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Laboratory Investigation of Sessile Oak Wood Thermal Degradation

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Short Report

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Abstract

Fire resistance is an important fire parameter. Currently, wood that is flammable is often preferred as a building material. To protect the building from fire, we must know its fire characteristics, as well as fire resistance. According to the Act of the National Council of the Slovak Republic no. 314/2001 Coll. on fire protection, an investigator who investigates the cause of the fire, when and where the fire occurred, the initiators of the fire, and how the fires spread. To understand the fire behaviour, it is important to know the parameters such as wood properties, heat transfer in the wood and, finally, the thermal degradation of the wood. An equally important parameter is the thickness of the charred layer, thanks to which we can determine the charred rate from which the initiation time of a fire can be estimated. In this work, we loaded the samples with heat fluxes of 15 and 30 $kW \cdot m^{-2}$ and then we compared the initiation times of the samples. We also monitored the course of temperatures on thermocouples T1, T2, T3, T4 at the proposed heat fluxes. From the measured values, we determined the rate of charring, mass loss and the rate of burning at different thermal loadings. We also determined the thickness of the charred layer using manual measurements.

Keywords: oak wood; rate of charring; thermal degradation.

1 Introduction

According to the Act of the National Council of the Slovak Republic No. 314/2001 Coll. [1], a fire is an undesirable burning that is spontaneous, where several materials burn at the same time. It is very dangerous for the lives of people, animals and has devastating effects on property. For a fire to be initiated, it is necessary to establish the triangle of burning. Fuel and an oxidizing agent must be present. The burning triangle is also considered in the test methods. A fire has four phases: an initiation, propagation, fully developed fire, and the decay. A special category is represented by substances which are capable of self-ignition [2]. The most important stage is initiation. During it, a chemical reaction takes place to form a flame, heating the fuel so that gases are formed on its surface. When the gases reach the desired temperature, the molecules that make up the gases break down and the fragments thus disintegrated are combined with oxygen to form new molecules – water molecules and carbon dioxide. With imperfect combustion, even more products are produced [3]. When burning, pyrolysis sometimes occurs, which can proceed without an oxidizing agent. This is the decomposition of materials that are exposed to heat. Chemical and physical changes take place in this process [4].

When a fire occurs, it is important to find out its cause. According to the Act of the National Council of the Slovak Republic No. 314/2001 Coll. on Fire Protection, the state fire supervision investigates the cause of the fire through the fire investigator. A special case for fire investigation is in wooden buildings. The fire resistance of these structures, or structures made of wood, depends on the rate of charring. According to this parameter, the degree of damage to wood can be determined, as well as residual wood, in which degradation processes have not taken place. The Eurocode 5 is used to calculate the fire resistance of wooden constructs [5]. When wood burns, thermal decomposition of the bonds of its components takes place, the chemical composition changes and new products are formed. A charred layer is formed, which is formed on the surface of the wood under high temperature loading. The formation of a charred layer has many advantages. It prevents air from entering the inner parts of the wood cross-section, relieves burning and exhibits very good thermal insulation capabilities [6]. The rate of charring is one of the most important properties of wood and wooden products. It is one of the input data for calculating the fire resistance of wooden structures. In addition, wood charring rate is a widely used parameter during fire investigations (7). The rate of charring of wood is influenced by the density and moisture content of the wood, the heat flow, and the concentration of oxygen in the air (8). The charring rates are calculated from the depth of charring and the time when the material is subjected to thermal loading (7). Lipinskas [9] found that the differences between the different types of wood (coniferous, deciduous) in the charring layer are very small, negligible. Charring takes place in the process of pyrolysis, which results in the specific mass of the wood being reduced (2).

The aim of the paper is to determine the selected parameters of Sessile oak wood for the study of thermal degradation processes: time to initiation, rate of burning, thickness of charred layer.

2 Material and Methods

The samples were produced from the Sessile oak stem harvested at the Kremenný Jarok locality, situated at an altitude of 320 m above sea level. This territory is under the administration of the University Forestry Enterprise of the Technical University in Zvolen (Slovakia). The stand age was ca. 110 years.

The size of samples used in the work was of 40 x 50 x 50 mm. Samples were air conditioned to a moisture content of 10 ± 0.15%. We subjected the samples to a thermal loading with two heat flux values, i.e., 15 and 30 $kW \cdot m^{-2}$. In the study, we repeated the test for each heat flux 10 times.

