

## **DETERMINATION OF THE CRITICAL HEAT FLUX FOR FLOATING FLOORING**

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### **ABSTRACT**

The paper deals with the possibility of floating flooring ignition due to radiant heat. Samples of floating flooring with dimensions of  $100 \pm 1$  mm x  $100 \pm 1$  mm and thickness of 6 mm were thermally loaded by different densities of external heat flux. The flaming combustion was initiated either solely by means of radiant heat, or in combination with electric spark igniter. Cone calorimeter was used for the determination of the critical heat flux. Time to ignition for each sample was recorded and the obtained data were used for the calculation of the critical heat flux density.

**KEY WORDS:** Time to ignition, cone calorimeter, critical heat flux, floating flooring, radiation heat,

### **INTRODUCTION**

There are three types of wood flooring: laminate flooring, engineered flooring and solid wood flooring. The laminate flooring consists of HDF (high-density fiberboard) as the core material, while the engineered flooring consists of plywood with a thin fancy veneer.

Manufacturers state that laminate flooring technology was invented in 1977 (Egger 2014, Pergo, Hdm, Tampa flooring company). The technology gradually gained a stronger position in the market and nowadays is the laminate flooring very popular. It provides an affordable alternative to wooden floors which it often imitates by its color and finish. Another positive feature is its relatively simple and quick assembly (Kim and Kim 2016).

Recently, several authors researched the effects of increased temperature on the floating flooring, substances likely to be released into the environment were observed (Lee et al. 2012, Wiglusz et al. 2002, An et al. 2011). Since only a relatively small amount of information about the combustion of laminate flooring is available, it is important to focus on different materials which they comprise of.

Classically produced laminate flooring is made up of three layers: Overlay and decor layer, core layer and backing layer (Fig. 1 core layer and backing layer (Fig. 1).

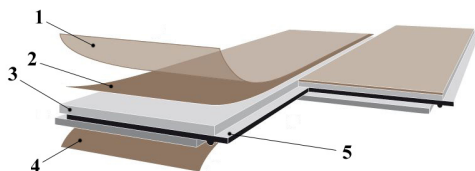


Fig. 1: Layers of floating laminate flooring; 1 – top layer, 2 – decor layer, 3 – central layer, 4 – rears side, 5 – click mechanism (European Producers of Laminate Flooring).

It is produced in board form. The production process involves the individual layers in the laminate flooring being pressed together under high pressure and at high temperature. The topmost layer of a laminate flooring (also known as top layer) consists mostly of melamine resin which gives the flooring its good durability. It protects the underlying decorative layer. The central layer in a laminate flooring is made of Medium Density Fibreboard (MDF) or High Density Fibreboard (HDF). The stabilizing layer, a compact elastic paper, makes up the bottom layer of laminate flooring and is what gives the floor its stability (European Producers of laminate flooring a, European Producers of laminate flooring b).

Melamine is used in the synthesis of melamine resin. It is a heterocyclic tri-amino compound containing a tri-amino substituted 1, 3, 5-triazinic skeleton. Its thermal degradation in air flow occurs in one event, between 256°C and 402°C, with a peak of 392°C. The flame retardant effect is due to a sudden thermal induced decomposition at a relative elevated temperature and a significant endothermic effect. The gases evolved by decomposition are helpful by stopping, whatever, ignition and/or burning process (Ledeti et al. 2014). Melamine resins are water clear, so they are generally used for products where the color or pattern of the substrate is retained with a transparent melamine protective coating or binder. They have excellent color, hardness, and solvent, water, and chemical resistance, heat resistance, and humidity resistance (Fink 2013).

