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# Performance of Attached Decks Subjected to Ember Top-of-deck and Flame Impingement Under-deck Exposures

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**Abstract**

Attached decks are a vulnerable component of a building in wildfire-prone areas. Once ignited, decks can expose a building's cladding (siding), exterior 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 building.

In a wildfire, decks are typically exposed to embers (firebrands) on their top surface and flame impingement to their bottom side. In this research, the vulnerability of decks to ember attack on the top surface and flame impingement at the bottom was investigated. Moreover, the ability of the current deck standards (State Fire Marshal (SFM) Standard 12-7A-4A and ASTM E2632) to predict the performance of different decking assemblies during a wildfire was assessed from experimental and computational perspectives.

Deck research at IBHS began with the evaluation of the vulnerability of decks to wind-blown embers. This research provided evidence that the top surface of redwood (Sequoia sempervirens) decks was particularly vulnerable to ignition by embers. Ignition typically occurred from ember accumulation in gaps between deck boards at joist crossings, which is an area where wind-blown vegetative debris can accumulate. This finer fuel can facilitate ignition by embers. After ignition, fire propagated both parallel and perpendicular to the test building. Although the mechanism was different, propagation did not depend on the orientation of the deck boards (or support joists).

The research on decks was followed up by testing deck assemblies exposed to under deck flame impingement. Several combinations of substructure (i.e., the structural support system) and walking surfaces were evaluated. These results highlighted the vulnerability of joists in the deck assembly. In North America, a wood or plastic composite walking surfaces installed over a wood substructure is the most common decks are built. Our tests showed that once the joist ignites due to the initial flame impingement exposure, it can burn for an extended period and expose the bottom side of the deck boards to flames. It was observed that if a joist was not engulfed in flames, the boards above them do did burn. Hence, one major finding from this study was regarding the impact of the substructure overall deck performance and the importance of explicitly considering the structural support system in any standard test method used to evaluate performance. It also supported the benefit of advocating the use of a noncombustible structural support system in new construction.

While using metal substructures significantly reduced the vulnerability of decks to wildfires (considering both ember and flame exposures), it might not be an affordable option to retrofit existing decks. To address this issue, different types of walking surfaces were tested. It was concluded that continuous noncombustible walking surfaces such as no-gap metal boards or a concrete slab surface limited the availability of oxygen and stalled flame spread in the under-deck area.

## 1. The IBHS Research Center Test Chamber

The Insurance Institute for Business & Home Safety (IBHS) is a non-profit corporation that operates a natural hazards research facility located in Richburg, South Carolina. The experiments take place at the center square of the test chamber, measuring 145 ft x 145 ft (44.2 m x 44.2 m). The west wall of the chamber is equipped with 105 fans. Each fan is 5.5 ft (1.68 m) in diameter and collectively can create a time history of fluctuating wind speeds from 12 mph (5.3 m/s) to 120 mph (53m/s). The test chamber is also equipped with eight ember generators, each one with the capacity to produce about 120 embers per second with mass between 0.01 to 1 gram. Figure 1a and 1b show IBHS test chamber. Figure 1c shows a snapshot of a deck exposed to embers [Alfano et al. 2017].

a

b

c

***Figure 1. IBHS test chamber (a) inside (b) outside (c) ember generators schematic***

## 2. Ember Exposure to Decks

This series of experiments investigated the ignition potential of eight different types of deck boards exposed to wind-blown embers. The materials evaluated included solid wood and plastic composite deck board products. Six of the products evaluated complied with the provisions specified in Chapter 7A of the California Building Code [CBC 2019], 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 and transition to flaming combustion. At locations where embers accumulated, however, smoldering was often observed.

The medium-density softwood product (CBC Chapter 7A compliant) and one of the plastic composite products (CBC Chapter 7A non-compliant), exhibited sustained flaming when subjected to an ember exposure. Transitory flaming was observed in the high-density hardwood decking product (CBC Chapter 7A compliant). The time-to-ignition (flaming) for the decking products varied from 12 minutes for the non-FRT softwood deck to 47 minutes for one of the plastic composite products. Photographs of ignited non-FRT softwood deck is shown in Figure 2. 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. It was observed that 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 transitioned to flaming as a result of airflow between the deck boards. This allowed fire to continue to propagate all the way to the building.

