STUDY OF THE HEAT FLOW EFFECT ON LAMINATE FLOORING

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Abstract — *The effect of heat flow on laminate flooring with the thickness of 7 mm was tested in this paper. As the testing equipment a cone calorimeter complying with standard ISO 5660-1was used. Following variables were monitored: time to ignition, time to termination of combustion, heat release rate, weight loss rate, concentration of carbon oxides contained in the combustion gases, smoke rate and exhaust gas temperature of combustion products. The maximum concentration of carbon dioxide was recorded while higher heat flux was used and a higher concentration of carbon monoxide was used while the samples were thermally strained by lower heat flux. Also when higher heat flux was applied a shorter time to ignition and time of combustion termination was recorded, however heat release rate and weight loss were increased. In each experimental measurement shown in the graph at a higher heat flux its course was shifted towards lower values.*

Keywords — *initiation, laminate flooring, heat release rate, concentration of carbon oxides*

Abstrakt — *V tomto článku sa testoval vplyv tepelného toku na laminovanú podlahu hrúbky 7mm. Ako testovacie zariadenie bol použitý kónický kalorimeter spĺňajúci normu ISO 5660-1, na ktorom sa sledoval čas do iniciácie, čas do terminácie horenia, rýchlosť uvoľňovania tepla, rýchlosť hmotnostného úbytku, koncentrácia oxidov uhlíka v spalinách, rýchlosť tvorby dymu a teplota spalín v mieste odberu plynných produktov horenia. Pri vyššom tepelnom toku bola zaznamenaná v spalinách vyššia maximálna koncentrácia oxidu uhličitého a pri zaťažení vzorky nižším tepelným tokom bola vyššia koncentrácia oxidu uhoľnatého. Taktiež pri zvolenom vyššom tepelnom toku bol pozorovaný nižší čas do zapálenia vzorky a čas jej dohorenia, avšak vzrástla rýchlosť uvoľňovania tepla a hmotnostný úbytok. V každom experimentálnom meraní znázornenom na grafe bol priebeh v prípade vyššieho tepelného toku posunutý smerom k nižším hodnotám.*

Kľúčové slová — *iniciácia, laminátová podlaha, rýchlosť uvoľňovania tepla, koncentrácia oxidov uhlíka*

1. INTRODUCTION

Laminate floors are classified as composite materials. They consist of several thin layers of one or more impregnated materials together glued by appropriate agglutinant (artificial resin). In the terms of fire safety it is important to understand the behavior of wood-fiber materials during thermal stress because they are among the widely used materials for constructing, flooring or decorating purposes.

Therefore, there is growing need to find alternative raw materials and increase the utilization rates of wood resources including wood-based panels, such as particle board (PB), medium density fiberboard (MDF), plywood, hardboards and wood flooring [1, 2, 3].

The base material, which is used to manufacture laminate flooring is a high density wood-fiber board. It is rather a complex process to adjust wood-fiber boards in the production and almost impossible to do because of ecological and economical grounds. It is possible to only modify the finished material, which is then mainly applicable in the compressing process, where the fire retardant is applied which is pressed into to the boards. This adjustment can be characterized as one-sided finish [4].

In terms of flammability properties we have to include the character of ground wood, used technology of production (dry and wet process). Limiting factor is also the size of the wood element e.g. wood fibers. The density of wood-fiber boards can also partially affect some of the fire-technical properties [4].

The ignition of wood depends on many factors including the species, grain orientation, moisture content, exposure conditions and the inherent variability of wood as a natural material. An average ignition temperature of

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wood can be obtained from the critical heat flux derived from the ignition time measurements [5].

Branca and Di Blasi also consider that the wood is constituted of cellulose, hemicellulose and lignin and its thermal degradation is associated with the one of these three components. Hemicellulose decomposes at 225 – 325 °C, cellulose at 325 – 375 °C, whereas lignin decomposes gradually over the largest temperature range of 250 °C – 500 °C [6], [7].

Lignocellulose materials allocate two distinct stages of thermal degradation during thermogravimetric analysis. For samples of wood-fiber insulation heated by rates of 1.78 $°C.min^{-1}$ and 3.68 $°C.min^{-1}$ the first phase of decomposition occurred at temperatures of 215 °C – 335 °C and the second phase at 385 °C – 425 °C. At heating rates of 7.60 $°C.min^{-1}$ and 11.27 $°C.min^{-1}$ both phases continuously forged and this was observed in the temperature range of 235 °C – 345 °C, optionally 335 °C – 520 °C. At temperatures above 520 °C the decomposition of the samples have virtually finished. The maximum rates of weight loss periodically occurred in the first step of decomposing while their values of weight loss with increasing heating rate raised [8].