Medium and high density fiberboards (MDF and HDF) are wood-based composites formed by break down softwood and hardwood into wood fibers, in a defibrator, combining it with wax and resin, and forming panels by applying high-temperature and pressure in a hot press. MDF typically has a density of 600-800 kg·m<sup>-3</sup>, while HDF has a density of 800-1.100 kg·m<sup>-3</sup> (Ayrilmis 2007) According to Fang et al. the process of combustion of wood can be divided into four steps (Fang et al. 2006):

1. before 150°C, moisture is vaporized;
2. from 150 to 400°C, volatiles are released from sample and burns;
3. above 400°C, few of volatiles are released and semi-coke material burns until the temperature reaches 700 °C;
4. from 800°C to 1100 °C, the remaining semi-coke reacts with carbon dioxide,

Similar results state Magdziarz and Wilk (2013), who divided combustion process into three stages. The first stage corresponded to loss of moisture and very light volatile compounds. The temperature range of the first stage was from ambient temperature to about 200°C. In the second stage (200°C – 600°C) a significant drop in mass was observed, caused by the thermal decomposition of hemicellulose, cellulose and lignin. Once the temperature was higher than 600°C mass loss was brought to an end by thermal decomposition. Three steps of mass loss is

also described by Liu et al. (2002) The first step (to temperatures between 180°C – 192°C) is due to water evaporation. The second step (to temperatures between 359°C – 380°C) results from the pyrolysis of hemicellulose and cellulose. The pyrolysis of lignin contributes partly to the second and third steps, and the third step (to temperatures between 496°C – 570°C) is largely affected by oxidation (Liu et al. 2002).

## MATERIAL AND METHODS

Commercially available 7 mm thick laminate floating flooring was used as a test sample. 24 square shaped samples with sides of length of  $100 \pm 1$  mm were cut out of the basic material. The actual thickness of the samples was 6.6 mm. Surface of the samples is shown in Fig. 2. The total number of tested samples was 24 pieces, for each heat flow 3 samples were tested using spark igniter and 3 samples without it. The flaming combustion of the sample after its ignition is shown in Fig. 3.

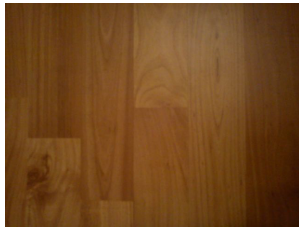


Fig. 2: Floating flooring sample.



Fig. 3: Sample after ignition.

Diagram of the test device is shown in Fig. 4. All unexposed sides of sample were coated with aluminum foil and placed on a pad of mineral wool located on the bottom of sample holder (2). Subsequently, the holder with the sample was placed under the cone heater (4).

A spark igniter was moved over the surface of the sample (3) in the case of testing with igniter. The removal of the thermal degradation products of tested material was secured by exhaust system which consisted of Hood (5) ducts and fan. Exhaustion rate was set to  $0.024 \text{ m}^3 \cdot \text{s}^{-1}$ .

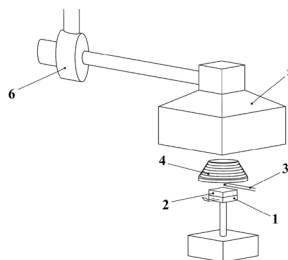


Fig. 4: Test device: 1 – holder of sample, 2 – sample, 3 – spark igniter, 4 – cone heater, 5 – hood, 6 – fan (Rantuch et al. 2016).

The external heat flux densities applied to the samples were  $35 \text{ kW} \cdot \text{m}^{-2}$ ,  $40 \text{ kW} \cdot \text{m}^{-2}$ ,  $45 \text{ kW} \cdot \text{m}^{-2}$  and  $50 \text{ kW} \cdot \text{m}^{-2}$  in the case of testing without igniter, and  $30 \text{ kW} \cdot \text{m}^{-2}$ ,  $35 \text{ kW} \cdot \text{m}^{-2}$ ,  $40 \text{ kW} \cdot \text{m}^{-2}$  and  $45 \text{ kW} \cdot \text{m}^{-2}$  in the case of testing with igniter, since lower densities of heat flux

are sufficient for sample ignition in this case. Time to sample ignition was recorded. The used equipment was part of the cone calorimeter complying with ISO 5660-1 (2002) and ISO 5660-2 (2002). The ambient temperature during the measurements was  $29 \pm 1^\circ\text{C}$  and moisture content  $39 \pm 1\%$ .

### Critical heat flux

The critical heat flux is defined as the minimum external heat flux required for achieving piloted ignition of an exposed sample (Spearpoint and Quintiere 2001).

