

MILAN PROTIĆ¹
 NIKOLA MIŠIĆ²
 MIOMIR RAOS³
 SREĆKO SEKULIĆ⁴

^{1,2,3}University of Niš,
 Faculty of Occupational Safety
⁴Sigurnost d.o.o. Niš

¹milan.protic@znrfak.ni.ac.rs

²nikola.misic@znrfak.ni.ac.rs

³miomir.raos@znrfak.ni.ac.rs

⁴sreckosekulic@hotmail.rs

SOLID WOOD FLAMMABILITY TESTING

Abstract: Household furniture usually contains at least partly some kind of wood material which brings additional fire hazards in enclosures. The number of different wood products is used in furniture manufacture and each of these classes has different flammability characteristics. In this work, we conducted a number of experiments to assess these characteristics for solid oak and fir board samples. Experiments were conducted on mass loss calorimeter for heat fluxes of 30 40 and 50 kW/m². Obtained results were in close agreement with the literature findings.

Keywords: solid wood, enclosure fire, flammability, combustion.

INTRODUCTION

According to the Food and Agriculture Organization of the United Nations (FAO), industrial round-wood removals worldwide in 2018 reached 2.028 million m³ [1]. Sawn-wood production was on the level of 493 million m³, while global wood-based panel production reached 408 million m³ [1]. Sawn hardwood is an important wood product. It is used for the production of furniture (29 percent) as well as for moldings (20 percent), structural housings (18 percent), floorings and paneling (8 percent), and decoration (8 percent) [2]. From these figures, it is clear that considerable quantities of wood material are used for producing household furniture. Wood is flammable and as such presents fire hazards. Enlarged quantities of wood in enclosures consequently bring elevated fire risk. Wood for furniture comes in different forms - as solid wood, particleboard, plywood, fiberboard and each of these classes has different flammability and combustion characteristics. This asks for a systematic approach that will provide insights into the combustion behavior of different wood products and help to improve the existing fire models.

Combustion of wood and charring materials, in general, is a complex process. It encompasses many sub-processes. Water evaporation is the first process that starts when the specimen is exposed to incident heat flux. Pyrolysis/gasification follows. This second stage is often called devolatilization. During this phase, the material loses light volatile compounds generated as a result of thermal degradation of main biomass building compounds: cellulose, hemicellulose, and lignin. The combustion process starts when the concentration of volatiles and temperatures reach appropriate levels. Ignitability of tested material highly depends on the presence of ignition source. Ignition temperatures are considerably lower for piloted ignitions. Flaming combustion proceeds after the ignition. It highly depends on the production rate of volatiles from burning material. Flaming combustion ceases when the concentration of volatiles drops below the lower

flammability limit. Onwards combustion proceeds as char burning. This phase is also called glowing.

In order to assess the fire risk in enclosures and develop reliable numerical models, flammability and combustibility characteristics of materials should be known with acceptable accuracy. Most reliable results regarding the fire performance of materials can be gathered from intermedium to large scale fire tests: Single Burning Item (the SBI) EN 13823 [3], ISO 9705 [4], ASTM E1474 [5] and ASTM E2067 [6]. While being accurate and reliable these tests are expensive and cumbersome. However, Babrauskas showed that the number of results from full-scale fire tests can be predicted, with acceptable accuracy, from tests performed on bench-scale instruments [7]. The most frequently used instrument for performing bench-scale experiments and gathering relevant flammability and combustibility data is the cone calorimeter developed by NIST (National Institute of Standards and Technology) in the eighties. Material testing should be conducted according to ISO 5660 [8].

This paper aimed to study combustibility and flammability studies of solid wood board specimens used for fabricating household furniture. Oak (*Quercus cerris*) and Fir (*Abies alba*) wood samples with a thickness of 10 and 20 mm were tested. Experiments were performed under the three incident heat fluxes of 30, 40, and 50 kW/m².

MATERIALS AND METHODS

Materials

Experiments were performed on solid wood boards from oak and fir. Wood specimens were provided from the local sawmill. The samples were cut to a dimension of 100 x 100mm. Specimen thicknesses were 10 and 20 mm. Before tests, samples were wrapped with Al foil. Ceramic fiber blankets were placed below the samples. In between the bottom of the sample holder and ceramic blanket, the ceramic block was fitted. All the tests were performed with the retainer frame. Samples before the test are shown in Figure 1.



Figure 1. *Fir (left) and Oak (right) board samples*

Samples were conditioned in laboratory (temperature 22 ± 2 °C and relative humidity $50 \pm 5\%$) for two

months before testing. Testing for each material and heat flux was repeated at least twice in order to check the repeatability of obtained results. All the samples were tested in a horizontal position.

Composition and heating values for higher heating values for Fir and Oak are shown in Table 1. Data were compiled from various resources [9]. The composition is reported on a mass basis, for dry samples. Heating value is expressed for higher heating value (Hh) in [kJ/kg]. Values fluctuate through literature but provided numbers present averages. From the table, it is obvious that values are very similar for different wood species tested.

