Firebrand Production from Building Components Fitted with Siding Treatments

Sayaka Suzuki¹ and Samuel L. Manzello²

¹Large Fire Laboratory
National Research Institute of Fire and Disaster (NRIFD)
Chofu, Tokyo, 182-0082 JAPAN
sayakas@fri.go.jp

²Fire Research Division
National Institute of Standards and Technology (NIST)
Gaithersburg, MD 20899-8662 USA
samuelm@nist.gov

ABSTRACT

Firebrand production from real-scale building components under well-controlled laboratory conditions was investigated. Re-entrant corner assemblies were ignited and during the combustion process, firebrands were collected to determine the size/mass distribution generated from such real-scale building components under varying wind speed. In prior work, a unique ignition methodology was developed to generate firebrands from re-entrant corner assemblies constructed of wood studs and oriented strand board (OSB). In this study, this ignition methodology was applied to re-entrant corners constructed from wood studs/OSB but fitted with actual siding treatments (tar paper and cedar siding) to determine the influence of siding treatments on firebrand generation from wall assemblies. Firebrands were collected with pans filled with water, and then the size and mass of firebrands were measured after drying. The size and mass distributions of firebrands collected in this study were compared with the data from prior component tests as well as the limited studies available in the literature on this topic. Some firebrands were found to be lighter for a given projected area than others, likely produced from cedar siding or tar paper. The effects of applied siding treatments on firebrand production are discussed in detail.

FOR SUBMISSION: Fire Safety Journal

INTRODUCTION

Wildland-Urban Interface (WUI) fires have caused significant destruction to communities in Australia, Chile, Greece, Portugal, Spain, and the USA. In 2009, fires in Victoria, Australia caused the death of more than 100 people, destroying more than one thousand structures. The 2007 Fires in Greece destroyed several hundred structures and caused the deaths of more than 70 people.

For many years, firebrands have been known to be a significant cause of structure ignition in WUI fires as well as large urban fires. Sparse data exist with regard to firebrand size distributions from actual structures or large outdoor fires, such as WUI and urban fires [1-3]. Historically, most of the firebrand studies have focused on the travel distance of firebrands [4-7]. In WUI fires, the structures themselves may be a large source of firebrands, in addition to the vegetation [8-12]. Yet, due to lack of quantitative information available on production of firebrands from structures, it cannot be determined if firebrand production from structures is a significant source of firebrands in WUI fires. In the case of urban fires in Japan, structures are responsible for firebrand production, but as in the case of WUI fires, little is known about firebrand size/mass distributions produced.

For completeness, a review of the literature is provided regarding known studies on the quantification of firebrands from burning structures and actual WUI/urban fires. Only a *limited* number of studies have been conducted. These literature survey results are summarized in **Table 1**.

Vodvarka [1] measured firebrand deposition by laying out 3 m x 3 m sheets of polyurethane plastic downwind from five separate residential buildings burned in full-scale fire experiments. Three of the structures were standard frame construction with wood siding. The fourth was asphalt siding applied over sheet rock which covered the original shiplap. The fifth structure was a brick veneer over a wood frame. The total number of firebrands

collected from these structure fires was 4,748. Very small firebrands dominated the size distribution with 89 % of the firebrands exhibiting projected areas less than 0.23 cm².

Vodvarka [2] measured the fire spread rate, radiant heat flux, firebrand fallout, pressures, and gas composition from eight separate building burn experiments. Firebrands were collected by laying out sheets of polyurethane plastic downwind from three of eight experiments. Two of the buildings were all wood construction; and one was cement-block construction, and had wooden floors and asphalt shingles over wood sheathing. In total, 2,357 firebrands were collected. More than 90 % of the firebrands had a projected area less than 0.90 cm² and 85% of the firebrands were less than 0.23 cm² in projected area. Only 14 firebrands had projected areas larger than 14.44 cm² in three experiments.

