

## **Analysis of the heat release rate and susceptibility to ignition for selected samples of wood and wood-based materials**

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**Abstract:** The article presents an analysis of the heat release rate for samples of wood and wood-based products. The susceptibility to ignition of the tested materials was discussed, with a review of the time until ignition for various samples, the average values of the specific extinction area ( $SEA_{av}$ ), as well as the surface temperature of samples needed for ignition of volatile flammable products. The application of lignocellulosic composites with polystyrene and mineral wool leads to a reduction in the  $HRR_{av}$  value as compared to non-modified samples of pine and oak, as well as considerably elongates the time needed until ignition of the sample.

*Keywords:* heat release rate, specific extinction area, lignocellulosic composites, ignition time

Wood belongs to flammable materials, which right from the beginning of our civilisation was used as considered to be one of the most important construction materials. It is first of all used in construction as a structural material, as well as for the production of furniture or other interior fit-out elements. Unfortunately this is an easily flammable material.

The impact of appropriate heat exposure on wood and wood-based materials leads to physical and chemical changes. In fire conditions of importance is the initial temperature of thermal decomposition, during which chemical bonds are broken in the wood structure and gaseous flammable products are released, which may burn over the surface of the material. This process would be of a self-sustaining nature if the burning gases supply sufficient heat to the material to allow continuation of release of gas-steam flammable products. Most frequently in the presence of oxygen from the air volatile flammable products may form a flammable mixture over the surface of the material. Such a mixture may be ignited in two ways:

- if the generated flammable gases reach a concentration within the range of explosive limits, then after provision of pilot energy stimulus (such as a fire or electric spark) ignition may take place. This phenomenon is called imposed (piloted) ignition;
- the second way of igniting the flammable volatile phase is self-ignition (spontaneous ignition, inflammation). This phenomenon proceeds without the piloted stimulus. A condition for ignition of the flammable mixture is the necessity of achieving a temperature of self-ignition (ignition) of at least one of the flammable components in the air [1 - 5].

For ignition of the flammable volatile phase to take place, the following conditions have to be met:

- the material surface has to achieve the minimum temperature, at which the flow of the gas-steam mixture (the volatile phase) is sufficient for ignition or the inflammation (sustaining the flame combustion);
- achievement of the critical stream of a mass of volatile products formed of the flammable material, which determines combustion;
- assuring the minimum external heat stream necessary to ignite the flammable volatile phase obtained from a solid material [1].

As regards thermally thick materials, i.e. with a thickness over 1mm, the sample thickness is much bigger than the characteristic thickness of the heated layer. In practice this

means that the dimension of sample thickness is given in centimetres. For this type of samples the ignition time of flammable volatile products is inversely proportional to the net heat flow square from the material sample surface according to the following formula:

$$t_i = \frac{\pi}{4} \rho c k \left( \frac{T_i - T_o}{\dot{q}_{net}''} \right)^2 \quad (1)$$

where:  $t_i$  - time until pilot ignition [s],  $T_i$  - temperature of material surface during pilot ignition [K],

$T_o$  - temperature of the surroundings [K],  $\dot{q}_{net}''$  - net heat flow from the surface of the material [kW].

The presented formula allows describing only relatively simple aspects of thermal radiation ignition. This implies that processes taking place in the gaseous and solid phase are simplified by the fact that in the solid phase the variable density of the absorbed heat flux, the impact of the heat exchange and mass in solid material being broken down are not taken into consideration.

This paper concerns a comparative analysis of materials made of wood (pine, oak) and wood based materials (lignocellulosic composites with polystyrene and mineral wool), with respect to testing the heat release rate at external heat exposure of 25 kW/m<sup>2</sup> and susceptibility to ignition. It analyses times until ignition of the flammable gaseous phase and critical temperatures of the surface of tested materials that determine the formation of a mass stream of flammable volatile products.

## DESCRIPTION OF TEST MATERIAL

The tests were conducted with the use of dried seasoned samples of the oak and the pine, and cellulose composite materials with polystyrene and mineral wool.

Boards with a 10% admixture of mineral wool had a density of 600kg/m<sup>3</sup> and dimensions 330 × 330 × 12 mm. The boards were made of industrial pine flakes (6.0% moisture content) and commercial mineral wool (2.2% moisture content). A UF resin was used as adhesive hardened with 10% NH<sub>4</sub>Cl. UF 50 parts by weight, water 12 parts by weight. Glue load was 10 wt%. Purely pine-flake boards were used as reference.

