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THE PROGRESSIVE TEST METHOD FOR ASSESSING THE THERMAL RESISTANCE OF SPRUCE WOOD

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ABSTRACT

The article is focused on the evaluation of spruce (*Picea abies* L.) wood used in building construction using a new method, according to utility model application PUV 160-2021, which is a progressive modification of the standard test method according to standard STN EN ISO 11925-2. The aim of the paper is an experimental assessment of the thermal resistance of a selected lignocellulosic material – spruce wood, applying a progressive laboratory test method. Using this method, the flame spread over the surface of the selected material and the mass loss when the sample is exposed to a small, directed flame are determined. The results of the laboratory test method application showed a significant effect of the angle of inclination (0°, 45°, 90°) of the sample on the evaluation criteria.

Key words: lignocellulosic material, progressive laboratory test method, flame spread, mass loss, angle of sample inclination.

INTRODUCTION

Wood is the oldest material used in construction. Due to the importance attached to the sustainable use of natural resources, wood is currently gaining in popularity. It excels in high mechanical resistance, low thermal conductivity and, in addition, it is an easily available raw material, environmentally friendly. It is a material that has a relatively inhomogeneous anisotropic structure and consists of a complex of macromolecular substances (cellulose, hemicelluloses, lignin, and extractives) (DIETENBERGER 2002).

The disadvantage of wood as a building material is its flammability. Flammability is a general term that describes the properties of a material in response to fire. It cannot be expressed by a single value because it is affected by several parameters. Flammability assessment methods are essential in the evaluation of materials (QUINTIERE 2017).

At present, the choice of building materials is influenced by many factors. In addition to several good properties, the impact on the environment is also a very important factor (KADLICOVÁ *et al.* 2017). Many standardized and non-standardized test methods are used for testing materials and building structures. Standardized test methods are mainly used to demonstrate compliance with the requirements for a material or product in force. Non-standardized test methods are used mainly in the field of science and research, but also in the field of fire investigation (TISCHLER and MAJLINGOVÁ 2018).

Tests dealing with the evaluation of materials in terms of reaction to fire belong to the group of laboratory test methods. According to standard STN EN 13501-1 + A1 / Z1 (2017), we determine the reaction to fire for three product categories: construction products; floor coverings; thermal insulation products for linear pipes. One of the laboratory test methods used to evaluate the thermal resistance of wood is the flammability test. The test procedure is determined according to standard STN EN ISO 11925-2 (2020). This test determines the flammability of the product when exposed to a small, directed flame, placing the samples in a vertical orientation. This test is used for fire reaction classes B, C, D, E, B_{fl}, C_{fl}, D_{fl}, E_{fl}, B_L, C_L, D_L, E_L.

Flame propagation is a fire engineering parameter that affects the entire combustion process. The rate of fire development depends on the flame spread. Flame propagation can be considered as gradual ignition, in which the leading edge of the flame acts as a source of heat and as a source of initiation. The speed of flame propagation may depend on the physical properties of the material as well as its chemical composition. Unlike liquid surfaces, the solid surface can be in any orientation, which can have a dominant effect on fire behaviour (Fig.1). This is especially true for flame propagation, as it is controlled by a mechanism that transfers heat in front of the burning zone and this is strongly influenced by the surface geometry and slope (DRYSDALE 1999).

