IBHS RESEARCH

The Ability of the Current ASTM Test Method to Evaluate the Performance of Deck Assemblies Under Realistic Wildfire Conditions

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CONTENTS

INTRODUCTION

The goal of this report is to evaluate the assumptions in State Fire Marshal (SFM) Standard 12-7A-4A and ASTM E2632. These standards describe testing methods for evaluating deck materials performance when exposed to wildfire. The objective is to determine whether the assumptions in the test protocols adversely affect the evaluation of deck boards and whether they realistically assess the vulnerability of the entire deck assembly when exposed to under-deck flames.

Attached decks are a vulnerable component of a building in wildfire-prone areas. Once ignited, decks can expose a building's cladding (siding), wall components such as windows and doors, and the under-eave area to flames and radiant heat. This exposure can result in severe damage or destruction of the structure.

Figure 1. Examples of burning decks causing damage to the main structure of (A) a commercial wine tasting room in Napa Valley and (B) a residential structure in Santa Rosa during the 2020 Glass Fire.

Post-wildfire investigations and lab studies have shown that decks initially ignite on both the top and bottom surfaces of the deck during wildfires [1–7]. Quarles et al. [8] reported that flames from burning trees that impinged on the underside of attached decks resulted in deck ignitions and subsequent loss of homes during the Waldo Canyon Fire in Colorado Springs, Colorado. Maranghides, et al. [7] identified three locations of deck ignitions:

- Near the footers
- On the top surface
- On the underside where combustible material had accumulated and ignited

The location where firebrands (embers) accumulated depended on air flow patterns around the building, the roughness of the deck surface, and location of objects on the top of the deck, such as patio furniture.[1]

For bare decks, firebrands primarily accumulate either on the top of the joists in the gap between deck boards or at the gap between the deck and the wall [9]. Experiments conducted at the IBHS Research Center by Quarles and Alfano [6] found that ignition of the top surface of the deck resulted from firebrands accumulating in the gaps between deck boards, on top of a support joist (Figure 2A). When sufficient thermal energy exists, either by firebrands igniting debris or from an accumulation of firebrands, the deck boards or joists ignite (Figure 2B).

For decks where joists were installed perpendicular to the building, once ignition occurred the fire spread in a smoldering phase along the joist toward and away from the building under an average wind speed of 18 mph. At the deck board gaps, the smoldering combustion transformed to flaming (Figure 2C) due to the airflow between the deck boards. This allowed fire to continue to propagate all the way to the building. The fire did not transition to flaming combustion at the deck board gaps without the wind and eventually self-extinguished before reaching the structure.

In California, the requirements for the fire performance of decks are provided in Chapter 7A of the California Building Code [10]. The most recent version of Chapter 7A requires the walking surface of decks to be constructed with materials that comply with one of seven options. Nominally combustible materials typically comply with Chapter 7A provisions using the sixth option, which states:

> *Any material that complies with the performance requirements of SFM Standard 12-7A-4A when attached exterior wall covering is also composed of noncombustible or ignition-resistant material.*
>
> *Exception: Wall material may be of any material that otherwise complies with this chapter when the decking surface material complies with the performance requirements ASTM E84 with a Class B flame spread index.*

Nominally combustible decking products comply with Chapter 7A by meeting the requirements of SFM 12-7A-4A. This standard evaluates the performance of decking material to an under-deck exposure and requires that the peak heat release rate not exceed 269 kw/m2. This provision allows many combustible deck boards, including non-fire-retardant-treated redwood and many plastic composite decking products to comply with Chapter 7A. The exception regarding Class B flame spread index included in the code language allows these compliant deck boards to be used adjacent to any siding product that otherwise complies with the provisions of Chapter 7A.

Above-deck exposure and the deck's structural joists have a major influence on ignition, growth, and propagation of a fire. In addition, the SFM 12-7A-4A test standard makes numerous simplifications that may not be representative of real-world conditions such as:

- Deck size. SFM 12-7A-4A uses a 2 ft x 2.4 ft (0.70 m x 0.73 m) deck, which is not representative of deck sizes in the real world.
- No wind during tests. Wind conditions affect the performance, ignition, and propagation of fire on a deck [6]. Ignition of structures and decks often occurs during red flag conditions where high winds are present [11].
- Joists are not considered an adjustable variable although they have been found to contribute to the fire intensity of the decks in a consistent manner.