Boards with a 20% addition of polystyrene with a density of 500kg/m<sup>3</sup> and thickness of 18 mm. The boards have been made at the Department of Wood Based Panels, Faculty of Wood Technology, the Warsaw University of Life Sciences – SGGW. Foamed polystyrene in the form of granules in amount of 5%, 10% and 20% was added to core layer of the boards so that the assumed density of the board could be maintained. All variants of the boards were bonded with UF resin (glue rates: face layer – 8%, core layer – 12%). Mixing of the components (polystyrene + wood chips) and formation of the boards was done manually with the use of a special mould.

## TESTING METHODOLOGY

The tests were carried out on a cone calorimeter in accordance with provisions of the standard ISO 5660, making use of a heat flux with a density of: 25 kW/m<sup>2</sup>, type of initiation of the combustion reaction – ignition (the presence of the so-called external piloted stimulus), at horizontal orientation of the samples in relation to the radiator.

## TEST RESULTS

Results of tests for samples of the pine and the oak and of cellulose components with polystyrene and mineral wool were presented in the below tables - Table 1 and Table 2, and on figures 1 and 2. For each of the samples delimited was the coefficient of HRR<sub>av</sub>, SEA<sub>av</sub>, t<sub>ignition</sub>, MLR<sub>av</sub>, CO<sub>av</sub>, CO<sub>2av</sub>. In addition with the use of a thermovision camera a measurement

was made of the temperature of samples at the time of ignition and immediately after extinguishing of the flame.

Name of material	HRR <sub>av</sub> [kW/m <sup>2</sup> ]	SEA <sub>av</sub> [m <sup>2</sup> /kg]	t <sub>ignition</sub> [s]	MLR <sub>av</sub> [g/m <sup>2</sup> s]	CO <sub>av</sub> [kg/kg]	CO <sub>2av</sub> [kg/kg]
oak	91	37	644	12.6	0.05	1.13
pine	108	194	63	7.2	0.03	1.01
pure particle board	52	25	1482	3.9	0.1	1.27
particle board with 10% mineral wool	51	44	855	5.7	0.06	1.06
particle board with 20% polystyrene	84	221	1157	4.6	0.09	1.48
particle board with bisided lamination	82	16	1793	7.6	0.02	1.12

<b>SAMPLE</b>	<b>Temperature of sample at the time of ignition</b>	<b>Temperature of sample at the time of flame extinguishing</b>
pine	<b>220°C</b>	<b>610°C</b>
oak	<b>460°C</b>	<b>625°C</b>
pure particle board	<b>520°C</b>	<b>610°C</b>
particle board with 10% mineral wool	<b>500°C</b>	<b>590°C</b>
particle board with 20% polystyrene	<b>560°C</b>	<b>590°C</b>
particle board with bisided laminated	<b>550°C</b>	<b>590°C</b>

