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BURNING RATE OF SELECTED HARDWOOD TREE SPECIES

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ABSTRACT

The paper is aimed at determining the fire-technical properties of the selected central European hardwood tree species: black locust, European white birch, European beech, sessile oak and Norway maple. The measurements will be mentioned in a database of tree species. The reactions of the tree species were monitored using the following evaluation criteria: (mass) burning rate, time when the peak value was achieved and the ratio of the two values. The evaluation criteria reflected the behavior of the material when exposed to radiation or flame source and the two combined, or simultaneous exposure to both flame and radiant heat source according to the selected mode of the thermal load. The results presented in the paper showed the effect of the source itself, as well as the effect of the given tree species on the evaluation criteria. The experiment results proved that, when exposed to a radiant heat source, the shape of the curves was different for all the given tree species. Oak and locust tree showed high resistance to ignition and burning. In the case of flame and combined heat source, where the size of the peak in the first few seconds of the experiment is of the greatest importance, the shape of the curves differed. In this case, locust and oak tree reached positive values.

Key words: hardwood, burning rate, flame source, radiant heat source.

INTRODUCTION

For an objective evaluation of the materials for fire protection purpose, a large number of evaluation criteria has been created. In most cases, the criteria evaluate the changes in physical properties which occur in the process of heating or the actual burning of such material. One of the oldest criterion is the change in weight – i.e. weight loss. This criterion is a part of many modern contemporary methods. A logical fact is that material shrinks when burning and the criterion of weight loss is a clear indicator of this happening. In most cases, this criterion is measured over a certain period of time specified in the conditions for the given test method.

Weight loss was the first evaluation criterion used to assess the ignition and burning of materials. It had been applied for the Schlytter method in 1898 (Osvald 1997) and it was used for numerous series of test methods in the decades to follow. The materials containing water started to be evaluated in the 80´s (wood, plasterboard materials, etc.), however, this evaluation criterion provided misleading information.

Water evaporating from the material caused the change in weight which was figured in the total weight loss as the result of burning. A certain disproportion, quality evaluation and application of the test results occurred. Various test methods therefore began to make use of other evaluation criteria. Modern test methods start to use this evaluation criterion anew. It is no longer measured discontinuously (initial and final weight) but it is a continuous measurement in short time intervals allowing to assess this change as weight loss and mass burning rate. Various studies deal with the topic using various types of wood and wood-based materials (MITTEROVA *et al.* 2014; OSVALDOVA 2005; ZACHAR, MARKOVA 2009; SOTOMAYOR, MAKOVICKA 2017).

Wood is a material capable of flame as well as flameless burning (smouldering). It is important to observe weight loss not only during the time interval which is prescribed for the test but also after the completion of the test. A situation - when weight loss increases due to flameless burning or, on the contrary, weight loss reaches negative values (especially when using samples of larger dimensions) when the samples absorb moisture from the surrounding environment - might happen.

The aim of the experiments was to record the change in weight loss in its dynamic form for the selected tree species, to monitor burning rate as well as its significant indicators, the peak value and the time necessary to achieve the value and their mutual ratio.

METHODOLOGY OF THE EXPERIMENT

Test specimens

The following wood species were used for the experiment: black locust ACA (*Robinia pseudoacacia* L.), European white birch BIR (*Betula verucosa* Ehrh.), common beech BEE (*Fagus silvatica* L.), sessile oak OAK (*Quercus petraea* Liebl.), and Norway maple MAP (*Acer platanoides* L.).

The dimensions of each test specimen was 40 × 20 × 20 mm. The input values, the weight and the size of the test specimens were stated and the density at the given moisture level was calculated (the difference was not greater than ± 15 kg/m^3 for the given tree type) prior to the experiment. The moisture content of the test specimens was 8 ± 1 %. 15 samples were made and tested for each tree species. Average values of these 15 measurements are stated in the paper. The test specimens were sorted in alphabetical order but, given the length of paper, they were not specified from the wood processing point of view.

Tab. 1 Average values of the weighted standard deviation.