We carried out the measurement using a measuring apparatus, which is maintained at the Industrial Property Office of the Slovak Republic under utility model No. 9373 [10]. It is designed to measure the rate of burning and the rate of charring of polymers.

The testing apparatus consisted of a ceramic infrared lamp, digital scales, a control device, and a temperature measuring device. Using thermocouples, we measured the temperature in samples. The temperature measuring device and the scales were connected to a computer, and values were recorded every 10 s. The temperature in the sample was measured by the thermocouples, inserted into the pre-drilled holes. The holes were 10 mm apart (depth).

Each experiment lasted for 30 minutes.

We measured the thickness of the charring manually. Before testing, we measured the thickness of the samples at 9 different locations using a sliding gauge. Then, after thermal loading and subsequent cooling, we cleaned the sample, scraped off the charred layer, and measured the sample again in the same 9 places. At the end, we evaluated the results.

3 Results and Discussion

3.1 Results in relation to time to initiation

According to the measured values of the time to initiation, we can confirm the fact that the higher the heat flux, the less time the sample needed to initiate. The longest time for initiation needed samples thermally loaded by the heat flux of 15 kW·m^{-2}, which was of 140 s on average. On the contrary, we found the shortest time for samples loaded with a heat flow of 30 kW·m^{-2}, where this time was 24 s on average.

3.2 Results in relation to mass loss

The relative mass loss of a sample depends on the thermal loading duration as well as applied heat flux. For all samples, it was confirmed that the longer the heat flux acts on the sample, the greater the mass loss achieved by the sample. Based on the determination of the mass loss, we calculated the rate of burning of oak wood.

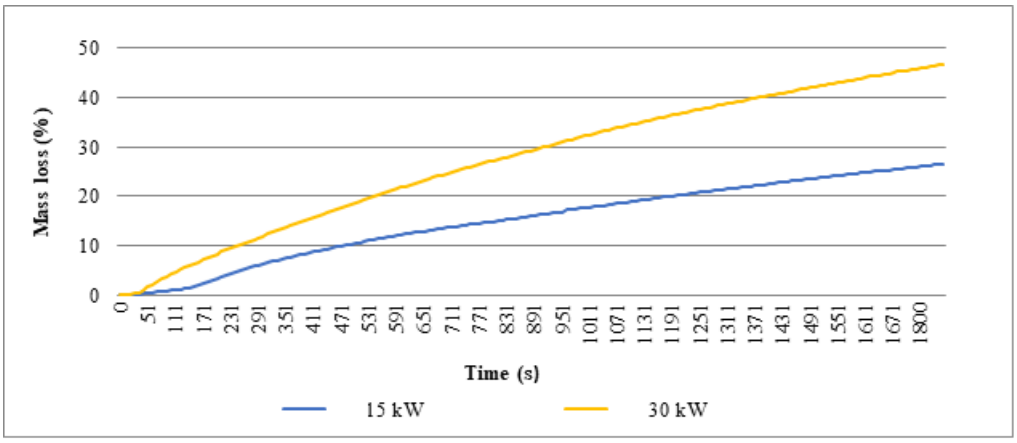

Fig. 1 Course of relative mass loss

From the graph (Fig. 1) we can see that if we set the heat flux to 15 kW·m^{-2}, the sample achieves the mass loss only less than 30 %. Conversely, at the heat flux of 30 kW·m^{-2}, the sample achieved almost 50 % of the mass loss.

3.3 Results in relation to rate of burning

The rate of burning, as well as the mass loss, depends on the time and heat flux that acts on the sample. The greater the heat flux acts on the sample, the sooner it reaches the maximum rate of deburring. As the heat flux increased, the rate of combustion also increased (Fig. 2).

