Fire Safety Journal 110 (2019) 102913

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: http://www.elsevier.com/locate/firesaf

Influence of board spacing on mitigating wood decking assembly ignition

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ABSTRACT

As part of recent building code change discussions, it has been suggested that by increasing the spacing of boards, it may be possible to mitigate ignition of wood decking assemblies from wind-driven firebrand showers. An experimental series was undertaken to vary the board spacing from 0 mm (no gaps), 5 mm, and 10 mm, to determine if it was possible to observe reduced ignition propensity of full-scale wood decking assemblies fitted to a reentrant corner wall assembly. In these experiments, three common wood types were used and firebrand showers were directed at the wall/decking assemblies using wind speeds of 8 m/s generated using a realistic-scale wind tunnel. Based on the results of these experiments, it was observed that board spacing significantly influenced ignition propensity of these assemblies. Ignition events were observed for all board spacing considered and in particular, more ignition points were observed for a board spacing of 10 mm.

1. Introduction

Across the globe, there exist many recent examples of large outdoor fires. Perhaps the most common are wildland fires that approach urban areas. These are often called Wildland-Urban Interface (WUI) fires. Two recent examples are the 2019 WUI fires that occurred in South Korea and those in 2018 in Northern California in the United States. The recent Northern California fires destroyed more than 18,804 structures with scores of fatalities. In countries that are less developed, there have been large fires that have occurred in informal settlements. Two recent examples are those in the Philippines as well as South Africa, both in 2017. There have also been large urban fires in Japan, a country with no large wildland fire problem or informal settlement situation. Such urban fires have been recorded for centuries in Japan's history [1].

A shared feature in the rapid spread of large outdoor fires are the production or generation of new, far smaller combustible fragments from the original fire source referred to as firebrands. In the case of WUI fires, the production of firebrands occurs from the combustion dynamics of vegetative and man-made fuel elements, such as homes and other structures. For urban fires and informal settlement fires, firebrands are produced primarily from man-made fuel elements [2].

An approach to reduce ignition of structures in urban fires has long been the development and adoption of building codes and standards. These guidelines provide the basis for fire resistant construction in many of the developed countries throughout the world [3]. In the United States, for example, such codes and standards have been in existence much longer for urban fires, while WUI fire building codes and standards are far newer, due to the more recent WUI fire problem in this country. It is therefore not surprising that WUI fire codes and standards remain largely unproven to actually mitigate WUI fire spread and structure ignition processes. The problem is simply due to the fact that WUI fire science is much less developed than more mature areas of fire safety science [4].

Wood decking assemblies are common construction feature for homes and have been known for some time to be vulnerable to ignition from firebrands generated in large outdoor fires. Such knowledge has been garnered from after fire investigations in both Australia and the United States [5]. Recent experiments by the authors have demonstrated that various wood decking assemblies are *indeed* ignitable by wind-driven firebrand showers. In the current California and ASTM decking assembly test methods [6–7], a firebrand is simulated by placing a burning wood crib on top of a section of a decking assembly under an air flow. The dynamic process of multiple firebrands bombarding decking materials as a function of time is not adequately represented in these standards. Based on firebrand attack from real fires, it is expected that multiple firebrands would deposit within gaps/crevices between or on deck boards. Recent experiments have demonstrated the current deficiencies of standard test methods to mitigate wood decking assembly ignition processes [8–9]. The use of decking assemblies may also be seen in recent construction for Japanese homes.

As part of recent building code change discussions, it has been suggested that by increasing the spacing of boards, it may be possible to mitigate ignition of wood decking assemblies from wind-driven firebrand showers. As a result, an experimental series was undertaken to vary the board spacing from 0 mm (no gap), 5 mm, and 10 mm, to determine if it was possible to observe reduced ignition propensity of

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https://doi.org/10.1016/j.firesaf.2019.102913
Received 25 July 2019; Received in revised form 28 October 2019; Accepted 5 November 2019
Available online 8 November 2019
0379-7112/Published by Elsevier Ltd.

full-scale wood decking assemblies fitted to a reentrant corner wall assembly. In these experiments, three common wood types were used and firebrand showers were directed at the wall/decking assemblies using wind speeds of 8 m/s. This wind speed was purposely selected since it is known such wind speed easily ignited wood decking assemblies in the past. The present experiments build on prior work by the authors that focused on fixed board spacing of 5 mm; a current recommended spacing [10].