Yoshioka *et al.* [13] measured the size and mass of firebrands from the real-scale wooden house in the Building Research Institute's (BRI) Fire Research Wind Tunnel Facility (FRWTF) in Japan. Two square pans, both 1 m x 1 m, were placed 2 m from the house to collect firebrands: one was filled with water (wet pan) and the other without water (dry pan). The total number of firebrands collected in their study was 430; 368 from a wet pan and 62 from a dry pan. It was reported that 83 % of the firebrands in the wet pan were between 0.25 cm² and 1 cm² projected area while 53 % of those from the dry pan were between 0.25 cm² and 1 cm² projected area. Only 1 of 368 in the wet pan and 4 of 62 in the dry pan were larger than 4 cm² projected area. The far less numbers of firebrands with projected areas between 0.25 cm² and 1 cm² in the dry pan appeared consistent with the continued burning of the firebrands in the absence of quenching by water.

Shinohara *et al.* [14] investigated the characteristics of firebrand produced from a fire in Beppu-city, Oita, Japan in January 2010. This fire occurred under an average wind speed of 7.2 m/s – 12.1 m/s, with a maximum wind speed of 20.1 m/s. In total, 28 firebrands were collected with witness information. All of the firebrands collected here were from

downwind; no firebrands were found from upwind side. Most of firebrands were less than 0.5 g with less than 10 cm² projected area.

Ohmiya and Iwami [15] also investigated the hotel fire in Shirahama-city Wakayama, Japan in November 1998. The wind speed at the time of fire was around 7 m/s; it was believed that copious amounts of firebrands were produced during the fire. Survey of local residents was conducted in order to examine the relationship between firebrands and spot fires. The survey showed that most of the firebrands observed were less than 5 cm in maximum dimension.

Suzuki *et al.* [16] collected firebrands from fire experiment conducted in a two-story house located in Dixon, CA. Debris piles were used to ignite the structure, and it took approximately two hours after ignition for complete burn down. A large amount of water was poured onto the structure several times to control the fire since the house was located in a populated section of downtown Dixon. Firebrands were collected with a series of water pans placed near (4 m) the structure and on the road about 18 m downwind of the structure. A total of 139 firebrands was collected at the two measurement locations. All the firebrands collected from the burning house were less than 1 g and almost 85 % of the firebrands collected 18 m from the structure, and 68 % of firebrands 4 m from the structure, were less than 0.1 g. In terms of the projected area, most of the firebrands, 95 % of those from 18 m downwind from the structure and 96 % of those 4 m from the structure, were less than 10 cm² in projected area.

Suzuki *et al.* [17] investigated firebrand production from real-scale building components under well-controlled laboratory conditions using BRI's FRWTF in Japan. Specifically, wall and re-entrant corner assemblies were ignited and during the combustion process, firebrands were collected to determine the size/mass distribution generated from such real-scale building components under varying wind speed. The purpose of those

experiments was to determine if useful information regarding firebrand generation may be obtained from simple components tests. Component experiments are far simpler than full scale structure experiments. It was observed that similar mass distributions of firebrands were observed from components to the available full scale structure tests in the literature. The results are compared to the experiments outlined in this paper and are presented below.

Suzuki *et al.* [18] also investigated firebrand production from simple structure under well-controlled laboratory conditions also using BRI's FRWTF in Japan. The dimensions of structure were 3 m (W) x 4 m (L) x 4 m (H, including roof assemblies). The structure was constructed with studs and oriented strand board (OSB). The firebrands were collected using pans filled with water as the structure burned under an applied wind of 6 m/s. In this experiment, more than 90 % of firebrands were less than 1 g and 56 % were less than 0.1 g. These results are also compared to the experiments outlined in this paper and are presented below.

Recently, a full-scale three story wooden school building burn was performed under the direction of Hasemi [19] in order to investigate fire safety of wooden school structures. Three experiments were performed; however, firebrands were observed only in the first experiment. The size of the wooden school was 16 m long x 50 m wide x 15 m high. As a part of measurements, firebrands were collected over the range of fields [20]. Due to experimental challenges, the minimum size of firebrands collected in their study was around 0.5 mm while the maximum flying distance of firebrands were 1655 m from the school. The sizes of most firebrands were found to be between 1 cm and 3 cm. The projected area and mass of firebrands were measured. Overall, the projected area and mass of firebrands decreased as the lofting distance increased. The greater the distances were, the smaller the mass per projected area became.

