FIREBRAND ATTACK ON CERAMIC TILE ROOFING ASSEMBLIES

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ABSTRACT

The present study is concerned with investigating the ignition of ceramic tile roofing assembles (Spanish tile roofing) to a controlled firebrand attack using the Firebrand Generator. Current standards exist to test ignition of roofing decks to firebrands by placing a burning wood crib on top of a section of a roof assembly under an air flow. The dynamic process of multiple firebrands landing under ceramic tiles/gaps as a function of time is not taken into account. The results of a parametric study on the ignition propensity of ceramic tile roofing assemblies under a firebrand attack using the Firebrand Generator installed inside the Fire Research Wind Tunnel Facility (FRWTF) at BRI is presented and discussed.

INTRODUCTION

Evidence suggests that firebrands are a major cause of structural ignition in Wildland-Urban Interface (WUI) fires in the USA and urban fires in Japan[1-2]. Structures that are more resistant to ignition from a firebrand assault in both WUI fires and urban fires are clearly desired. To reduce structure losses from a firebrand attack, potential structure ignition mitigation strategies include retrofitting existing structures; building codes/standards are needed for new construction. Unfortunately, attempting to quantify vulnerabilities that exist on structures to a firebrand attack has not been considered in detail.

To this end, a unique experimental apparatus, known as the NIST Firebrand Generator, has been constructed to generate a controlled and repeatable size and mass distribution of glowing firebrands. Since wind plays a critical role in the spread of WUI fires in the USA and urban fires in Japan, NIST has established collaboration with the Building Research Institute (BRI) in Japan. BRI maintains one of the only full scale wind tunnel facilities in the world designed specifically for fire experimentation; the Fire

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Research Wind Tunnel Facility (FWRTF). The marriage of the NIST Firebrand Generator and BRI's FRWTF is leading to progress in accessing vulnerabilities of structures to a firebrand attack.

The Firebrand Generator has been used to study the penetration of firebrands into building vents[3]. The WUI California Building Standards intended to mitigate firebrand penetration through building vents by recommending a screen size of 6 mm motivated that study but this size was not based on scientific testing but rather a best guess[4]. A structure was installed inside the FRWTF and a gable vent was installed on the front face of the structure and three different steel screens were installed behind a gable vent to ascertain the ability of the screen to block firebrands from penetrating into the structure. Behind the screens, shredded paper of fixed moisture content was placed in pans to observe if the firebrands that penetrated the vent and subsequent screen were able to produce an ignition event. Firebrands were blown through the vent and were pressed against the steel screen. The firebrands were not quenched by the presence of the screen and would continue to burn until they were small enough to fit through the screen opening. For all screen sizes tested, the firebrands were observed to penetrate the screen and produce a self-sustaining smoldering ignition inside the paper beds installed inside the structure. For the 6 mm screens tested a majority of the firebrands simply flew through the screen, resulting in an ignition of the paper behind the screen considerably more quickly as compared to the smaller screen sizes of 3 mm and 1.5 mm.

Subsequent to this, the Firebrand Generator was used to investigate the vulnerability of full scale sections of asphalt roofing assemblies (base layer material, tar paper, and shingles) as well as only the base layer roofing material, such as oriented strand board (OSB)[5]. In those experiments, a custom mounting assembly allowed for the construction of flat roof subsections as well as the construction of valleys (angled) roofs. For ignition testing of base layer roofing materials only (bare OSB), at an angle of 60°, the firebrands were observed to collect inside the channel of the OSB crevice. The firebrands that collected in the crevice produced smoldering ignition where they landed, eventually resulting in several holes in the OSB. The OSB continued to smolder intensely near the locations where the firebrands landed. Eventually a transition to flaming ignition was observed on the back side of the OSB. As the angle was increased to 90°, similar behavior was observed where the firebrands that collected initiated intense smoldering. Eventually, holes were formed at these locations in an identical manner to the 60°. While smoldering ignition was observed, it was not possible for a transition to flaming to occur. As the angle was increased to 135°, ignition was no longer possible. It is important to realize that bare OSB is not used as the surface material in roofing but roofs in a state of ill repair may easily have base layer materials such as OSB exposed to the elements.