1.1. Experimental description

As the experimental procedures for firebrand generation were the same in the prior work when conducting experiments here at 8 m/s (to compare results), some details are repeated here for completeness. All experiments used the full-scale Continuous Feed Firebrand Generator (FS-CFFG) [8–9]. This version of the device is modified from the NIST Dragon and consists of two parts, the main body (Dragon component), and continuous feeding component (see Fig. 1). A fan, to provide airflow, was connected to the main body; details described below [8–9]. To produce firebrands required a feeding system to meter in specific amounts of wood pieces. Details of the feeding system are presented elsewhere [8–9]. Douglas-fir wood pieces machined to dimensions of 0.79 cm (H) by 0.79 cm (W) by 1.27 cm (L) and were used to produce firebrands. These dimensions correspond to the virgin wood; *i.e.* pre-combustion inside the Dragon. The same-size wood pieces have been shown to be similar to sizes determined from full-scale conifer tree combustion, as well size distributions surmised from WUI fires [8–9].

The fan speed was selected to generate firebrands with the desired combustion characteristics (3.0 m/s airflow); glowing combustion. While glowing firebrands were the focus here, flaming firebrands could also be generated as part of additional studies [8–9]. The experimental device was installed inside the test section of the wind tunnel facility at the Building Research Institute (BRI). To produce the wind field, up to 10 m/s (±1 m/s), required the use of an axial fan. The wind speed was checked by using a vertical, twenty-one measurement location hot wire anemometer assembly. The measurement point closest to the ground had the most variation, so the uncertainty of ten percent considers all the measurement points [8–9].

The overall cross section of this facility is 500 cm wide by 400 cm high. As a result of these scoping investigations, the reentrant corner was placed at a distance of 325 cm downstream of the FS-CFFG. The dimensions of the reentrant corner assembly were 122 cm wide by 244 cm high on each side. The walls of the reentrant corner were lined with gypsum board (12.5 mm thick) since these experiments were focused on deck assembly ignition, not the ignition of the wall assembly itself.

Each of the decking assemblies was installed inside the reentrant corner assembly at the ground. The decking assemblies were 1.2 m by 1.2 m in dimension. Western Red Cedar (361 kg/m^3), Douglas-fir (534 kg/m^3), and Redwood (437 kg/m^3) were used as the decking board materials, as these are very common wood types used by homeowners [8–9]. The actual dimensions of all decks boards were: 2.5 cm thick by 13.7 cm wide (Western Red Cedar), 2.5 cm thick by 13.9 cm wide (Douglas-fir); 2.5 cm thick by 13.7 cm wide (Redwood). While these board thicknesses were chosen to develop a database of various decking assembly performance, naturally it is possible to use boards with other dimensions. The spacing of the decks boards was varied from 0 mm (no gap), 5 mm, to 10 mm. The boards were installed using a wood supporting frame (support boards were 3.8 cm thick by 14.0 cm height) with members spaced 40.6 cm on center. Fig. 2 displays the orientation of the decking boards for all experiments as well as the various spacing used.

Careful, systematic procedures were completed for each experiment. The deck assembly was fitted inside the reentrant corner. The wind tunnel speed was set to the desired level (8 m/s). Wood pieces were loaded into the cylinder storage container and the air compressor needed to provide compressed air for the pneumatic cylinder and gate system was switched on (air compressor pressure was set to 0.7 MPa). The blower was set at 3.0 m/s, and two propane burners were ignited and inserted into the side of the device. The propane burners were operated continuously during the experiment. The pneumatic piston was then activated and the sliding rod was positioned to allow wood pieces to enter the volume in the metal sleeve. The sliding rod was moved to push the wood pieces (0.2 kg) to the first gate. The gate was opened, closed, and the second gate was then opened, and the wood fell into the main body (Dragon). The feeding was initially varied to determine the optimal conditions for continuous firebrand showers. It was observed that 0.2 kg, inserted every 15 s (0.8 kg/min), provided an adequate firebrand generation rate to ignite building materials [8–9]. Table 1 lists the total number of experiments conducted.

