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Initial study on thatched roofing assembly ignition vulnerabilities to firebrand showers

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ABSTRACT

Structures fitted with thatched roofing assemblies are prone to ignition during the course of large outdoor fires. Experiments with thatched roofing assemblies were performed by using a reduced-scale continuous-feed firebrand generator in a wind facility to investigate fundamental ignition mechanisms. The wind speed was varied from 3 m/s to 6 m/s to observe the ignition and flame spread of thatched roofing assemblies. It was observed that firebrands penetrated into the thatched roofing assembly, sometimes unseen from the outside, resulting in ignition and ultimately rapid flame penetration. Information obtained in this study would be useful to evaluate and develop effective counter measures to protect historical structures with thatched roofing assemblies, especially for historical buildings, such as The United Nations Educational, Scientific and Cultural Organization (UNESCO)'s world heritage sites in Japan.

1. Introduction

It is well known that structures with thatched roofing assemblies are prone to ignition during the course of large outdoor fires [1]. Counter measures to prevent structures fitted with thatched roofing assemblies from igniting have been studied and external sprinklers have been implemented, especially for historical buildings, such as The United Nations Educational, Scientific and Cultural Organization (UNESCO)'s world heritage sites in Japan shown, as shown in Fig. 1. The efficacy of these countermeasures is unknown, as they are not linked to actual large outdoor fire exposures. One significant danger to important UNESCO cultural heritage sites is the exposure to firebrands. Firebrands are produced when structures and vegetation burn. These firebrands may easily be transported in the wind and result in firebrand showers that attack structures.

Fundamental ignition studies of thatched roofing assemblies by firebrands have never been carried out. It is believed that firebrands may penetrate the thatched roofing assembly and smolder, which eventually leads to ignition and damage to buildings [1]. Past experiments with thatched roofing assemblies were performed with a burning wood crib placed on the roof top or using a gas burner, rather than simulating the actual phenomena of firebrand showers attacking the thatched roofing [2,3]. While these studies are described in Japanese [2,3], the use of wood cribs to simulate firebrand exposure is identical to other roofing test methods. The dynamic process of multiple wind-driven firebrands landing and then being transported under gaps that may exist for roofing assemblies as a function of time is not considered in current roofing assembly test standards [4,5]. Manzello et al. [4,5] revealed the vulnerabilities of tile roofing assemblies to ignition under a controlled wind-driven firebrand attack using the NIST Firebrand Generator.

In this initial study, the reduced-scale continuous-feed firebrand generator (the continuous-feed baby Dragon) was used to simulate firebrand showers attacking a mockup thatched roofing assembly under varying wind speed in a wind facility. The ignition mechanism of has been elucidated for the first time under conditions of firebrand showers attacking thatched roofing assemblies.

2. Experimental description

A reduced-scale continuous feed firebrand generator was used to generate firebrand showers. The description here closes follows Suzuki and Manzello [6] but is repeated here for completeness. To couple it with wind facility at the National Research Institute of Fire and Disaster (NRIFD), the original reduced-scale continuous feed firebrand generator [7] was modified. This reduced-scale continuous feed firebrand generator consisted of two parts; the main body and continuous feeding component (see Fig. 2). The feeding part was connected to the main

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Fig. 1. Gasshou-style house, which have thatched roofs, in Shirakawa-go, Gifu, Japan, registered as UNESCO's cultural heritage in 1995.