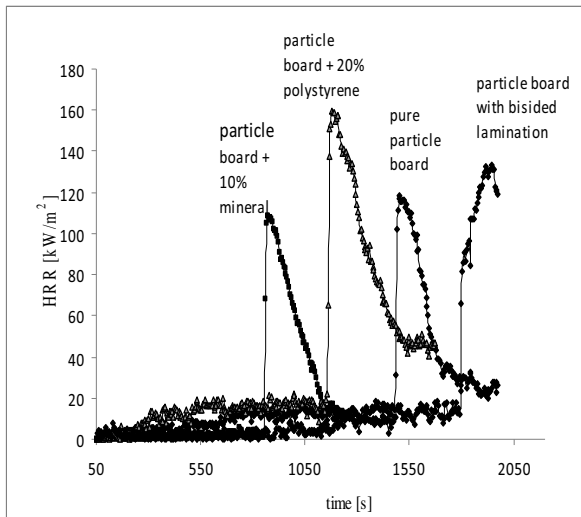


Fig. 1. Heat release rate for modified wood samples

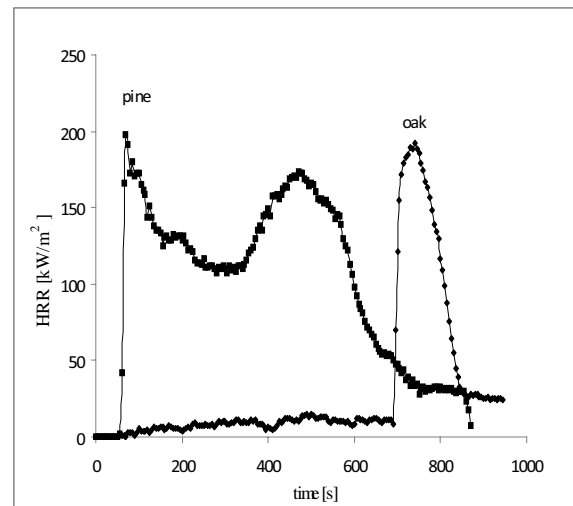


Fig. 2. Heat release rate for non-modified wood samples

## CONCLUSIONS

A review of obtained results allows drawing of the following conclusions:

1. The application of lignocellulosic composites with polystyrene and mineral wool causes a reduction in the  $HRR_{av}$  values as compared to samples of the pine and the oak.
2. On the basis of the heat release rate curves from the tested materials it may be presumed that in the first stage of testing HRR values are low, because the initial phase consists in heating up and thermal decomposition of the samples. This process lasted at least 50 seconds until the ignition moment took place of the flammable volatile products, which is illustrated by a raise of the heat release rate curve until it reaches maximum values.
3. As regards the pine it was found that in the 55<sup>th</sup> second an increase of the heat release rate (HRR) took place, which was followed by a decline of the HRR curve, after which its repeated raise may be seen. The first maximum HRR peak is a result of the piloted ignition of the gaseous flammable products of thermal decomposition. The second HRR peak is an effect of cracking of the carbonised layer formed on the wood sample. Moreover, on the HRR curve there is a characteristic 'saddle' which is proof of the formation of carbonised layers on the surface of the samples.
4. As regards the oak and wood-based material samples only the first maximum HRR peak is visible, formed as an effect of ignition of gaseous flammable thermal decomposition products. After that a fall in the HRR value takes place as an effect of the formed carbonised layer, which forms a barrier for the supplied heat and oxidation processes.
5. Piloted ignition occurs the soonest for the pine and oak samples. The application of admixtures for wood such as lignocellulosic composites with polystyrene and mineral wool leads to considerable elongation of the ignition time of the sample.
6. The highest average smoke release value  $SEA_{av}$  for non-modified wood samples were recorded for the pine. This value is over five-fold higher than for the oak.

7. As regards wood-based materials, the maximum mat  $SEA_{av}$  value was obtained for a particle board with a 20% admixture of polystyrene. This value is almost fourteen times higher as compared to a bilaterally laminated particle board.

8. The lowest values of  $CO_{av}$  and  $CO_{2av}$  released from 1 kilogramme of tested material under the impact of the heat flux with a density of  $25 \text{ kW/m}^2$  both for non-modified wood and with admixtures were obtained for a bilaterally laminated particle board with polystyrene.

9. As regards the oak and the pine,  $CO_{av}$  values released from 1 kilogramme of the tested material are lower in relation to wood-based products with the exception of a bilaterally laminated particle board.

10. The ignition temperature displayed by the thermovision camera for wood-based samples (lignocellulosic composites with polystyrene and mineral wool) are higher than for samples of non-modified wood (oak and pine). A particular difference in temperatures is visible for the pine and for wood-based samples.

11. The temperature values of samples after extinguishing of the flame both for non-modified wood and with admixtures are similar and remain within the range of  $590^\circ\text{C}$  to  $625^\circ\text{C}$ .

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**Streszczenie:** *Analiza szybkości wydzielania ciepła oraz podatność na zapłon dla wybranych próbek drewna i materiałów drewnopochodnych. Drewno – materiał palny, już od początku naszej cywilizacji było stosowane jako podstawowy materiał budowlany. Jak każdy materiał posiada pewne wady. W przypadku drewna jego słabym punktem jest łatwopalność. Celem niniejszej pracy jest analiza porównawcza szybkości wydzielania ciepła oraz podatności na zapłon materiałów wykonanych z drewna (sosny, dębu) oraz drewnopochodnych (kompozyty lignocelulozowe z polistyrenem oraz wełną mineralną).*