Investigation of the Fire Hazard Characteristics of Wood Using Infrared Thermography

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Investigation of the Fire Hazard Characteristics of Wood Using Infrared Thermography

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Abstract
The different wood samples (flat and cylinder samples) were exposed to combustion modeled by forest fuels to study the effect of combustion under the laboratory conditions, using infrared diagnostics. The temperature profiles were obtained on the surface of wood samples, and the heat-stressed areas were found during the model combustion representing a ground fire of weak intensity. Also the effect of fire front on the surface of wood samples (pine, aspen and larch) was studied to estimate the effect of fire retardant treatment "FUKAM". Infrared thermography was used as a diagnostic method. The surface temperature distribution was obtained for the test wood samples after exposure to a fire front that was modeled using pine needles. The fire hazard characteristics of wood after fire retardant treatment showed a significant reduction in the surface temperature and the resistance to fire for the chosen parameters of the experiment compared to the same untreated samples.

Introduction

Wildfires cause significant material and economic damage to the territories. Numerous theoretical [1–3] and experimental investigations [4–7] conducted to study the effect of fires do not explain the mechanism of fire transition to the wooden constructions, their ignition and subsequent combustion.

In recent years the increase in the number of fires has been observed in the settlements which are adjacent to the forest area or located in the forest. It should be noted that this problem is very acute in many countries: Brazil, Australia, China, Greece, Portugal, the USA, Russia and other countries, since a large number of settlements are located close to the forest.

The literature provides a huge amount of theoretical and experimental data on the fire hazard properties of wood [8], the study of burning particles acting on wooden constructions [9–11], and the effect of intense heating through thermal radiation [4,11–13]. It is of interest to study the effect of fire retardants on the fire hazard properties of wood exposed to combustion under laboratory conditions.

A huge problem in the study of combustion is to determine the temperature of combustion and objects. To conduct the experimental studies of combustion and wildfires, there is a need to use a large number of thermocouples for recording the temperature fields. This fact causes certain technical difficulties. Modern methods of IR-diagnostics and the use of thermal imagers eliminate the need for a large number of thermocouples which perturb the investigated medium during measurements. At the same time, a much better resolution in space and time can be obtained using infrared diagnostics.

This paper presents investigation on the influence of the combustion site modeled by a forest fuels (FF) on wood specimens of different profiles (flat and cylinder specimens) with the use of IR diagnostics and the effect of fire retardant treatment «FUKAM» on the fire hazard characteristics of pine, aspen and larch [14].

Experimental Setup

Infrared thermography was used as a diagnostic method. The chief advantage of IR measurements is the high spatial and temporal resolution of IR imagers [15].

The scheme of the setup is shown in Figure 1:

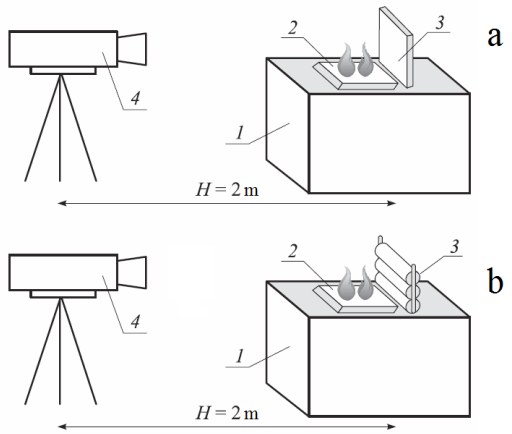


Figure 1: The scheme of the experiment for the flat wood sample (a) and cylinder (b):
1 – experimental plot; 2 – site with forest fuels,
3 – wood sample, 4 – thermal imager JADE J530SB

The model of a ground forest fire of low intensity was used, since this fire was the most widespread in the natural environment, the modeling of which under laboratory conditions did not require significant maintenance costs [16].

Investigations were carried out using a thermal imager JADE J530SB.

Recording was conducted from a distance of 2 m and the aim of research was to determine the temperature at the wood surface under the fire exposure. The input data recording program for the infrared imager was developed on the basis of the

LabVIEW program complex. The frame frequency was 50 frames/sec.

The moisture content of the samples was controlled using a moisture analyzer AND MX-50 with an accuracy of 0.01 %, and the mass of the samples was controlled using an electronic balance AND HL-100.