Finally, Manzello and Foote [3] examined the size distribution of firebrand exposure

during the Angora Fire, a severe WUI fire in California, USA in 2007. In that study, a trampoline, which was exposed to wind-driven firebrands during the fire, was collected for analysis. The burn areas of the round trampoline base were assumed to be generated from firebrands and measured by digital image analysis. The trampoline section that was analyzed had an overall area of 10.5 m² with 1,800 burn holes. The single largest hole in the trampoline base had a 10.25 cm² burned area. It was observed that more than 85 % of the burned areas from firebrands were less than 0.5 cm² and more than 95 % of them were less than 1.0 cm². In addition to the trampoline data, burn patterns on building materials and plastic outdoor furniture were observed at 212 individual locations on or near numerous buildings in the Angora Fire. A large majority of these firebrand indicators were less than 0.40 cm² with the largest being 2.02 cm² or 0.64 cm x 3.18 cm. Most of the burn patterns on building materials consisted of shallow scorch or char marks on wooden or composite lumber decks. The Texas Forest Service has used this methodology to collect firebrand size distributions from the recent Texas Bastrop Complex fires in 2011, as well, and reported similar findings to the 2007 Angora fire; significant numbers of very small firebrands (< 0.5 cm²) were produced [21].

In order to understand the mechanism of WUI fire spread and growth, it is necessary to understand firebrand production both from vegetation and structures. To this end, firebrand production from real-scale building components under well-controlled laboratory conditions was investigated. Re-entrant corner assemblies were ignited and during the combustion process, firebrands were collected to determine the size/mass distribution generated from such real-scale building components under varying wind speed. Some results of firebrand production from wall assemblies with cedar siding applied were presented in conference proceedings [22, 23], but this paper provides a more detailed description of these experiments.

EXPERIMENTAL DISCRIPTION

Experiments were performed in BRI's FRWTF by varying the wind speed. In our previous research [17], wall assemblies and re-entrant corner assemblies were used in experiments; however, in order to examine the effect of siding treatment, only a re-entrant corner assembly, shown in **Fig. 1** was used in this study. The reasons are: data sets were collected for re-entrant corners under various wind speeds in our prior work [17], affording a similar comparison to this study where siding treatments applied, and it is believed that the re-entrant corner assembly may better simulate firebrand production from a full-scale structure, as compared to an individual wall, as it allows for more detailed construction considerations and larger fire sizes. The schematic of the experimental layout is shown in **Fig. 2**.

The re-entrant corner assemblies used in the experiments were 1.22 m wide for each side by 2.44 m high. Wood studs (2 x 4) were spaced 40 cm on center and oriented strand board (OSB) was used as the base sheathing material. Cedar siding treatments were selected in this study since it is thought to be the source of firebrands. Tar paper was applied on the OSB, and then cedar siding was added on top of the tar paper, following typical construction techniques in the USA (**Fig. 3**).

The assemblies were installed inside the test section of the FRWTF at BRI shown in **Fig. 2**. The facility was equipped with a 4.0 m diameter fan to produce a wind field up to a 10 m/s ($\pm 10\%$). The wind velocity distribution was verified using a hot wire anemometer array. To track the evolution of the size and mass distribution of firebrands, a series of water pans was placed downstream of the assemblies.

The ignition method used in this study was developed in a previous study [17]. This method provides repeatable conditions to collect firebrands during combustion of the assemblies. It is important to realize that it is very difficult to simulate the conditions of an

actual WUI fire in a controlled laboratory setting. The effect of wind speed on firebrand size and mass distribution generated from a given assembly configuration is an important parameter to study. For this study, each assembly was ignited using a propane gas T-shaped burner with a heat release rate of 26 kW positioned adjacent to the assemblies for 10 min under conditions of no wind. The T-shaped burner was placed on the outside of the assemblies since the purpose of this study was to simulate ignition from an outside fire. If the burner was applied under wind (e.g., 6 m/s), flaming combustion of the assembly was difficult to achieve due to convective heat loss from the applied wind flow. In addition, another advantage of ignition under no wind, with the burner applied for the same duration for each assembly, was that it provided more repeatable initial conditions for the experiments. Specifically, the area exposed to direct flame contact was similar for a given assembly. If igniting under wind, in addition to large convective heat loss, the contact area of the flame onto the OSB surface of the assembly became unsteady.