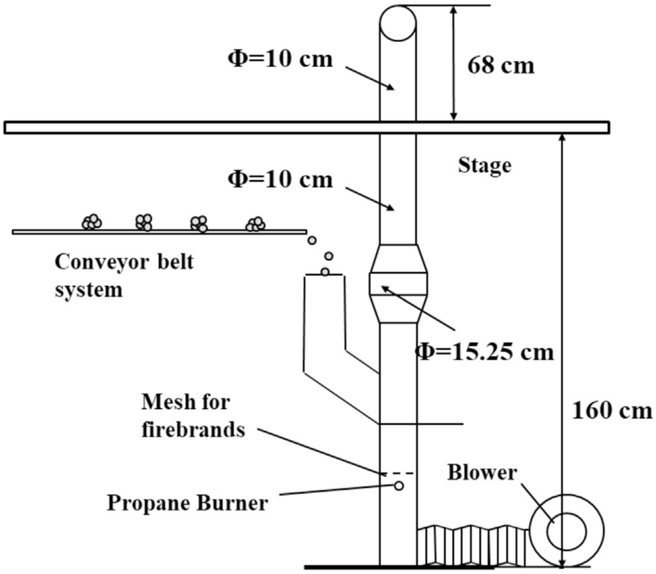

Fig. 2. Schematic of reduced-scale continuous-feed firebrand generator.

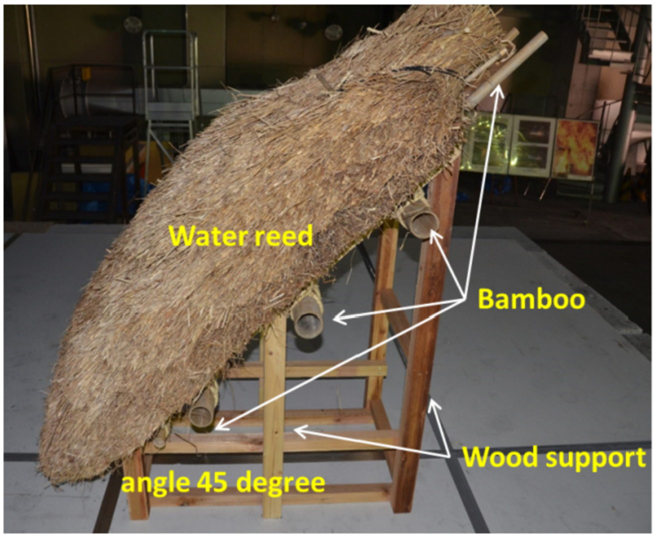

Fig. 3. Thatched roofing assembly mock-up used for the experiment.

body and had two gates to prevent fire spread. Each gate was opened and closed alternatively. A blower was also connected to the main body and this was needed to loft and control the combustion state of the generated firebrands. The blower speed at the exit was set to 4.0 m/s to generate glowing firebrands. When the blower was set to provide an average velocity below 4.0 m/s, insufficient air was supplied for combustion and this resulted in a great deal of smoke being generated in addition to firebrands. Above 4.0 m/s, smoke production was mitigated but then many firebrands produced were in a state of flaming combustion as opposed to glowing combustion. In these experiments, glowing firebrands were desired, so these were generated. A longer main body was adapted so that only the firebrand generator part was above the stage, so the feeding part was not affected by wind. The efficacy of a smaller sized firebrand generator to develop continuous firebrand showers has been described in detail elsewhere [7].

A conveyor was used to feed wood pieces continuously into the device. For all tests, Japanese Cypress wood chips were used to produce firebrands. These same size wood pieces have been shown to produce firebrands within projected area/mass of burning structures [6,8]. As indicated, a conveyor was used to feed wood pieces continuously into the device. The conveyor belt was operated at 1.0 cm/s, and wood pieces were put on the conveyor belt at 12.5 cm intervals. The wood feed rate was fixed at 80 g/min, near the upper limit of reduced-scale firebrand generator.

As the base of the fan used to generate the wind field is located 1.6 m from the floor, the conveyor was placed under a custom stage designed for experiments when using NRIFD's wind facility (see Fig. 2). The flow field was measured to be within ± 10% over a cross-section of 2.0 m by 2.0 m.