The samples of pine, aspen and larch were used as the samples which imitated the wood used in constructions. The dimensions of the samples in the experiment were (L × W × H): 0.23 × 0.02 × 0.1 m for pine, 0.17 × 0.02 × 0.1 m for aspen, and 0.16 × 0.02 × 0.12 m for larch. During the experiments, the moisture content of the samples was 5.55 % for pine, 5.83 % for aspen, 3.76 % for larch, and 8.03 % for pine needles. The FF mass maintained constant and was 50 g in the experiment, thus modeling a ground fire of weak intensity. The density of wood ρ = 640 kg/m^3.

Combustion, simulated by forest fuel (FF), consisted of pine needles (*Pinus Pinaster*) and represented a site with a width that was close to the size of the wood sample. FF load ρ_{FF} = 55.5 kg/m^3 (Fig. 2).

Figure 2: Digital pictures of pine needles samples (Pinus Pinaster)

The mass of forest fuels M_{FF} = 50 g. Ambient temperature fixed at 293 K for all experiments reported here

Investigation of the Effect of the Combustion Site on Wood Specimens with the Use of IR Diagnostics

In the infrared region the sample surface characteristics were recorded using a thermal imager JADE J530SB with a 2.5–2.7 micron optical filter [15] that allowed a temperature to be measured in the range of 500–850 K. In order to record a temperature in the range of 293–550 K, the recording was conducted without a filter.

To estimate the effect of the combustion site on wood specimens by the method of IR diagnostics with the help of the Altair software for working with an infrared imager, we chose a region on the surface of wood specimens and constructed a temperature-time curve (Fig. 3).

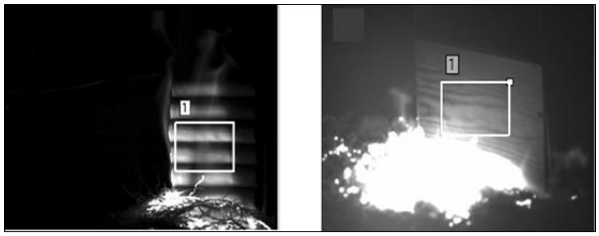


Figure 3: Thermogram of fire exposure on the pine wood samples: a) – cylinder form; b) flat form

Figure 4 displays the typical temporal evolution of the temperature in the area 1 (Fig. 3) for the cylinder form pine sample.

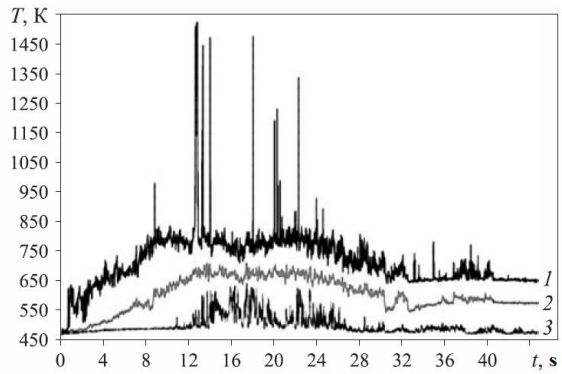


Figure 4: Temporal evolution of the temperature: 1 – maximum value; 2 – medium; 3 – minimum

The results of the experimental studies showed the effect of ground forest fire on the flat and cylinder samples of birch. The maximum temperature was determined on the surface of the wood pine samples exposed to combustion, using infrared thermography. For the chosen parameters of the experiment, the surface temperature was as follows: 800-810 K for flat samples, and 807-832 K for cylinder samples.

Studying the Effect of Fire Retardant Coating on the Fire Hazard Characteristics of Wood

The development of chemical industry led to the development of means such as fire retardants which prevent partially or completely the ignition of treated surfaces. On the market there are a lot of such means which have the different technical parameters and a different degree of toxicity.

The liquid means «FUKAM» was used as a fire-bio wood protection applied to sawn, dressed and log building elements for housing, public, industrial and agricultural purposes [14].

Consumption of the means «FUKAM» corresponds to the ASTM E119–00a [17] that provides the fire retardant properties was approximately 400 g/m^2, which corresponds to the second group of fire retardant resistance.

The dipping treatment of the sample was used as a method to add a fire retardant solution to the wood

sample. The wood samples were in the liquid solution "FUKAM" for 3 hours, so that the wood was completely covered with liquid. Then the samples were placed in a force-draft oven FDO-0.5-200 with a temperature of 343 K until complete drying.

The experiment was conducted as follows. The FF site *2* (Fig. 1) was located in front of the sample and ignited by a linear source located under the site. The produced fire front acted upon the wood sample *3* (Fig. 1) that was vertically fixed. The sample surface was recorded using a thermal imager *4* (Fig. 1). The experiment was conducted in two stages. At the first stage, the wood samples were studied without fire retardant treatment. At the second stage, the samples were covered with a fire-retardant coating. A series of three repetitions were conducted for each stage. The processing of data was carried out using the Altair software.

