylene (PE) thermoplastics. Some of the decking products complied with the standard test method specified in the California Building Code Chapter 7A and some did not.

The PC products were either capped—including a thin, surrounding layer of textured plastic—or not capped. Examples of capped and non-capped PC products are shown in Figure 7 and Figure 8, respectively. Because PC products are produced in a co-extrusion process, the capping material and the core material need not be the same, although they can be. Although the composition of the cap material was not determined, it was important to incorporate both kinds of products in the experimental design because the outermost layer could influence the response of a decking product to an ember exposure.

Table 2. Information for deck board products used in experiments.

Deck Name	Abbreviation	Type	7A Compliant	Capped
PVC Composite	PVC	PC	Yes	No
PE Composite 1	PE-1	PC	No	No
PE Composite 2	PE-2	PC	Yes	No
PE Composite 3	PE-3	PC	Yes	Yes
PE Composite 4	PE-4	PC	No	Yes
High-Density Tropical Hardwood	H	Wood	Yes	N/A
Medium-Density Softwood	S	Wood	Yes	N/A
FRT Wood	FRT	Wood	Yes	N/A

Figure 7. Example of a capped PC deck board. Note the reddish outer layer surrounding the lighter gray core material.

Figure 8. Example of a non-capped PC deck board.

Test Details

Preliminary tests were conducted to determine whether the typical surface roughness of a deck would influence the natural stagnation point where ember accumulation would be maximum, and if not, to determine the location on an attached deck where ember accumulation would be greatest.

To evaluate this potential for ember accumulation, two large test decks were constructed and attached to the test building. Test Deck No. 1 was attached to the front, and Test Deck No. 2 was attached to the back of the building. Test Deck No. 1 included a re-entrant corner assembly and Test Deck No. 2 did not. The building was rotated to selected orientations and subjected to an ember exposure at both medium- and high-speed wind records. The location of maximum ember accumulation was visually observed and documented.

Based on the results of these tests, the orientation where the test building and deck were perpendicular to the wind was selected for the remainder of the tests to evaluate ignition potential. The medium-speed wind record resulted in the greatest accumulation on the deck, so this wind speed was selected for use in all subsequent tests.

Based on results from the preliminary tests, experiments to evaluate the ignition potential of decking to an ember exposure were conducted with the 5-ft x 5-ft test material deck inserted into a larger deck that was 20 ft wide by 12 ft deep. The larger deck surface was covered with a panelized, non-paper-faced gypsum product. A framed, movable wall was incorporated into the building design to create a re-entrant corner (Figure 9).

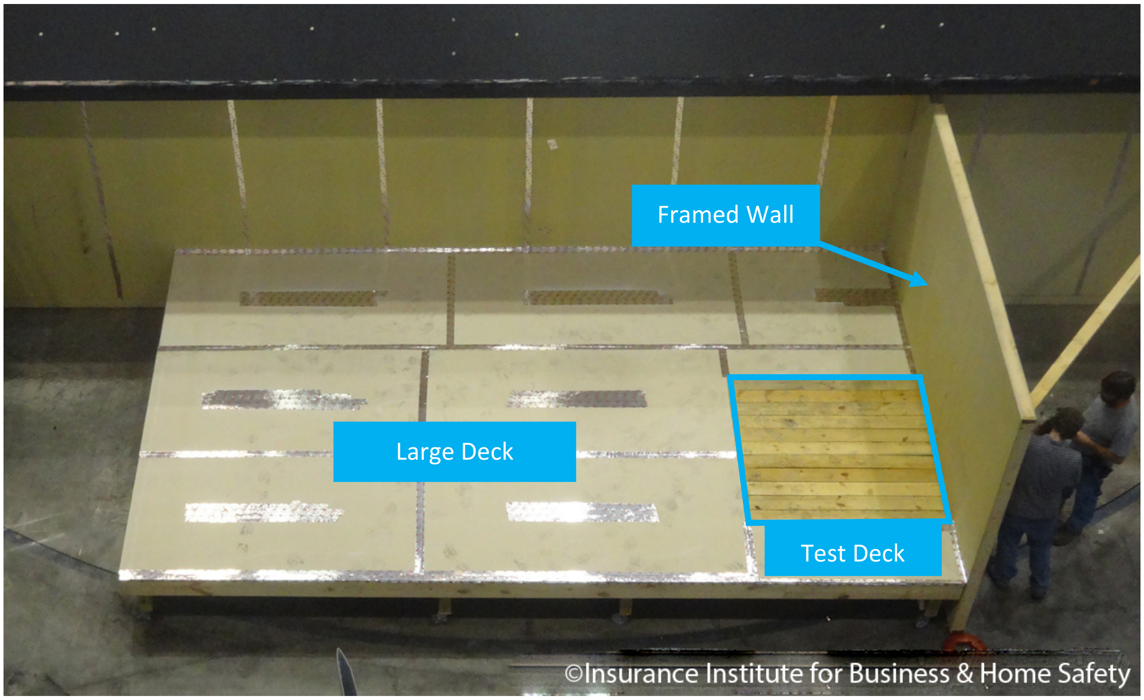

Figure 9. Test setup for ember exposure on decks.

During each test, the test deck was covered until, based on visual observation, the ember generator output reached a steady state. At that time, the cover was removed and a ⅛ in. x 3 in. x 5 ft metal bar was placed in the first gap between deck boards on the fan side of the deck (Figure 10). The purpose of the metal bar was to provide and mimic a location on the deck, usually created by deck furniture or planters, where ember accumulation could occur.