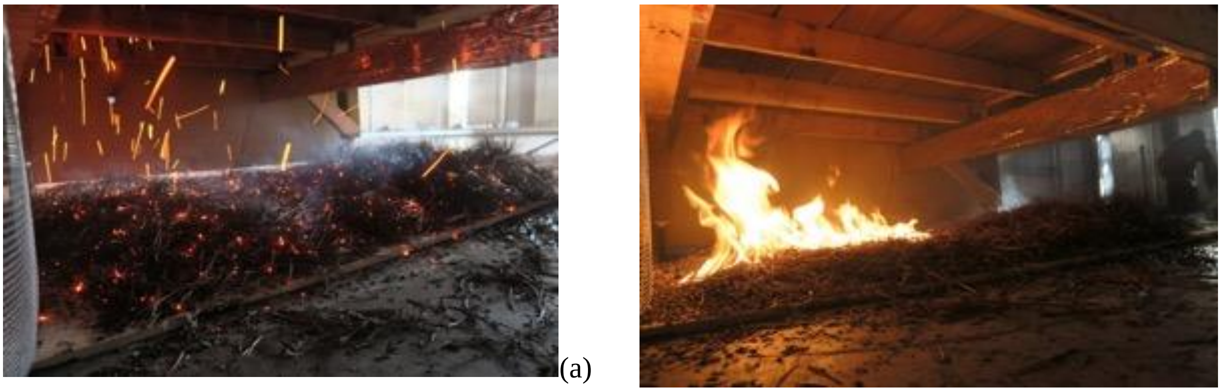
***Figure 2. Top of deck (left) and under-deck (right) views of ignited decks during the ignition potential series of experiments. Table 1 tablulates a summary of all the ember exposure tests.***

***Table 1. Summary of the ember exposure tests***

| Deck Name | Chapter 7A Compliant | Density[1] (g/cm³) | Performance | |
|---|---|---|---|---|
| | | | Replication 1 | Replication 2 |
| PVC Composite | Yes | 0.68 | Smoldering | Smoldering |
| PE Composite 1 | No | 0.97 | Smoldering | Sustained Flaming[2] |
| PE Composite 2 | Yes | 1.19 | Smoldering | Smoldering |
| PE Composite 3 | Yes | 1.03 | Smoldering | Smoldering |
| PE Composite 4 | No | 1.21 | Smoldering | Smoldering |
| High-Density Tropical Hardwood | Yes | 1.15 | Smoldering | Transitory Flaming[3] |
| Medium-Density Softwood | Yes | 0.51 | Sustained Flaming | Sustained Flaming |
| FRT Wood | Yes | 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

It was also observed that embers dropped into and through the gap, onto the surface below and had the potential to ignite fine fuels underneath (Figure 3). This highlights the risk of underdeck flame impingiment and importance of removing combustible materials from the under-deck área, even if vertically enclosed around the deck perimeter.



(a) (b)

***Figure 3. Ember penetration through gaps between deck boards; (a) embers falling to ground and (b) resulting in the ignition of pine needles that accumulated under the deck.***

## 3. Underdeck Flame Exposure to Decks

Although maintaining the under-deck area is necessary to reduce the vulnerablity of decks in a wildfire, post-event investigations have shown that these recomendation are often overlooked. Depending on the frequency of maintenance around a building, a noticeable amount of fuel can accumulate under a deck. If this fuel is ignited by wind-blown embers, the flame might be tall enough (depending on fuel load, wind speed, and deck height) to reach the deck structure. People also store combustibles, such as firewood, under decks [Maranghides et al. 2015]. Ignition of these materials intensifies the under-deck flame exposure. In this case, the under-deck flame exposure would be more intense and may last longer than exposure from burning wind-blown debris.

Provisions in Chapter 7A of the California Building Code allow the use of many combustible deck board products. These materials include non-fire-retardant treated wood (e.g., redwood and western red cedar) and plastic composites. These decking products can be installed over combustible or noncombustible joists. Whereas the current standard test method includes the substructure in the tested assembler, the arrangement is fixed, and therefore does not consider the substructure system as a variable. To sumarize, the current standard test method evaluates a (1) 2ft x 2.4 ft deck, (2) a “no wind” condition and (3) does not consider the structural support system as a variable[CBC 2019].

To assess the efficacy of the current test methods, all three of the above-mentioned assumptions were challanged by more realistic wildfire conditions. Six-foot by six foot (1.8 x 1.8 m) deck assemblies were exposed to under deck flame in the presence of a 19 mile per hour (8.5 m/s) constant wind speed. The deck assemblies had different combinations of substructure and walking surfaces. Metal and Southern yellow pine substructures were tested with redwood, plastic composite and metal deck boards. It was observed that all the currently compliant deck boards burn extensively and expose the cladding adjacent to the under-deck portion of the attached building to a high thermal insult. Figures 4 and 5 show the progression of fire for redwood deck boards installed over southern yellow pine and the respective wall temperature for different products respectively.