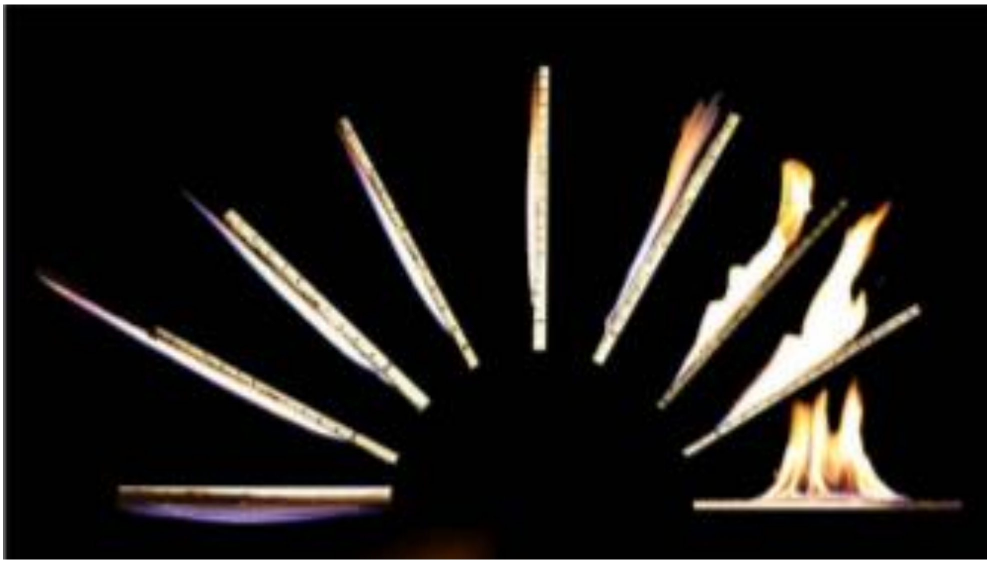

Fig. 1. Flame propagation at different angles of inclination (GOLLNER *et al.* 2017).

The flame spread not only across the surface of the material, usually after ignition, but it is also the fastest, and therefore the most dangerous, upwards. This makes the vertical propagation of the flame up or throught the ceiling (along the direction of air flow) a serious fire safety problem due to the accelerating potential for flashover with high-rates of heat release and the formation of smoke and toxic gases. In contrast, the descending or lateral propagation of the flame (against the direction of air flow) is slow, creepy, there is also a slope of the surface of the flammable material) (DIETENBERGER and HASBURGH 2016).

The aim of the paper is an experimental comparison of the thermal resistance of a selected lignocellulosic material – spruce wood, under the load of a flame source depending on the angle of inclination of the sample. We chose three different angles of inclination of the sample (0 °, 45 °, 90 ° to the test flame) for experiment.

MATERIAL AND METHODS

The selected type of lignocellulosic material was spruce wood (*Picea abies* L.), commonly used as a building material. For the experiment, carried out in laboratory conditions, we subjected samples of spruce originating from a 120-year-old stand at an altitude of 800 m above sea level. For the purposes of the test method 30 pieces of the test specimens were handled from logs with dimensions of 250 mm × 90 mm × 10 mm.

In creating the methodology, we also relied on standards that relate to the evaluation of materials in terms of reaction to fire. The standard test method for the flammability of construction products exposed to direct flame is the method according to STN EN ISO 11925-2 (2020), which evaluates the flammability of products when exposed to a small, directed flame with the placement of samples in a vertical orientation.

When testing samples of lignocellulosic material, we used a progressive test method – modification of the flammability test, the procedure of which is specified in utility model application PUV 160-2021 (2021). This method assesses the flame spread over the surface of the lignocellulosic material under the load of the flame source, depending on the angle of inclination of the sample as well as the mass loss of the samples. The device for determining the speed of flame propagation on the surface is shown in Figure 2.

When providing the progressive test method, the samples are mounted in the device holder at three different angles. The required flame height is set with the propane burner valve and the flame is applied to the test sample for a specified time (10 min). The mass of the tested samples is also recorded at regular 10-s intervals using the KERN PES 6200-2M electronic scales and the KERN Balance Connection program. Subsequently, we calculated the relative mass loss from the measured values according to equation (1) for each sample (KAČÍKOVÁ *et al.* 2008).

$$\delta_m(\tau) = \frac{m\,(\tau_0) - m\,(\tau)}{m\,(\tau_0)} \cdot 100 \quad (\%) \tag{1}$$

Where: $\delta_m(\tau)$ – relative mass loss over time (τ); $m\ (\tau_0)$ – sample original weight (g); $m\ (\tau)$ – sample weight at time (τ) (g).

The experiments were performed at three different angles of inclination of the sample (0 °, 45 °, 90 ° to the test flame). We performed 10 experiments for each angle of inclination of the sample, which represents 30 experiments at 3 angles of inclination of the sample.