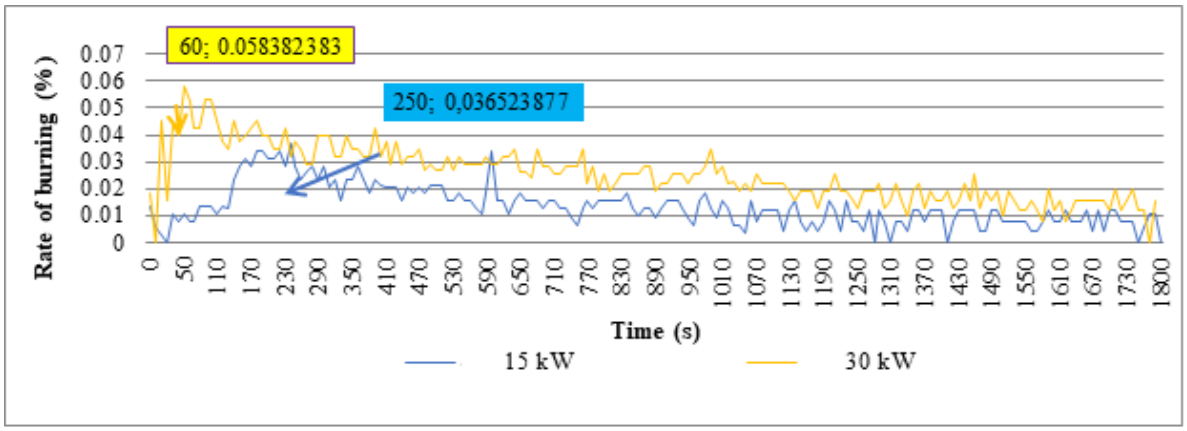

Fig. 2 Relative mass rate of burning course related to the heat flux applied

As seen in Fig. 2, when setting the heat flux to 15 kW·m^{-2}, the sample reached a maximum burning rate (0.036 %) in 250 s. This value of the rate of combustion was the smallest measured value. Conversely, when we set the heat flux to 30 kW·m^{-2}, the sample reached its maximum burning rate as early as 60 s. The achieved value was like that of a heat flux of 15 kW·m^{-2}, namely 0,060 %.

The course of temperatures in the sample affects the magnitude of the heat flux (Fig. 2). When higher heat flux applied to the sample, it reached the rate of combustion faster than when the heat flux was less.

3.4 Results in relation to achieved temperature course

The course of temperatures also depends on the thermal loading duration on the sample. For thermocouples T3 and T4, we did not reach the charring temperature. For the T2 thermocouple we reached a temperature of 300 °C only at the end of the measurement, but only at a heat flux of 30 kW·m^{-2}. If the samples had been exposed to heat flux longer, we would have measured the temperature of 300 °C on other thermocouples, too.

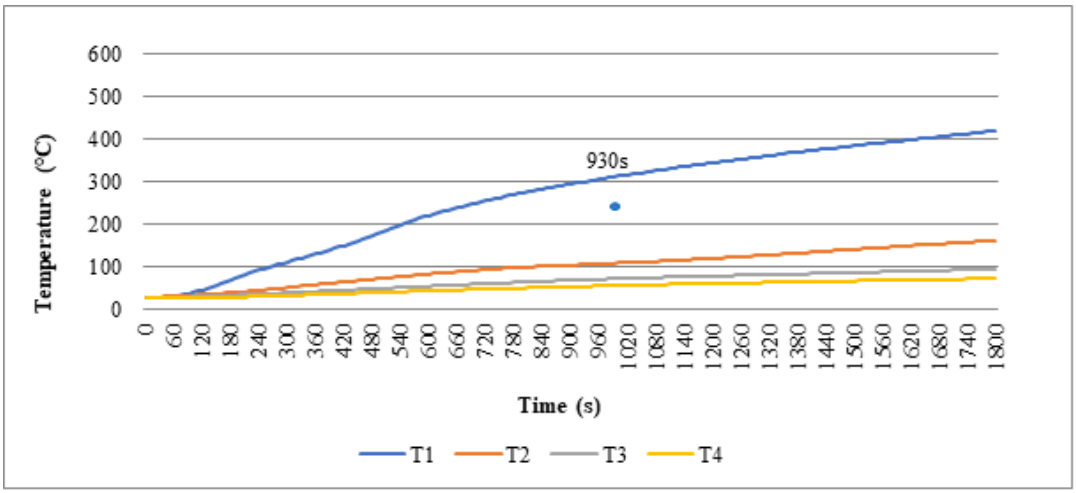

Fig. 3 Temperature course by thermal loading of 15 kW·m^{-2}

Figure 3 shows the course of temperatures in the samples under the thermal loading with a heat flux of 15 kW·m^{-2}. The highest temperature was reached by the sample on the thermocouple T1 (10 mm deep in the sample). Charring also took place only at this depth, since only the T1 thermocouple recorded the charring temperature of 300 °C at 930 s.