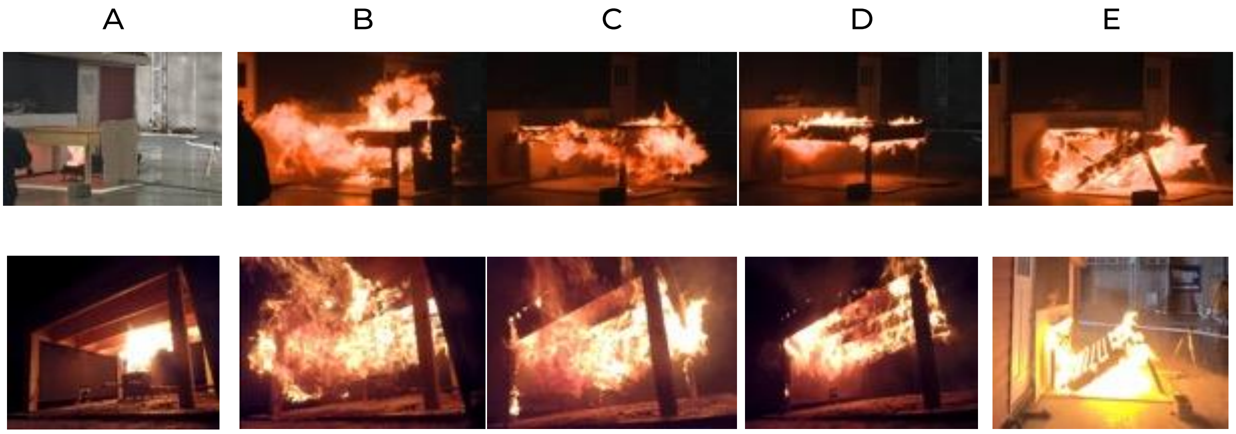



***Figure 4. Time-lapse of a redwood deck with Southern Yellow Pine joists test from two angles. (A) After 5 seconds. (B) After 2 minutes. (C) After 5 minutes. (D) After 7 minutes. (E) After 10 minutes***

These tests highlighted the contribution of the deck’s substructure in the fire. It was observed that if a joist was not engulfed in flames, the boards above them do did burn. To evaluate this observation in detail, the wood and plastic composite combustible decks boards were installed over a metal substructure and exposed to the same under-deck fire source. Figures 6 and 7 show the progression of fire for redwood deck boards installed over southern yellow pine and the wall temperature for different products respectively.

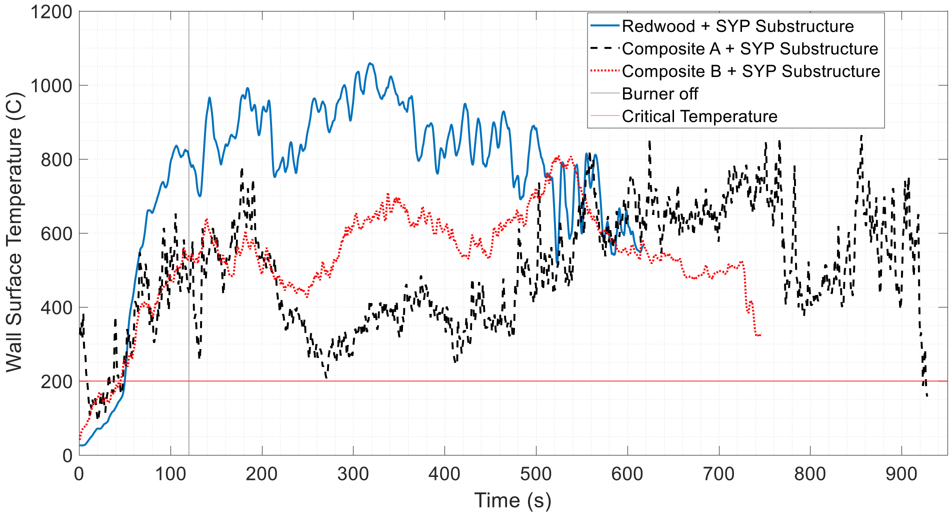



***Figure 5. Siding temperature at the under-deck area for different deck boards over Southern Yellow Pine structure.***

A (start of the test) B (after 5 minutes) C (after 15 minutes)

***Figure 6. Time-lapse of redwood (first row), composite A (second row), and composite B (third row) decks with metal joist test.***

The ignition temperature of wood depends on samples' thermophysical properties (moisture content, geometry, ,density, and some external parameters such as the test apparatus, and piloted/autoignition conditions. The resuts of ignition temperature of wood show a wide span of ignition temperatures of 210–497_C for piloted ignition and 200–510_C for autoignition. [Babrauskas 2002]. From these observations, it can be concluded that that "if a wood specimen is ignited under external heating barely sufficient to ignite it, it will ignite at approximately 250_C regardless of the type of heating arrangement [Babrauskas 2002]."