There are two possible ways of radiative ignition: one is auto-ignition and the other is piloted ignition. Auto-ignition results solely from the external heating of the material substrate, without the presence of a high temperature source near the material surface. Piloted ignition refers to forced ignition of the combustible vapors by a high temperature pilot (Brown et al. 1988). Therefore, the recorded times to ignition were for the cases of radiant heat and the combination of the radiant heat and electric spark ignitor.

Tewarson (2002) states, that the inverse of the square root of time to ignition is expected to be a linear function of the external heat flux away from the critical heat flux value:

$$\sqrt{\frac{1}{t_{ig}}} = \frac{\dot{q}_s'' - \dot{q}_{cr}''}{TRP} \quad (1)$$

where:  $t_{ig}$  - time to sample ignition,  
 $\dot{q}_s''$  - surface density of external heat flux,  
 $\dot{q}_{cr}''$  - critical heat flux,  
 $TRP$  - thermal response parameter.

Critical heat flux can then be determined using equation of the dependence of density of the external heat flux and the reciprocal of the square root of time to ignition of the sample at the time close up to infinity.

Spearpoint and Quintiere (2001) described model in which the ratio of incident heat flux to the critical heat flux values was between 0.758 and 0.768, and therefore it can be considered being approximately 0.76. For the calculation of the critical heat flux it is then possible to use the same method as in the previous model, but adjusted by the constant:

$$\sqrt{\frac{1}{t_{ig}}} = \frac{\dot{q}_s'' - 0,76\dot{q}_i''}{TRP} \quad (2)$$

where:  $\dot{q}_i''$  is intercept with the abscissa of a straight line fit through the plot of  $t_{ig}^{-0,5}$ . (Xu et al. 2015) Zhang et al. (1996) based on the assumption that the critical heat flux can be obtained by plotting the imposed heat flux against reciprocal ignition time:

$$\dot{q}_s'' = \left(\frac{C}{t_{ig}}\right)^n + \dot{q}_{cr}'' \quad (3)$$

where  $C$  - constant,  
 $n$  - a chosen ignition time index to give the best straight line fit.

For material with density of  $500 \text{ kg}\cdot\text{m}^{-3}$ , emissivity of 1 and ignition temperature ranking from  $250^\circ\text{C}$  to  $550^\circ\text{C}$  Janssens (1991) calculated  $n$  in dependence from ignition temperature from 0.539 to 0.561. Thus  $n = 0.547$  still appears to be a good average and equations of the following form can be used (Eq. 4) :

$$\dot{q}_s'' = \dot{q}_{cr}'' \left[ 1 + 0,73 \left( \frac{k\rho c}{h_{ig}^2 t_{ig}} \right)^{0,547} \right] \quad \varphi = 1 + 0,73 \left( \frac{1}{t_{ig}} \right)^{0,547} \quad (4)$$

where:  $k$  - thermal conductivity,  
 $\rho$  - density,  
 $c$  - specific heat capacity,  
 $h_{ig}$  - convection coefficient at ignition,  
 $\varphi$  - non-dimensional irradiance.

In addition to the methods of critical heat flux calculation that consider ignition of materials in infinite time, some authors state that in practical terms it is more favorable to apply the heat flow needed to initiate the flaming combustion to a certain period of time. Brown et al. (1988) based on the equation:

$$t_{ig} = \frac{\pi k \rho c}{4} \left( \frac{T_{ig} - T_0}{q_s} \right)^2 \quad (5)$$

Extrapolation to 600 s, the recommended time limit for ignition in cone calorimeter, represents the minimum external flux (MERF) necessary to produce pilot ignition after a protracted exposure of 600 s to irradiative heating.

A more practical application of the ignition times would involve determining irradiance required to cause ignition at some other time, such as 300 s, for example. This represents an estimate of the maximum external flux from fire in the environment where composites are used that the composite could withstand before the material would begin to contribute to the fire growth. (Brown et al. 1988) Fateh et al. (2014) based on the same relationship as Brown et al. (1998), but they are considering a maximum time to ignition of 30 minutes.

## RESULTS

During the increase of floating flooring surface temperature by the means of radiant heat, formation of gas bubbles under the top layer occurred. The top layer manifested as virtually non-flammable. The initiation of flaming combustion occurred in almost all cases after the breaking of this lawyer, when the release of decomposition gases of floor fiberboard occurred.