The type of fuel underneath or around the deck creates different thermal exposure intensities. If the accumulated wind-blown vegetative debris underneath the deck ignites, it can create a relatively short (2 to 5 minute) exposure with peak heat release rates of 10–90 kW/m2 [12,13]. Lumber and furniture, however, can burn for a much longer time (about 10 to 30 minutes) with peak heat release rates of 40–70 kW [13]. This long and intense exposure can be eliminated by not storing combustibles near the building and under the deck. However, wind-blown debris can accumulate overtime, depending on the frequency of fuels management around the house. The exposure intensity and duration vary with different parameters such as wind speed, available fuel and moisture content, none of which are controllable in an outside environment.

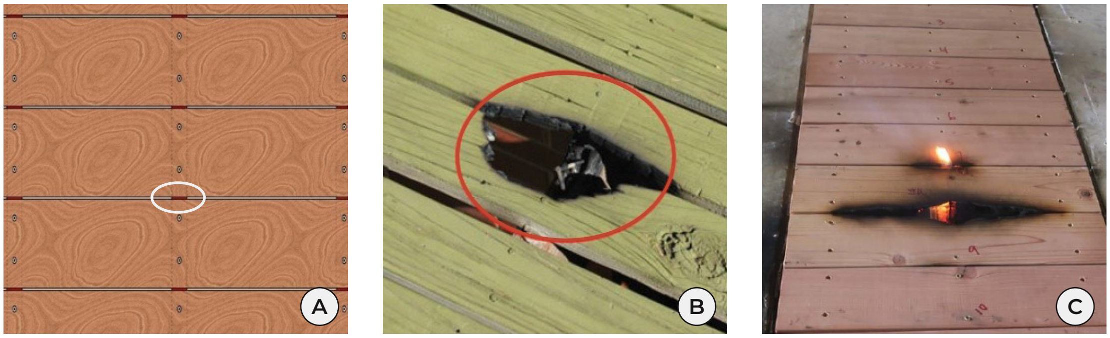

Figure 2. (A) Ignition starting points on the deck from firebrand exposure. (B) Firebrands igniting the joist/board interface [1]. (C) Fire propagation after ignition by igniter in different directions and transition to flaming at the gaps.

METHODOLOGY AND EXPERIMENTAL SETUP

SFM 12-7A-4A uses several simplifications that may affect the evaluation of fire performance of decks in an unrealistic way. The objective of the current research was to assess the ability of the current test method (SFM 12-7A-4A and ASTM E2632) to evaluate the performance of deck assemblies under realistic wildfire conditions. In this study, the effect of changing three conditions (listed below) in the current SFM-7A-4A and ASTM E2632 test methods were examined in detail.

IBHS testing included the following modifications to the SFM-7A-4A test method:

- The dimensions of the test deck were increased from 2 ft x 2.4 ft (0.70 m x 0.73 m) to 6.6 ft x 6.6 ft (2 m x 2 m). These dimensions were chosen considering the outlet size of the wind tunnel specified in ASTM E108. The capability to conduct this standard test is available at many commercial fire labs.
- The tests were performed using two different wind conditions:
  - A constant 14 mph (6.2 m/s) wind
  - A fluctuating wind with a mean of 19 mph (8.5 m/s) and 3 second gusts of 26 mph (11.6 m/s)

Figure 3 depicts the time history of the wind traces used in this research. These traces were 30 minutes long and were repeated when longer duration tests were conducted.

- Two different deck substructures were examined, wood and metal joints, to evaluate their impact on deck board performance along with overall deck assembly performance.

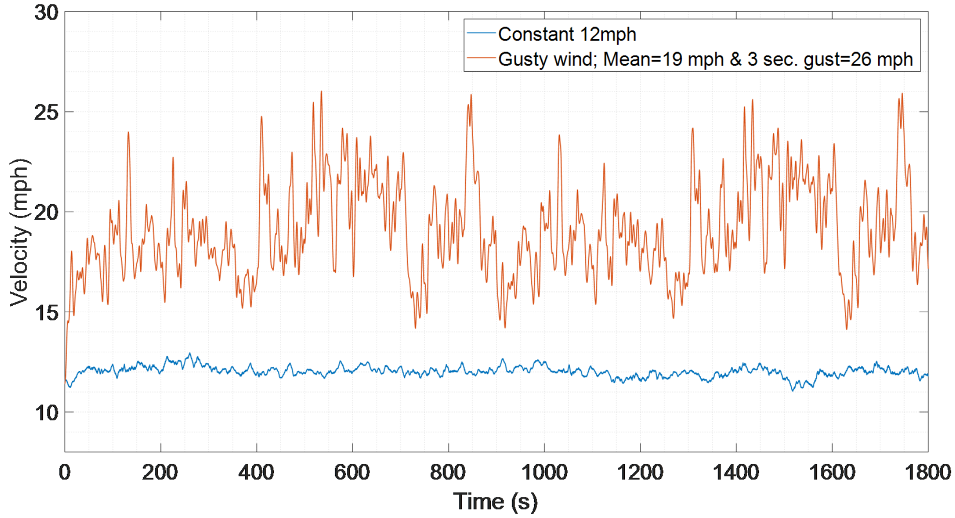

Figure 3. Time history of wind traces measured at 8 ft above the ground.