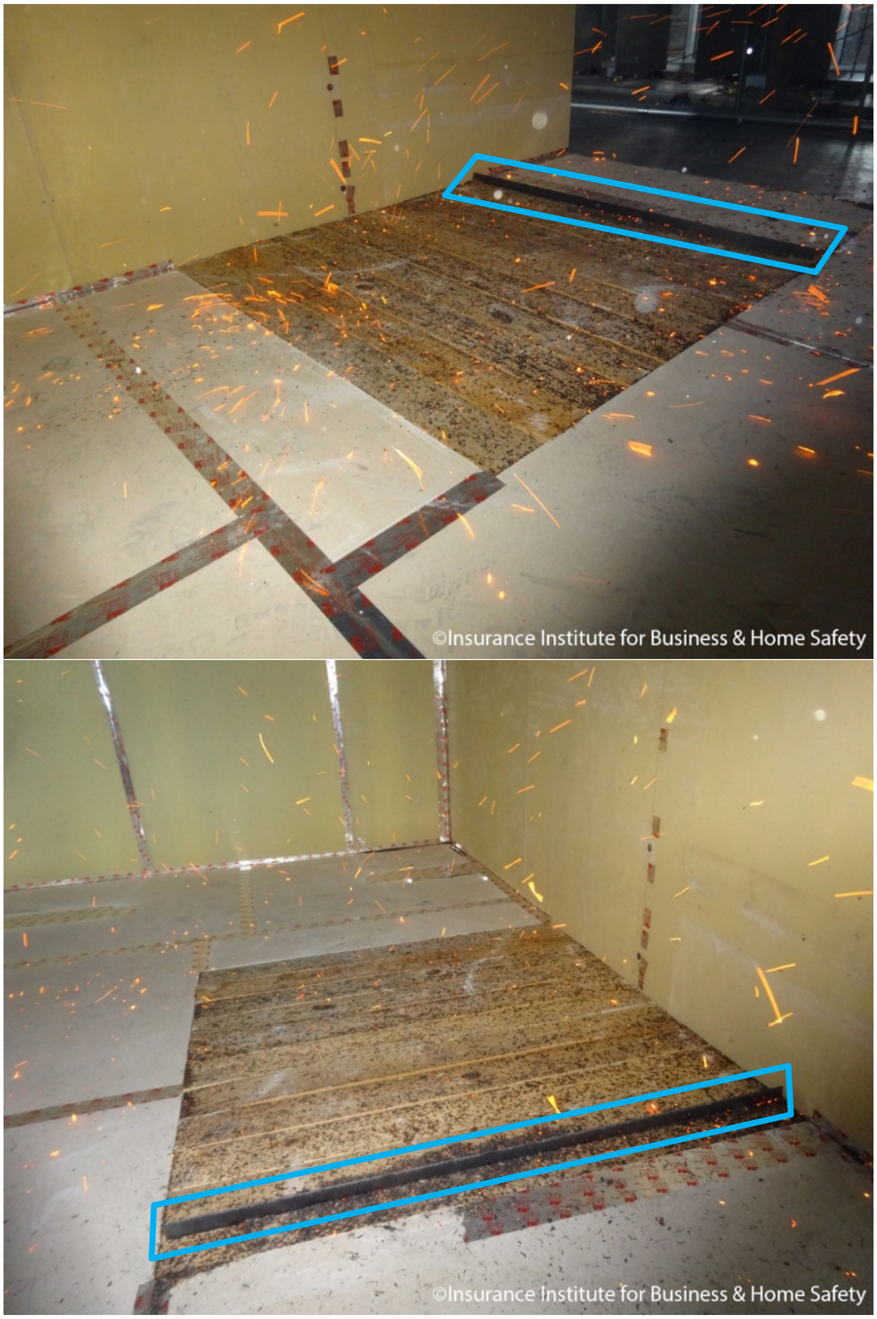

Figure 10. Test deck with metal bar inserted in gap between deck boards; view toward fan array (top) and view toward test building (bottom).

At this point, the test was started. The testing sequence consisted of:

1. An ember exposure for 30 minutes at medium wind speed.
2. A continuation of the ember exposure, with wind speed reduced to idle (10–12 mph [4.5–5.4 m/s]) for five minutes. At the medium wind speed, embers accumulated, but the generation of vertical and horizontal vortices caused many of the embers to be blown off the surface of the deck. The idle wind speed

allowed more embers to accumulate on the surface and potentially allowed for smoldering combustion to transition to flaming combustion.

3. A continuation of the ember exposure at the medium, fluctuating wind speed for an additional 30 minutes.
4. At the end of the second, 30-minute, medium wind-speed interval, the generators were turned off. The decks were observed for 10–15 minutes to monitor for any smoldering and transitioning to flaming combustion, or to document any changes in flame behavior if the deck had ignited. The decks were often prodded, using a metal bar to assess whether an introduction of oxygen would allow smoldering to transition to flaming combustion. During this observation period, the wind speed was varied based on deck behavior.

If flaming combustion occurred, the time was noted. If flaming occurred during the first 30-minute interval, steps 2 through 4 were eliminated, but the 30-minute wind trace was continued while the burning deck was monitored.

Each deck board product was tested twice. In addition to visual observations of the deck response, the test decks and framed wall were instrumented with thermocouples (Figure 11 and Figure 12). Heat flux sensors were placed on the framed wall (Figure 12).

Measurements of gap width were initiated before and after the test based on observations that smoldering and charring were increasing the width of the gap between deck boards in solid wood decks and generally decreasing gap width in PC decks. Refer to Figure 11, where the location of deck support joists is indicated by numbered blue boxes. The gaps between deck board were measured at each joist crossing of the deck boards along joist number 2 (as indicated by the bold red line).

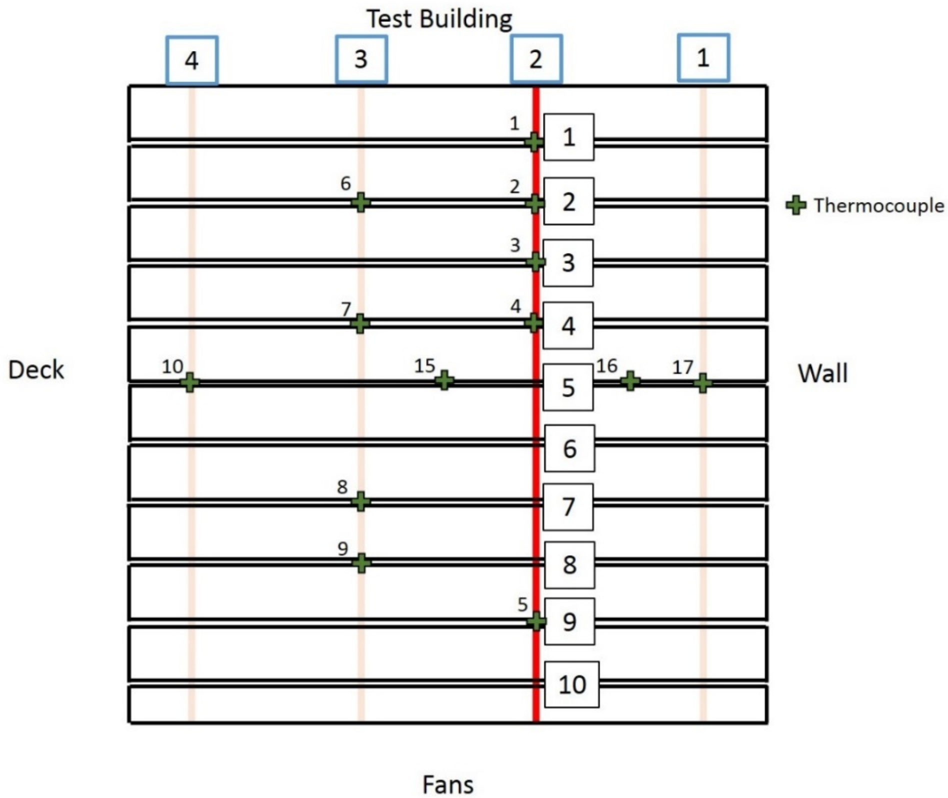

Figure 11. Location of thermocouples along the 5 ft x 5 ft test deck, as indicated by the green plus symbols. The metal bar was placed in the gap between deck boards indicated by the box numbered 10. At the edge of decks, deck boards extended 6 in. beyond the joists.

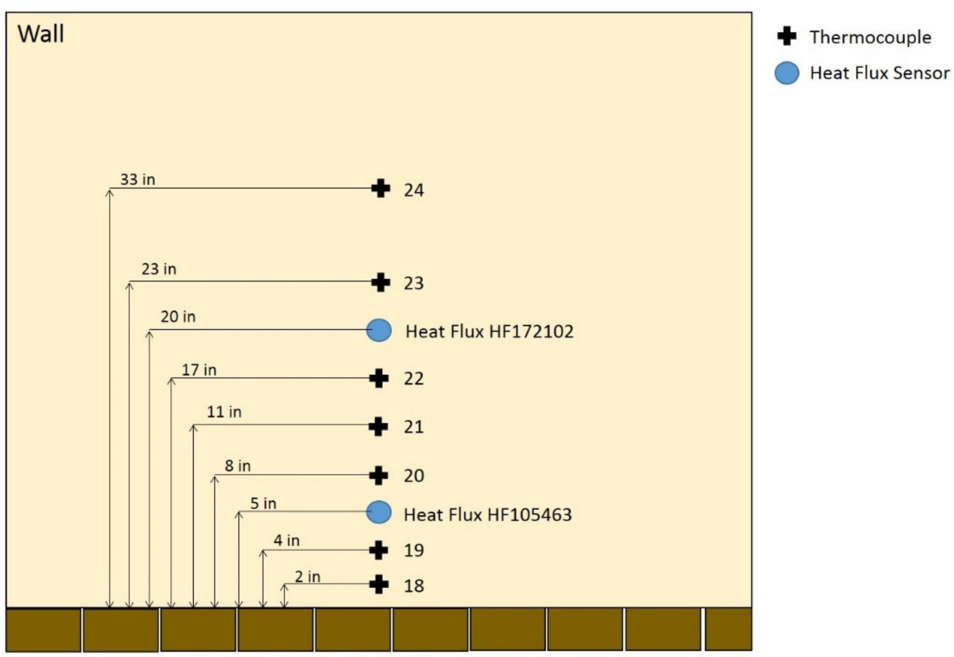

***Figure 12**. Location of thermocouples and heat flux sensors on the section of the framed (movable) wall located next to the 5-ft x 5-ft test deck.*