Tab. 1: Average time to ignition of the samples at various heat flux densities.

	External heat flux density (kW·m <sup>-2</sup> )	Mean time to ignition (s)
Without igniter	35	27
	40	134
	45	75
	50	52
With igniter	30	143
	35	86
	40	69
	45	46

This phenomenon occurred during the testing conditions with and also without the igniter. It is therefore possible to confirm the hypothesis described in the introduction, that melamine resin has excellent heat resistance properties. The time to ignition of the samples declined with increasing heat flux density (Tab. 1), which is a logical consequence of increased amount of energy received by the sample surface.

The times to ignition were significantly higher in the cases of test conditions without spark igniter. Also the dispersion of individual values was higher, which represented 276 s at the heat flux density of 35 kW·m<sup>-2</sup>. The lowest dispersion was observed at heat flux density of 45 kW·m<sup>-2</sup>, which was 5 s for both methods.

Dependencies shown in Figs. 5 and 6 were obtained after the implementation of data from Tab. 1 to the Eqs. 1 - 5. The critical heat fluxes of floating flooring samples were acquired from the equations of the dependencies of trend lines.

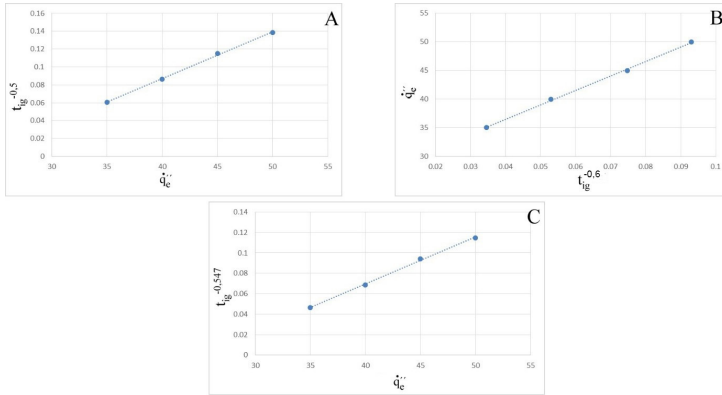


Fig. 5: Graphic representation of the dependencies of time to ignition and external heat flux densities in the case of sample ignition without spark igniter: A – Eqs. 1, 2, 5; B – Eq. 3; C – Eq. 4.

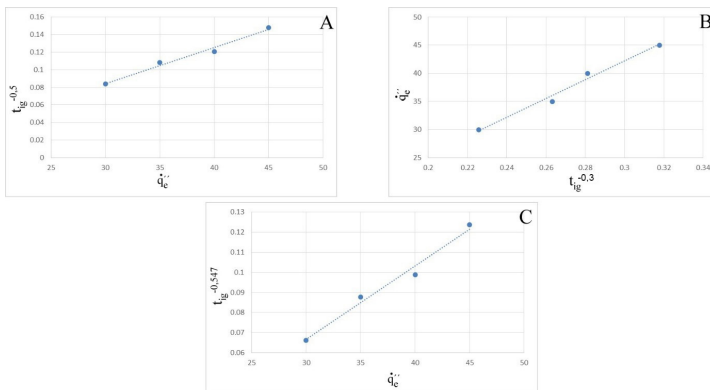


Fig. 6: Graphic representation of the dependencies of time to ignition and external heat flux densities in the case of sample ignition with spark igniter: A – Eqs. 1, 2, 5; B – Eq. 3; C – Eq. 4.

The critical heat flux density was significantly higher in the case of igniter absence as can be seen in Tab. 2.

Tab. 2: The critical heat flux densities and squares of correlations of corresponding equations.