Three different deck board materials were chosen for use in this study:

- Redwood
- Composite A (Chapter 7A compliant)
- Composite B (not Chapter 7A compliant)

The wooden joists (2 x 10) and posts (4 x 4) were Southern Yellow Pine. The metal joists were galvanized steel. The redwood and composite deck assemblies weighed approximately 300 and 400 pounds, respectively. To replicate decks in a red flag warning condition, the moisture content of the decks had to be less than 15%. Given the weight of the decks, it was challenging to measure their moisture content using the ASTM D4442 method.

To estimate the time required to achieve the required moisture content, samples for each deck assembly were placed in a dry kiln (Figure 5A). The kiln's dry and wet bulb temperatures were set to 140° F (60° C) and 75° F (24° C), respectively. Using psychrometric charts, the nominal relative humidity of 2.5% can be derived for the kiln. The decks were weighed and their moisture content calculated every 8–12 hours, which is a modified ASTM D4442 procedure. After 48 hours, the decks' weight had reached a steady state, suggesting a moisture content of 5%–9%. As a result of this trial, all samples were placed in the dry kiln for two days prior to testing.

Figure 4 shows the IBHS test chamber. Tests can take place at the center square of the chamber, measuring 145 ft x 145 ft (44.2 m x 44.2 m). The flow is generated by 105 fans. Each fan is 5.5 ft (1.68 m) in diameter and can create a time history of wind speeds from 12 to 120 mph[14].

Immediately prior to the start of an experiment, the test deck was placed at the centerline of the 40-foot side of the house described above. A 1 ft x 1 ft burner was placed underneath the center of the deck. This burner generated an 80 Kw/m2 fire intensity. The distance between top of the burner and bottom of the deck boards was 27 inches. Figures 5B, 5C, and 5D show a deck prior to testing.

Figure 4. IBHS test chamber.

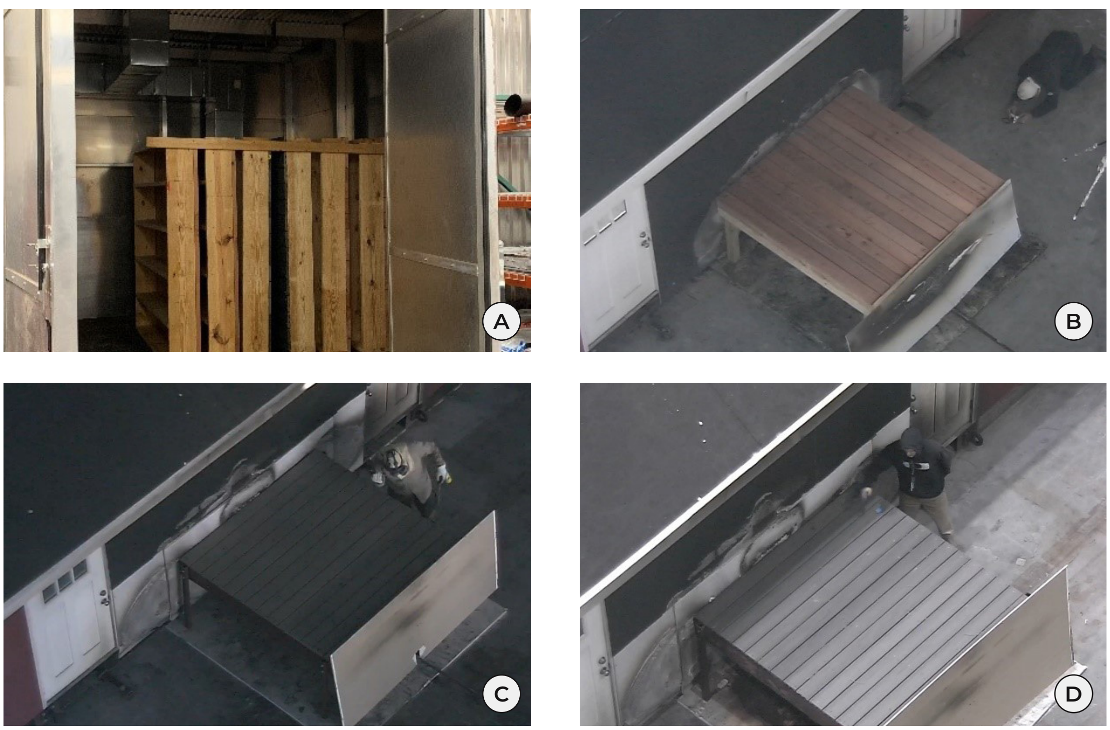

Figure 5. (A) Decks in the kiln. (B) Redwood. (C) Composite A. (D) Composite B.