Results and Discussion

Ember Exposure Ignition Potential

Visual evidence of smoldering and flaming ignition were the principal indicators of deck board performance. Ignition results and density data for the decking products are given in Table 3. With one exception, the PC decking products initially exhibited smoldering combustion, but did not transition to flaming. During Replication 2 for the PE-1 decking product, sustained flaming occurred after an approximate 48-minute ember exposure. The transitory flaming observed in the high-density, solid wood decking product (H) began approximately 47 minutes into the test. The medium-density, solid wood decking product (S) developed sustained flaming after an approximate 12-minute ember exposure. The approximate 12-minute time-to-ignition for the medium-density decking product was consistent for both replications.

Table 3. Observations of smoldering and flaming ignition during ember exposure tests.

Deck Type	Density[1] (g/cm^3)	Performance	
		Replication 1	Replication 2
PVC	0.68	Smoldering	Smoldering
PE-1	0.97	Smoldering	Sustained Flaming[2]
PE-2	1.19	Smoldering	Smoldering
PE-3	1.03	Smoldering	Smoldering
PE-4	1.21	Smoldering	Smoldering
H	1.15	Smoldering	Transitory Flaming[3]
S	0.51	Sustained Flaming	Sustained Flaming
FRT	0.50	Smoldering	Smoldering

1. Nominal moisture content, 8% (oven dry basis). Density on current mass, current volume basis.
2. Continuous flaming for more than five seconds.
3. Continuous flaming for less than five seconds.

Manzello and Suzuki (2017) reported ignition of solid wood decks subjected to ember exposures (referred to as *firebrands* in their publication). The deck-to-wall intersection in a re-entrant (interior corner) assembly was reported to be the vulnerable location, not specifically the gaps between deck boards. Exposure was reported in terms of a mass flux (mass of embers per unit time per unit area) and not time. A direct comparison to the results reported here cannot be made because mass flux was not determined.

Nagaoka et al. (1988) reported that the time-to-ignition for wood material increased with increasing density. The results reported in Table 3 were in general agreement with that finding for wood and PC decking materials. The PE-1 material had the lowest density of the polyethylene-based decking products included in these tests and did not comply with the California Building Code (Chapter 7A) performance requirements for decking. In addition to a slightly lower density, PE-1 may not have had the same amount of fire-retardant chemicals as the other complying products, including the PE-3 product, which had a density only slightly higher than PE-1. The chlorine content in the lower-density PVC product likely had a positive effect on the performance of that decking product. Similarly, the fire-retardant chemical in the FRT solid wood product improved its resistance to an ember exposure, as did the higher density of the non-FRT hardwood.

Flame heights in the medium-density softwood decking were low, never more than a few inches (approximately 60 mm) high as shown in Figure 13. Flaming continued until the distance between the deck boards and joists increased to the point where between-member radiant heat transfer decreased (Figure 14).

To evaluate the contribution of the support joist to this scenario, an additional test was conducted where the joists were covered with a foil-faced tape product. The foil-faced tape covered the top edge of the joist and half of each wide face. Under this scenario, the deck boards still ignited and transitioned to flaming. When foil-faced tape was installed on the joists, flaming ceased when the gap between deck boards increased. The protected joist did not ignite and consequently did not participate in the radiant heat exchange.

Figure 13. Flame heights (never more than a few inches high) on ignited, medium-density softwood deck. Flaming was sustained when there was sufficient heat transfer between components (i.e., deck boards and joists), after which flaming ceased.

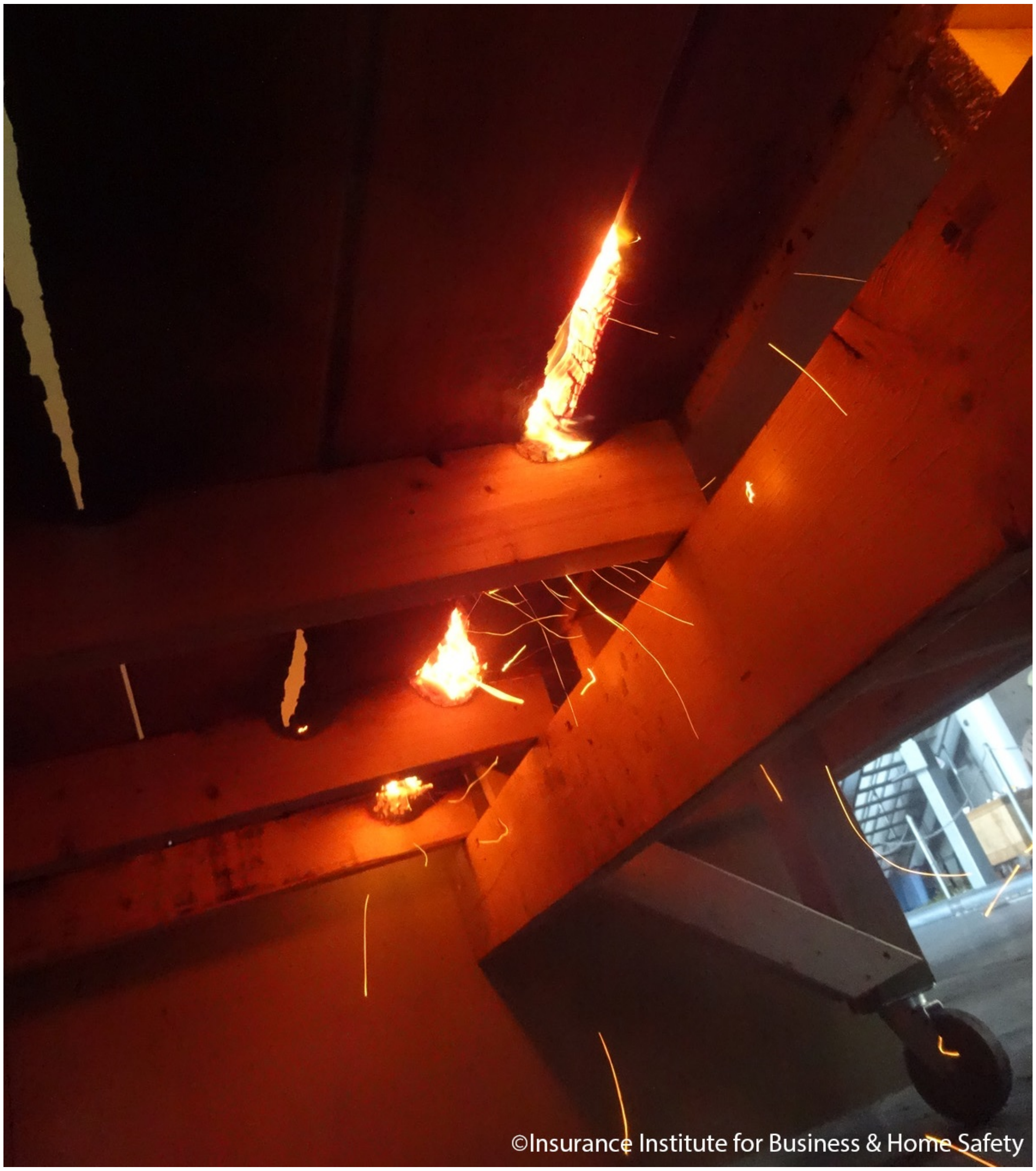

Figure 14. View of underdeck area. Flaming transitioned back to glowing/smoldering when the gap between deck boards and joists reached a point where flaming could not be sustained by radiant heat transfer.