When asphalt shingles were applied (OSB, tar paper, and asphalt shingles), at 60° and 90°, several firebrands were observed to become trapped along the channel of two sections and along the seams of the shingles. However, no ignition events were observed on the shingles; the firebrands were only capable of melting the asphalt shingles. As the angle was spread further, fewer firebrands were observed to become trapped in the seam of the two sections, in similar manner to base layer OSB tests described above. While these tests did not consider the influence of aged shingles or pre-heated shingles, the results indicated that firebrands can melt asphalt shingles. Once the firebrands penetrate the shingles, the base layer (OSB) was found to be ignited rather easily[5].

The current study is concerned with investigating the ignition of ceramic tile roofing assemblies (so called Spanish tile roofing) to a controlled firebrand attack using the Firebrand Generator. Current standards exist to test ignition of roofing decks to firebrands (*e.g.* ASTM E108[6]) by placing a burning wood crib on top of a section of a roof assembly under an air flow. The dynamic process of multiple firebrands landing under ceramic tiles/gaps as a function of time is not taken into account. To support this supposition, Mitchell and Patashnik[2] investigated the 2003 Cedar Fire and reported a possible correlation between homes that were ignited and those homes fitted with ceramic tile roofing (Spanish tile roofing). Unfortunately, to date, there has been no quantitative testing conducted anywhere to address these issues.

To this end, a parametric study on the ignition propensity of ceramic tile roofing assemblies under a firebrand attack using the Firebrand Generator installed inside the Fire Research Wind Tunnel Facility

(FRWTF) at BRI was conducted. To investigate the influence of an applied wind field, the experiments were conducted using BRI's FRWTF.

EXPERIMENTAL DESCRIPTION

Figure 1 is a drawing of the NIST Firebrand Generator. A brief description of the device is provided here for completeness and follows prior descriptions very closely[3,5]. This version of the device was scaled up from a first-generation, proof-of-concept Firebrand Generator[7]. The bottom panel displays the procedure for loading the Norway Spruce (*picea abies Karst)* tree mulch into the apparatus. Norway Spruce (*picea abies Karst)* was chosen since it belongs to the *Pinaceae* family, which includes such species as Ponderosa Pine (*Pinus Ponderosa)* and Douglas-Fir *(Pseudotsuga menziesii)*; common conifer species dominant in the USA. In addition, Norwegian Spruce is found in more than 20 states in the USA. These trees were used as a source for mulch for the Firebrand Generator since they were quite easy to locate in Japan.

The mulch pieces were deposited into the firebrand generator by removing the top portion. The mulch pieces were supported using a stainless steel mesh screen (0.35 cm spacing), which was carefully selected. Two different screens were used to filter the mulch pieces prior to loading into the firebrand generator. The first screen blocked all mulch pieces larger than 25 mm in diameter. A second screen was then used to remove all needles from the mulch pieces. The justification for this filtering methodology is provided below. A difference in these tests, as compared to prior work using the Firebrand Generator, was the mulch loading was varied from 2.1 kg to 2.8 kg. The mulch was produced from 6.0 m Norway Spruce trees. The firebrand generator was driven by a 1.5 kW blower that was powered by a gasoline electrical generator. The gasoline electric generator provided the blower with the necessary power requirements (see figure 1). These power requirements were not available at the FRWTF, necessitating the use of a portable power source.

After the Norway Spruce tree mulch was loaded, the top section of the firebrand generator was coupled to the main body of the apparatus (see figure 1). With the exception of the flexible hose, all components of the apparatus were constructed from either galvanized steel or stainless steel (0.8 mm in thickness). The blower was then switched to provide a low flow for ignition (1.0 m/s flow inside the duct measured upstream of the wood pieces). The two propane burners were then ignited individually and simultaneously inserted into the side of the generator. Each burner was connected to a 0.635 cm diameter copper tube with the propane regulator pressure set to 344 kPa at the burner inlet; this configuration allowed for a 1.3 cm flame length from each burner[1,3]. The Norway Spruce mulch was ignited for a total time of 45 seconds. After 45 seconds of ignition, the fan speed of the blower was increased (2.0 m/s flow inside the duct measured upstream of the wood pieces). This sequence of events was selected in order to generate a continuous flow of glowing firebrands for approximately six minutes duration.