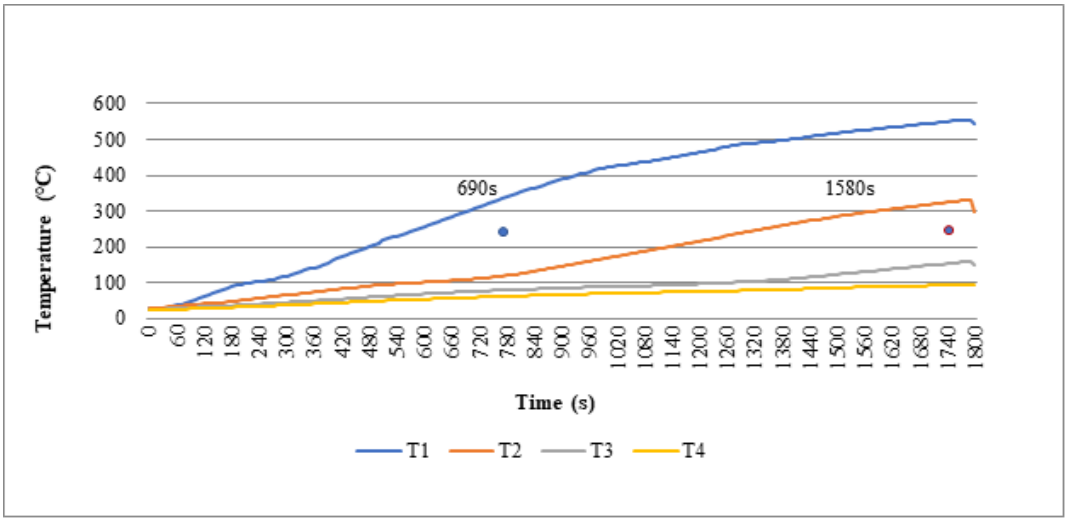

Fig. 4 Temperature course by thermal loading of 30 kW·m^{-2}

When the samples were loaded with a heat flux of 30 kW·m^{-2} (Fig. 4), the sample reached the charring temperature on two thermocouples, T1 and T2. On the thermocouple T1, it reached temperature of 300 °C earlier, already at 690 s. On the T2 thermocouple, the charring process began a little later, only at 1,580 s.

From the measurements, we found that the course of temperatures on individual thermocouples depends on the depth to which we insert the thermocouple, as well as on the heat flux and the time during which the sample is exposed to thermal loading.

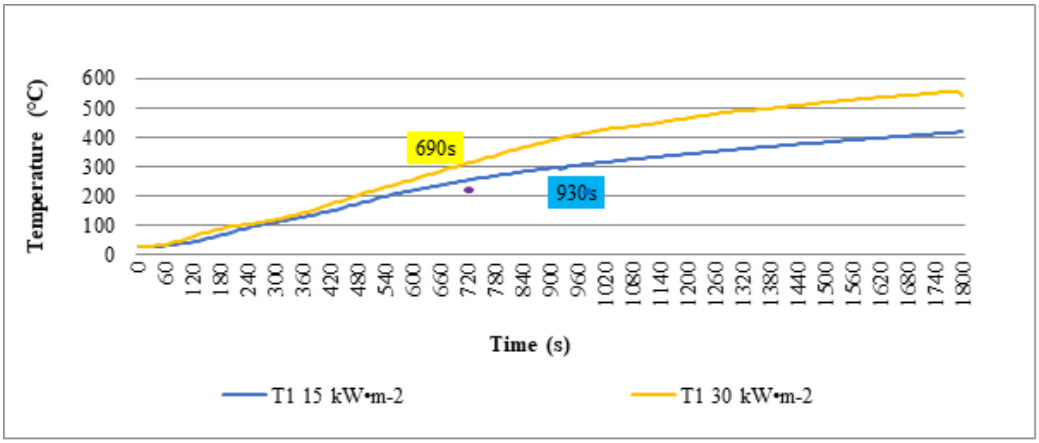

Fig. 5 Temperature course in the depth 10 mm underneath the sample surface

From the graph (Fig. 5), we can determine that on the thermocouple T1, placed 10 mm underneath the surface of the sample, the temperature of 300 °C was first reached by samples loaded with the heat flux of 30 kW·m^{-2} at 690 s. This temperature was most slowly reached by samples loaded with a heat flux of 15 kW·m^{-2} at 930 s.