Blanchi and Leonard (2005) conducted a post-fire study of the 2003 fires in the Australian Capital Territory (ACT) and reported that timber decks were vulnerable to multiple ignitions from ember attack. They also stated that, if left unattended, these small ignitions can grow to a point where the fire threatens components of the building envelope, including exterior walls, windows, and doors. The 2003 ACT post-fire findings generally agree with results of the experiments reported here. The flame heights were low when decks ignited, and flame height did not grow during the time the experiments were run. In these experiments, additional combustible items (such as vegetative debris) were not present. Wind-blown ember exposures resulted in ignitions at multiple locations on the deck where either smoldering or flaming ignitions occurred. As shown in Figure 13, flame heights were low.

As previously stated, the principle objective of this series of experiments was to evaluate the ignition potential of decking under an ember exposure and the (combustible) test decks were placed within a larger deck having a noncombustible surface. Because the combustible decking did not extend to the test building, it was not possible to evaluate the potential for flame spread to the test building. As already stated, flaming self-extinguished when gap between decking and joists reached a certain distance. In this series of experiments, the deck boards were consistently parallel to the test building and perpendicular to the wind direction and movable wall.

Although not investigated in this series of experiments, the accumulation of vegetative debris at the deck-to-wall juncture and in gaps between deck boards would likely facilitate ignition and possibly the transition from smoldering or glowing to flaming. As shown in Figure 15, testing at the IBHS Research Center has consistently demonstrated that an ember exposure will result in the flaming ignition of bark and pine needle mulch products. The packing density of pine needles and other vegetative debris would likely be different in a deck board gap compared to a mulch product or accumulation on a roof, which would affect ignition potential.

Figure 15. Ember ignitions of pine needle mulch at the base of an exterior wall (top) and pine needle debris at a roof-to-wall intersection (bottom). Photos are from experiments conducted at the IBHS Research Center in 2011.

Ember Accumulation Patterns and Implications

Ember accumulation patterns and stagnation zones are shown in Figure 16. The circulation patterns on the deck resulted in embers dropping into gaps between deck boards. At joist locations, the embers accumulated in the gaps between deck boards on top of the joist (Figure 17). Flaming and smoldering ignitions consistently initiated in the gaps where deck boards crossed joists, or at the edge of the test decks where there was an underlying horizontal surface where embers could accumulate. Accumulation at these locations occurred regardless of deck board type. Small piles of embers also accumulated at some locations on the deck board surfaces. Accumulation always occurred on both sides of the metal bar and at deck perimeter locations where the test deck abutted the solid surface deck. Smoldering was often observed at these locations.

Figure 16. Ember accumulation areas on deck.

Figure 17. Ember accumulation in gap between deck board above a support joist.

In non-joist locations, embers dropped into and through the gap, onto the surface below (Figure 18).

Figure 18. Ember penetration through gaps between deck boards and accumulating on the ground below.

Embers falling through gaps between deck boards could ignite fine combustible fuel beneath the deck. To demonstrate this potential, a test was conducted that incorporated pine needle debris below the deck (refer to Figure 19). As was the case for other experiments, this test was run using the medium wind-speed record. The ember exposure resulted in smoldering combustion for most of the ember exposure period. Smoldering transitioned to flaming when the wind speed was lowered to the idle condition. The ignition of the fine fuels from embers that fell through the gaps between deck boards provides additional supporting evidence that storage of combustible materials under the deck should be avoided.

The gap between deck boards did not change measurably with the PC products, but consistently increased with the solid wood products. This increase was on the order of 0.02 in. for the FRT decking product (also a medium-density softwood, but a different species than the non-FRT softwood product). The increase in gap width for the non-FRT wood decks varied depending on whether or not flaming occurred in the deck board gap, but ranged from about 0.1 in. for the high-density hardwood decking product to 0.3–0.5 in. for the medium-density softwood decking product. Increasing gap width would potentially increase the ember flux through the gaps, increasing the exposure to any combustible materials under the deck. Minimal change in gap width in the PC products would not result in increased ember deposition in the underdeck area.

Figure 19. Ember penetration through gaps between deck boards; embers falling to ground (top) and resulting in the ignition of pine needles under deck (bottom).

Thermocouple and Heat Flux Measurements

In addition to visual observations of deck behavior, heat flux sensors and thermocouples were used in the framed wall and in gaps between deck board and joist (shown in Figure 11 and Figure 12.) Key highlights from the data are presented here.

Examples of thermocouple readings at a joist crossing and in an open gap are shown in Figure 20 and Figure 21. Data from a medium-density softwood deck is shown in Figure

20. Data from a PE-1 deck is shown in Figure 21. For both products, temperatures were higher in the location where embers accumulated in a gap located over a joist. Flaming ignition was observed at this location on the softwood deck, but not on the PC deck. As indicated by the recorded temperatures, flaming ignition was not observed at the mid-joist locations (Figure 20-B and Figure 21-B) where embers fell through the gap and onto the ground. This supports the observations regarding conditions where flaming ignition occurred during these tests.