With the application of the T-shaped burner to the assembly under no wind, flaming combustion was observed on the exterior of the cedar siding. Once the burner was switched off, the wind tunnel was switched on. Firebrands were collected until the assemblies were consumed to such a degree that they could no longer support themselves (loss of structural integrity). **Fig. 4 (a)** displays an image after the ignition of re-entrant corner assemblies and **Fig. 4 (b)** displays an image after the wind tunnel was on. The assemblies were also tethered to the wind tunnel using fine wires to prevent them from collapsing due to the applied wind field. Firebrands were collected using a series of water pans placed behind the assemblies shown in **Fig. 2**. Water was necessary to quench the combustion of the generated firebrands. After deposition into the water pans, firebrands were filtered from the water using a series of fine mesh filters. Firebrands were dried in an oven at 104 °C for 24 h. **Fig. 5** shows images of typical firebrands collected in this study.

Image analysis software was used to determine the projected area of a firebrand by converting the pixel area using an appropriate scale factor. It was assumed that deposited firebrands would rest flat on the ground and the projected areas with the maximum dimension and the second maximum dimension of three dimensions were measured (for cylindrical and flat shaped firebrands respectively). Images of well-defined shapes (e.g. circular objects) were used to determine the ability of the image analysis method to calculate the projected area [16]. Based on repeat measurements of different areas, the standard uncertainty in determining the projected area was $\pm 10 \%$. The mass of each firebrand was measured by a precision balance with 0.001 g resolution. Repeat measurements of known calibration masses were measured by the balance which was used for the firebrand mass analysis. The standard uncertainty in the firebrand mass was approximately $\pm 1 \%$.

RESULTS & DISCUSSIONS

Fig. 6 shows the mass and size distributions of firebrands collected in this study compared with those from the building components with no siding applied [17]. In order to be able to show detailed comparison, **Fig. 6** is limited to the mass up to 2.5 g and the projected area up to 25 cm². **Fig. 6** shows that some of firebrands collected in this study have some similarity to re-entrant corners without cedar siding, while the projected area of firebrands was also larger at certain mass for re-entrant corners fitted with cedar siding (e.g. 0.5 g).

The percentages of firebrands with less than 1 cm² projected area from the experiments with cedar siding conducted under 6 m/s and 8 m/s wind were 39 % and 77 %, and those firebrands with less than 10 cm² projected area were 75 % and 97 %, respectively. In terms of mass, 67 % and 90 % of firebrands from re-entrant corners fitted with cedar siding under 6 m/s and 8 m/s were less than 1 g. The largest firebrand collected in this study had

110 cm² projected area with 25 g mass, which is considered as a part of wood studs.

It was found that the experiment under 6 m/s produced lighter firebrands than the one under 8 m/s because the water pan location for both experiments was the same and many larger firebrands generated under the 8 m/s wind condition were lofted beyond the pan location.

The distribution of the size and mass of firebrands from assembly with cedar siding under 6 m/s can be divided into two parts: firebrands similar to those from assembly with no sidings under 6 m/s and lighter firebrands at a certain mass. It is assumed that the firebrands which have similar size and mass to the firebrands from previous study [17] were generated from OSB/studs while firebrands with lighter mass at a certain mass were generated from cedar sidings/tar paper.

Fig. 7 shows the size distribution of firebrands collected in this study compared with Vodvarka's study [1] and our previous work [17, 18]. **Fig. 7** shows that the peaks of the size distributions of firebrands collected from components with cedar siding under 6 m/s and 8 m/s applied wind were between 0 cm² and 0.23 cm² projected area and between 0.23 cm² - 0.90 cm² projected area, respectively. These peaks are found to be shifted to smaller size compared to the experiments with no siding, whose peaks are between 0.90 cm² – 3.61 cm² under 6 m/s and 8 m/s winds. Yet, the size distributions of these experiments were still larger and broader than the ones from Vodvarka's study [1].