Table 1. *Composition and heating values of fir and oak*

	C	H	O	N	S	A	Hh
Fir	50.35	6.14	43.18	0.05	-	0.28	21101
Oak	49.89	5.98	42.57	0.22	0.05	1.29	19992

Method

Mass loss calorimeter apparatus

Experiments were performed in Mass loss calorimeter made by Fire Testing Technology - FTT (East Grinstead, UK). Mass loss calorimeter is a device used for reaction-to-fire characterization of a solid sample in a similar way as in cone calorimeter. The material testing procedure is set up in ISO 17554 [10] and EN ISO 13927 [11]. Apparatus was put in a specially designed fume cupboard in order to extract the fire effluents. Installation is shown in Figure 2.



Figure 2. *Mass loss calorimeter inside the specially designed fume cupboard*

Exhaust gas system with appropriate ports for gas sampling and temperature and velocity measurement was manufactured according to requirements defined in ISO 5660 [8].

Calibrations were performed before the tests. Three calibration procedures were undertaken. Initially, the cone heater was calibrated for incident heat fluxes of 30, 40, and 50 kW/m². Calibration was performed with the Schmidt-Boelter water-cooled heat flux meter (Medterm, Huntsville, USA). In the second step, the thermopile system was calibrated with methane sand burner for appropriate heat release rates. Calibration was performed for 5 kW, 4 kW, 3 kW, 2 kW, 1 kW, 0.75 kW and 0.5 kW. Finally, the load cell was calibrated, zeroed, and spanned for expected specimen masses.

Distance between the exposed surface of tested samples and the cone heater was set to 25 mm. Additionally, volumetric flow in the exhaust gas system was set to 0.024 m³s⁻¹. Combustion tests were performed under the well-ventilated conditions.

Results and discussion

During the tests following parameters were recorded/calculated:

- Ignition time (s)
- Flameout time (s)
- Peak HRR (kW/m²)
- Peak EHC (MJ/kg)
- Peak MLR (g/s)
- Time to peak HRR (s)
- Time to peak EHC (s)
- Time to peak MLR (s)
- Mean HRR (kW/m²)
- Mean EHC (MJ/kg)
- Mean MLR (g/s)
- Total heat release (MJ/m²)
- Percentage mass lost (%)

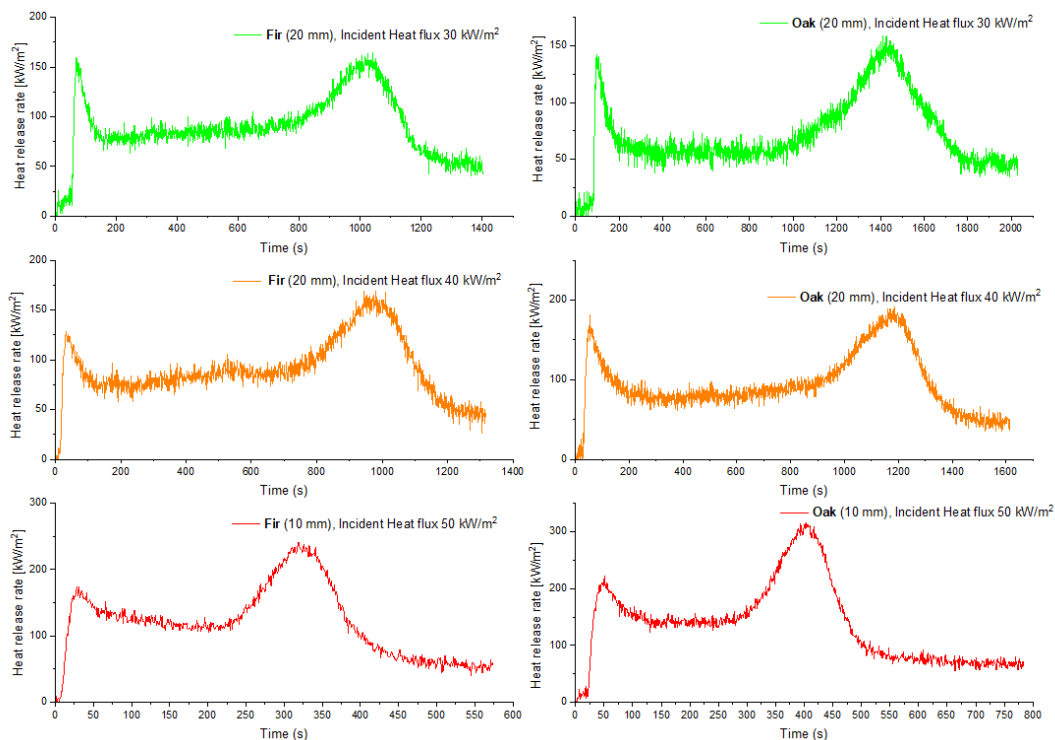
Results for both specimens, for three tested incident heat fluxes, are summarized in Table 2.