Among the inorganic gaseous decomposition products during thermic stress of lignocellulose materials there are carbon oxides that are predominate in the air wherein the carbon dioxide reaches higher concentrations such as carbon monoxide. Thermal decomposition of cellulose emits a small amount of sulfur dioxide and nitrogen oxides. While the course of the release of carbon dioxide is similar to oxides of carbon, nitrogen oxides are released only within relatively narrow temperature interval, while a substantial majority of those gases is nitric oxide [9].

Decreasing oxygen concentration increases the amount of carbon residues during thermal decomposition of wood and also during higher temperatures of the decomposition (600 °C) the concentration of nitrogen oxides, carbon monoxide and the total amount of organic carbon raises. This will also reduce the time required for the combustion [10], [11].

The CO yield of the laminate flooring was the lowest among the wood-based panels due to the fire retardant property of the melamine–urea–formaldehyde, resin-treated, deco paper [1]. A major impact of the fire is due to the inhalation of toxic gases present in smoke which cause over than 75 % of fire fatalities. The main toxic products are CO, HCN and irritant or acidic gases. The quantity emissions of those toxic gases depends on the material itself but is largely influenced by the conditions (environment) of the thermal decomposition and the fire [12]. According to M.T. Gratkowski The minimum heat flux for smoldering ignition was experimentally determined to be 7.5 $kW.m^{-2}$ [13].

2. MATERIAL AND METHOD

2.1 Samples description

The test sample was a commercially available laminate flooring of 7 mm thickness. This is a composite consisting of 90 % wood fiber boards of high density and gum resins [14]. Two square shaped samples cut from the base material with a side length of 100 ± 1 mm were used. The real thickness of the samples was 6.6 mm. Weight of sample A was 59.2 g and weight of sample B was 58.4 g.

2.2 Experiment description

To determine the effect of heat flux applied on the laminate flooring samples a cone calorimeter method was used. The equipment scheme is shown in figure 1.

The samples were coated on five sides by aluminum foil of 0.1 mm thickness and inserted into the holder. Subsequently they were together placed under a horizontal orientated cone radiator at a distance of 25 mm, while the top layer was facing upwards. The weight loss of the samples was monitored by precise weights mechanically connected to the holder. Decomposition products were vented away by pipe duct with flow of 24 ± 2 $dm^3.min^{-1}$, from which gas samples were taken for the purposes of analysis. Into the suction line was placed an optical system designed for characterization of smoke density. The exact conditions under which the test proceeded are shown in Table 1.

