Studying firebrands interaction with flat surface of various wood construction materials in laboratory conditions

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Abstract. The behavior of wood building materials (plywood, oriented strand board, particle board) exposed to burning and smoldering firebrands is investigated in this work. To control the temperature on the surface of the samples, an infrared camera (JADE J530SB) with a 2.5–2.7 micron optical filter that can record the temperature in the range of 300–800 °C was used. The Canon HF R88 video camera was used to evaluate the ignition delay and the behavior of firebrands after falling onto the surface of wood building material samples. In the wind speed range of 0–1 m/s, the ignition of the samples was not observed. A small amount of additional oxidant influx in the landing zone of firebrands caused their slow smoldering on the surface until complete combustion. Thus, it can be concluded that smoldering natural firebrands does not affect the ignition of wood building material samples for the selected experimental parameters. The probability of ignition and the ignition delay of wood were determined depending on the size and number of firebrands, the presence of the air flow in the landing zone of particles, as well as on the initial temperature of wood. The experimental temperature distribution was obtained on the surface of wood exposed to the model ground fire using infrared thermography.

1. Introduction

At present, there is a need in experimentally verified information on how the smoldering firebrands that are produced in the front of a fire ignite buildings during wildland-urban interface fires, being also the sources of urban fires [1–3].

In the construction industry, pine wood is used, as a rule, as a bearing construction, and leaf wood is used as a finishing material. One of the factors determining the fire hazard of wood is its ability to ignite and spread combustion. In addition, wood well absorbs water, rots in the atmosphere of high humidity, is subjected to deformation and cracking due to frequent wetting and drying. Wood boards have an obvious advantage over natural analogs, since they contain substances that help eliminate such disadvantages or reduce their manifestation.

Some recommendations were developed for the use of thermography in fire resistance and fire hazard tests of wood building materials; however, the available data require additional experiments aimed at investigating the fire hazard characteristics of different materials, used in construction, for modeling various types of heat exposure, including spot fires.

Currently, the modern methods of infrared (IR) diagnostics are being widely used to study combustion behavior and natural fires [4–7]. It is noteworthy that in the literature there is still lack of the results on the use of noncontact methods during the tests of wood constructions and construction materials for fire-resistance [8–10]. In particular, paper [10] presents the experience of noncontact
method using for temperature measurement in laboratory and during field fire tests of building parts and constructions made of wood. Some recommendations on the use of thermography in testing wood construction materials for fire resistance and fire hazard have been formulated. But the available data requires additional experiments to study the fire hazard characteristics of different construction materials. Thus, the purpose of the work is to investigate the behavior of wood building material samples exposed to burning and smoldering natural firebrands.

2. Laboratory setup and experimental procedure

The laboratory setup was used to study the probability of ignition of wood building materials by burning and smoldering firebrands (figure 1). The experimental procedure, as well as the main elements of the laboratory setup for dropping the firebrands are given in detail in [11].

![Figure 1. Schematic of the experimental setup: 1–laboratory autotransformer; 2–heating element; 3–pallet; 4–wood sample; 5–euvette; 6–stopper; 7–heat gun; 8–burner; 9–tripods; 10–samples of firebrands; 11–bracket.](image)

The experimental setup included: a JADE J530SB infrared camera with an 2.5–2.7 micron optical filter that records the temperature in the range of 300–800 °C; a Canon HF R88 video camera for evaluating the ignition delay and the behavior of firebrands after falling onto the surface of the wood building material samples; an AND MX-50 humidity analyzer for controlling the humidity of the samples; an AND HL 100 laboratory scales for controlling the initial mass of firebrands and the mass of wood samples.

The humidity of firebrands did not exceed 10 % and was 6–8 % for wood building material samples. Plywood, particle board (PB), oriented strand board (OSB), and spruce building board were used as the samples of wood building materials.

The main parameters of the samples are presented in table 1.

| Parameters of building material samples | Plywood | OSB | PB |
|----------------------------------------|---------|-----|----|
| Size (mm)                              | 150×150 | 150×150 | 150×150 |
| Thickness (mm)                         | 21      | 18  | 18  |
| Density (kg/m³)                        | 650–690 | 570–590 | 570–590 |
| Spruce                                 | 200×100 | 510–530 |

The samples were isolated from the environment by insulating material in such a way that one of the surfaces was exposed to heat of landing particles. In the experiments, the conditions were created to model a case when a wooden building was exposed to heat flow from an approaching front of a forest fire [12, 13]. The wood sample was preheated to a temperature of 200–220 °C for 4 minutes [14, 15].

The heating temperature of the wood surface was controlled with an infrared camera JADE J530SB. The process was recorded in the spectral range of 3.1–3.3 μm. This spectral range is used to work with objects that have a temperature in the range of 200–800 °C.

Earlier, in the work [16] it was reported that burning particles of bark and branches are formed most often in a large forest fire. In this experiment, pine branches and rectangular strips had the sizes...
that coincided with the typical particle sizes determined in field experiments [16]. The particle sizes were as follows: diameter (2÷4, 4÷6, 6÷8 mm) and length (20±2; 40±2; 60±2) mm.

Smoldering particles that act on the surface of the sample are of particular interest in the study. In these experiments, it is modelled a case when smoldering firebrands that are formed during a wildland fire can accumulate on the roof and in the corners of buildings and fences, or find a way to get inside buildings and ignite them.