The Firebrand Generator was installed inside the test section of the FRWTF at BRI. The facility was equipped with a 4.0 m fan used to produce the wind field and was capable of producing up to a 10 m/s wind flow. The wind flow velocity distribution was verified using a hot wire anemometer array. To track the evolution of the size and mass distribution of firebrands produced, a series of water pans was placed downstream of the Firebrand Generator. Details of the size and mass distribution of firebrands produced from the Firebrand Generator are presented below.

RESULTS AND DISCUSSION

The Firebrand Generator was designed to be able to produce firebrands characteristic to those produced from burning trees. Manzello *et. al.*[8,9] have done a series of experiments quantifying firebrand production from burning trees. In that work, it was observed that more than 85 % of the firebrands produced from trees were less than 0.4 g. The input conditions for the firebrand generator were intentionally selected to produce firebrands with mass up to 0.2 g. This was accomplished by sorting the

Norway Spruce tree mulch using a series of filters prior to being loaded into the firebrand generator. A similar filtering procedure was used previously when other conifer species were used as the mulch source[3,5].

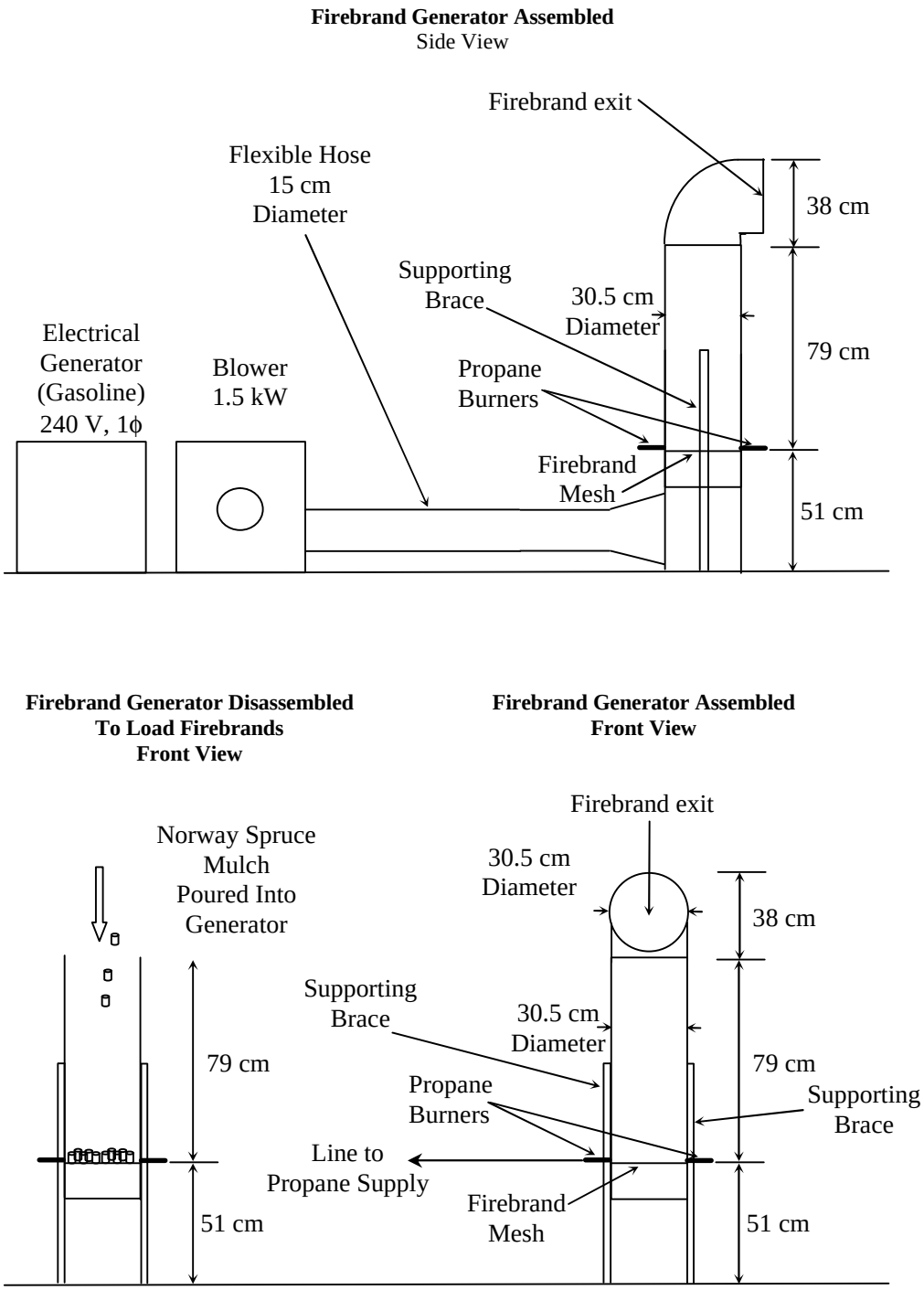

Figure 1 Firebrand Generator - Top Panel shows the device fully constructed while the bottom panel displays the procedure for loading the device.