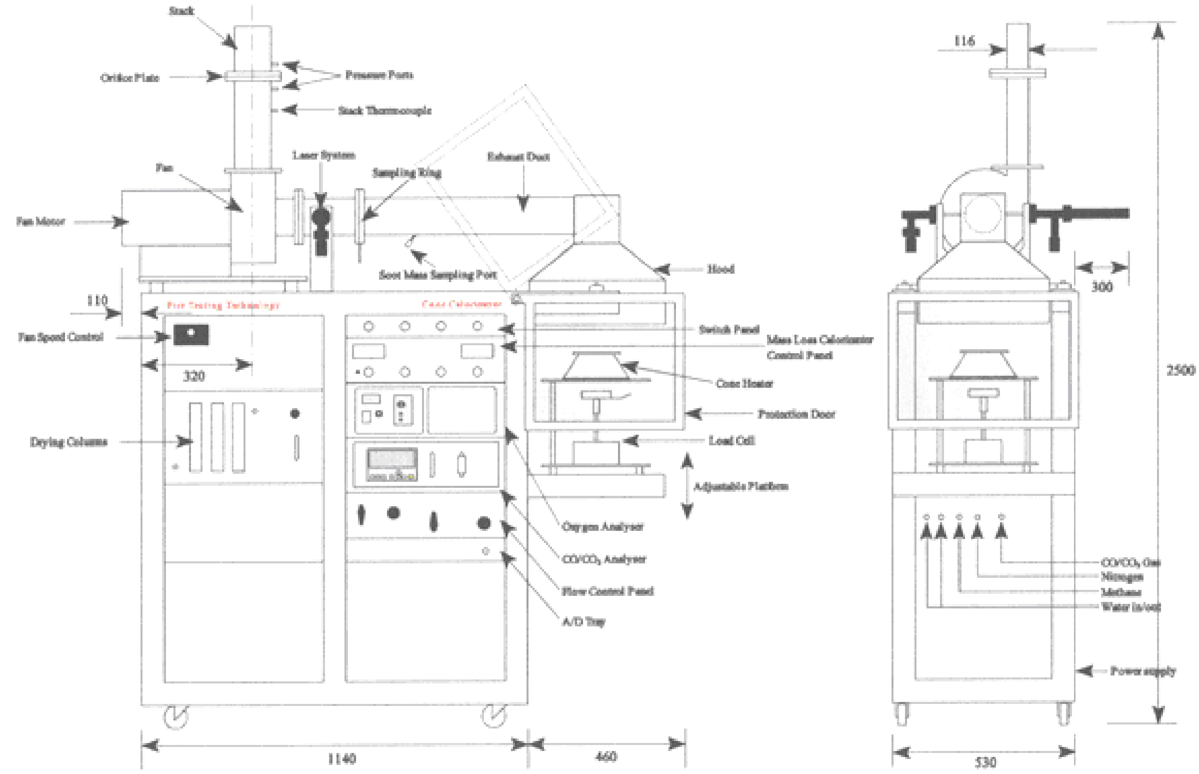

Fig. 1.: Schematic representation of the cone calorimeter [15]

Tab. 1.: Conditions during the testing of samples

Condition	Sample A	Sample B
Heat flux [kW.m^{-2}]	25	50
Ambient temperature [°C]	24	22
Pressure [Pa]	100654	100755
Relative humidity [%]	45	50
Orientation	Horizontal	Horizontal

3. RESULTS AND DISCUSSION

During application of heat flow on the laminate flooring several properties were monitored. The time to ignition, time to termination of combustion, total heat release, heat rate and weight loss of the sample. The results are shown in Table 2. It is obvious that the intensity of the heat flux had a significant impact on all of the following characteristics. With its increase the time to ignition as well as the time to termination of combustion were decreased. The total heat release, heat release rate and weight loss was increased. These changes occurred as a result of higher energy transferred by radiation to the surface of the testing material. Thermal decomposition of the sample is thus accelerated and the related phenomena occurred earlier and at a higher intensity.

Time to ignition of sample was similar to cherry wood as Yang, et all. referred at the heat flow of 30 kW.m^{-2} during 193 s and 50 kW.m^{-2} during 49 s. However the average rate of heat release was significantly lower than in the above mentioned study [16]. Grexa and Lübke also referred for three-layer wood particleboard similar results of 33 s at 50 kW.m^{-2} [17].

Tab. 2.: Comparison of measurement results for both heat flows

	25 kW.m^{-2}	50 kW.m^{-2}
Time to ignition [s]	298	34
Time to termination of combustion [s]	717	400.
Total heat release [MJ.m^{-2}]	95,9	101.9
Heat release rate		
- average [kW.m^{-2}]	58.96	74.88
- maximal [kW.m^{-2}]	256.00	308.94
Weight loss		
- average [g.s^{-1}]	0.031	0.042
- maximal [g.s^{-1}]	0.219	1.036

Mentioned progress of curves is even more obvious in the case of continuous measured properties, whether it is a case of the heat release rate (Figure 2), amount of nitrogen oxides in the flue gas (Figures 3 and 4), rate of weight loss (Figure 5), smoke release rate (Figure 6), or flue gas temperature (Figure 7). There is a noticeable shift of the curves to the right at each of shown graphs corresponding with lower heat flux output in comparison with the curve corresponding to the higher heat flow to the right.

The heat release rate in the first phase of the sample testing, during which the flame does not occur has almost zero value. This indicates that the interaction of the sample material strained by heat flux with atmospheric oxygen was negligible. Subsequently, at the time of initiation a sharp increase in the rate of heat release was seen due to exothermic oxidation of gaseous decomposition products. At the time of 65 s (for the heat flux of 50 kW.m^{-2}), respectively 365 s (for the heat flux of 25 kW.m^{-2}) from the beginning of the test it reaches a maximum. In the next course of the curve it decreases to 160 s. In the case of the sample strained by higher heat flux during 405 s. Before termination of combustion process of the sample occurs in both cases the second peak which reaches a higher value than the first local maximum. The difference between the peaks is during lower heat flux of emitter more significant. After completion of combustion, a slow and almost linear decrease occurs in the rate of heat release to almost zero values at the end of the experiment.

The measured values are in accurate correlation with the results of the rate of heat release during the exposure of laminate flooring to heat flux of 50 kW.m^{-2} as described by Lee et al., who presented slightly higher values of peaks [18].