The optimum ignition time of firebrands was preliminarily selected to achieve the smoldering phase of firebrands [17]. The time during which firebrands were exposed to the burners depended on the size, number and diameter of particles. The particle temperature was monitored using a JADE J530SB infrared camera. The ignition time is presented in Table 2.

| Pine branches | Diameter of firebrands (mm) | Exposure time (s) |
|---------------|-----------------------------|-------------------|
|               | 2–4                         | 10                |
|               | 4–6                         | 15                |
|               | 6–8                         | 18                |
| Rectangular strips | Length of firebrands (mm) | Exposure time (s) |
|                | 20                          | 15                |
|                | 40                          | 20                |
|                | 60                          | 25                |

In real fires, different wooden structures and fuel bed are exposed to firebrands and a number of natural factors, in particular, to a heated air flow from the front of a fire. In the experiments, smoldering firebrands dropped on the wood samples were blown with a heat gun (Interskol FE-2000-E) by a heated air flow at a speed of 2 m/s and 2.5 m/s with corresponding temperatures of 60 °C, 110 °C. The flow speed was determined using a CFM Master 8901 anemometer with a measurement error of 2 %. The choice of these speeds can be explained by the fact that with further increase in the speed, the firebrands were blown away beyond the area under study, and at lower speeds the probability of the sample ignition by smoldering and burning firebrands was very small. A nozzle was used to direct the air flow to the surface of the wood sample in the area of dropping of firebrands.

A series of experiments began with one smoldering particle, then two and up to 10 particles, thereby modelling the ignition of wood by both a single particle and “fire rain”. Each experiment was repeated three times. If in one of the three cases the ignition occurred, the wood sample was considered to be ignited.

3. Results of experiment

It was found that ignition of the samples was not observed in the wind speed range of 0–1 m/s. A small amount of additional oxidant influx in the landing zone of firebrands resulted in the fact that the transition to intense flame combustion did not occur, and the smoldering of particles continued until their complete combustion. Thus, it can be concluded that natural smoldering firebrands with the selected experimental parameters does not affect the ignition of samples of wood building materials.

In a series of the experiments, the probability of ignition of the preheated surface of plywood, PB, OSB and spruce samples was evaluated depending on the type, size and number of burning and smoldering firebrands interacting with this surface at different wind speeds.

Figure 2 shows the graphs of the probability of spruce wood ignition depending on the number and size of smoldering pine branches, as well as on the speed of the air flow.
Figure 2. Ignition of spruce wood samples as a function of length, diameter and number of smoldering pine branches at air flow velocity of 2.5 m/s.

With an increase in the diameter of branches and velocity V = 2 m/s, the number of firebrands sufficient to ignite the wood sample decreases. It was found that the surface was ignited by firebrands with geometrical sizes exceeding 20 mm and a diameter of 6 ÷ 8 mm. In this case, as can be seen in the graph, with an increase in the size, their number decreases. Also, the number of particles affects the wood ignition. The minimum total area of smoldering particles, equal to the product of the number of particles, sufficient for ignition, and their characteristic area increases significantly during the transition from spruce wood to wood building materials. In particular, for OSB and PB samples, the minimum area increased by 40% on average, and for a plywood sample, at a speed of 2 m/s, the area increased by more than 60%.

Figure 3 shows the ignition of the samples of spruce and wood building materials under different experimental conditions. The type of particles (pine branches and rectangular strips) as well as the speed of the incoming air flow from a heat gun were varied.

Figure 3. Ignition of samples of spruce and wood building materials at different wind speeds and types of particles 40 mm in length.
Considering the previously obtained results, it can be concluded that the probability of ignition of wood samples increases, both with increasing the size and the diameter of particles; therefore, the largest diameter $d = 6 \div 8$ mm was chosen as an example in experiments. It can be seen that the spruce wood is more susceptible to ignition; at wind speeds of $2 \div 2.5$ m/s, ignition occurred when 3 particles were landed, while for building wood materials the average threshold value of the particles resulting in ignition was 6–9 particles.

![Figure 4. Photographs of ignition of a plywood sample by firebrands.](image)

Figure 4 shows the typical photographs of ignition of a plywood sample by smoldering firebrands, which were dropped in the amount of 7 strips 40 mm in length. The air flow speed was 2.5 m/s. It was found that in this case, the transition from the smoldering firebrands to the flaming ones due to the influx of the oxidizer from the heat gun occurred at the 25th second, then ignition was observed on the surface of plywood.

**Conclusions**

In this work the behavior of wood building material samples (plywood, oriented strand board, particle board) exposed to burning and smoldering natural firebrands is investigated.

The ignition of the samples was not observed in the wind speed range of $0 \div 1$ m/s. A small amount of additional oxidant influx in the particle landing zone resulted in their slow smoldering on the surface until complete combustion. Thus, it can be concluded that smoldering natural firebrands with the selected experimental parameters does not affect the ignition of the samples of wood building materials.

The probability of ignition and the ignition delay of wood were determined depending on the size and number of firebrands, the presence of the air flow in the landing zone of particles, as well as on the initial temperature of wood.

The minimum total area of smoldering firebrands, equal to the product of the number of particles, sufficient for ignition, and their characteristic area, increases significantly during the transition from spruce wood to wood building materials. In particular, for OSB and PB samples the minimum area increased by 40 % on average, and for plywood sample the area increased by more than 60 % at a speed of 2 m/s.

With the selected experimental parameters, wood building materials (plywood, OSB, PB) turned out to be more resistant to ignition. Apparently, this is due to the fact that the composition of the studied samples contains additional binding components (synthetic resins, etc.). In addition, these building materials are characterized by a lower roughness of the surface, in contrast to the standard spruce building board.

Infrared diagnostics allowed estimating the temperature on the surface of the samples, selecting the optimal heating time, and controlling the smoldering phase of firebrands before their dropping.

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