It was observed that cedar siding produced firebrands with large projected area and low mass that were easily lofted under the applied wind for very long distance, as compared to experiments using re-entrant corners constructed of only OSB/wood studs. These results suggest siding treatments do indeed influence of the firebrand production process.

More data is needed for firebrand size/mass distributions from not only structures, but also actual WUI and urban fires [24]. The experiments presented here *attempted* to collect

fundamental information on firebrand production from structural components, but how these data are related to firebrand production from actual WUI and urban fires remains elusive.

As indicated above, the Angora fire data set, and the Texas fire data set, remain the only known detailed data on firebrand size distributions from actual WUI fires [3, 21]. Similarly, little quantitative information on firebrand size/mass distributions regarding urban fires in Japan is available. Rapidly deployable instrumentation packages that can be placed in the path of WUI/urban fires to collect information on firebrand fluxes generated in *actual* WUI/urban fires would be desirable [25]. One of the authors has developed such a system to quantify heat flux from WUI fires and the concept was vetted in prescribed fires, but this methodology must be extended to collect needed firebrand flux from actual WUI fires [10]. It is difficult to simulate the range of WUI fuels (*e.g.* ~~100~~ hundreds of structures) and wind speeds in prescribed fires in a safe controlled manner, and as a result, using only firebrand data from prescribed fires will not give meaningful data from actual WUI events. Prescribed fires are, however, a useful place to test a conceptual firebrand flux instrument package.

Recently, attempts to simulate firebrand generation from trees were made by Barr and Ezekoye [26] and Tohidi et al [27]. The approach used in those studies are very interesting and authors hope that this new structure firebrand generation data may be used to guide structure generation firebrand simulations. Unfortunately, there is very limited data sets on firebrand production from structures and the authors hope these data sets help improve understanding of this complex problem.

SUMMARY

Firebrand generations from wall assemblies applied with cedar siding treatments under laboratory condition were observed, and firebrands were collected and compared with previous studies. It was observed that the size and mass ranges of firebrands from the wall

assemblies with cedar siding treatment were similar to the ones from the wall assemblies with no siding treatment. However, it was observed that lighter firebrands at a certain projected area were produced due to cedar siding. The peaks of the size distributions of firebrands collected from the wall assemblies with cedar siding have shifted to the smaller size compared with the ones with no siding. The results of these experiments clearly show that siding treatments have an effect on the firebrand generation process.

ACKNOWLEDGEMENTS

The authors would like to extend sincere appreciation to Dr. Ichiro Hagiwara of BRI (Japan) for allowing us to use the Fire Research Wind Tunnel Facility (FRWTF) to conduct the experiments described in this paper. Mr. Marco Fernandez of NIST is acknowledged for carefully preparing shipments to Japan for this experimental campaign.

REFERENCES

- [1] F.J. Vodvarka, Firebrand Field Studies—Final Report, IIT Research Institute, Chicago, IL, 1969.
- [2] F.J. Vodvarka, Urban Burns-Full-scale Field Studies—Final Report, IIT Research Institute, Chicago, IL, 1970.
- [3] S.L. Manzello, E.I.D. Foote, Characterizing Firebrand Exposure During Wildland-Urban Interface Fires: Results of the 2007 Angora Fire, *Fire Tech.*, 50 (2014) 105-124.
- [4] F. Albini, Spot Fire Distances From Burning Trees – A Predictive Model, USDA Forest Service General Technical Report INT-56, 1979.
- [5] C.S. Tarifa, P.P. del Notario, F.G. Moreno, On the Flight Paths and Lifetimes of Burning Particles of Wood, *Proc. Combust. Inst.* 10 (1965) 1021- 1037.