A mock-up thatched roofing assembly was constructed for this experimental series and the size of the mock-up was 0.9 m (W) x 1.1 m (H) x 0.4 m (maximum thickness) with an angle of 45°. The thatched roofing assembly was made from water reed (main material), bamboo and wood frame, shown in Fig. 3. The assemblies were constructed by Japanese construction companies licensed in traditional thatched roofing assembly fabrication techniques. The average moisture content of water reed was 10% on a dry basis.

The thatched roofing assembly was placed 0.5 m downwind from the baby Dragon. This location was picked for the roofing assembly to receive an adequate amount of firebrand showers [6]. Experiments were performed under two wind speeds, 3 m/s and 6 m/s.

3. Results and discussion

Experiments were performed to obtain the fundamental characteristics of generated firebrands; namely the mass and size. Pans filled with water were placed downstream from the reduced-scale continuous feed firebrand generator under different wind speeds. Water is necessary to suspend combustion of the firebrands. If there was no water, firebrand combustion would ensue, and the size and mass would continue to reduce. Firebrands were collected from pans by fine-mesh filters and dried in an oven at 104 °C, until the firebrands were completely dried. The drying time was determined by measuring the firebrand mass as a function of time.

The mass and projected area of the generated firebrands from the reduced-scale firebrand generator is displayed in Fig. 4. The projected area of a firebrand was determined by using image analysis software. A firebrand was laid flat so that the maximum projected area of a given firebrand was measured. The photograph of the firebrand was taken along with the known scale factor. The uncertainty of the projected area was determined by the repeated measurements of well-defined objects [8] and found to be ± 10%. The mass of each firebrand was measure by a scale with 0.001 g resolution. The uncertainty of the mass was determined by the repeated measurements of the known mass and found to be ± 1%. The characteristics of firebrands in this study for all

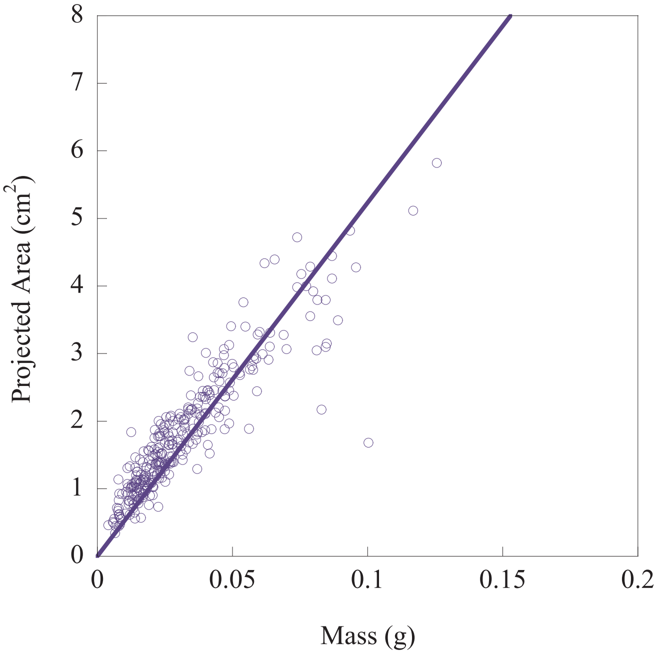

Fig. 4. Projected area as function of mass of the firebrands produced using reduced-scale continuous-feed firebrand generator.

experiments were observed to be similar regardless wind speeds used. The average mass and standard deviation of each firebrand for all was obtained to be 0.03 g ± 0.02 g.

It is important to quantify the arrival number flux of firebrand at the roofing assembly as function of wind speed. Not all firebrands from the reduced-scale firebrand generator arrive at the roofing assembly and the number of firebrands arriving on thatched roof was measured to be 8.3/sec and 7.3/sec under 3 m/s and 6 m/s wind, respectively. These values were determined from detailed analyses of video records. The presence of higher wind speeds resulted in slightly less firebrands arriving at the roofing assembly location, due to enhance flow recirculation. Most of the firebrands landing on the roof landed on the lower half of roof. Fig. 5 displays the arrival and penetration process of firebrands for wind speeds of 3 m/s. The water reed materials easily collected firebrands and multiple firebrands may be seen inside that penetrated under the surface of the roofing assembly.