Method	Igniter	Critical heat flux density (kW·m <sup>-2</sup> )	R <sup>2</sup> (-)
Tewarson (2002)	Yes	9.5	0.9828
	No	23.6	0.9983
Speapoint and Quintiere (2001)	Yes	12.5	0.9828
	No	31.0	0.9983
Zhang et al. (1996)	Yes	-7.9	0.9836
	No	26.4	0.9987
Janssens (1991)	Yes	11.8	0.9822
	No	24.9	0.9986
Brown et al. 1 (1988)	Yes	19.5	0.9828
	No	31.4	0.9883
Brown et al. 2 (1988)	Yes	23.6	0.9828
	No	34.7	0.9883
Fateh et al. (2014)	Yes	15.3	0.9828
	No	28.1	0.9883

It ranges from 23.6 kW·m<sup>-2</sup> to 34.7 kW·m<sup>-2</sup>. In contrast, the critical heat flux decreases to 9.5 kW·m<sup>-2</sup> – 23.6 kW·m<sup>-2</sup> in the case, when the igniter is used. Critical heat flux density is negative in the case of calculation according to the Zhang et al. (1996) method and obviously, this result cannot be considered as correct. Since this is a specific method, largely dependent on the amount of measurement data, it can be assumed that in the case of greater number of measurements would the calculated value be more close to the results of other methods.

Relatively broad ranges in the critical heat flux densities are caused by the use of methods calculating with a final time in which the ignition can occur. In terms of safety, it is preferable to incline towards lower values.

## DISCUSSION

The measured floating flooring sample is, as already mentioned in the introductory section, a composite material with wood-based core. Speapoint and Quintiere (2001) determined the critical heat flux for different woods in the ranges of 8.2 kW·m<sup>-2</sup> - 12.2 kW·m<sup>-2</sup> for along grain and of 1.1 kW·m<sup>-2</sup> - 7 kW·m<sup>-2</sup> for across grain. Since the distribution of wood fibers in the same position as in the case of across grain is highly unlikely in the case of fiberboard, it is appropriate to compare the results with case of along grain. Due to the method of calculation used in this work, it is ignition by an external igniter. The determined critical heat flux rate represents only negligibly higher value of 12.5 kW·m<sup>-2</sup>.

According to Janssens (1991), the range of critical heat flux for wood is in range of 9.7 kW·m<sup>-2</sup> - 14 kW·m<sup>-2</sup>. In this case, the critical heat flux calculated for the floating flooring (11.8 kW·m<sup>-2</sup>) is within the range valid for the materials tested by the author.

Tsai (2009) compared the difference between ignition of horizontally and vertically positioned samples ignited by an external source. For wood fiberboard, he determined critical heat flux of 9.7 kW·m<sup>-2</sup> ± 1 kW·m<sup>-2</sup> for vertical positioning and critical heat flux of 8.6 kW·m<sup>-2</sup> ± 1 kW·m<sup>-2</sup> for horizontal positioning. Floating floor samples were tested solely in the horizontal

position and all critical heat flux values are slightly higher except the calculation according to Zhang et al. (1996). This can be caused by a glossy surface layer, as evidenced by the results of Toal et al. (1989), who states that at lower fluxes, the gloss paint was observed to act as an ignition retardant.

Critical heat flux values of  $13 \text{ kW}\cdot\text{m}^{-2}$  -  $15 \text{ kW}\cdot\text{m}^{-2}$  were determined by measurements for the maximum time to ignition of 1800 s by Fateh et al. (2014) for plywood. The critical heat flux for these samples obtained by calculation was  $10.5 \text{ kW}\cdot\text{m}^{-2}$  -  $11 \text{ kW}\cdot\text{m}^{-2}$ . In the above-mentioned work the samples were ignited by the spark igniter. The critical heat flux required for ignition of the floating floor using the same igniter was at comparable level to that of the mentioned plywood measurements.

The work of Brown et al. (1988) focused on the testing of composites based on synthetic polymers. The wide range of materials also corresponds to a large range of critical heat fluxes, which are for ignition within 600 s in range from  $12 \text{ kW}\cdot\text{m}^{-2}$  to  $31 \text{ kW}\cdot\text{m}^{-2}$  and for ignition within 300 s in the range from  $18 \text{ kW}\cdot\text{m}^{-2}$  to  $40 \text{ kW}\cdot\text{m}^{-2}$ . Similar critical heat flux as for the floating floor was determined for the brominated polyester Glass woven roving, and poly (phenylene sulphine) with mat prepreg glass woven.