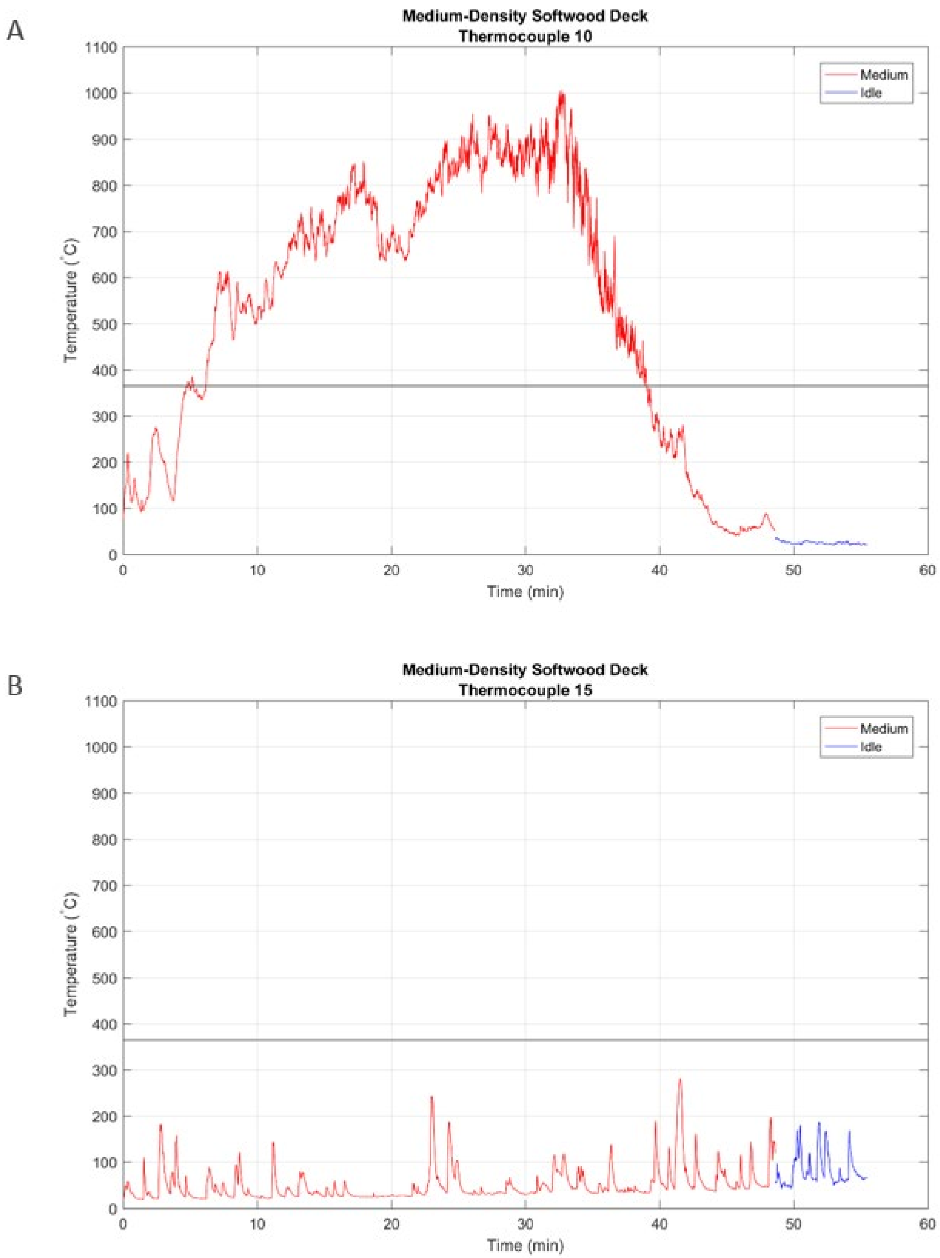

Figure 20. Temperature data collected for the medium-density softwood at a between-deck-board gap and joist crossing (A) and at a between-deck-board gap between joists (B). The approximate ignition temperature of wood is indicated by the horizontal black line (Janssens, 1991).

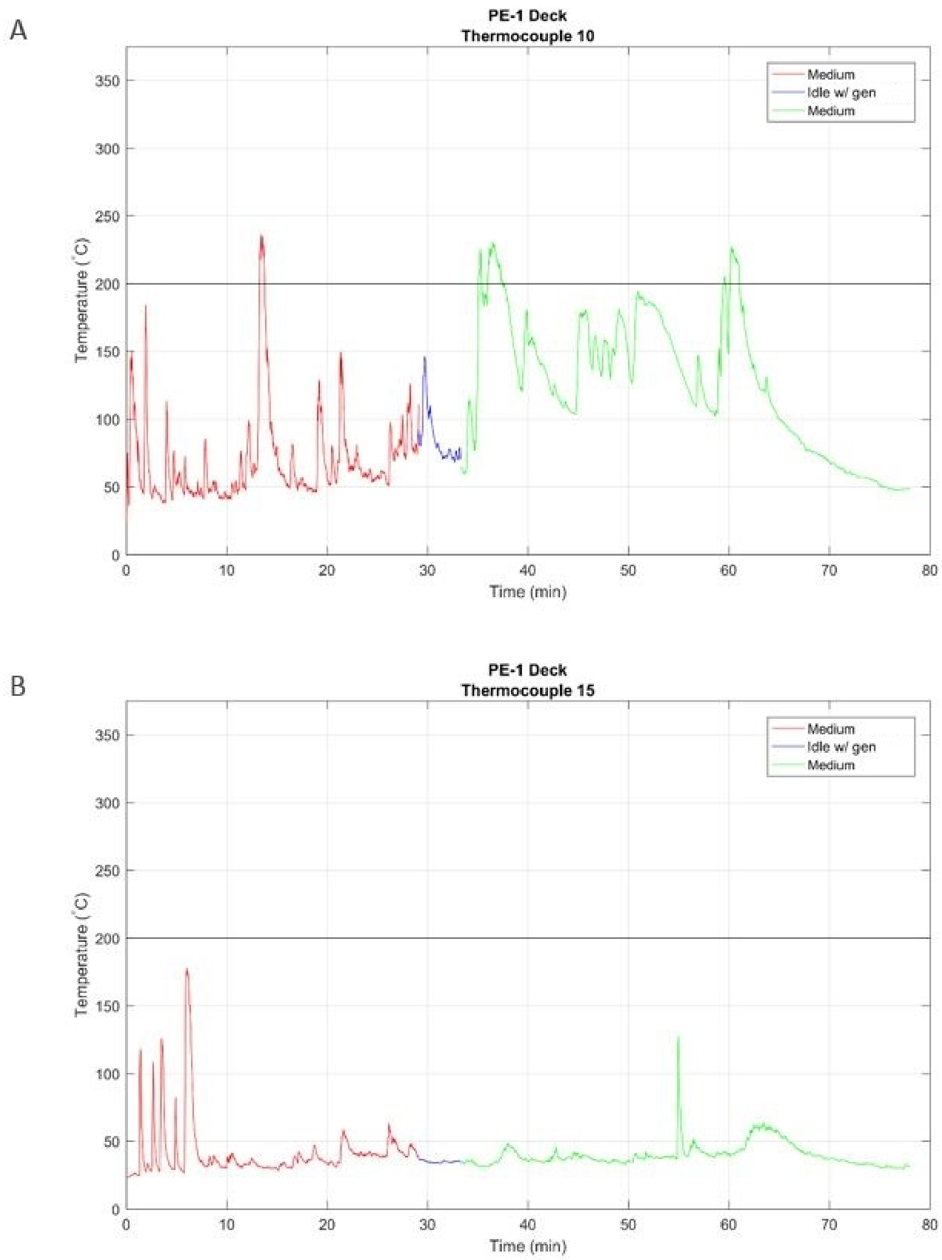

Figure 21. Temperature data collected for the PE-1 deck at a between-deck-board gap and joist crossing (A) and at a between-deck-board gap between joists (B). The lower-bound ignition temperature of a PC is indicated by the horizontal black line.

Figure 22 shows the heat flux time series for the two non-FRT solid wood decks tested. Figure 22-A is for the medium-density softwood deck that ignited. The thermocouple data for this test was shown in Figure 20-A. Figure 22-B shows the heat flux data from a high-density, tropical hardwood. In this case, the deck smoldered, but did not transition to sustained flaming. The heat flux sensors were located 20 in. above the deck surface. The magnitude of the heat flux was relatively low and did not exceed 8 kW/m² for either deck. Even where flaming ignition occurred, flame height never exceeded a few inches regardless of deck type, so heat flux was consistently low. Cohen and Butler (1998) reported that 8 kW/m^2 was lower than that required to ignite wood, even under a piloted ignition scenario.