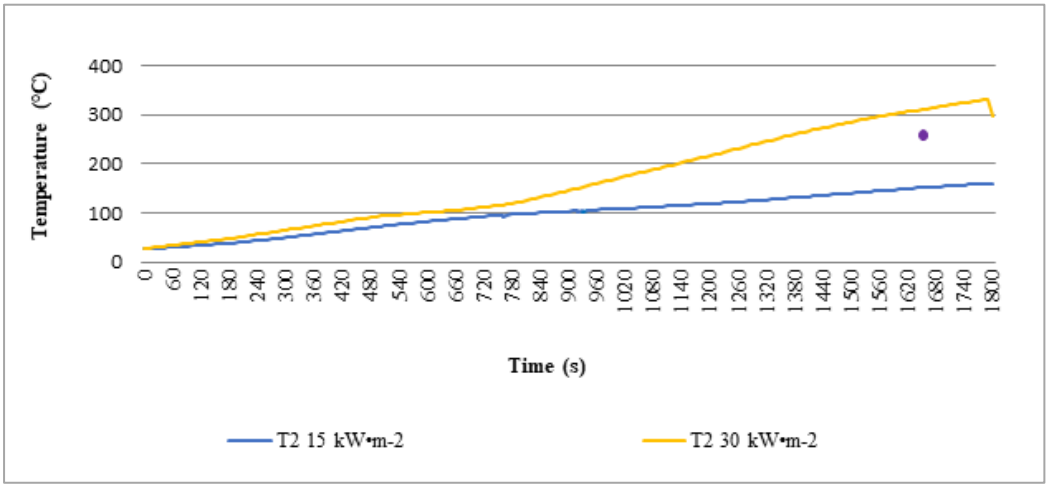

Fig. 6 Temperature course in the depth 20 mm underneath the sample surface

Thermocouple T2 inserted in the depth of 20 mm underneath the surface of the sample (Fig. 6) reached the charring temperature only under a thermal loading of 30 kW·m^{-2}, with a maximum heat flux of 30 kW·m^{-2}. The magnitude of the thermal loading was not sufficient for thermal degradation and subsequent charring formation.

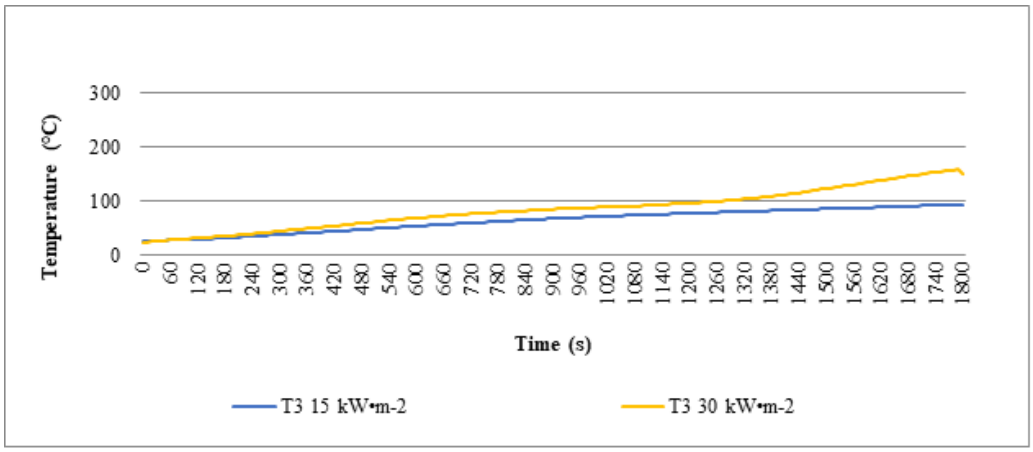

Fig. 7 Temperature course in the depth 30 mm underneath the sample surface

The thermocouple T3 which we inserted 30 mm below the surface of the sample (Figure 7) did not reach a temperature of 300 °C. There was no process of charring.