The number flux (number of firebrand generated/m^{2}s), exiting the

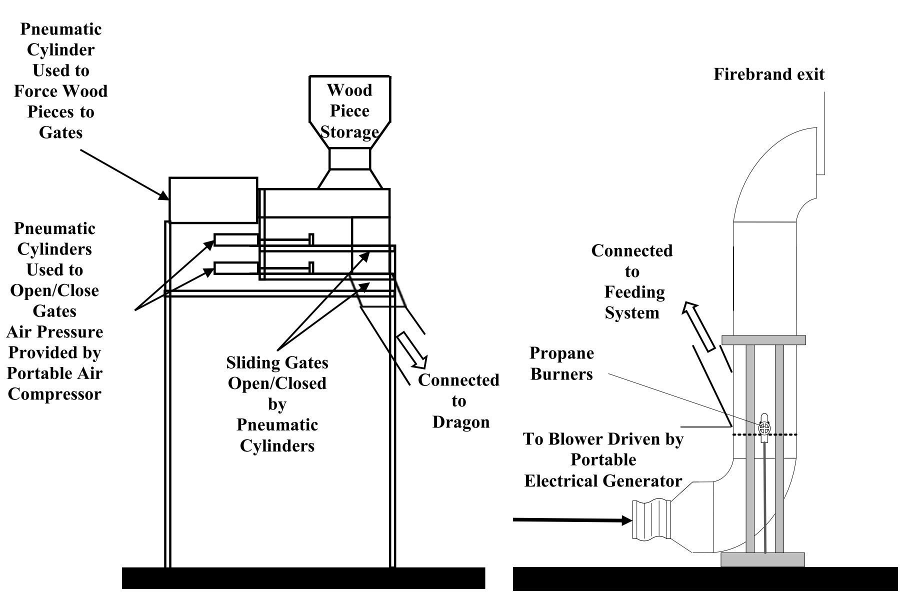

Fig. 1. Drawing of experimental device used to generate controlled firebrand showers. The device was installed inside the test section of a wind tunnel facility.

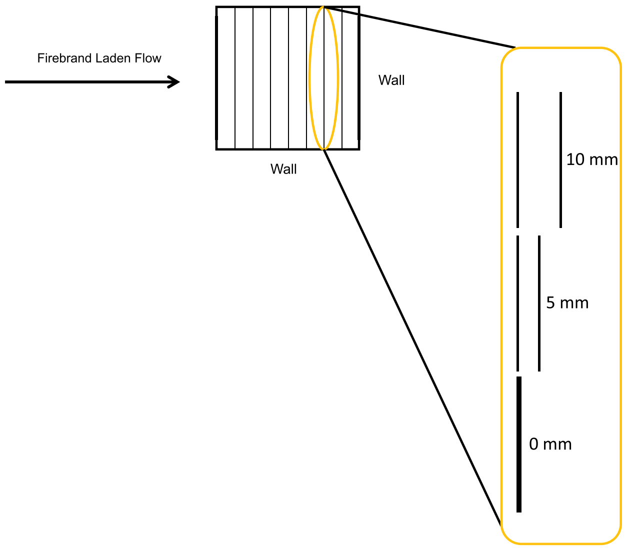

Fig. 2. Simple schematic showing board spacing: 0 mm (no gaps); 5 mm, and 10 mm. The direction of flow with firebrands is also shown.

outlet duct, was measured at a wood piece feed rate of 0.8 kg/min. To determine the number flux, the number of firebrands was counted from video recordings. The number flux reached a steady value of $341/m^2s \pm 30/m^2s$. Mass flux data (mass of firebrands generated/m^2s) were calculated by multiplying the number flux and the average mass of each firebrand. To determine the firebrand mass, experiments was also conducted using a series of water pans placed downstream of the FS-CFFG. Without water pans, the firebrands would continue to burn and by the time collection was completed; only ash would remain. After the experiment was finished, the pans were collected, and the firebrands were collected from the water, using a series of fine-mesh filters. As in previous work, the mass versus drying time was monitored to determine the duration need to completely dry the firebrands. The mass was measured using an electric balance. The mean mass and standard deviation of the firebrands were $0.05\ g \pm 0.02\ g$. Therefore, the mass flux of generated firebrands was calculated to be $17\ g/m^2s \pm 1\ g/m^2s$.