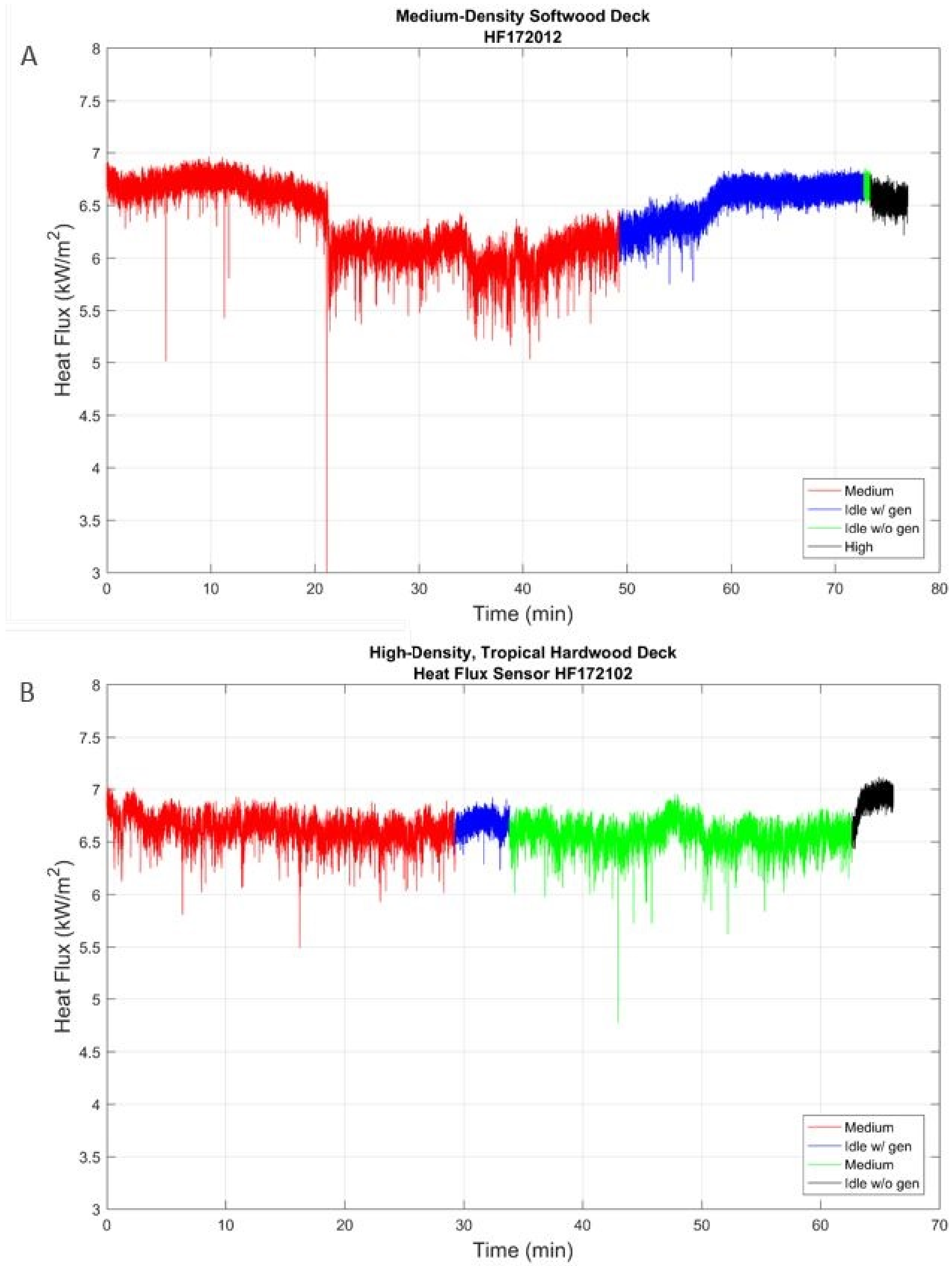

Figure 22. Heat flux sensor data collected at medium wind speed for medium-density softwood that ignited (A) and high-density, tropical hardwood that only smoldered (B).

Application to Existing Standard Test Methods for Combustible Decking Products

Ember exposure is not directly considered by test standard SFM 12-7A-4 which is the test procedure referenced by Chapter 7A in the California Building Code (2009) and applicable to decking products. This is the only building code that provides a path for acceptance of nominally combustible decking products that cannot meet the requirements of an ignition-resistant material. The referenced standard test methods use a flaming exposure, applied either under a deck or on top of a deck, to evaluate the performance of a decking product. The underdeck flaming exposure mimics one resulting from the ignition of vegetation or other combustible materials located either under the deck or downslope from a deck overhanging a slope. To comply in California, decking products need only comply with the provisions of the underdeck portion of the test method. The crucial acceptance criteria for this standard method is that the test deck cannot exceed the 25 kW/ft^2 (270 kW/m^2) maximum heat release rate.

Results of these experiments indicated that the PC products were less vulnerable to ignition from wind-blown ember deposition on the top of the deck compared to the non-FRT, medium-density softwood decking product. However, one of the repeat tests for PC product PE-1 did exhibit sustained flaming ignition (flaming for more than five seconds) after more than a 45-minute exposure. The high-density hardwood decking product compared favorably to PC products, exhibiting transitory flaming events (flaming for less than five seconds) only after more than a 45-minute exposure.

Heat release rate was not measured during these ember exposure experiments. However, based on author-witnessed observations during numerous underdeck flame exposure tests at the University of California Fire Laboratory where heat release was measured, the heat release rate from the decks that transitioned to flaming would not have exceeded the level specified by SFM 12-7A-4. The medium-density softwood decking eventually self-extinguished once the deck boards and joists burned apart.

This was not the case for the PE-1 decking product. Flaming continued until it was extinguished by test personnel approximately 30 minutes after ignition. Fire growth was occurring, particularly on the bottom surface of the deck, as evidenced by increased horizontal flame spread (Figure 23).

During these tests, heat flux measurements at the side wall locations were consistently low and never exceeded a level where piloted ignition of combustible siding would occur. The heat flux sensors were not located in an underdeck location, but in this case, two joists and the between-joist spacing separated the burning deck from the wall.

Figure 23. Flame spread in the underdeck area of PC product PE-1.

The ability for a decking product to self-extinguish within 40 minutes after the underdeck gas burner is turned off is part of the acceptance criteria of the standard test method. Based on language in the code, however, it is not required for a product to comply.

These experimental results and the compliance provisions provided in Chapter 7A point to a limitation in the way nominally combustible decking products are accepted. As stated by Blanchi and Leonard (2005), and anecdotally acknowledged by firefighting professionals, wind-blown ember ignitions of buildings that are ultimately destroyed during a wildfire typically start out as small fires. Left unattended, these small fires grow. A critical component in understanding the vulnerability of a deck attached to a building is whether flames from an ignited deck can spread to the building and whether it will eventually self-extinguish. It may be impractical for a test conducted in a commercial fire lab to evaluate flame spread under wildfire conditions, with the complexity of a deck attached to a building. However, evaluating the ability to self-extinguish is a reasonable objective. These experiments did not evaluate the potential for flames from a burning deck to spread to a building, but a future study is planned to evaluate this scenario.

The current experiment evaluated the performance of the decking assembly without the presence of vegetation or other combustible materials that could be located under or on a deck. Although Chapter 7A, the IWUIC, and NFPA 1144 all provide provisions for creation (and assumed maintenance) of a defensible space zone on the property, ignition of nearby combustible materials would likely result in a more severe exposure to the deck and reduce the ability of a material to self-extinguish. Incorporation of a noncombustible zone that includes the entire footprint of the deck as part of the defensible space, would limit this possibility.

Summary and Conclusions

This series of experiments investigated the ignition potential of eight different types of deck boards exposed to wind-blown embers. The decking products included solid wood and plastic composite decking products. Most of the tested products complied with the provisions specified in Chapter 7A of the California Building Code (2009), but two did not.