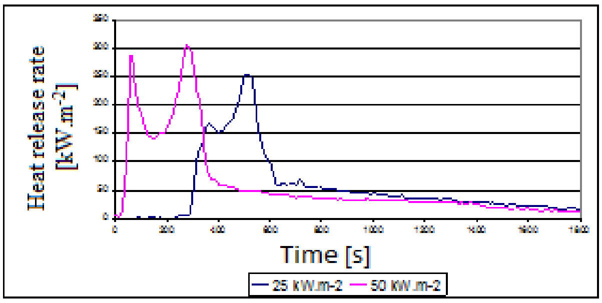

Fig. 2.: The rate of heat release during the test

The concentration courses of carbon monoxide in the flue gas (Figure 3) are quite different in used heat fluxes. In either case, although it is possible to identify three separate areas but their corresponding maximum levels and timeframes vary considerably.

In the case of heat flux of 25 kW.m^{-2} it is possible to define a first region from the start of the test to the time of 415 s. At the time of ignition of the sample is apparent short sharp decrease in the concentration of CO is probably caused by improving the combustion of the sample. In this area the maximum is indistinctive and can be observed at the time of 345 s. The second area is from the left side bordered by the end of the first area and from the right side by the time of 525 s. The maximum value occurs at the 525 s. and is more clearly visible than in the case of the first area. Finally, the third section covers the rest of the test. In addition to significantly longer time is has also quite clear peak at the time of 845 s.

During the heat flux of 50 kW.m^{-2} the first phase ends at the time of 170 s. from the start of the test. Its course is marked and at the time of 70 s. reaches a sharp peak, which has compared with the value measured at the lower heat flux much higher value. The second area continued to the time of 350 s. The concentration of CO in the waste gas remains higher than in the corresponding region of the heat flux of 25 kW.m^{-2} however the difference is not as significant as in the first area. Curve reaches its maximum at the time of 315 s. In the third area, the maximum concentration values of CO are similar to those measured in the first area however the maximum is not that obvious. This occurred in the 895 s.

From the measured results it can be concluded that carbon monoxide is released in particular during the later stages of decomposition laminate at lower heat flux, while at higher heat flux the maximum concentrations are similar in different stages. This is probably due to the improved efficiency of combustion of the carbonaceous residue influenced by higher heat flux, which results in releasing more carbon dioxide and less carbon monoxide.

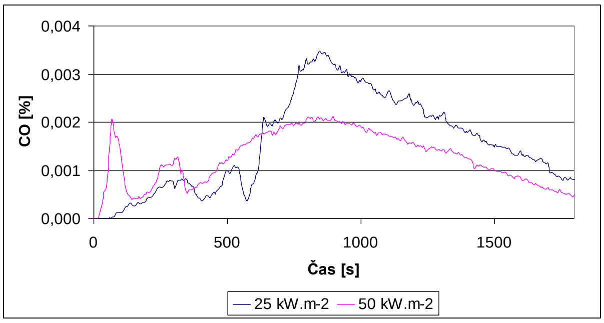

Fig. 3.: The concentration of carbon monoxide during the test

Change in the concentration of CO is virtually similar to heat release rate in the course of measurement (Figure 4). Although the heat release rate measured using a cone calorimeter is calculated from the loss in oxygen concentration in the exhaust gas it is obvious that the main product of the floating floor thermooxidation under the conditions of testing is carbon dioxide. This is supported by the fact that the measure did not take place in a closed container but the surface of the sample was kept under a stream of air from the environment. Thus, a complete combustion products were produced during the thermal decomposition.

From the comparison of a concentration curves of CO and CO_2 it is obvious that the third phase of CO releasing is partially covered by the phase where CO_2 concentration was relatively low. At this stage of decomposition probably occurred primarily the reaction of the carbonaceous residue with atmospheric oxygen, resulting in a less efficient combustion.

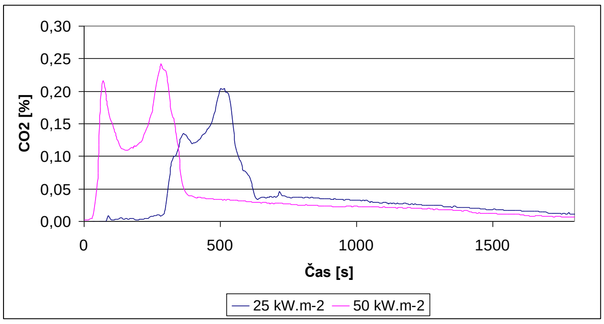

Fig. 4.: The carbon dioxide concentration during the test

The speed dependence of weight loss of the samples in time (Figure 5) also copies the heat release rates curves. A significant mass decrease of samples occurs mainly during flame combustion when the chemical decomposition reactions are the fastest. After flame combustion completion, the rate of weight loss is significantly reduced.