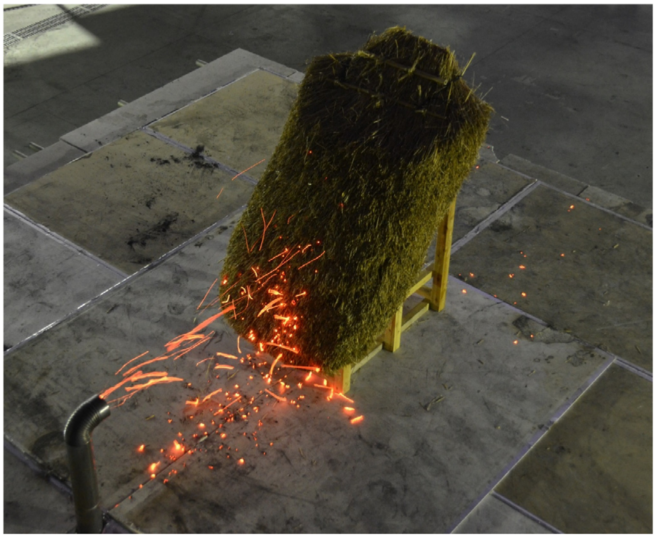

Fig. 5. Photograph demonstrating the penetration of firebrands into the water reed of the thatched roofing assembly at 3 m/s wind speed.

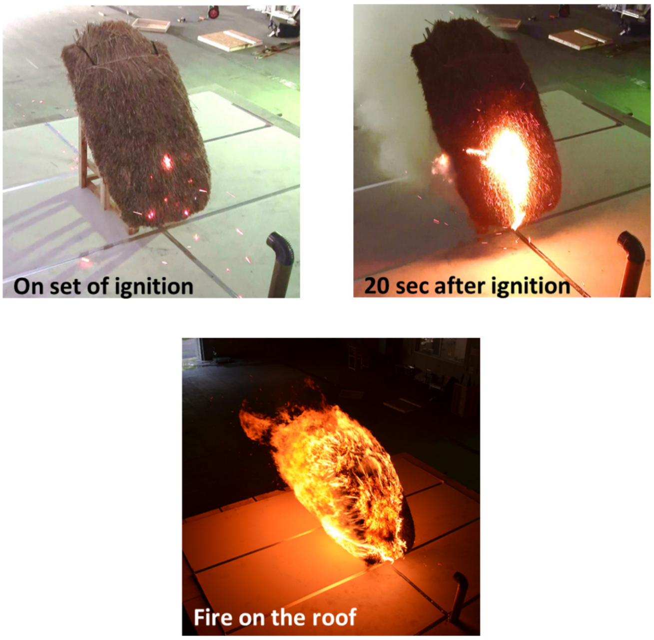

Fig. 6. Temporal evolution of thatched roofing assembly ignition during an experiment under a 6 m/s wind.

Images of an experiment under a 6 m/s wind are shown in Fig. 6. Similar to experiments at 3 m/s, no smoke was observed until ignition and once ignited, fire rapidly spread within the thatched roofing assembly. Fig. 6 shows that, within 20 s after the ignition, the flame reached the top of the roofing assembly and also penetrated through the assembly as the flame was seen from the back side.

It is of interest to compare the time to ignition of thatched roofing assemblies using the firebrand generator technology to the conventional fire testing methods using cribs [2,3]. Table 1 displays these results under a 3 m/s wind, as traditional tests in Japan are usually performed in this manner. It took longer to initially ignite the mock-up roofing assembly by glowing firebrands compared to the ignition by a flaming wood crib. This is natural due to the different initial combustion states, as the crib is in a state of flaming combustion. However, the important mechanism of flame penetration into the depth of the roofing assembly was completely different.