Each deck was subjected to an ember exposure of up to one hour and both quantitative and qualitative observations were made. Overall, most of the decks performed well in that they did not ignite. At locations where embers accumulated, smoldering was often observed. Two decking products, the medium-density softwood product (S) and the PC product PE-1, exhibited sustained flaming when subjected to the ember exposure. Transitory flaming was observed in the high-density hardwood decking product (H). The S and H deck boards complied with the requirements specified in the California Building Code (2009).

Results reported here agree with the findings of Dowling (1994), who reported an ember ignition scenario from accumulation in gaps between deck boards. Smoldering and flaming ignitions consistently occurred at a deck board gap above a joist.

This study expands on the existing information on the vulnerability of decks to a wind-blown ember exposure. The time-to-ignition (flaming) for the decking products varied from 12 minutes for the non-FRT softwood deck (S) to 47 minutes for PC product PE-1. Although neither the number nor mass flux of the ember exposure was quantified, this variation in time-to-ignition provides relative information on the susceptibility of decking products to ignition from wind-blown embers.

A realistic measure of flame spread and a provision that provides information on the ability of a product to self-extinguish would improve the procedures for evaluating the suitability of nominally combustible decking products for use in wildfire-prone areas. Given the use of these combustible products, more stringent defensible space requirements, such as the selection, placement, and maintenance of vegetation and other combustible materials on the property and adoption of an underdeck noncombustible zone would reduce the vulnerability of these products when attached to a building.

Additional information is provided in “Appendix: Fire Spread and Growth” which describes additional experiments to evaluate flame spread and growth.

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Appendix: Fire Spread and Growth

After the initial publication of the results of deck materials exposed to embers, additional experiments were performed to evaluate the fire spread and growth characteristics of various deck board products. This appendix describes those experiments and the results.

Experimental Procedure

All test decks were 2 ft wide x 5 ft long. Three deck board products were used (refer to Table 2 for specific information):

- Medium-density solid wood (S)
- High-density solid wood (H)
- PE-2 composite decking product

Decks with boards parallel and perpendicular to the test building were incorporated into the experimental design (Figure 24). The nominal gap between deck boards was ⅛-in., but some experiments were conducted with a nominal ¼-in. deck board spacing. For decks where deck boards were perpendicular to the test building, joist spacing was 16 in. on center. Joist spacing was less than 16 in. on center when deck boards were parallel to the test building.

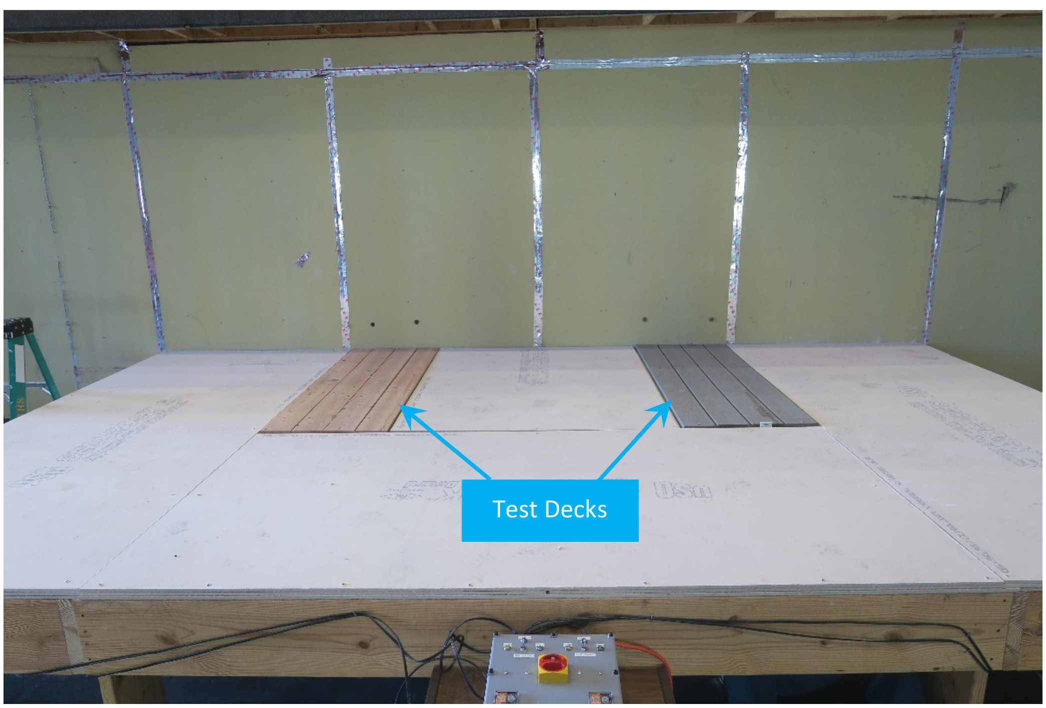

Figure 24. Test setup used to evaluate flame propagation and fire growth for decks exposed to embers.

In this series of experiments, testing used the same wind speed record used in the ignition potential tests, a non-fluctuating wind speed of approximately 12 mph (approximately 5.4 m/s), and a *no-wind* condition. Experiments were conducted where wind flow was parallel and perpendicular to the deck surface.

Ember generators were not used in this series of experiments. Instead, small radiant heaters were positioned in the gap between the deck boards and used to ignite the deck boards. This is the location where ignition consistently occurred in the ignition potential experiments. Only one radiant heater at a time was installed on a test deck.

For this series of experiments the radiant heaters were on an automatic timer system that was set to a cycle of 30 seconds on, 90 seconds off. This on/off cycle was meant to simulate a re-supply of embers that would occur when embers from a burning wildfire or other combustibles were threatening a home.

Results and Discussion

The ignition results using the radiant heaters were representative of observations made during the ignition potential experiments. Sustained flaming developed after one-to-two ignition cycles in the medium-density softwood decking. Sustained flaming did not develop in the high-density hardwood and PE-2 decking products, even after up to 18 on/off cycles. Any flaming that did occur between deck boards would quickly self-extinguish. Charring of the deck material after a number of heater on/off cycles reduced the likelihood of flaming. As a result, discussion of flame propagation and fire growth is limited to the medium-density softwood decking product.

Fire propagation occurred either in the gap between deck boards or in the interface between the top of a joist and bottom of a deck board (Figure 25 and Figure 26). This observed propagation occurred regardless of whether wind direction was parallel or perpendicular to the deck.

Flame spread and fire growth was dependent on wind speed. Ignited deck boards and joists self-extinguished during tests conducted in ambient air flow conditions (fans off). Lateral, forward (towards the building), and backward (away from the building) propagation occurred during tests run with the constant and fluctuating wind speed records. Flame propagation to the building was slow, taking as long as two hours to travel 6 ft from an ignition point to the building.