For tests when wind was present after the burner was ignited, the turbulence of the wind caused the flame to tilt and move randomly. Therefore, it is possible that decks might not experience the same exposure under different wind conditions, or even test-to-test, due to the short duration of the ignition phase when the burner was on. To control this variability, drywall was installed to block the wind during the exposure time (see Figures 5B, 5C, and 5D). After gas flow to the burner was turned off, the drywall was removed, and the entire deck assembly was exposed to wind.

The decks and wall to which the test deck was attached were instrumented with 15 high temperature K-type thermocouples. Data collection was at 100 Hz and began just before igniting the burner and ended when the deck collapsed, or the fire propagation stopped.

Figure 6. Thermocouple map on the deck and wall.

RESULTS AND DISCUSSIONS

This section is divided into two parts. The first part describes the observations made while varying a single key parameter in the current test methods (SFM 12-7A-4A and ASTM E2632). The second part describes the factors to consider to combine all of the modifications as a single test.

CURRENT TEST METHOD—SFM 12-7A-4A

Three replicas (Redwood deck boards and Southern Yellow Pine) were tested following the requirements of SFM 12-7A-4A. Figure 7A shows a sample deck, tested under the current test method procedures, 15 minutes after the start of the test (12 minutes after the under-deck burner was extinguished). As shown, there is a thin char layer (Figure 7B) on the boards. A visual observation confirmed that the Peak Heat Release Rate was below the maximum allowable 269kW/m2. The lower thermal conductivity of the char layer acts as an insulator that protects the inner portion of the deck board from thermal-related damage. Hence, only a small amount of the material participates in the combustion process.

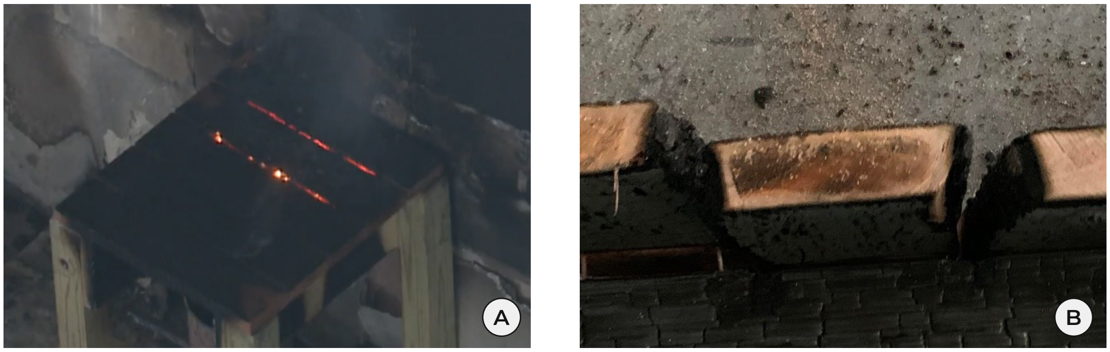

Figure 7. Replicating the current test method. (A) Fire intensity after 15 minutes (12 minutes after shutting off the gas burner). (B) Cross-section of the burned deck.

Larger Deck Size

As previously discussed, decks attached to homes or businesses would be substantially larger than the decks used in SFM-7A-4A. The tests described in [10] were repeated with larger specimens as described in "Methodology and Experimental Setup."

In the case of the larger decks, the thermal attack from identical under-deck flame is distributed over a larger surface than they would be with the smaller desks. Figure 8A and 8B show a comparison of the deck temperatures 90 seconds after burner ignition for the small and large decks, respectively. This distributed heat experienced by the larger deck resulted in a slower burning process and reduced the thickness of the charred layer. Hence, eventually a large amount of the available fuel participated in the combustion and caused a more intense exposure from the burning deck to the siding on the building, as shown in Figure 8C.