Fig. 7 shows the differences between these ignition mechanisms. Due to the continual shower of firebrands from the firebrand generator, multiple glowing firebrands penetrated the water reeds. These glowing firebrands accumulated, and flaming ignition was first observed on the surface as the continual airflow resulted in the smoldering ignition to transition to flaming ignition. Once flaming ignition was achieved due to accumulated firebrands on the surface, the ignition very quickly penetrated into the roofing assembly, as there were multiple smoldering locations already within the assembly. The differences in flame penetration were vastly different; on the order of only 200 mm within 1 min for the glowing firebrand shower scenario versus 400 mm in 22 min for the crib ignition scenario.

4. Summary

Experiments with thatched roofing assemblies were performed by using the continuous-feed reduced-scale firebrand generator in NRIFD's wind facility to investigate ignition mechanisms. The wind speed was varied to observe the ignition and flame spread of thatched roofing assemblies. It is revealed that firebrands penetrated into the thatched roofing assembly, sometimes unseen from the outside, resulting in ignition and ultimately rapid flame penetration. Basic information obtained in this study would be useful to evaluate and develop effective

Table 1
Comparison of time to ignition of thatched roofing assemblies using reduced-scale continuous feed firebrand generator to that of conventional crib tests under 3 m/s wind.

Ignition methods	Specimen of the mock-up	Time to ignition	Flame penetration
A flaming wood crib [2] (Roof brand test)	1600 mm (L) x 1000 mm (W) x 400 mm (thickness) with an angle of 45°	0 s (ignited immediately after placing a crib)	400 mm/22 min
Firebrand Showers	1100 mm (L) x 900 mm (W) x 400 mm (maximum thickness) with an angle of 45°	81 s (from the first firebrand landed on the roof)	200 mm (estimated)/within 1 min

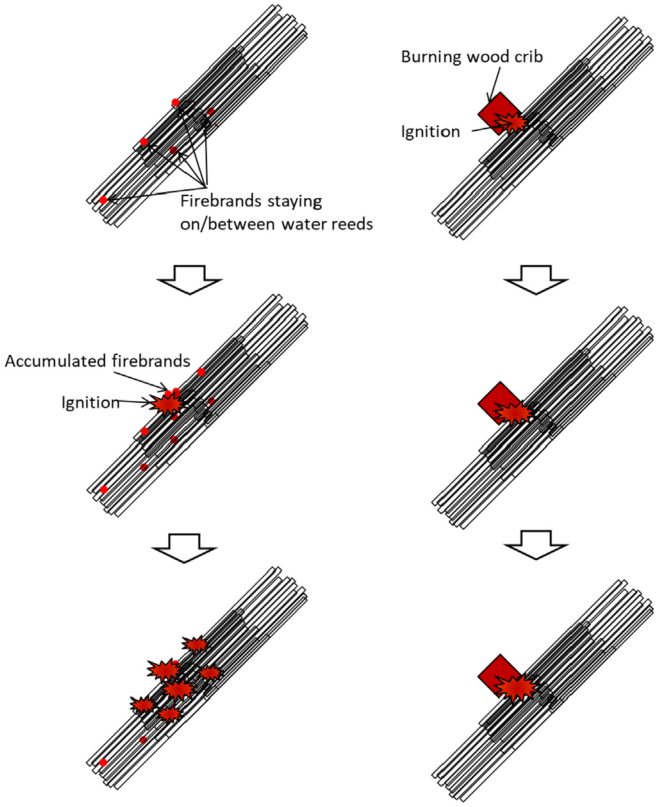

Fig. 7. Schematic of the difference of ignition mechanisms of thatched roofing assembly between firebrands (left) and a burning wood crib (right).

counter measures to protect historical structures with thatched roofing assemblies.

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