Results and Discussion

The surface temperature distribution was obtained for the test wood samples (Figure 5).

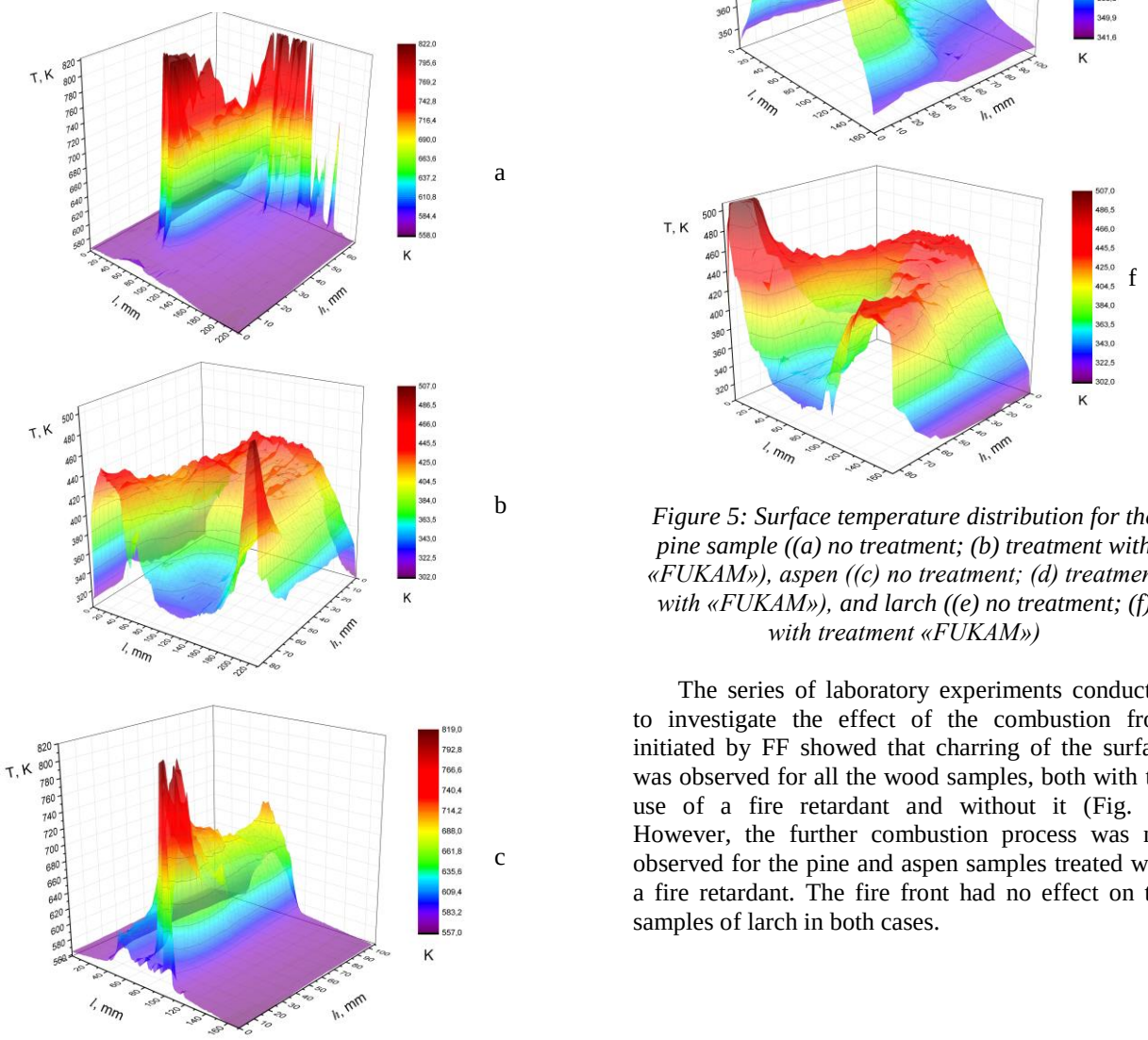
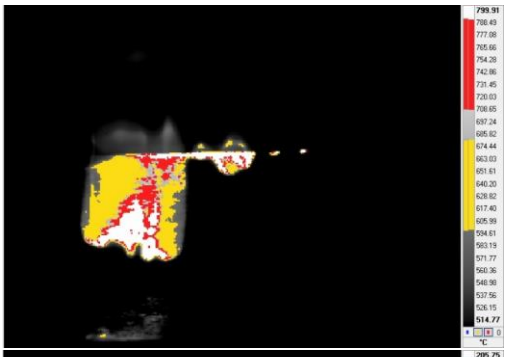
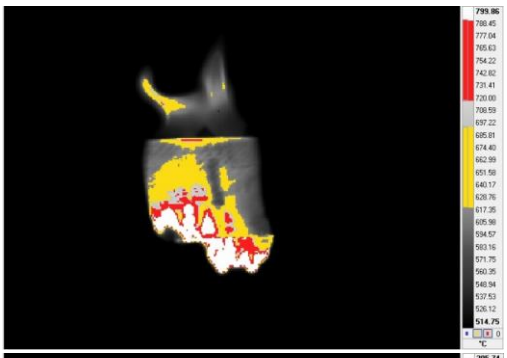