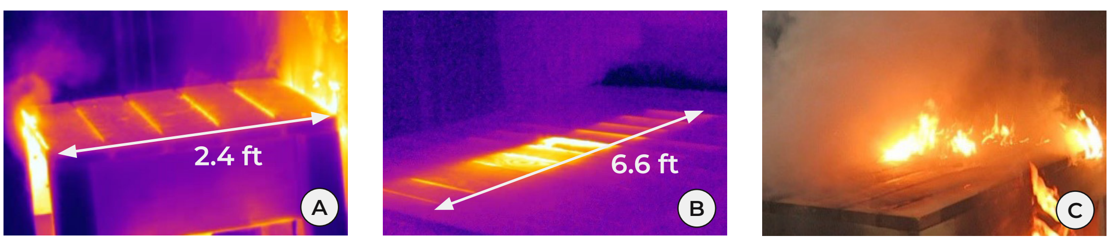

Figure 8. (A) Distribution of heat under a 2 ft x 2.4 ft deck 90 seconds after igniting the burner. (B) Distribution of heat under a 6.6 ft x 6.6 ft deck 90 seconds after igniting the burner. (C) Intensity of the fire for a 6.6 ft x 6.6 ft deck 40 minutes after turning off the burner.

Adding Wind to the SFM-7A-4A Test Protocol

Most wildfires occur during red flag warning days [15] which are always accompanied by elevated wind speeds (20 mph or higher and/or gusts to 35 mph or higher) and low relative humidity (minimum relative humidity 15% or less). Therefore, understanding the potential role of wind on the performance of decking material is a critical part of the assessment.

As previously discussed in "Methodology and Experimental Setup," the standard deck specimens (2 ft x 2.4 ft) were exposed to two different wind conditions. In both scenarios with wind, the fire intensity was distinctly higher than the no-wind case discussed in "Current Test Method—SFM 12-7A-4A." During the tests with wind, decks burned for more than 40 minutes with sustained flames and burning particles falling from the deck as shown in Figure 9. While the fire behavior is significantly different between the wind and no-wind cases, detecting differences between different wind tests was not the objective of this study.

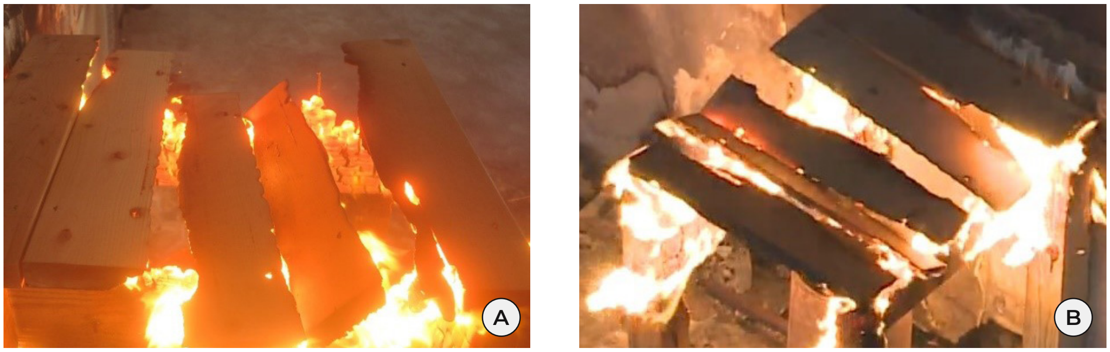

Figure 9. Effect of adding wind to current test method (2 ft x 2.4 ft decks).

INTEGRATING ALL THE MODIFICATIONS

In the previous section, the effect of each modification in isolation was explained. In a real-world scenario, all of these components would happen at the same time.

After exposing a 6.6 ft x 6.6 ft deck to an 80 kW under-deck flame for 3 minutes in the presence of wind, the entire assembly (joists, posts, red wood deck boards, and thermocouples on the deck) burned in less than 15 minutes. This intense exposure raised the temperature in the area underneath the deck beyond the tolerance of the high-temp thermocouples within minutes of starting the test. Consequently, without losing the generality, the exposure duration was reduced to 2 minutes in this research.

Another key observation in the under-deck flame exposure tests was the contribution of combustible joists in the fire dynamic (Figure 10 and Figure 11). The contribution of a deck's substructure to the initiation, intensity, and growth of fire has been observed in both post-event investigations [1,5,7] and lab experiments [6].