Wood	Density kg/m^3	Weighted standard deviation σ	Selected weighted standard deviation
ACA	784.21	378.38	384.84
BEE	694.67	317.23	322.65
BIR	644.38	300.01	305.14
MAP	619.55	285.69	290.57
OAK	751.14	365.38	371.63

Test procedure

Radiant heat source (R)

Test specimens were placed under the thermal radiator and, at the same time, Sarto Connect program was launched. This program recorded the weight of test specimens every 10 seconds. This means that the computer recorded the weight of test specimens in 10 second intervals. After 15 minutes, Sarto Collect stopped operating. If the test specimen burned down within the 15 minutes, the experiment was over. The heat output of the radiator was 1000 W. The distance between the sample and the radiator was 30 mm.

Flame source (F)

The test procedure was identical to the one described in the previous paragraph. Unlike the previous experiment, a flame source, a small burner and propane butane were used for this experiment as prescribed by STN EN ISO 11925-2 directive (STN EN ISO 11925-2:2003).

Combined Thermal Load (C)

Combined thermal load means the exposure of the test specimens to a radiant heat source and a flame source using the same device (as for the radiant heat source experiment) and the same measuring procedure of the input parameters of test specimens. The surface of test specimens was exposed to a flame source. If no ignition occurred, it was repeated in 10 second intervals. After 15 minutes, Sarto Collect stoped operating. If the test specimen burned down within 15 minutes, the experiment was over.

Evaluation criteria

Relative burning rate was determined according to the relations (1) and (2).

$$v_r = \left|\frac{\partial \delta_m}{\partial \tau}\right| \quad (\%/s) \qquad (1)$$

or numerically

$$v_r = \frac{|\delta_m(\tau) - \delta_m(\tau + \Delta\tau)|}{\Delta\tau} \quad (\%/s) \qquad (2)$$

where:

v_r - relative burning rate (%/s),
$\delta_m(\tau)$ - relative weight loss in time (τ) (%),
$\delta_m(\tau+\Delta\tau)$ - relative weight loss in time (τ + Δτ) (%),
$\Delta\tau$ - the time interval when the weights are subtracted (s).

Ratio P represented the maximum burning rate divided by the time when it was reached. The ratio was determined according to the relation (3).

$$P = \frac{v_{rmax}}{\tau} (\%/s^2) \qquad (3)$$

where:

P- the ratio of maximum burning rate divided by the time when it was reached ($\%/s^2$),
vr max- maximum burning rate (%/s),
τ- the time when the maximum burning rate was achieved (s).

Results and discussion

The aim of the experiment was to compare the reaction of the selected tree species on thermal heat source, radiation heat source, flame heat source or a combination of the three types. The aim was not to evaluate the effect of the source. Burning rate course for each type of heat source is shown in Figures 1 to 3 and the average peak values are given in Table 1.

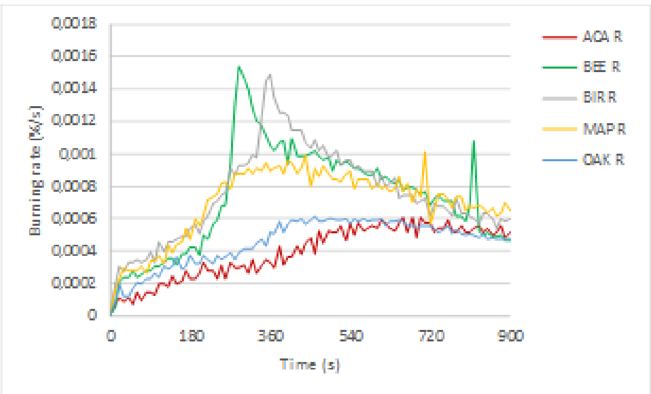

Fig. 1 Burning rate course of the selected tree species exposed to radiant heat source.