Firebrand sizes using this device fed with Douglas-fir wood pieces have been linked with those from burning vegetation and prior WUI fires [8–9]. The firebrand sizes generated using this device were similar with the characteristics of firebrand exposure at a single location during a severe WUI fire in California [8–9]. Empirical characterization of firebrand exposure is limited, especially with respect to firebrand size distributions during actual WUI fire conditions. These differ with the size of firebrands suggested in existing standard test methods and WUI fire protection building construction recommendations [6–7].

2. Results and discussion

The first series of experiments were conducted for board spacing of 0 mm (no gap); that is no spacing. Such a configuration is not realistic but was done to simply see if it was still *possible* to sustain ignition. As it is common knowledge, wood expands and contracts as it absorbs moisture from the surrounding environment. For these reasons, installing deck boards with no spacing would not bode well for an actual decking assembly installed adjacent to houses. For all wood types considered, firebrands accumulated inside the corner for applied wind speeds of 8 m/s (see Figs. 3–5). Firebrand combustion produced smoldering ignition in the deck board and this then resulted in smoldering combustion of the supporting members. It was very interesting to observe the smoldering combustion processes tunneled down into the decking assembly supporting frame, further suggesting the dangers of these types of assemblies when exposed to firebrand showers. It is important to observe that the tunneling of the smoldering combustion processes resulted for all three wood types considered.

These results were then compared to prior work by the authors that considered 5 mm board spacing; a recommended practice [**10**]. In that study, for wind speed of 8 m/s, firebrands were observed to accumulate near the corner of deck/reentrant corner assemblies and this resulted in flaming ignition of the decking boards. Ignitions occurred near the corner in five out of six experiments while in one case firebrands caused ignition near the front of the decking assembly. Fig. 6 shows the severity of ignition on the assemblies. The supporting joists, as well as deck boards, were also ignited. Firebrands that accumulated between the gaps caused ignitions. The mass of firebrands required to reach flaming ignition was determined to be 7 g–25 g of firebrands under a wind speed of 8 m/s for a board spacing of 5 mm, for the three wood types considered. The highest wood density (Douglas-fir) resulted in the largest mass required for flaming ignition.

The final series of experiments increased the board spacing to 10 mm. As it was believed by the authors that 10 mm would be a highly vulnerable situation for ignition, it was decided to use Redwood, a wood with density in between Western Red Cedar and Douglas-fir to simply verify this. In experiments, firebrands were trapped at multiple locations (see Fig. 7) due to the larger board spacing. Not only did the large spacing result in more surface ignitions, multiple firebrands also were easily able to fall through the board spacing, resulting in a large number of firebrands under the decking assembly itself (see Fig. 8). In these experiments, the floor was lined with non-combustible material to avoid

Table 1
Moisture content dry basis (%) of the deck boards used in all experiments. MC was determined by oven drying the samples at 104 °C. A total of 12 full-scale experiments were conducted for a board spacing of 0 mm (no gaps) and 5 mm. Two full-scale experiments were conducted for a board spacing of 10 mm.

	0 mm		5 mm		10 mm	
Cedar	11.4% MC	13.6% MC	11.7% MC	11.7% MC	NA	
Redwood	10.9% MC	14.4% MC	12.2% MC	12.2% MC	11.8% MC	12.7% MC
Douglas-fir	15.3% MC	15.5% MC	12.7% MC	12.6% MC	NA	

Fig. 3. Images of ignition observed for 0 mm board spacing (no gaps); Western-Red Cedar.

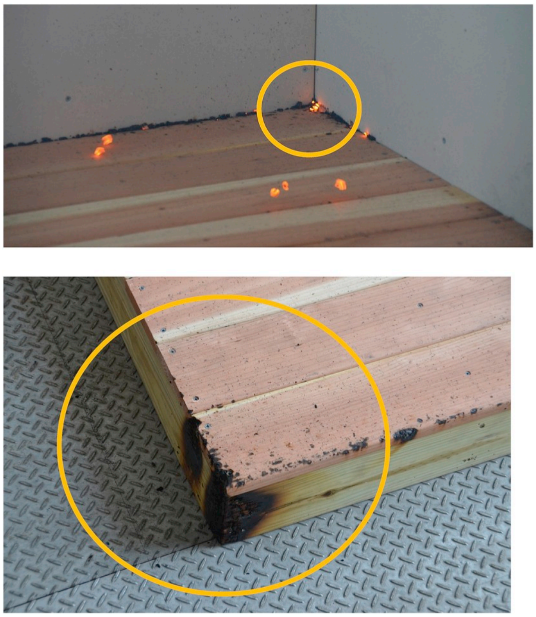

Fig. 4. Images of ignition observed for 0 mm board spacing (no gaps); Redwood.