Combustible Substructure Contribution to Fire Intensity

Examining the fire dynamics under both the smaller and larger decks, with and without the presence of wind, the joists were found to be a major contributor to the fire dynamics of the burning deck. Joists are typically perpendicular to the building, which creates several bays at the bottom side of the deck boards and blowing wind can easily channel through these bays. Combustible joists, if ignited, can carry the fire toward the building in the presence of wind and expose the siding of the building to direct flame contact. In addition, the vortices created around the building can carry the flame in random directions and expose the entire field of the deck to the under-deck flame from burning joists. In other words, a 2- or 3-minute exposure from the burner transforms to a much longer exposure to the decking material caused by the burning joists. If a joist was not engulfed in fire, the boards above it did not burn. Figure 10 shows this phenomenon for redwood boards installed over a substructure made from Southern Yellow Pine.

Figure 10A to 10C are taken in different tests. Figure 10D to 10G shows the fire growth in one test. In this test, the gradual growth of fire on the joist caused the entire bay to be involved in the fire.

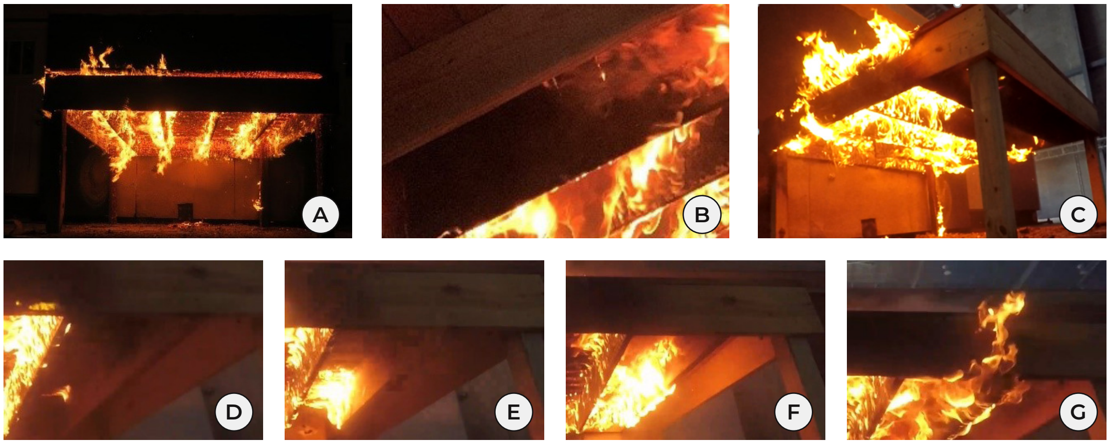

Figure 10. Combustible joists provide a constant heat source to the deck boards.

Under the reduced (2 minute) exposure, in the presence of wind, Chapter 7A compliant deck assemblies burned intensely. Figure 11 depicts a time-lapse for a redwood deck exposed to a gusty wind from two different angles; the first row is a corner view and the second row is an under-deck view.

Figure 11. Time-lapse of a redwood deck with Southern Yellow Pine joists test from two angles. (A) After 5 seconds. (B) After 2 minutes. (C) After 5 minutes. (D) After 7 minutes. (E) After 10 minutes.

Columns A and B in Figure 11 show the deck 5 seconds after igniting the burner and just before turning off the burner, respectively. Column C shows the deck almost 7 minutes after ignition of the burner. During the test, the flame stayed underneath the deck boards for the majority of the time. The fire started consuming the edges of the combustible boards, widening the spacing between the boards, and eventually creating enough space between the boards to allow the flame to rise above the deck. This transition is shown in Column D. Column E shows the collapse of the deck after almost 15 minutes. Note that in Figure 11E the change in the angle of the last photograph is because the below-deck camera was damaged by the intensity of the fire and an image from different camera was used.

Similar observations were made for composites A and B, but the fire growth happened at a slower rate. Figure 12 shows the temperature measured on the wall underneath the deck over 15 minutes. As shown in Figure 12, the temperature on the wall kept rising after igniting the burner and stays above 200°C (392°F) until the deck collapses. Note that 200°C (392°F) was conservatively chosen as the critical ignition temperature [16].