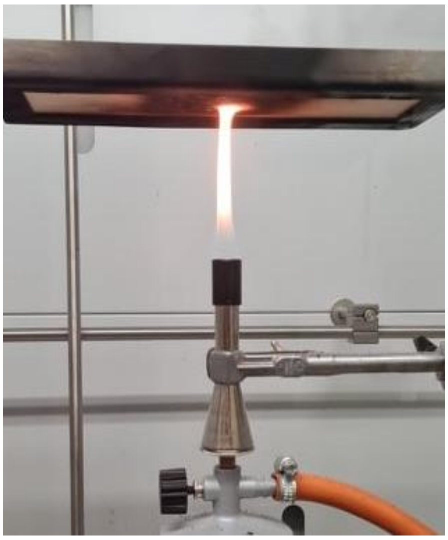

Fig. 2. Device for determining the speed of flame propagation on the surface.

RESULTS AND DISCUSSIONS

Flame propagation is a fire property that affects the entire combustion process. Based on testing of different materials by other authors i.e., HUANG *et al.* (2015), who also investigated flame propagation over the sample surface, we selected a progressive test method.

Using the test method described in the material and methodology section, a series of experiments were performed to study the flame spread over the surface of spruce wood and the mass loss of the test samples after exposure to the test flame. The results of the studied evaluation criteria are shown in Figures 3 to 5.

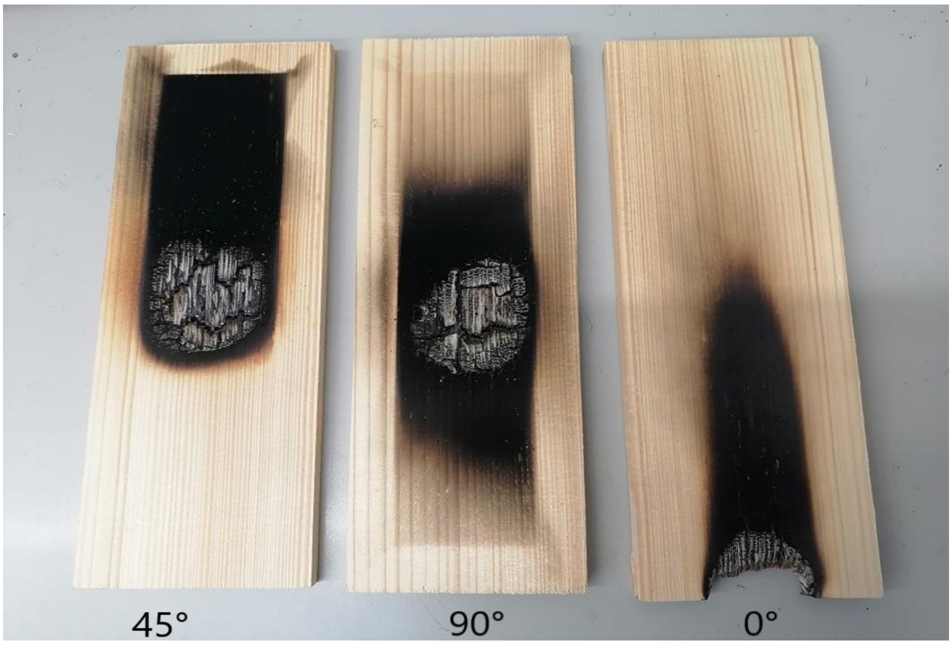

Fig. 3. Photo documentation of samples after the experiment.

According to the obtained results (Fig. 3) we can say that there is a higher risk of flame propagation with the test flame at 0 ° angle of inclination of the sample. When the samples were thermally loaded at 0 °, their burning was significantly more intense, the flame not only spread along the front side of the samples, but also spread to the back side of the sample. Also, depending on the angle of inclination of the sample, we see an observable difference (in terms of burn-in), the observable difference was also in the charred layer. While at 90 ° the flame penetrated their inner layers, at 45 ° it remained on the surface and spread upwards. From the resulting samples we can state that the samples at 45 ° and 90 ° angle of inclination showed more positive results compared to the samples at 0 ° angle of inclination compared to the action of the flame. It follows that the flame propagates over the surface of the material usually immediately after ignition, but the flame propagation is faster when there is an ascending flame propagation on the vertically oriented fuel surface. The cause is a change in the physical interaction between the flame and the unburned fuel when the orientation of the fuel changes i.e., a change in the direction of propagation of the released flammable gases (ascending) with respect to the direction of flame propagation.