Fig. 5. Images of ignition observed for 0 mm board spacing (no gaps); Douglas-fir.

Fig. 6. Images of ignition observed for 5 mm board spacing; Western-Red Cedar [9].

Fig. 7. Images of ignition observed for 10 mm board spacing; Redwood.

any ignitions underneath the decking assembly. Yet, in actual situation, the large number of firebrands may easily ignite any combustibles under the decking assembly surface.

In prior work for a wood deck board spacing of 5 mm, a correlation was developed to determine the time to reach sustained flaming ignition for an applied wind speed of 8 m/s (Mass FI (g) = 0.03ρ (kg/m^3), where ρ is the wood density) [9]. As indicated, in those experiments, the decking assemblies were exposed to similar firebrand size and mass distributions to the present experiments. These sizes and masses are shown in Fig. 9.

At a board spacing of 0 mm (no gaps), only smoldering ignition was observed, so the firebrand mass required for sustained smoldering ignition (SI) was compared with the results at 5 mm and 10 mm board spacing in Fig. 10. The onset of SI was based on the observation of intense smoke generation. The average firebrand mass required for SI was plotted and the error bars in Fig. 10 represent the standard deviation. The total number of firebrands arriving on the surface of the deck was determined to estimate the number and thus mass required for SI.

Fig. 8. After the decking assembly was removed, it was seen that many firebrands fell through the boards (10 mm) and were deposited underneath the assembly. The floor was lined with non-combustible material to avoid any ignitions underneath the decking assembly. Yet, in actual situation, the large number of firebrands may easily ignite any combustibles under the decking assembly surface.

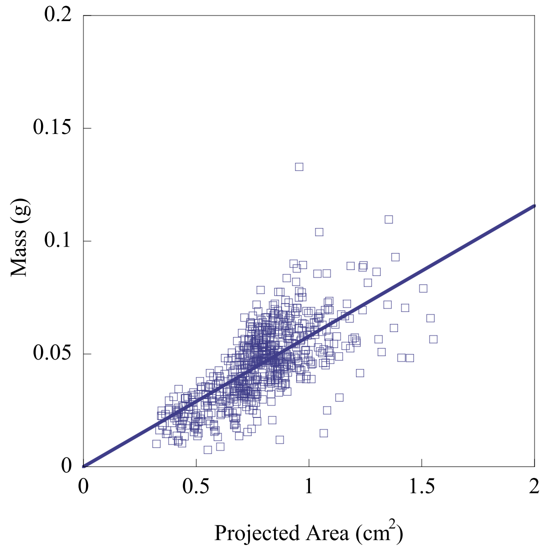

Fig. 9. Size and mass of firebrands generated from the FS-CFFG [9]. As the repeatability has been verified over the course of many studies, a curve fit is used to describe the sizes for wind speeds of 8 m/s.

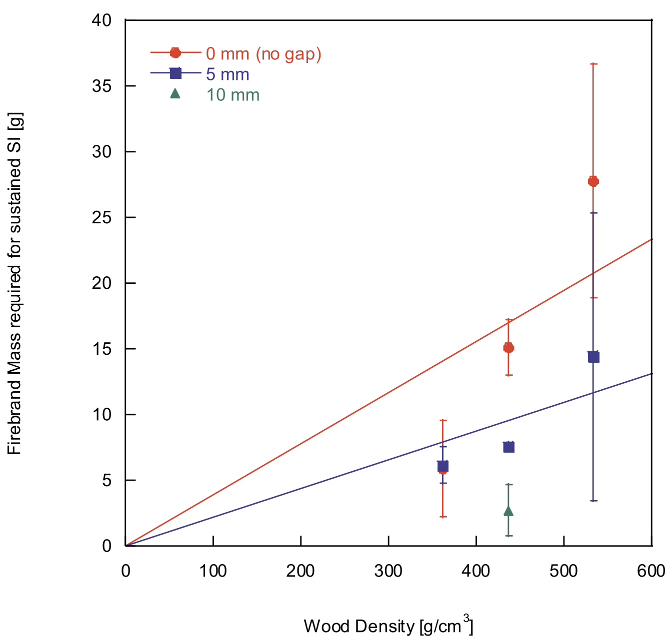

Fig. 10. Firebrand mass required for sustained smoldering ignition (SI) versus wood densities for 0 mm board spacing (no gaps), 5 mm board spacing, and 10 mm board spacing. The curve fits are proposed correlations for mass require for sustained SI.