The firebrands produced from the Firebrand Generator were captured using an array of water filled pans (see Figure 2). The generated firebrands landed in the water filled pans and the presence of water quenched combustion. The firebrands were subsequently removed from the water pans and dried. Since many of the firebrands produced are cylindrical, the length and diameter of the generated firebrands was measured using calipers. This information was then used to calculate the surface area of the firebrands produced and was plotted as a function of the measured firebrand mass (see Figure 3). Figure 3 also displays the same analysis performed for firebrands collected from Douglas-Fir trees as well as Korean Pine Trees under similar tree moisture content. From the figure, the firebrand generator was capable of approximating the size and mass distribution of firebrands from burning trees up to 0.2 g; similar results have been shown for other mulches used[3,5]. The uncertainty in determining the surface area is ± 10%.

After the size and mass distribution of firebrands produced from the Firebrand Generator was determined, a custom mounting assembly was constructed to support full scale sections of ceramic tile roofing materials inside the FRWTF. For all the tests conducted, the Firebrand Generator was located 2.0 m from the mounting assembly.

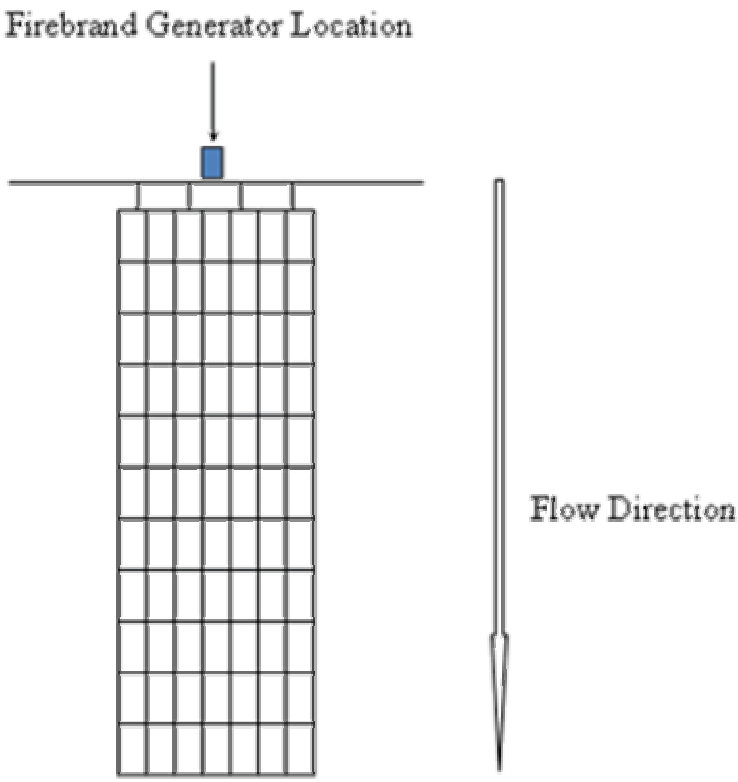

Figure 2 Array of water filled pans used to collect firebrands produced using Firebrand Generator.