Table 2. Flammability parameters for fir and oak

	Incident heat flux (kW/m ²)	30	40	50*
Ignition time (s)	Oak (<i>Quercus cerris</i>)	83	30	25
	Fir (<i>Abies alba</i>)	55	16	11
Flameout time (s)	Oak (<i>Quercus cerris</i>)	1737	1433	565
	Fir (<i>Abies alba</i>)	1252	1199	452
Peak HRR (kW/m ²)	Oak (<i>Quercus cerris</i>)	158.88	193.02	317.80
	Fir (<i>Abies alba</i>)	164.73	170.09	242.26
Peak EHC (MJ/kg)	Oak (<i>Quercus cerris</i>)	79.45	79.33	69.00
	Fir (<i>Abies alba</i>)	79.03	78.90	79.36
Peak MLR (g/s)	Oak (<i>Quercus cerris</i>)	0.23	0.19	0.27
	Fir (<i>Abies alba</i>)	0.21	0.18	0.26
Time to peak HRR (s)	Oak (<i>Quercus cerris</i>)	1430	1186	403
	Fir (<i>Abies alba</i>)	1040	981	319
Time to peak EHC (s)	Oak (<i>Quercus cerris</i>)	564	155	490
	Fir (<i>Abies alba</i>)	836	1073	396
Time to peak MLR (s)	Oak (<i>Quercus cerris</i>)	87	1097	417
	Fir (<i>Abies alba</i>)	68	24	81
Mean HRR (kW/m ²)	Oak (<i>Quercus cerris</i>)	79.09	101.93	169.24
	Fir (<i>Abies alba</i>)	97.13	95.89	139.61
Mean EHC (MJ/kg)	Oak (<i>Quercus cerris</i>)	11.40	12.40	14.00
	Fir (<i>Abies alba</i>)	14.60	14.19	15.38
Mean MLR (g/s)	Oak (<i>Quercus cerris</i>)	0.06	0.07	0.11
	Fir (<i>Abies alba</i>)	0.06	0.06	0.08
Total heat release (MJ/m ²)	Oak (<i>Quercus cerris</i>)	131.51	143.25	91.74
	Fir (<i>Abies alba</i>)	117.02	113.52	61.70
Percentage mass lost (%)	Oak (<i>Quercus cerris</i>)	76.20	76.68	80.17
	Fir (<i>Abies alba</i>)	83.49	81.87	84.44

Of all parameters describing fire behavior, the heat release rate can be regarded as the single most important variable in fire hazard [12].

Heat release rates for both materials for all tested heat fluxes are shown in Figure 3.

**Figure 3.** Heat release rates for Fir and Oak for different incident heat fluxes

As was expected rising heat flux reduces ignition time. It is noticeable shorter for fir specimens. Additionally, the heat release rate curves have a similar shape. This shape is characteristic of charring materials. The first peak corresponds to the ignition of volatiles. Afterward, a period of sustained flaming follows. Next, a higher peak emerges at the moment when heat from the surface of the specimen reaches the bottom end of the material. From this moment on, the material starts burning from the whole volume. Obtained results were compared with findings from the literature [13,14]. Similar profile shapes were noticed.

CONCLUSION

In this work flammability and combustibility characteristics of two solid wood types were experimentally determined. From this work following conclusions can be derived:

- Heat flux of less than 30 kW/m² is sufficient to ignite fir and oak solid wood boards;
- Critical flux should be searched in the range between 20 and 30 kW/m²;
- Ignition time (for piloted ignition) is considerably shorter for fir than for the oak. This observation is more pronounced for higher heat fluxes;
- Heat release rate profiles have two pronounced peaks, which corresponds very well with literature findings and
- Fir burns much faster than oak.

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BIOGRAPHY of the first author

Milan Protić was born in Niš, Serbia, in 1979. He received a diploma in mechanical engineering and a Ph.D. degree from the University of Niš, Faculty of Occupational Safety in Niš. His main areas of research include renewable energy sources, district heating systems, combustion, and fire research. He works as an assistant professor at the Faculty of Occupational Safety in Niš, University of Niš.



ISPITIVANJE UPALJIVOSTI DRVETA

Milan Protić, Nikola Mišić, Miomir Raos, Srećko Sekulić

Rezime: Nameštaj u domovima najčešće u izvestoj meri sadrži drvo što uvećava požarno opterećenje u zatvorenim prostorima. Za izradu nameštaja se koriste različite vrste drveta čije se karakteristike upaljivosti značajno razlikuju. U ovom radu izvršeno je ispitivanje karakteristika upaljivosti uzoraka hrasta i jele. Ispitivanja su izvršena na kalorimetru za ispitivanje toplotne snage za toplotne flukseve od 30, 40 i 50 kW/m². Dobijeni rezultati su u saglasnosti sa rezultatima iz literature.

Ključne reči: drvo, požari u zatvorenim prostorima, upaljivost, gorivost.