- [6] I.K. Knight, The Design and Construction of a Vertical Wind Tunnel for the Study of Untethered Firebrands in Flight, *Fire Tech.* 37 (2001) 87-100.
- [7] H.H. Wang, Analysis on Downwind Distribution of Firebrands Sourced from a Wildland Fire, *Fire Technology* 47 (2011) 321-340.
- [8] Koo E, Pagni PJ, Weise DR, Woycheese JP (2010) Firebrands and spotting ignition in large-scale fires. *International Journal of Wildland Fire* 19 :818–843.
- [9] Mohamad El Houssami, Eric Mueller, Alexander Filkov, Jan C. Thomas, Nicholas Skowronski, Michael R. Gallagher, Kenneth Clark, Robert Kremens, Albert Simeoni, Experimental Procedures Characterising Firebrand Generation in Wildland Fires, *Fire Technology*, (published online 10.1007/s10694-015-0492-z)
- [10] Manzello SL, Park S-H, Cleary TG (2010) Development of rapidly deployable instrumentation packages for data acquisition in wildland–urban interface (WUI) fires. *Fire Safety Journal* 45:327–336.
- [11] Manzello SL, Cleary TG, Shields JR, et al. (2008) Experimental investigation of firebrands: generation and ignition of fuel beds. *Fire Safety Journal* 43 :226–233.
- [12] Manzello SL, Maranghides A, Mell WE (2007) Firebrand generation from burning vegetation. *International Journal of Wildland Fire* 16:458–462.
- [13] H. Yoshioka, Y. Hayashi, H. Masuda, T. Noguchi, Real-Scale Fire Wind Tunnel Experiment on Generation of Firebrand from a House on Fire, *Fire Sci. Technol.* 23 (2004) 142–150.
- [14] M. Shinohara, K. Sugii, M. Hosokawa, The influence of Characteristics of Firebrands on the Flight Distance – Based on the Field Survey of the City Fire under the Strong Wind in Beppu-city, Oita, in January 2010-, Report of National Research Institute of Fire and Disaster, No. 113, Chofu, Tokyo, 2012 (in Japanese).
- [15] Y. Ohmiya and T. Iwami, An Investigation on the Distribution of Firebrands and Spot

- Fires due to a Hotel Fire, *Fire Sci Technol.* 20 (2000) 27-35.
- [16] S. Suzuki, S.L. Manzello, M. Lage, G. Laing, Firebrand Generation Data Obtained From a Full Scale Structure Burn, *Int. J. Wildland Fire* 21 (2012) 961–968.
- [17] S. Suzuki, S.L. Manzello, Y. Hayashi, The Size and Mass Distribution of Firebrands collected from Ignited Building Components Exposed to Wind, *Proc. Combust. Inst.* 34 (2013) 2479–2485.
- [18] S. Suzuki, A. Brown, S.L. Manzello, J. Suzuki, Y. Hayashi, Firebrands Generated from a Full-Scale Structure Burning Under Well-Controlled Laboratory Conditions, *Fire Safety Journal*, 63 (2014) 43-51.
- [19] Y. Hasemi, N. Yasui, N. Itagaki, J. Izumi, T. Osaka, T. Kaku, T. Naruse, I. Hagiwara, K. Kagiya, J. Suzuki, K. Kato, Full-scale fire tests of 3-story wooden school building, World Conference on Timber Engineering, Quebec City, Canada, August 2014
- [20] Y. Hayashi, T. Jaishi, J. Izumi, T. Naruse, N. Itagaki, R. Hashimoto, N. Yasui, Y. Hasemi, Firebrands Deposition and Measurements of Collected Firebrands Generated and Transported from a Full-scale Burn Test using a Large Wooden Building, *AIJ J. Technol. Des.* 20 (2014) 605-610 (in Japanese)
- [21] S. Rissel, and K. Ridenour., Ember Production During the Bastrop Complex Fire, *Fire Management Today*, 72: 7-13 (2013).
- [22] S. Suzuki, and S.L. Manzello, Effect of Siding Treatment on Firebrand Production from Building Components, Fire and Materials Conference, San Francisco, CA, 2015.
- [23] S.L. Manzello, S. Suzuki, J. Suzuki, Y. Hayashi, Firebrands Generated from Full-scale Building Components and Structures under an Applied Wind-Field, 2013 International Fire Science and Engineering (INTERFLAM) Conference, Nr Windsor, UK, July 2013.
- [24] S.L. Manzello, Enabling the Investigation of Structure Vulnerabilities to Wind-Driven

Firebrand Showers, *Fire Safety Science* 11 (2014) 83-96.