In their work, Shi and Chew (2012, 2013) state, that the critical heat flux for wood is  $11 \text{ kW}\cdot\text{m}^{-2}$  in the case of ignition source, and  $25 \text{ kW}\cdot\text{m}^{-2}$  in the case without ignition source. Mehaffey (2002) determined critical heat flux for ignition of wood without igniter to values around  $28 \text{ kW}\cdot\text{m}^{-2}$ . From the results of the floating floor, critical heat flux calculation within infinite time determined values in the interval  $23.6 \text{ kW}\cdot\text{m}^{-2}$  -  $31 \text{ kW}\cdot\text{m}^{-2}$ . For calculations taking into account ignition in finite time, its value ranged between  $28.1 \text{ kW}\cdot\text{m}^{-2}$  and  $34.7 \text{ kW}\cdot\text{m}^{-2}$ . These values are practically the same as those for wood. Thus, it can be said that, in terms of critical heat flux, the floating floor, both using and without an igniter, behaves similar to other wood-based materials.

## CONCLUSIONS

Floating flooring samples were exposed to an external heat flux of sufficient density to ignite them. The ignition of the first half of the samples was caused exclusively by thermal radiation and by the combination of thermal radiation and spark igniter in the case of the other half of samples. The coating of the flooring acted as a retarder and none of the samples ignited as long as there was no breach of the coatings integrity.

In the terms of the critical heat flux required to ignite the sample it can be stated, that higher values have been calculated for the test conditions without the igniter ( $9.5 \text{ kW}\cdot\text{m}^{-2}$  -  $23.6 \text{ kW}\cdot\text{m}^{-2}$ ) than for the conditions with the igniter ( $23.6 \text{ kW}\cdot\text{m}^{-2}$  do  $34.7 \text{ kW}\cdot\text{m}^{-2}$ ). Values from lower bounds of this range appear as more appropriate in practical application of the results. The method according to Brown et al. and Fateh et al. offer calculation of the critical heat flux rather for specific environment. The method according to Zhang et al. appears to be unsuitable for application in the case of floating flooring, because of the resulting negative value of the critical heat flux.

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## REFERENCES

1. An, J. Y., Kim, S., Kim, H. J., 2011: Formaldehyde and TVOC emission behavior of laminate flooring by structure of laminate flooring and heating condition, *Journal of Hazardous Materials* 187 (1–3): 44-51.
2. Ayrimis, N., 2007: Effect of panel density on dimensional stability of medium and high density fiberboards, *Journal of Materials Science* 42 (20): 8551-8557.
3. Egger, 2014: Precision engineering for the senses, *Laminate Flooring Home Decor Magazine* 2015 -2016: 6-7.
4. European Producers of Laminate Flooring a, Quality and Innovations, in <https://www.eplf.com/en/laminate-made-europe/quality-innovation>
5. European Producers of Laminate Flooring b, Laminate A-Z, in <https://www.eplf.com/en/services/laminate-a-z>
6. Fang, M. X., Shen, D. K., Li, Y. X., Yu, C. J., Luo, Z. Y., Cen, K. F., 2006: Kinetic study on pyrolysis and combustion of wood under different oxygen concentrations by using TG-FTIR analysis, *Journal of Analytical and Applied Pyrolysis* 77 (1): 22-27.
7. Fateh, T., Rogaume, T., Luche, J., Richard, F., Jabouille, F., 2014: Characterization of the thermal decomposition of two kinds of plywood with a cone calorimeter – FTIR apparatus, *Journal of Analytical and Applied Pyrolysis* 107: 87-100.
8. Fink, J. K., 2013: *Reactive polymers fundamentals and applications*, William Andrew Publishing, Oxford, 576 pp.
9. Hdm, Contour flooring: Flooring with natural character, in <http://www.hdm.info/en/products/floors/contour-floor.html>
10. ISO 5660-1, 2002: Reaction-to-fire tests -- Heat release, smoke production and mass loss rate -- Part 1: Heat release rate (cone calorimeter method)
11. ISO 5660-2, 2002: Reaction-to-fire tests -- Heat release, smoke production and mass loss rate -- Part 2: Smoke production rate (dynamic measurement)
12. Brown, J. E., Braun, E., Twilley, W. H. 1988: Cone calorimeter evaluation of the flammability of composite materials, National Bureau of Standards, Gaithersburg, 74pp.
13. Janssens, M.L., 1991: A thermal model for piloted ignition of wood including variable thermophysical properties, *Fire Safety Science* 3: 167-176.
14. Kim, S., Kim, H. J., 2006: Thermal stability and viscoelastic properties of MF/PVAc hybrid resins on the adhesion for engineered flooring in under heating system; *ONDOL, Thermochemica Acta* 444 (2): 134-140.
15. Ledeti, I. , Vlase, G., Vlase, T., Doca, N. , Bercean, V. , Fulias, A. , 2014: Thermal decomposition, kinetic study and evolved gas analysis of 1,3,5-triazine-2,4,6-triamine, *Journal of Thermal Analysis and Calorimetry* 118 (2): 1057-1063.
16. Lee, Y. K., Kim, H. J., 2012: The effect of temperature on VOCs and carbonyl compounds emission from wooden flooring by thermal extractor test method, *Building and Environment* 53: 95-99.
17. Liu, N.A., Fan, W., Dobashi, R., Huang, L., 2002: Kinetic modeling of thermal decomposition of natural cellulosic materials in air atmosphere, *Journal of Analytical and Applied Pyrolysis* 63 (2): 303-325.
18. Magdziarz, A. , Wilk, M. , 2013: Thermal characteristics of the combustion process of biomass and sewage sludge, *Journal of Thermal analysis and Calorimetry* 114 (2), 519-529.
19. Mehaffey J., 2002: *Fire dynamics I: ignition and burning of solids*. Lecture notes, Carleton University, Ottawa, Ontario.