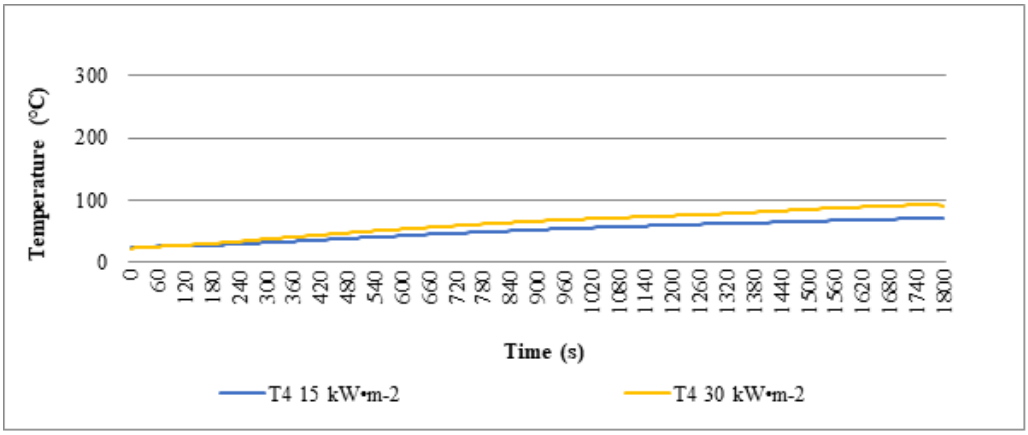

Fig. 8 Temperature course in the depth 40 mm underneath the sample surface

As with thermocouple T3, no charring occurred with thermocouple T4 (Fig. 8). The thermocouple inserted in the depth of 40 mm underneath the surface of the sample did not reach a temperature of 300 °C.

3.5 Results in relation to charred layer thickness

The thickness of the charring layer also depends on the magnitude of the heat flow. The greater the heat flux acts on the sample, the greater the thickness of the charring. We measured the thickness of the charring in two ways, manually and using a measuring apparatus. In both methods of measurement, the results were confirmed, they were almost identical.

When manually measuring the thickness of the charring layer, we found that the largest thickness of the charred layer was shown by wood at a heat flux of 30 kW·m^{-2}. It was up to 25.78 mm. Conversely, when we applied the sample with the heat flux of 15 kW·m^{-2}, the sample reached the thickness of charring only of 12.26 mm.

When measured the charring layer thickness by the second method, the mass loss of 26 % was achieved by the sample at heat flux of 15 kW·m^{-2}. The highest mass loss achieved the oak samples at a heat flux of 30 kW·m^{-2}, i.e., almost 50 %.

A more accurate method of thickness of charring measurement is a method using a measuring apparatus, since with the second method of measuring with a sliding gauge, the human factor may fail, which may result in measurement inaccuracies caused by inaccurate or incorrect work with the sliding gauge.

The thickness of the charring layer was also measured by other authors. Kocaefe et al. [11] studied aspen wood that was exposed to thermal loading in a thermogravimetric analyser. The samples had dimensions of 0.035 x 0.035 x 0.2 m. temperature was set at 220 °C. For 15 min, the mass loss was of 0,83 %. After 30 min, the mass loss increased to 1.79%. The highest mass loss of 2.12% occurred at 45 min. The experiment confirmed that the longer the sample was exposed to thermal loading, the extensive the mass loss.

In another experiment, Eseyin et al. [12] investigated the mass loss of torrefied cedar wood. The weight of the samples was 10 g and they exposed them to different heating rates (5, 10, 20, 30 ° $C \cdot min^{-1}$) and temperatures (100, 150, 200, 250, 300 °C) for 30 min. They described mass loss at temperatures of 200-250 °C as moderate. When they raised the temperature to 250-300 °C, the mass loss was more pronounced. The most extensive mass loss of 20 % was recorded at 300 °C.

4 Conclusions

We found that the greater the heat flux acts on oak wood, the faster initiation will take place and a fire will occur. If the sample is loaded with a smaller heat flux, its mass loss will be less than when loaded with a higher heat flux. The rate of burning of a sample is influenced by the value of the heat flux and the time of action of the heat flux on the sample.

We examined the course of temperatures when the heat flux changes on thermocouples at a depth of 10, 20, 30 and 40 mm. From measuring the charring rate of the sample, we found that the smaller the heat flux acts on the sample, the slower the charring takes place.

The achieved results from measurements can be applied in safety practice: in fire prevention, occupational health, and safety. For fire investigation purposes, information about the initiation time helps to predict the time of fire occurrence, which is very important for setting the fire reason. If we can determine the mass loss of wood, we also know the overall course of the fire and the duration of the fire, according to the verified conclusion that the longer a large thermal load is applied to the wood, the greater the mass loss of wood. The fire development rate can be determined using the data on wood burning rate. The charred layer of wood at the site of the fire is used to determine the fire temperature values (min. 300°C).

We can use these results as input data for computer-aided modelling of fire behaviour (compartment fires). The initiation time, the course of temperatures or the mass loss values can be used as inputs into the development of fire model for wooden structures in Ansys.

Acknowledgments

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