These uncertainties are due to repeated experiments and multiple ignition locations in some cases. For all wood decking types used in this experimental series, it was found that the firebrand mass required for SI increased as the density of decking materials increased. This was the same trend for flaming ignition (FI) shown in the past study [8–9].

The correlation was evaluated for the 10 mm board spacing experimental results, as sustained flaming ignitions were observed. Multiple ignition points were observed for the 10 mm board spacing experiments. The same methodology to calculate the mass of firebrands required for FI were used for this study [8,9]. Namely, the total number of firebrands arriving on the surface of the deck was determined to estimate the number and thus mass required for FI [8]. For Redwood, the correlation developed at 5 mm spacing suggest approximately 13 g of firebrands should be sufficient for sustained flaming ignition for wind speeds of 8 m/s. Comparing the results at 10 mm board spacing for Redwood at 8 m/s suggests that 2 g–9 g (average 4.0 g) were required (Fig. 11 displays average value and the error bars represent the standard deviation), which was less mass than mass required for sustained FI at 5 mm board spacing for Redwood. These differences are not due to moisture content (MC dry basis) of the boards, since MC was similar for the Redwood board used for the 5 mm and 10 mm spacing [9].

The influence of deck spacing was plotted against the firebrand mass required for sustained SI or FI (Fig. 12). For the three deck board spacing investigated, the firebrand mass required for sustained ignition (both SI and FI) decreased as the deck spacing increased.

It is interesting to compare these experiments to those conducted in a cone calorimeter. In experiments by Macindoe [11], the ignition source was not from actual firebrands but rather methenamine tablets. The board spacing used in all of the experiments was 10 mm. Even though 5 mm is a recommended spacing in Australia, 10 mm–12 mm has also been proposed for areas where homeowners are unlikely to wear high heel shoes and ease of litter cleaning is required, larger board spacing could be a worse-case scenario, and due to ignition source used (methenamine tables as opposed to actual firebrands), ignition could not be achieved using 5 mm board spacing in this simple setup [9]. Two deck board thicknesses were used by Macindoe [11], 2 cm and 5 cm. 2 cm is a more common board thickness and also corresponds to those used here as well (2.5 cm). Eight different wood species were used; these were (lowest to highest wood density): radiata pine, cypress pine, mountain ash, merbau, jarrah, red gum, spotted gum, and grey ironbark. Under conditions of no external radiant heat (i.e. cone heater switched off and ignition observed from methenamine tablets), no sustained flaming ignition was observed for 2 cm board thickness for MC (dry basis) 12–14%. As the MC was lowered, sustained FI was observed for some of the species at 2 cm board thickness. Once the board thickness was increased to 5 cm, all eight wood species sustained FI when the deck boards were oven dried. In general, it was noted that it was easier to ignite wood decking types with lower densities.

While these small-scale experiments were quite insightful, the present experimental results demonstrate significant differences. No