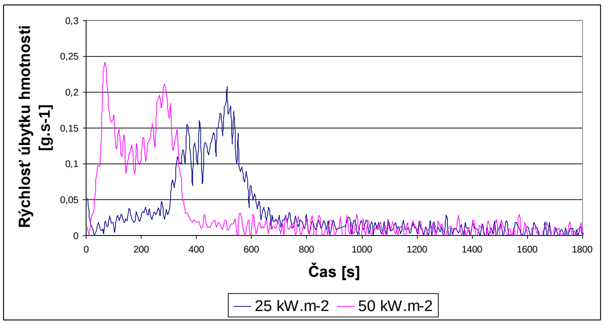

Fig. 5.: The rate of weight loss of the sample during the test

Smoke release rate during the measurement is graphically shown in figure 7. Similarly as with the continuous monitoring of the other parameters the higher heat flow lead to a shift of the graph of smoke release to the left. In both cases, there is an obvious decrease of the time of ignition of the sample. During the heat flux of 50 kW.m^{-2} it is possible to clearly identify three peaks, which occurred at a time of 35 s., 70 s. and 305 s. The first one is attributed to the state just before the ignition of the sample, second area to the maximum weight loss and the third area to a gradual extinguish of the flame. Similar course for floating floor is shown by Lee et al., whereby the peak of smoke release rate in the third phase occurs later and is higher than in the results therein reported [18]. The curve showing the course of smoke release rate under the heat flow 25 kW.m^{-2} is more fragmented, which could be due to a slower burning of sample and thus marked effect of exinronmental conditions on the formation of carbon black.

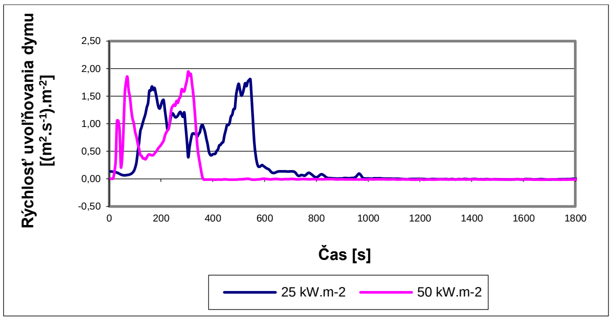

Fig. 6.: Smoke release rate during the test

The last continuously monitored variable was flue gas temperature at the sampling point of gaseous degradation products. The graphs in Figure 7 provide a relatively accurate correlation with the rate of heat release. At higher heat flow higher temperatures were measured, which was caused in addition to a higher heat release rate also by air heating caused by conical radiator which was clearly visible before igniting samples and after the fire extinguished. The diagram in these areas, the curve corresponding to higher heat flux virtually patterned the curve for lower heat flux, but is shifted upwards.

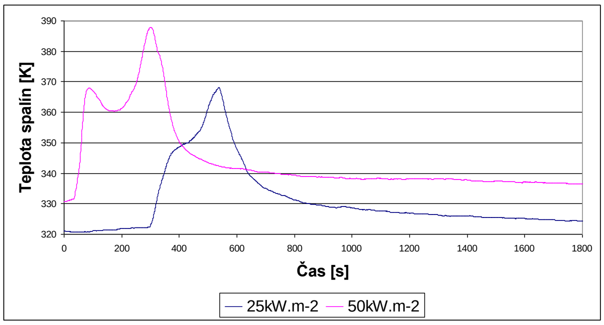

Fig. 7.: Progress of flue gas temperature at the site of sampling time

4. Conclusion

With increasing heat flux from 25 kW.m^{-2} to 50 kW.m^{-2} the time to ignition shortened by 88.6 % and the burning time of a sample of by 12.6 %. The average heat release rate increased by 27 % and the maximum heat release rate increased by 20.7.

In the case of continuously measured characteristics at higher heat flow a shift towards the beginning of the measurement occurred in the graphs. A higher levels of heat release rate, carbon dioxide concentration, weight loss rate and flue gas temperature at the sampling site are also attained. For the time course of CO concentration at the higher heat flow occurs an increase of values at the start and the drop at the end of the measurement. From the course of the smoke particles release rates a clear decline of the ignition time of the sample occurred in both cases. Curve appertained to higher heat flux contained clearly determinable peaks.

From the measured values resulted that the size of the heat flux applied to the floating floor has a significant influence on its decomposition and the associated fire-technical characteristics. During fire scenarios simulations it is therefore in terms of maximizing the information value of the results necessary to know, among other parameters also the heat flux density applied on the combustible material.

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