Figure 5: Surface temperature distribution for the pine sample ((a) no treatment; (b) treatment with «FUKAM»), aspen ((c) no treatment; (d) treatment with «FUKAM»), and larch ((e) no treatment; (f) with treatment «FUKAM»)

The series of laboratory experiments conducted to investigate the effect of the combustion front initiated by FF showed that charring of the surface was observed for all the wood samples, both with the use of a fire retardant and without it (Fig. 6). However, the further combustion process was not observed for the pine and aspen samples treated with a fire retardant. The fire front had no effect on the samples of larch in both cases.


a


b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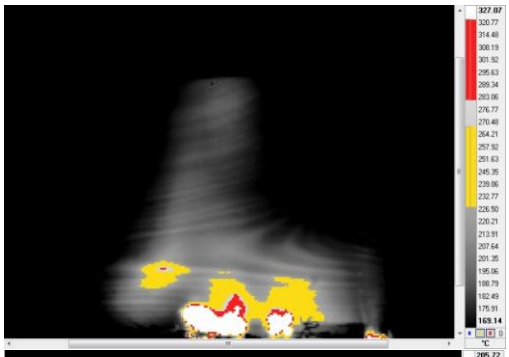
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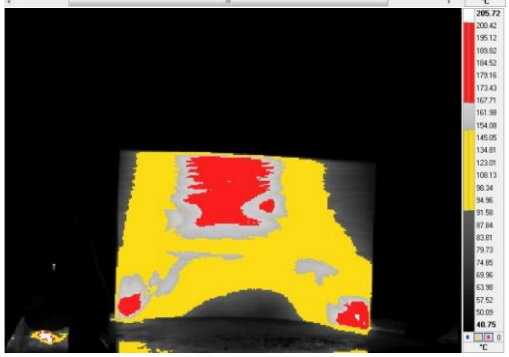
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Figure 6: Thermogram of the surface pine ((a) no treatment; (b) treatment with «FUKAM»), aspen ((c) no treatment; (d) treatment with «FUKAM») and larch ((e) no treatment; (f) treatment with «FUKAM»)) after the fire exposure

The maximum temperature that was reached on the surface of the samples without a coating was: 820 K for pine, 800 K for aspen, and 410 K for larch and with a coating was 456 K for pine, 506 K for aspen, and 471 K for larch. The nonuniformly laid FF layer was likely to influence on the difference in the temperature values for the larch samples. Fire-retardant treatment «FUKAM» could also influence on the sample heating.

Conclusion

To study the temperature fields on the surface of wood specimens under the action of the modeled combustion site on them, we used IR diagnostics with a spectral interval of 2.5–2.7 µm. The effect of ground forest fires and steppe fires on different wood samples was described by using the experimental data obtained, namely:

- The convex area and the ends of the cylinder samples were found to be most exposed to combustion;

- Using infrared diagnostics, the temperature was determined on the surface of the wood different samples exposed to combustion and was as follows: 800-810 K for flat samples, and 807-832 K for cylinder samples;

For the chosen experimental parameters the surface of the wood samples became charred, but flame combustion was observed only in a few cases, which appears to be connected to the small capacity

of the heat flow, as well as the short duration of its effect on wood, which is confirmed, in particular, by the work [18] that analyzes the experimental characteristics of ignition and combustion of wood subjected to the different thermal flows. As a result, it is concluded that the lower the intensity of the heat flow is, the more complete pyrolysis occur at a rate that is low to create a combustible concentration. In addition, as is known, for stable combustion the solid material should obtain the amount of heat that provides a continuous supply of the sufficient amount of gaseous combustible substances in the combustion zone [19].

The use of fire retardant treatment (for example a fire retardant «FUKAM») certainly increases the resistance of wood to fire, which is confirmed by the data on the sample surface temperature after exposure to model combustion.

Acknowledgements

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