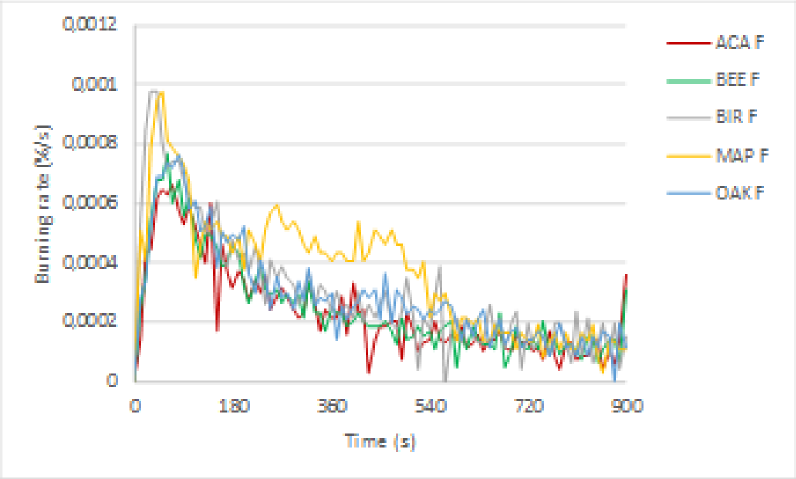

Fig. 2 Burning rate course of the selected tree species exposed to flame source.

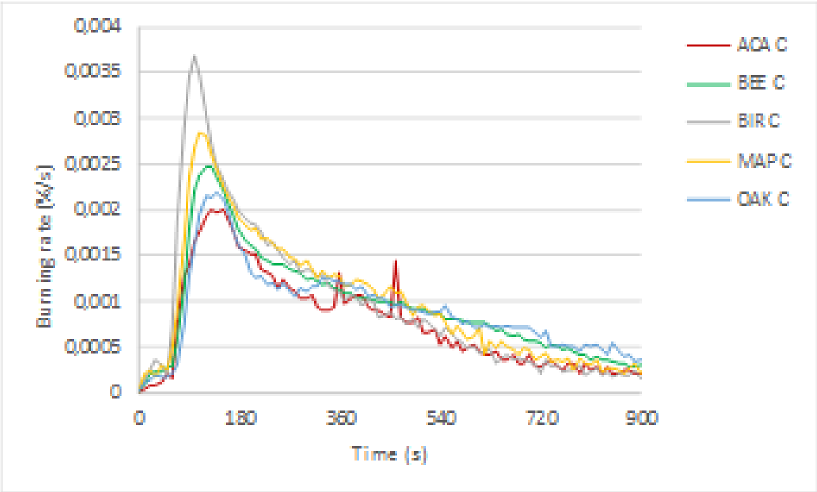

Fig. 3 Burning rate course of the selected tree species exposed to a combined heat source.

Tab. 2 Average values of the selected evaluation criteria.

Evaluation criteria	Heat source	Wood species				
		ACA	BEE	BIR	MAP	OAK
Burning rate (%/s)	R	0.00035	0.00154	0.00100	0.00091	0.00047
	F	0.00065	0.00068	0.00098	0.00095	0.00073
	C	0.00201	0.00248	0.00369	0.00284	0.00219
Time maximum burning rate (s)	R	320	290	320	310	340
	F	50	40	30	40	60
	C	130	130	100	110	140
Ratio P ($\%/s^2$)	R	1.08	5.32	3.12	2.94	1.38
	F	12.92	16.99	35.59	23.67	12.23
	C	15.47	19.07	36.92	25.86	15.63

The best indexes for each evaluation criteria were reached for the tree species with the highest density - locust and oak, whereas the worst ones were achieved for birch. In this case we assume that - besides density - chemical composition of the tree species (percentage of hemicellulose as well as other polysaccharide components of the wood of the given tree species) had an effect on the experiment results.

The experiment demonstrating various methods of wood ignition of the selected trees species (flame heat source, radiant heat source or both) was carried out by simulating real fires conditions. Radiant heat source is a common cause of fires. Since several test methods use flame heat source to determine fire technical properties of wood (OSVALD 1997), flame heat source was observed in more detail. The worst-case scenario is the combination of the two heat sources - radiant heat source "prepares the ground" for the material to burn. In such cases, even a weak flame is enough for the fire to develop in a short time span and its intensity may be relatively high. Thermal radiation in the interior is a crucial factor contributing to heat transfer caused by flames and hot surfaces. Radiation, i.e. heat flow, of 150 kW/m^2 and the temperature of gases reaching 1 000 °C can be observed in a fully developed fire. The thermal radiation values in the first stage of fire are usually ranging between 20–50 kW/m^2 (LIZHONG *et al*. 2000–2001).