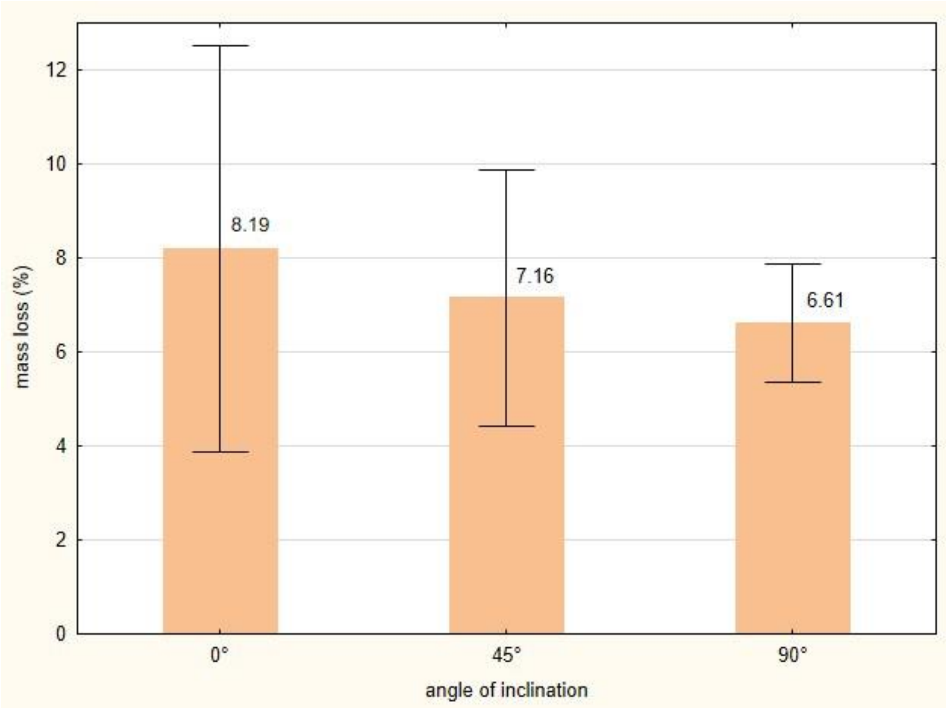

Fig. 4. Relative mass loss of tested samples in 600 s (average ± SE).

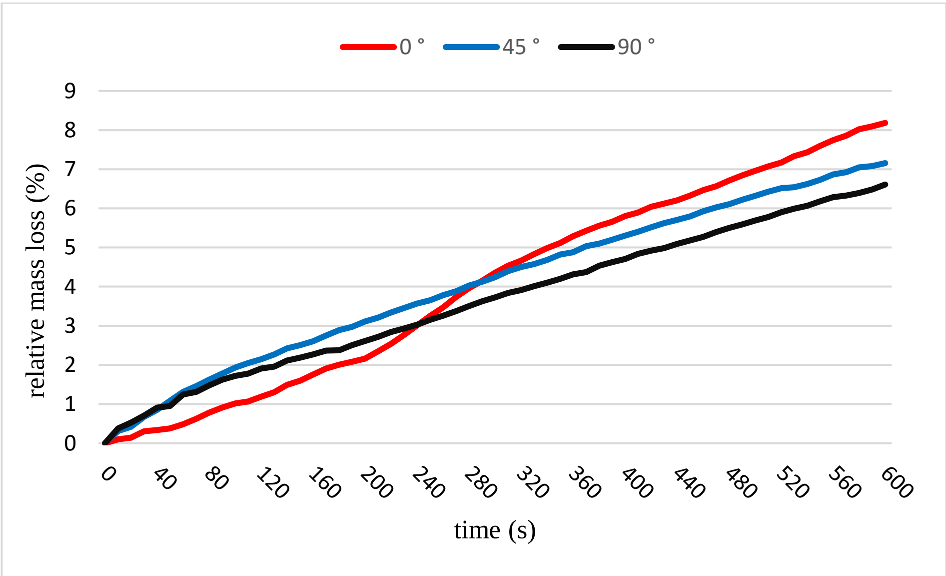

Fig. 5. Relative mass loss of tested samples (average values).