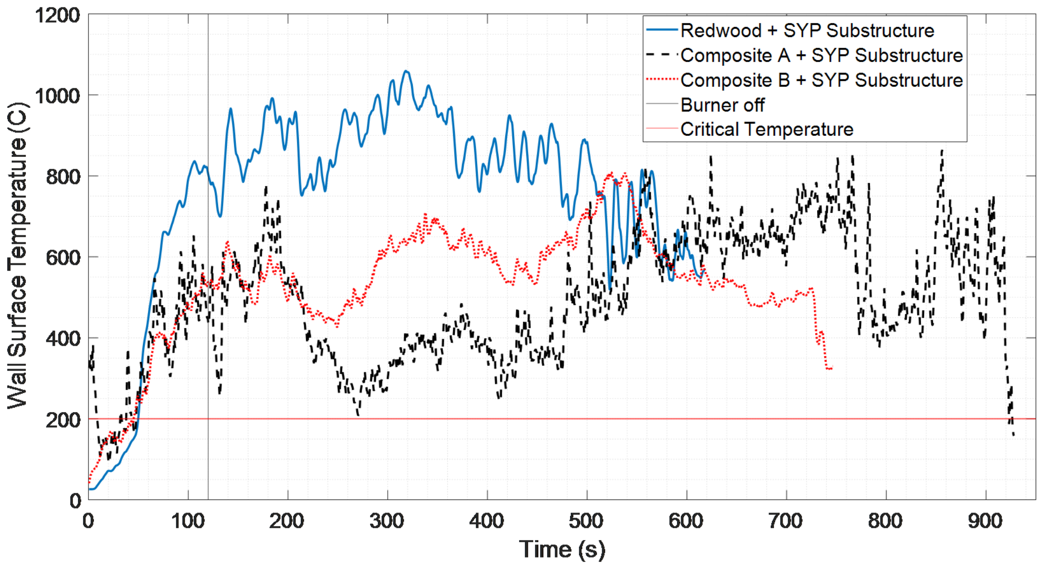

Figure 12. Siding temperature at the under-deck area for different deck boards over Southern Yellow Pine structure.

Metal Joists

To assess the effects of joists on the fire dynamics, the three deck board materials (redwood, and composites A and B) were placed above metal joists and exposed to a 2-minute 80 kW fire. Figure 13 shows the time-lapse of all three tested assemblies. While we did not measure the heat release rate in this research, comparing top rows in Figure 11 and Figure 13 revealed a markedly lower intensity fire with the metal joists under the same exposure. Also, the fire intensity is lower with composite boards relative to redwood.

A Start of the test | B After 5 minutes | C After 15 minutes

Figure 13. Time-lapse of redwood (first row), composite A (second row), and composite B (third row) decks with metal joist test.

Figure 14 tracks the temperature of the wall surface in the under-deck area. Redwood and composite A were subjected to a 2-minute 80 kW exposure. Composite B was subjected to a 3-minute exposure. After seeing the promising results of redwood and composite B over metal joists, the extended exposure time was chosen to assess the performance of metal joists in a more severe condition. After shutting off the burner, the temperature rapidly decreased and fell below the 200°C critical temperature. This shows that to understand the true vulnerability of decks, the selection and configuration of the joists is not independent and significantly affects the performance of the decking material. Therefore, joist configuration should be incorporated into the standard test method.

Comparing the wall temperature variations in Figure 12 and Figure 14 shows the contribution of combustible substructure in the fire. After shutting off the burner, in all cases in Figure 14, the temperature rapidly dropped. However, no obvious change in temperature behavior on the wall can be seen in Figure 12 after shutting of the burner.

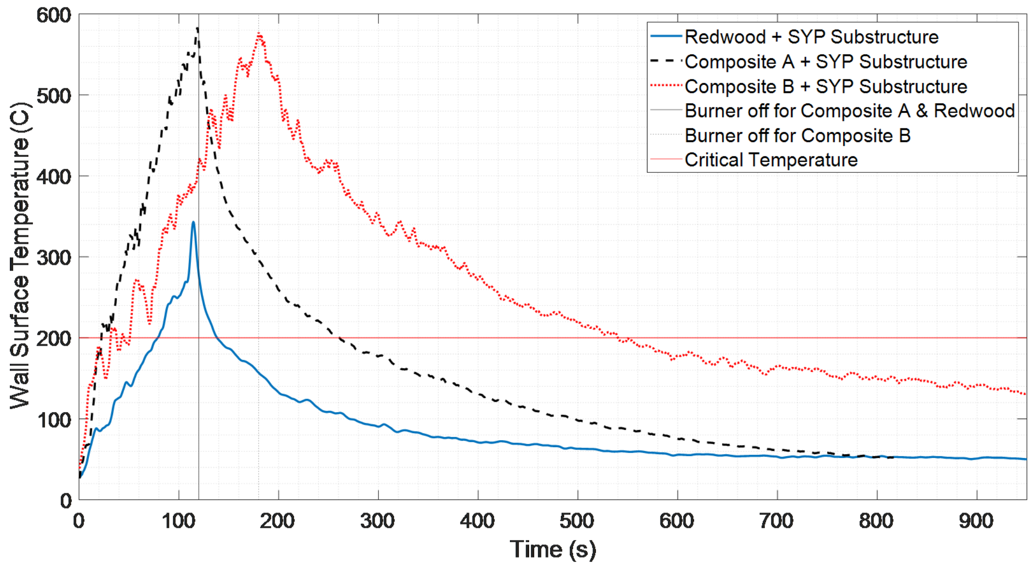

Figure 14. Siding temperature at the under-deck area for different deck boards over metal structure (exposure duration for Composite B is 1 minute longer).