Heat release rate is an important parameter used to predict the fire hazard of materials. It is defined as the amount of energy produced by a material in the process of burning per a unit of time (kW/m^2). According to (KARLSSON, QUINTIERE 2000), the curve of heat release rate is not constant in the entire course of burning. We came to the same conclusion during our experiments, although, instead of heat release rate course, mass burning rate course was used as the main criterion. The course of these curves differs, since it depends on the tree type as well as on the type of the source and the ignition method. Heat release rate, together with mass burning rate, are used to characterize the behavior of the material in the first stage of a fire (until flashover) (TRAN 1992, STROUP *et al*. 2004, SOTOMAYOR CASTELLANOS *et al*. 2017).

Burning rate is the main factor used even in modeling the fire resistance of wooden structures. TRAN and WHITE (1992) set the values for both - burning rate and weight loss - if the heat flows range between 15–55 kW/m^2. In this range, there is a linear increase in burning rate as the heat flow grows. It significantly depends on the tree species, its density and its main structural elements. Higher values were reached for the samples made from deciduous wood. The results suggest that charring rate is directly proportional to burning rate and inversely proportional to the density of non-degraded wood samples.

Trees with high density wood - locust and oak - proved themselves to be the best indicators for each evaluation criteria. Birch achieved the worst results. Although the goal of the experiment was not to compare loading conditions (for individual heat sources), we want to draw attention to different course of the curves for the each thermal load (see Fig. 1−3). In addition to significant impact of wood density and its moisture content, the percentage of basic structural elements of wood, when assessing materials from the fire-fighting perspective, appears to be significant as well. As stated by MAKOVICKÁ *et al*. (2016) and OSVALD (2016), wood density has a direct impact on its ignition and combustion. The two authors studied the impact of density not only by comparing different tree species, but also by monitoring different densities within one tree type. The impact of density manifested itself for one tree type even when treated with a fire retardant MAKOVICKÁ *et al*. (2016).

In this case, we can note that chemical composition of the tree species (mainly the percentage of hemicellulose and other polysaccharide components) had an impact on the results as stated in the works of BUBENÍKOVÁ *et al*. (2004), KAČÍKOVÁ *et al.* (2013), and MARTINKA *et al*. (2014). Several authors (ROWELL *et al*. 1984, TRAN, WHITE 1992, JANSSENS 2004, FANGRAT *et al*. 1998) confirmed that there is a statistically significant correlation between the number of the basic structural components of wood, e.g. lignin and the burning rate. The higher the lignin content is, the lower the burning rate is.

In the follow-up stages of the experiment, we recommend to evaluate the results from the point of view of the tree density and the percentage of basic structural components of wood. We recorded some minor variations in the behavior of the tree species i.e. beech which burning rate was higher when exposed to radiant heat source and the peak value was reached sooner than in the case of birch.

These results are essential for testing other non-European tree species. Although they were obtained using a non-standardized test, the measurements have a great information value dividing different types of tree species whilst paying attention to details. The results are applicable in practice, mainly when assessing facade elements and other types of wood cladding and their susceptibility to ignite due to radiant heat from adjacent building fire, directly from a heat source or the combination of the two.

CONCLUSION

Based on the given values we consider justified - when monitoring the fire-technical properties of a material - to apply both heat sources i.e. flame or radiant heat source or the combination of the two. Their intensity does not need to be high in order to determine the reaction of materials to the process that will bring about burning.

Standardized methods generally use samples of larger dimensions to determine their reaction to fire, which is logical and natural, but we recommend multiple small samples and a more thorough statistical evaluation as a follow-up method. The test confirmed that our experiment had some information value and determined the properties of wood in relation to its ignition, burning and a subsequent fire. Such methods are recommended even when testing other tree species i.e. tropical tree species or some modern tree modifications such as thermowood, aesthetic and also flame retardant treatment.

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