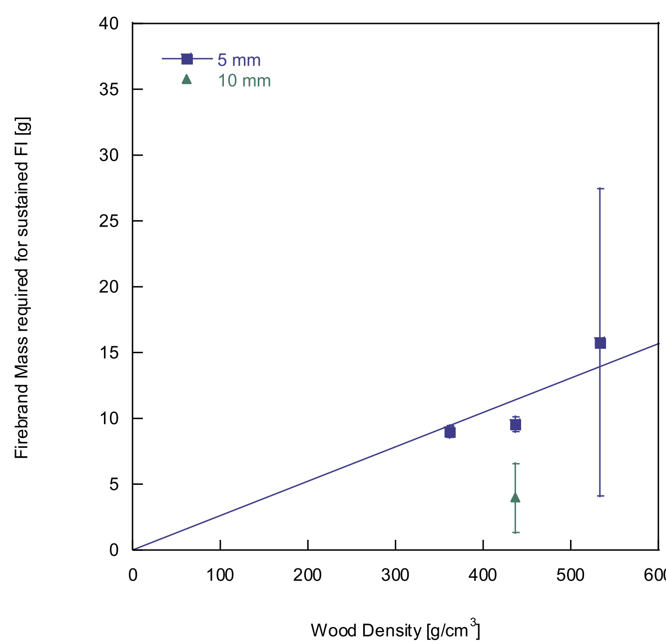

Fig. 11. Firebrand mass required for sustained flaming ignition (FI) versus wood densities for 5 mm board spacing and 10 mm board spacing (data from 5 mm board spacing is from [9]). The correlation proposed in [9] is once again shown as a curve fit to the 5 mm board spacing data.

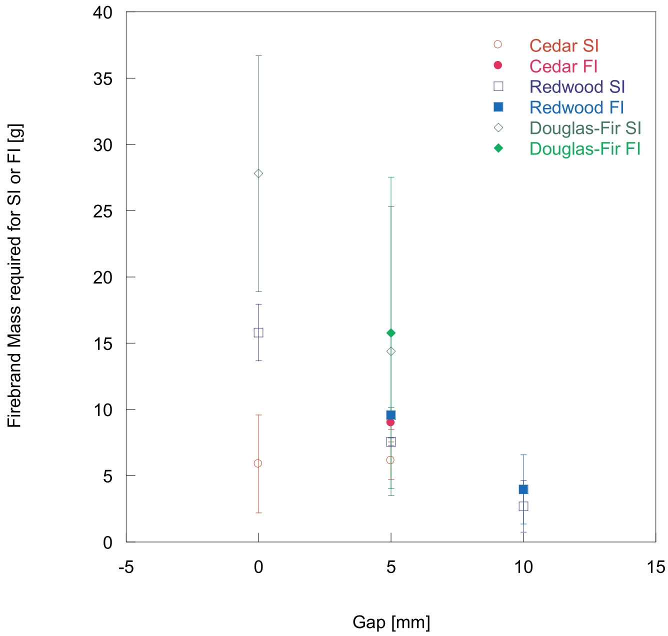

Fig. 12. Influence of deck board spacing versus firebrand mass required for sustained ignitions (SI and FI).

attempt was made here to oven dry the wood decking boards. Similar to previous experiments, the MC of the deck boards was within 11%–15% (all MC was determined by oven drying the samples at 104 °C; see Table 1). Presently, it was not difficult to ignite wood decking boards within the same MC range and similar deck board thickness range (2 cm versus 2.5 cm) using actual firebrand showers. Macindoe [11] was correct in suggesting that 10 mm spacing may be more of a worst-case scenario as compared to 5 mm spacing, as these experiments using full-scale decking assemblies exposed to wind driven firebrand showers have demonstrated this.

3. Summary

Wood decking assemblies are common construction feature for homes and have been known for some time to be vulnerable to ignition from firebrands generated in large outdoor fires. It has been suggested that by increasing the spacing of boards, it may be possible to mitigate ignition of wood decking assemblies from wind-driven firebrand showers. As a result, an experimental series was undertaken to vary the board spacing from 0 mm (no gaps), 5 mm, and 10 mm, to determine if it was possible to observe reduced ignition propensity of full-scale wood decking assemblies fitted to a reentrant corner wall assembly. In these experiments, three common wood types were used and firebrand showers were directed at the wall/decking assemblies using wind speeds of 8 m/s. These experiments build on prior work by the authors that focused on fixed board spacing of 5 mm; a current recommended spacing. Based on the results of these experiments, it was observed that board spacing greatly influenced ignition propensity of these assemblies. Not only did the large spacing result in more surface ignitions, multiple firebrands also were easily able to fall through the board spacing, resulting in a large number of firebrands under the decking assembly itself.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgements

SLM would like to thank the enormous support of Mr. Marco G. Fernandez, Engineering Technician at NIST, for providing the experimental supplies needed for these experiments. Both SLM and SS appreciate the support of the Building Research Institute (BRI), Japan, for allowing us to utilize the wind tunnel facility to conduct these experiments.

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