20. Pergo, Pergo history, in <http://pro.pergo.co.uk/en-gb/pergo-history>
21. Rantuch, P., Hrušovský, I., Martinka, J., Balog, K., 2016: Determination of the critical heat flux and the corresponding surface ignition temperature of expanded cork plates, In *Wood & Fire Safety: proceedings of the 8th International Conference*, Pp 261-268.
22. Shi, L., Chew, M. Y. L., 2012: Influence of moisture on autoignition of woods in cone calorimeter, *Journal of Fire Sciences* 30(2): 158-169.
23. Shi, L., & Chew, M. Y. L., 2013: Experimental study of woods under external heat flux by autoignition, *Journal of thermal analysis and calorimetry* 111(2): 1399-1407.
24. Spearpoint, M. J., Quintiere, J.G., 2001: Predicting the piloted ignition of wood in the cone calorimeter using an integral model - effect of species, grain orientation and heat flux, *Fire Safety Journal* 36 (4): 391-415.
25. Tampa flooring company, 2016, Laminate Flooring history, in <https://www.tampaflooringcompany.com/laminate-flooring-history>
26. Tewarson, A., 2002: SFPE Handbook of fire protection engineering, 3<sup>rd</sup> edition, National Fire Protection Association, Quincy, MA, 1604 pp.
27. Toal, B. R., Silcock, G. W. H., & Shields, T. J., 1989: An examination of piloted ignition characteristics of cellulosic materials using the ISO ignitability test, *Fire and Materials* 14(3): 97-106.
28. Tsai, K. C., 2009: Orientation effect on cone calorimeter test results to assess fire hazard of materials, *Journal of hazardous materials* 172(2): 763-772.
29. Wiglusz, R., Sitko, E., Nikel, G., Jarnuszkiewicz, I., Igielska, B., 2002: The effect of temperature on the emission of formaldehyde and volatile organic compounds (VOCs) from laminate flooring — case study, *Building and Environment* 37(1): 41-44.
30. Xu, Q., Chen, L., Harries, K. A., Zhang, F., Liu, Q., Feng, J., 2015: Combustion and charring properties of five common constructional wood species from cone calorimeter tests, *Construction and Building Materials* 96 (15): 416-427.
31. Zhang, J., Shields, T. J., Silcock, G. W. H., 1996: Fire hazard assessment of polypropylene wall linings subjected to small ignition sources *Journal of fire sciences*, 14: 67-84.

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