The relative mass loss course (Fig. 5) was similar for the 45 ° and 90 ° sample angles. We noticed a more significant difference at the 0 ° angle of inclination of the samples, in which a more significant mass loss occurred later, compared to the other two angles of inclination of the samples. At the same time, we can state that all woody plants lost less than 9% of their original weight in 600 seconds (Fig. 4). We recorded the worst results for samples at a 0 ° angle of inclination, which lost up to 8.18% of their weight, which we attribute to the faster spread of the flame. As we expected, even in the case of mass loss, the influence of the angle of inclination of the sample on the thermal degradation of wood was significantly manifested. This claim was confirmed as it was clear from the weight loss comparison that the samples at 90 ° tilt showed the lowest mass loss. If we compare the samples based on their angle of inclination, we can rank them in the order from the best results to the worst as follows: 90 °, 45 °, 0 °.

KMEŤOVÁ *et al.* (2020b) in a study aimed at comparing the thermal resistance of Scotch pine and Sessile oak for fire protection purposes, using the standard test method according to STN EN ISO 11925-2 found that there is a higher risk of ignition when the test flame acts on the edge of the tested sample compared with the action of the flame on the main surface. When the samples were thermally loaded at the edge, their burning was a bit more intense, the flame spread in the samples not only in the vertical direction, but also along the edge of the sample.

ZACHAR *et al.* (2012) in a study aimed at determination of selected fire properties of spruce wood, also used the standard test method according to STN EN ISO 11925-2. Their results confirmed the higher ignitability of edges of samples.

MITTEROVÁ *et al.* (2021), using a flammability test, investigated the spread of flame over the surface of untreated and retardation-treated spruce wood and, assessed its contribution to the development of the fire to which it was exposed. The results of the tests of the investigated material indicate that after treatment with flame retarding substances, its resistance to the flame to which it was exposed during the test increased, it did not ignite and thus did not spread the flame.The effectiveness of flame retardants on wood samples, has also been demonstrated by KAČÍKOVÁ *et al.* (2021). In their research, they dealt with the influence of nanoparticles TiO_2, SiO_2, ZnO and water glass on the thermal resistance of oak wood.

GAŠPERCOVÁ and MAKOVICKÁ-OSVALDOVÁ (2017) also studied and compared the flame length and mass loss of spruce and beech wood, which are often used in construction. The experiment was focus on testing the reaction to fire on two different types of surfaces, namely treated and untreated surfaces. The treated surface was sanded with sandpaper and the rough surface was only cut wood.

The spruce wood was also studied on the cone calorimeter (MARTINKA *et al.* 2018; MARTINKA *et al.* 2016). With the help of this device, we can determine several characteristics, for example charring rate or heat release rate, which is a key parameter for the calculation of fire resistance of timber structures and for fire investigation.

Many other authors are studying the flame spread of various materials. ZHANG *et al.* (2020) also investigated the effects of electric current and sample orientation on flame propagation over electric wires. GOLLNER *et al.* (2017), also addressed the effect of sample flow and inclination on flame propagation across solid fuels. Upward flame spreads are perhaps best studied, with various theories available to describe many aspects of the flame spread process. But even in this well-studied configuration, work is still needed to refine these results.

CONCLUSION

The aim of the paper was an experimental comparison of the thermal resistance of a selected lignocellulosic material – spruce wood, under the load of a flame source depending on the angle of inclination of the sample. For this purpose, a progressive test method was used - modification of the flammability test. In the evaluation, we focused on the effect of the angle of inclination of the sample against the test flame and the mass loss of the samples. From the results we can state that the best results in terms of mass loss compared to the angle of inclination 0 ° and 45 °, recorded samples with an angle of inclination of 90 °. Regarding the flame spread over the surface of the samples, it should be noted that the flame spread is faster if there is an ascending flame spread on the vertically oriented surface of the fuel. The obtained original experimental results and their interpretation are a contribution to the creation of a database of fire and material properties of wood for the needs of modelling the spread of fire in terms of fire protection. A new progressive test method has also been tested for the benefit of this research.

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