- [25] S.L. Manzello, Hardening Structures to Wildland-Urban Interface (WUI) Fire Exposures, *Advances in Forest Fire Research* (X. Viegas, Editor), 794-804 (2014). DOI:10.14195/978-989-26-0884-6_88.
- [26] B. W. Barr and O. A. Ezekoye, Thermo-Mechanical Modeling of Firebrand Breakage on a Fractal Tree, *Proc. Combust. Inst.* 34 (2013) 2649-2656.
- [27] A. Tohidi, N. Kaye, and W. Bridges, Statistical Description of Firebrand Size and Shape Distribution from Coniferous Trees for use in Metropolis Monte Carlo Simulations of Firebrand Flight Distance, *Fire Safety Journal*, 77 (2015) 21-35.

TABLE CAPTIONS

Table 1 Summary of firebrand production studies from structures and WUI/urban fires.

TABLE 1

	Peak Fire Intensity	Material Used	Wind Speed	Measurement Techniques	Significant Results
Vodvarka [1]	Not provided	standard frame construction with wood siding /asphalt siding applied over sheet rock / brick veneer over a wood frame	Not specified	Sheets of polyurethane plastic	89% of firebrands less than 0.23 cm ²
Vodvarka [2]	Not provided	all wood construction /cement-block construction with wooden floors and asphalt shingles over wood sheathing	Not specified	Sheets of polyurethane plastic	85% of firebrands less than 0.23 cm ²
Yoshioka <i>et al.</i> [13]	1.08 MW/m ²	fire prevented wood with outer wall siding and slate roofing	4 m/s	Pan filled with water and no water	83 % of firebrands in the wet pan between 0.25 and 1 cm ²
Shinohara <i>et al.</i> [14]	Not measured	Not mentioned	an average wind speed of 7.2 – 12.1 m/s, with the maximum wind speed 20.1 m/s	Collected after fire	Most of the firebrands less than 10 cm ² and 0.5 g
Ohmiya and Iwami [15]	Not measured	Not mentioned	an average 7 m/s	Survey	Most of the firebrands less than 5 cm maximum dimension
Structure Burn in CA [16]	Not measured	Wood and brick	6 m/s	Pans filled with water	All the firebrands less than 1 g
					most of the firebrands less than 10 cm ²
Components [17]	Not measured	OSB and wood 2x4 studs	6 m/s	Pans filled with water	more than 90 % of firebrands were less than 1 g
			8 m/s		more than 90 % of the firebrands less than 10 cm ²
Full-Scale Burn in Wind tunnel [18]	1.76 MW/m ²	OSB and wood 2x4 studs	6 m/s	Pans filled with water	more than 90 % of firebrands were less than 1 g
					more than 90 % of the firebrands less than 10 cm ²
3 story school building burn [19, 20]	Not mentioned	Wood and gypsum boards	4.6 m/s	Collected after fire	Most firebrands were found to be between 1 and 3 cm
Manzello and Foote [3]	Not mentioned	Not specified	4.5 m/s to 6.7 m/s (sustained) gusts to 13 m/s	trampoline outdoor furniture	more than 95 % of firebrands less than 1.0 cm ²
Rissel and Ridenour [21]	Not mentioned	Not specified	5.4 m/s to 6.3 m/s (sustained) gusts to 13 m/s	trampolines	more than 90 % of firebrands less than 0.5 cm ²

FIGURE CAPTIONS

Figure 1 Schematic of wall assembly with cedar siding treatment.

Figure 2 Experimental layout in wind tunnel.

Figure 3 Wall assembly applied with cedar siding (before the experiment).

Figure 4 (a) Image of the assembly after ignition (no wind) **(b)** Image of the assembly under applied wind.

Figure 5 Images of typical firebrands collected in this study (scale is 1 cm)

Figure 6 Comparison of the size and the mass of firebrands collected from the assemblies with and without cedar sidings under different wind speed.

Figure 7 Comparison of the size distribution of firebrands collected in this study and from the literature.

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

(a)

(b)

FIGURE 5

FIGURE 6

FIGURE 7