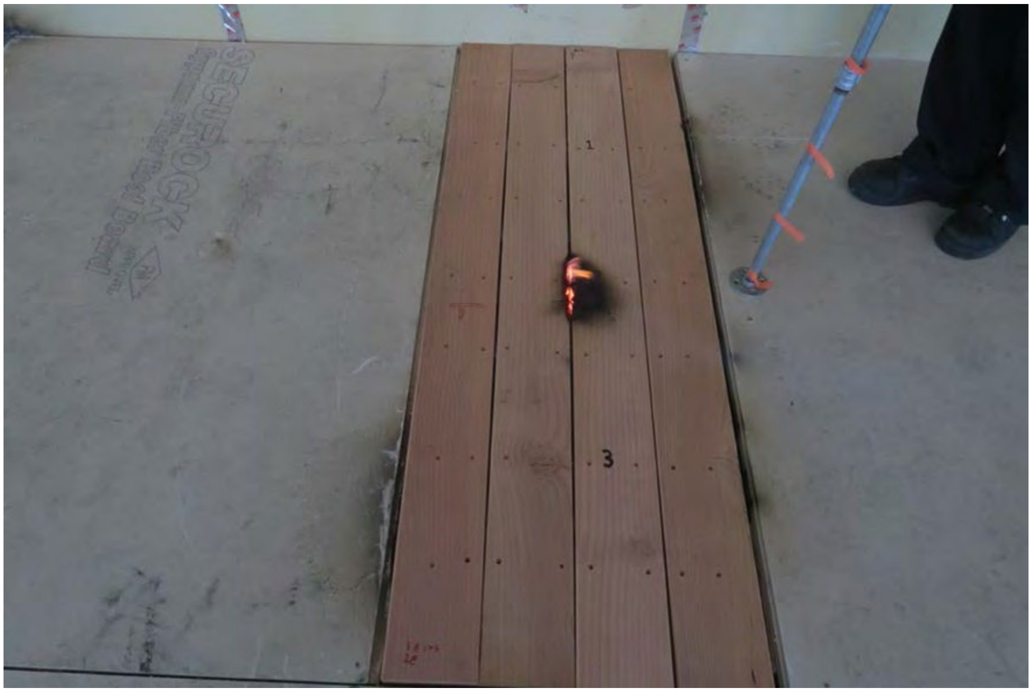

Figure 25. When deck boards were perpendicular to the building, fire spread toward the building occurred in the gap between deck boards.

Figure 26. When deck boards were parallel to the building, fire would propagate laterally (parallel to the building) in the gap between deck boards, and toward the building at the interface between the bottom of the deck board and top of joist. Flaming combustion would occur when the fire reached a gap. Smoldering combustion would occur in the underdeck region when propagation was occurring in the interface between the top of a joist and bottom of a deck board.

Like the ignition potential experiments, flame height on the ignited decks was low. When fire growth occurred, it was in the underdeck area and seemed to be dependent on the joist spacing. Joist spacing less than 12 in. on center appeared to be more vulnerable to fire growth in the underdeck area.

Two mitigation strategies were investigated to evaluate their effectiveness in limiting flame spread and fire growth:

- Increasing deck board spacing
- Using a foil-faced bitumen tape product applied to the top edge and upper portion of the sides of the joist (Figure 27)

When deck board spacing was increased to ¼ in. and the foil-faced tape was applied to the joist, the ignited deck boards self-extinguished once the fire spread 2–3 in. away from the joist.

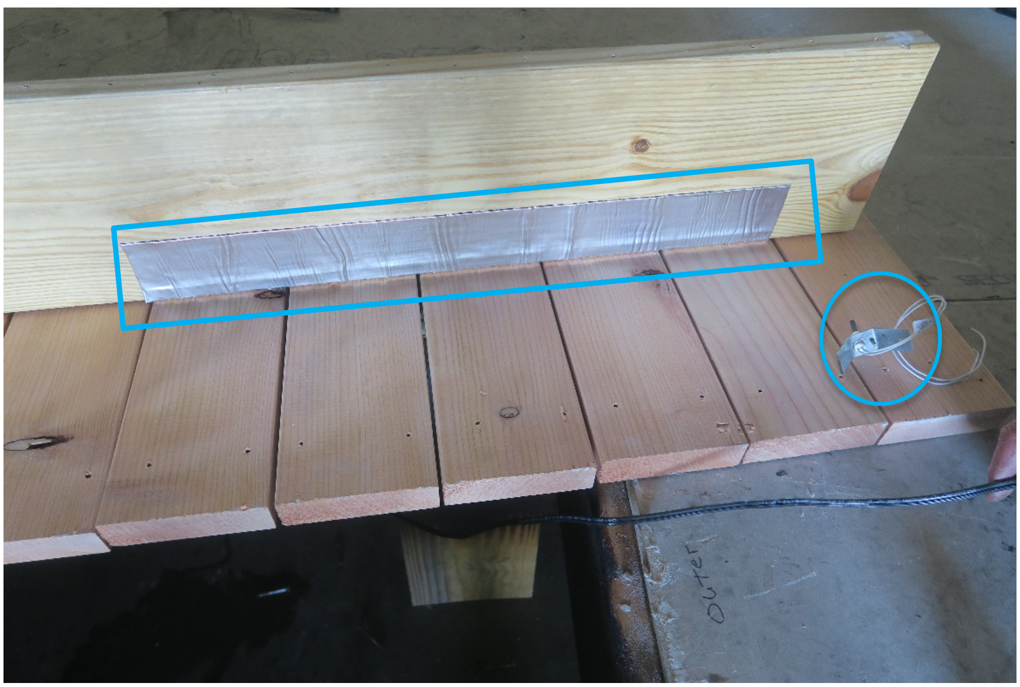

Figure 27. Foil-faced bitumen tape product applied to a section of the joist. The deck is shown prior to installing in the frame, and is upside down in this photograph. An uninstalled radiant igniter is shown on the right-hand side of the photograph.

Summary and Implications

1. Flame propagation in any direction did not occur during the “no wind” tests. At the constant and fluctuating wind speeds used in these experiments, propagation occurred by flaming and smoldering processes. The observed propagation scenarios included:
    - The gap between deck boards

- The interface between the top of joist and bottom of deck board

Fire spread could occur both towards and away from the building, and laterally (parallel to the building). The rate of flame spread was relatively low at approximately 3 ft/hr (0.9 m/hr).

2. Except in cases where the fire spread into an area with reduced joist spacing, flame heights were low. Although heat release rate was not measured, flame height would indicate that if measured, the heat release rate would have been low enough to comply with current provisions in Chapter 7A.
3. Under conditions evaluated during these experiments, a mitigation strategy that used an increased gap (from ⅛ in. to ¼ in.) between deck boards, and application of a foil-faced bitumen tape product to the upper edge of the joist and extending down a portion of each side, resulted in self-extinguishment of the deck boards after the flame propagated 2–3 in. away from the protected joist.

   Because joist spacing affects fire growth, increasing joist spacing to 24 in. on center would seem prudent, unless a composite decking material is used.

4. Based on the findings from these experiments, implications to California Building Code Chapter 7A and SFM Standard 12-7A-4 include:
   - The heat release rate requirement is a necessary but not sufficient predictor of deck board performance.
   - Not considering the ability of an ignited decking product to self-extinguish is a limitation of the current acceptance criteria.
   - Not considering the influence of wind on the performance of ignited decking products is a limitation of the current acceptance criteria.

     Although wind is included in the above deck brand test portion of the SFM Standard 12-7A-4, this part of the test method is not required by Chapter 7A.

   - While the current standard underdeck flame impingement test method is indicative of an exposure whereby wind-blown embers ignite combustible materials located under a deck, it does not simulate the ignition sequence of an ember exposure to the top of the deck.
   - The Class A burning brand test specified in the top of deck exposure component of the SFM Standard 12-7A-4 may be representative of a situation like a tipped over charcoal grill. However, the test is not representative of the wind-blown ember exposure where the ignition location is above a joist in the gap between deck boards.

Consideration of these experimental results and the compliance provisions provided in Chapter 7A point to a limitation in the way nominally combustible decking products are evaluated and accepted. A realistic measure of flame spread and a provision that provides information on the ability of a product to self-extinguish would improve the procedures by which nominally combustible decking products are accepted for use.