CERAMIC TILE ROOFING ASSEMBLIES

A full scale section (122 cm by 122 cm by 9 mm thick) of a ceramic tile roof assembly was constructed for testing (shown in figure 4). The pitch of the full scale section was fixed at 25°. To be able to control the moisture content of OSB base layer, the experiments were designed in a modular fashion. Specifically, the 122 cm by 122 cm full section was comprised of four separate OSB pieces. This allowed each section to be oven dried and once dried, simply reassembled inside the custom mounting frame.

A parametric was study was performed in an effort to quantify the range of conditions that ceramic tile roofing assemblies are vulnerable to ignition from firebrand attack. Table 1 displays the parameters that were varied in these experiments. A starting velocity of 7 m/s was selected since most of the

firebrands produced from the Firebrand Generator were observed to be lofted under these conditions. The velocity was subsequently increased to 9 m/s to ascertain if any the results were velocity dependent.

When new, ceramic tile roofing assemblies are constructed by placing a base layer of oriented strand board (OSB), then tar paper is installed on top of the OSB for moisture protection, and finally ceramic tiles are applied. In the USA, there has been a dramatic shift to the use of OSB in North America; historically plywood was the dominant material used in base layer of roofs[9]. The reason for this shift is based on cost; OSB is manufactured from smaller trees as compared to plywood and consists primarily of wood fragments. To simulate aged or weathered roofs, experiments were conducted without the application of tar paper. A survey was conducted of actual ceramic tile roofing assemblies and it was observed that the tar paper degrades after time[1].

Figure 4 displays a sequence of images obtained from the case of OSB/CT without the installation of bird stops. Not surprisingly, bird stops are intended to mitigate the construction of nests by birds under the ceramic tiles. Many ceramic tile roofing assemblies found in practice do not have bird stops installed[1]. Without the installation of bird stops, the firebrands were observed to be blown under the ceramic tiles. Eventually, several firebrands would collect and would produce smoldering ignition (SI) within the OSB base layer. With continued application of the airflow, holes were formed within the OSB and eventually the SI would transition to flaming ignition (FI). The same result was observed independent of the applied wind tunnel flow.