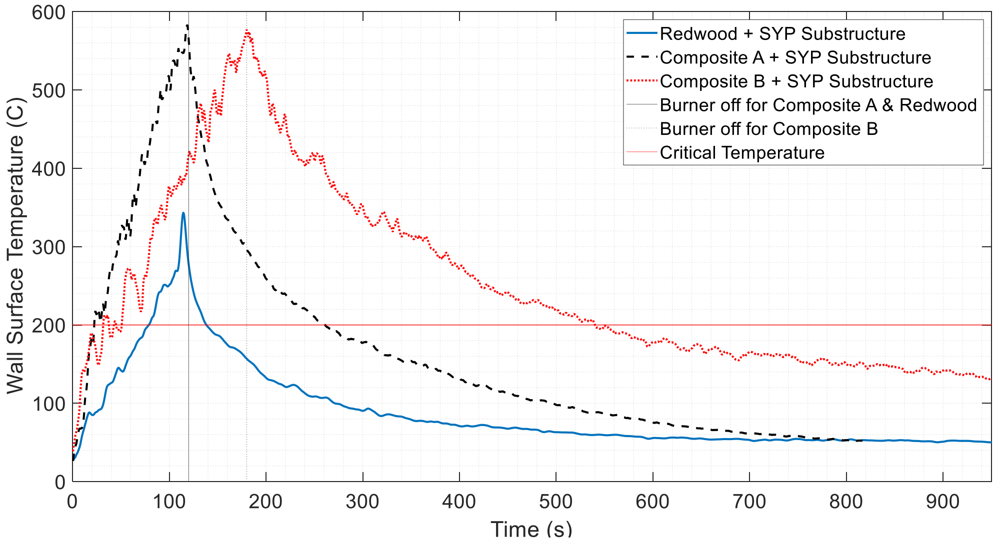



***Figure 7. Siding temperature at the under-deck area for different deck boards over metal structure (exposure duration for Composite B is 1 minute longer).***

Comparing the wall temperature variations in Figures 5 and 7 shows the contribution of a combustible substructure in the fire. After shutting off the burner after 2 or 3 minutes, in all cases (as shown in Figure 7), the temperature rapidly dropped. The results of these experiments demonstrate the benefits of using metal substructures for new decks. However, for existing decks changing the entire substructure could be cost prohibitive. To address this issue, the performance of two types of metal deck boards were evaluated. The Type 1 walking surface was aluminum and marketed as a waterproof product. The installation instructions for this product specified that there be no spacing between boards. These deck boards are engineered to properly address water drainage and thermal expansion. The Type 2 walking surface was also an aluminum product, however, installation instructions called for spacing between deck boards. Figure 8 shows the status of decks during the experiment from two views. As can be seen, the intensity of the fire between walking surfaces Type1 and 2 were notably different. For the Type1 walking surface the fire was in a smoldering phase while for Type2 walking surface the flames length extnding form under the deck was observed to be as high as two feet (0.6 m).

***(a)***
***SYP structure and walking surface Type1***

***(b)***
***SYP structure and walking surface Type2***

***Figure 8. Comparing Type1 (a) and Type2 (b) walking surfaces installed over a SYP substructure***

Table 2 summarizes the results of the underdeck tests. The time between twice of the exposure time and the end of the experiment was analysed for critical temperatures [Babrauskas 2002]. The last column of Table 2 shows if the temperature of the wall exceeded 250 degrees Celsius during this time.

***Table 2. Summary of the results of the underdeck tests.***

| Board | Sub-structure | Currently Chapter7A compliant | Wall temperature exceeds 250 C? |
|---|---|---|---|
| Redwood | SYP | Yes | Yes |
| Redwood | Metal | Yes | No |
| Composite A | SYP | Yes | Yes |
| Composite A | Metal | Yes | No |
| Composite B | SYP | No | Yes |
| Composite B | Metal | No | No |
| Metal No Gap | SYP | Yes | No |
| Metal Gapped | SYP | Yes | Yes |
| Metal No gap | Metal | Yes | No |
| Metal gapped | Metal | Yes | No |

## 4. References

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