COST

Estimating the cost of a deck over its lifetime is challenging. In addition to the initial costs, maintenance fees can be costly depending on deck size, design complexity, material, and intensity of weathering. While the initial cost of using steel joists is higher, their lifetime is claimed to be longer (typically 25 years). Steel joists are typically more resilient against weathering effects because they are galvanized. They also do not deform over time, which maintains a consistent flat decking surface and allows for longer spans requiring fewer columns. Note that many deck boards come with a warranty longer than the lifetime of wood substructures.

In addition to the above-mentioned parameters, the geographic area, market availability, seasonality, and design complexity will affect the cost of a deck. A 12 ft x 12 ft deck built with pressure-treated lumber joists and composite deck boards would cost $1,500–$2,500. Replacing pressure-treated wood substructure with metal would increase the cost $2,000–$3,500, approximately a 35% increase. Note that these estimates don't include labor cost.

TAKEAWAYS

Effective fuel management is the key to minimizing ignition risk for decks. Our research demonstrated that combustible deck assemblies (walking surface and substructure) were extremely vulnerable to an under-deck flame exposure. The intensity and duration of the under-deck flame exposure depends on the type and amount of fuel underneath the deck. Under-deck flame impingement is less likely if all combustibles are removed from the under-deck area.

For homes and buildings with decks overhanging a slope, vegetative fuel management down-slope is also essential in minimizing the potential of an under-deck flame exposure from burning vegetation. However, resiliency should not be completely dependent on an individual's vigilance.

Even if homeowners follow the best wildfire guidance and do not store combustible materials in the under-deck area, some vegetation and wind-blown vegetative debris might accumulate over time. Therefore, the performance of decks should be evaluated from a reasonable exposure simulating the fire intensity and duration caused by an accumulation of these vegetative fuels.

- Based on the deficiencies identified in the current SFM-7A-4A standard, the following modifications are suggested:

  The ASTM E2632 test method examines the response of the deck to an under-deck flame exposure but fails to assess the vulnerability of decks in a real-world wildfire scenario. Test parameters such as deck size, wind, and other construction details that played critical roles in evaluating deck performance are not currently addressed in the standard test method.

Effect of Wind

Available oxygen is an influential parameter in fire dynamics. A no-wind condition does not represent a real-word wildfire scenario. Moderate to high winds have been shown to be an influential parameter in all recent destructive wildfires.

Effect of Size

Available fuel is another influential parameter in fire dynamics. A relatively small deck led to misinterpretation of the experimental results. In this research, the 6.2 ft x 6.2 ft (2 m x 2 m) deck size was chosen after considering the size of the ASTM E108 tunnel that is available in many commercial fire labs.

Effect of Construction Details

The current test method does not consider joists as a variable in the general fire behavior of the deck. IBHS research has found that the performance of the deck walking surface is fundamentally influenced by the joist material. Therefore, the entire deck assembly should be considered in a test method to mimic real-world exposure.

Modifying either the deck size or the presence of air flow (wind) affects the fire dynamic, which resulted in unsatisfactory performance of decks made with Chapter 7A compliant combustible products. The results of this research showed that combustible deck assemblies ignited from an under-deck flame exposure posed a higher risk to the attached structure.

- Use of metal joists reduced the vulnerability of the deck from top-of-deck firebrand exposures. IBHS has previously observed that firebrands accumulate in between board gaps on top of the joist and noted that ignition started in this area. Once ignited, if the joists are perpendicular to the building, smoldering and flaming fire crept toward the house along the joist.
- Metal joists limit the streamwise fire growth toward the building by limiting the available fuel exposed to under-deck flame. The observations during this research show that in most cases, the deck boards had marginal contribution to the fire intensity if their supporting joists were not burning. In fact, combustible joists ignited first and prolonged the exposure time to the bottom side of the boards from a 2- or 3-minute burner exposure to a much longer exposure.
- Although metal joists cost about 30% more than preservative-treated wood joists, their lifetime is claimed to be longer. They are corrosion-resistant (galvanized), lightweight, and perfectly straight.

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