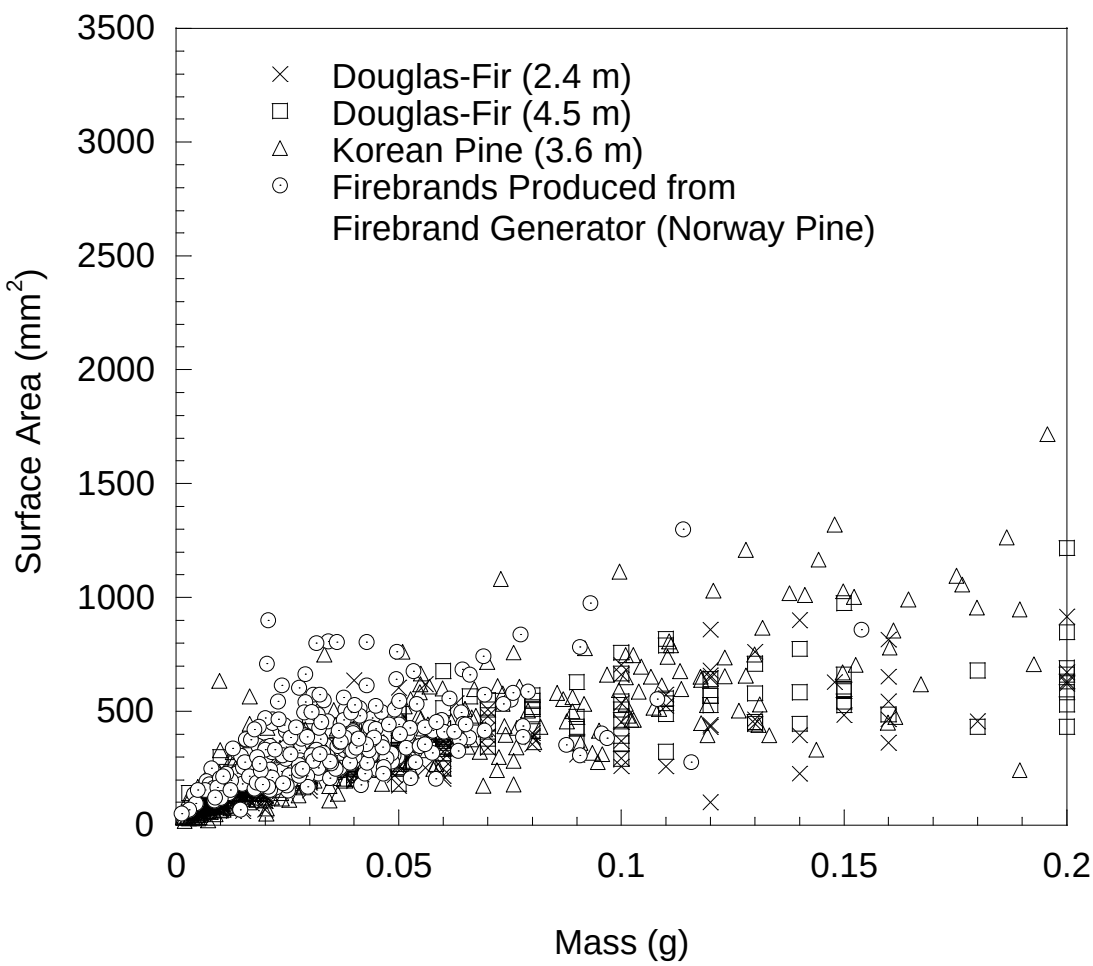

Figure 3 Firebrands measured from burning trees to those produced using Firebrand Generator.

U_8 (m/s)	OSB/TP/CT No Bird Stops	OSB/TP/CT With Bird Stops	OSB/CT No Bird Stops	OSB/CT With Bird Stops
7	SI	NI	SI to FI	SI
9	SI	NI	SI to FI	SI

Table 1 Range of parameters considered for ceramic tile roofing assemblies. Oriented Strand Board (OSB); TP (Tar Paper); CT (Ceramic Tiles); FI (Flaming Ignition); NI (No Ignition); SI (Smoldering Ignition). At minimum of three experiments were conducted at each condition. The OSB base layer was oven dried in each case. The mulch loading was varied initially and it was observed that repeatable ignition events were observed for all experiments once the mulch loading was set to 2.8 kg.

Subsequent to this, a series of experiments were conducted to simulate an aged ceramic tile roof assembly (tar paper not installed) but in this case bird stops were installed. Figure 5 displays images from these tests. Even though bird stops were installed, many firebrands were able to penetrate the gaps that exist between the tile and the bird stops. These firebrands were observed to produce SI within the OSB base layer resulting in holes in the OSB base layer in some cases. The same result was observed independent of the applied FRWTF flow. The SI ignition never transitioned to FI when bird stops were applied.

The use of tar paper was then used to simulate a newly constructed ceramic tile roof assembly. With the application of tar paper, experiments were conducted first without bird stops installed. Once again, firebrands were blown under the ceramic tiles. The firebrands were able to burn several holes within the tar paper and produce SI within the OSB base layer (see Figure 6). The SI was not intense enough to result in the production of holes within the OSB base layer.

The final tests that were conducted considered the application of tar paper with bird stops installed. These conditions resulted in no ignition in the tar paper and naturally no ignition within the OSB layer. The combination of the bird stop installation coupled with the tar paper provided a substantial barrier to ignition.

Figure 4 Images of experiments conducted using OSB/CT without bird stops installed. Intense SI was observed within the OSB base layer and eventually FI was observed.

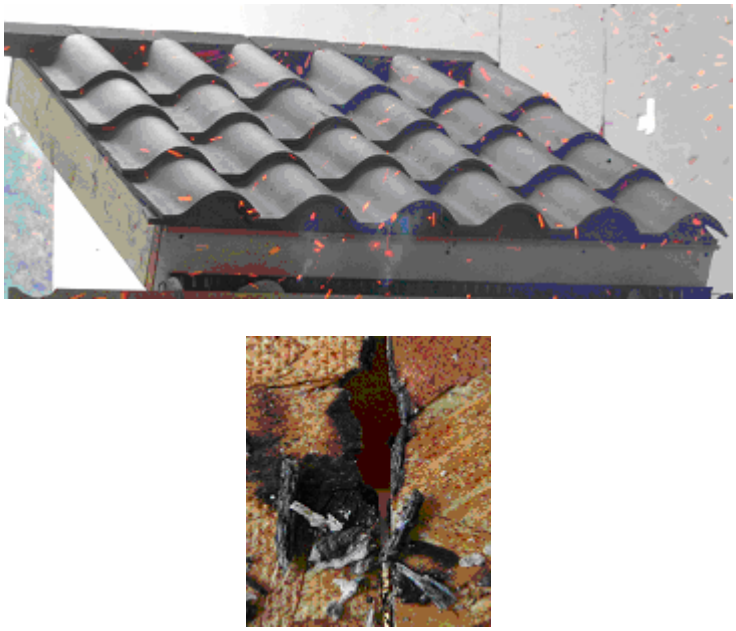

Figure 5 Images of experiments conducted using OSB/CT with bird stops installed. Intense SI was observed within the OSB base layer.

Figure 6 Images of experiments conducted using OSB/TP/CT without bird stops installed. SI was observed within the OSB base layer.

CONCLUSIONS

The present study investigated the ignition of ceramic tile roofing assembles (Spanish tile roofing) to a controlled firebrand attack using the Firebrand Generator. Aged or weathered ceramic tile roofing assemblies were simulated by not installing tar paper. For simulated aged ceramic tile roof assemblies, without the installation of bird stops, the firebrands were observed to be blown under the ceramic tiles. Eventually, several firebrands would collect and would produce smoldering ignition (SI) within the OSB base layer. With continued application of the airflow, holes were formed within the OSB and eventually the SI would transition to flaming ignition (FI). Simulated aged ceramic tile roof assemblies, with bird stops installed, were also constructed for testing. Even though bird stops were installed, many firebrands were able to penetrate the gaps that exist between the ceramic tiles and the bird stops. These firebrands were observed to produce SI within the OSB base layer; holes were observed in some cases within the OSB base layer. The SI ignition never transitioned to FI when bird stops were applied.

The use of tar paper was then used to simulate a newly constructed ceramic tile roof assembly. With the application of tar paper, experiments were conducted first without bird stops installed. Once again, firebrands were blown under the ceramic tiles. The firebrands were able to burn several holes within the tar paper and produce SI within the OSB base layer. The SI was not intense enough to result in the production of holes within the OSB base layer. Tests were then conducted that considered the application of tar paper with bird stops installed. These conditions resulted in no ignition in the tar paper and thus no ignition within the OSB layer. It appears that the combination of the bird stops coupled with the tar paper provided a substantial barrier to ignition.

These results are the first ever experiments to ascertain the vulnerabilities of ceramic tile roofing assemblies. The experiments using the Firebrand Generator are extremely conservative; the firebrand attack lasted for six minutes. In real WUI fires and urban fires, firebrand attack has been observed for several hours and with winds in excess of 20 m/s^{1-2}. Even under such conservative conditions in the present experiments, ceramic tile roofing assemblies were vulnerable to ignition from firebrand showers.

It is important to note that ceramic tile roof assemblies found on top of many homes also contain poorly aligned tiles[1]. All of the present data is presented for neatly aligned tiles. Additional experiments are in progress to investigate the influence of gaps within the tiles on the ignition propensity of ceramic tile roofing assemblies.

ACKNOWLEDGEMEMTS

Mr. Alexander Maranghides and Dr. William ‘Ruddy’ Mell of BFRL-NIST are acknowledged for conducting a detailed roofing survey in CA as part of a thorough post-fire assessment of an area devastated by the Witch Fire. Mr. Marco G. Fernandez, Engineering Technician of BFRL-NIST, is acknowledged for carefully preparing shipments of USA roofing materials to Japan. Mr. John R. Shields of BFRL-NIST is acknowledged for providing suggestions on the roof construction. Dr. Ichiro Hagiwara of BRI is acknowledged for his support of these experiments. Dr. Samuel L. Manzello would like to acknowledge financial support from a fellowship from the Japan Society for the Promotion of Science (JSPS).

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