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IMPACT OF THE ELECTRIC CABLES INSTALLATION ON THE IGNITION PARAMETERS OF THE SPRUCE WOOD SURFACE

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ABSTRACT

This study is aimed to investigate of an impact of electrical cables installed on Norway spruce (*Picea abies* (L.) Karst.) wood board surface on main ignition parameters (mainly critical heat flux, ignition temperature, thermal response parameter and thermal inertia). Ignition parameters have been determined by dependence of ignition times (raised to the power of -1, -1/2 and -0.547) on heat flux. Initiation times have been measured for three configurations of spruce wood boards with surface dimensions of 100 x 100 mm ± 1 mm (the first configuration: board without cables on surface, the second configuration: board with three electrical cables on surface - spacing between cables was equal to their diameter and the third configuration: board with five electrical cables - spacing between cables was equal to their diameter) at five heat fluxes (30, 35, 40, 45 and 50 kW·m^{-2}). Obtained results proved that installation of the electrical cables on the spruce wood board surface has a significant impact on the ignition parameters. The critical heat flux (8.5 kW·m^{-2}), apparent thermal inertia 0.20 ± 0.02 kJ^2·m^{-4}·K^{-2}·s^{-1} and ignition temperature 324 ± 105°C of spruce wood board increased up to 18 ± 3 kW·m^{-2} (critical heat flux), 0.68 ± 0.03 kJ^2·m^{-4}·K^{-2}·s^{-1} (apparent thermal inertia) and 475 ± 27°C (ignition temperature) by the installation of electrical cables on the surface of spruce wood board.

KEYWORDS: Critical heat flux, electrical cables, ignition parameters, thermal inertia, thermal response parameter, spruce wood.

INTRODUCTION

The critical heat flux is the lowest value of the heat flux that still initiates the material. In terms of initiation, a distinction is made between piloted ignition (decomposition products are acted upon by an auxiliary initiation source, e.g. an electric spark) and spontaneous ignition (thermal decomposition products are initiated by thermal radiation without an auxiliary initiation source). From the point of view of the method of determination, a distinction is made between critical heat flux and minimum heat flux. The critical heat flux is according to Mikkola and Wichman (1989), Janssens (1991), Delichatsios et al. (1991), Tewarson (2002), Spearpoint and Quintiere (2001) determined by the dependence of the initiation time raised to the power of -1, -1/2 or -0.547 on the heat flux. The value of the exponent depends on the chosen calculation method and the thermal thickness of the material. In the equation of statistical dependence compiled in this way, a value of time to ignition (after the exponentiation) is substituted by a value of zero (theoretically corresponds to infinite initiation time) and the critical heat flux is expressed from it. Lawson and Simms (1952) determined the critical heat flux from the dependence of the heat flux on the ratio of heat flux to ignition time raised to 1/2. The minimum heat flux is defined by Babrauskas (2003) as the average value of the highest value of the heat flux that does not yet cause initiation and the lowest value that already causes initiation.

The second important initiation parameter is the thermal inertia, which e.g. Patel et al. (2011) defines as the product of the coefficient of thermal conductivity, heat capacity and density of a material. The thermal inertia determines the resistance of the material to ignition and flame propagation over the surface (with increasing thermal inertia, the resistance of the material increases). The thermal inertia is calculated according to Eq. 1, which is given e.g. Tewarson and Ogden (1992):

$$k \cdot \rho \cdot c = \left(\frac{\mathrm{TRP}}{T_\mathrm{i} - T_0}\right)^2 \tag{1}$$

where: $k{\cdot}\rho{\cdot}c$ is product of thermal conductivity k ($\mathrm{kW{\cdot}m^{-1}{\cdot}K^{-1}}$) with density ρ ($\mathrm{kg{\cdot}m^{-3}}$) and specific heat ($\mathrm{kJ{\cdot}kg^{-1}{\cdot}K^{-1}}$) called thermal inertia ($\mathrm{kJ^2{\cdot}m^{-4}{\cdot}K^{-2}{\cdot}s^{-1}}$), TRP is thermal response parameter ($\mathrm{kW{\cdot}s^{1/2}{\cdot}m^{-2}}$) computed according to Eq. 2, that is stated by Fateh et al. (2014), T_i is ignition temperature (K) and T_0 is ambient temperature (K):

$$\mathrm{TRP} = \sqrt{\frac{4}{\pi}} \cdot \frac{1}{\mathrm{Sl}} \tag{2}$$

where: Sl is the slope of line that express the dependence of time to ignition to heat flux (-), the time to ignition can be powered on -1, -1/2, -0,547 or on other value (in dependency on used calculation method).

The thermal inertia can also be calculated according to Eq. 3 reported by Lawson and Simms (1952). Eq. 3 is in the original source given for Centimetres – gram – second system of units, so in this study it is modified to the form valid for SI system units:

$$k \cdot \rho \cdot c = 0.00175 \cdot \left(\frac{(q - q_\mathrm{cr})}{1046} \cdot t_\mathrm{ig}^{\frac{2}{3}} - 68\right) \tag{3}$$

where: q_{cr} is critical heat flux ($W \cdot m^{-2}$), q is heat flux for which thermal inertia is computed ($W \cdot m^{-2}$) and t_{ig} is time to ignition (s).

The third important initiation parameter is the ignition temperature on the surface of the material at the moment of initiation (hereinafter referred to as ignition temperature). Ignition temperature has a higher informative value than auto-ignition or spontaneous ignition temperature, which were determined by e.g. Zachar et al. (2012) and Vandlickova et al. (2020). The advantage of ignition temperature over auto-ignition or spontaneous ignition temperatures is the fact that ignition temperature is directly applicable in fire modeling and fire hazard assessment of materials. The ignition temperature of the material is calculated according to Eq. 4 given by Spearpoint and Quintiere (2001). A simplified form of Eq. 4 in the form of Eq. 5 is given by Xu et al (2015).

$$q_{cr} = \sigma\left(T_{ig} - T_0\right)^4 + h_c\left(T_{ig} - T_0\right) \quad (4)$$

$$T_{ig} = \left(\frac{q_{cr}}{\sigma}\right)^{1/4} \quad (5)$$

where: σ is the Stefan-Boltzmann constant ($5.67 \cdot 10^{-8}$ $W \cdot m^{-2} \cdot K^{-4}$), T_{ig} is ignition temperature (K), T_0 is the ambient temperature (293 K) and h_c is the natural convective heat transfer coefficient (normally assumed 5 $W \cdot m^{-2} \cdot K^{-1}$).

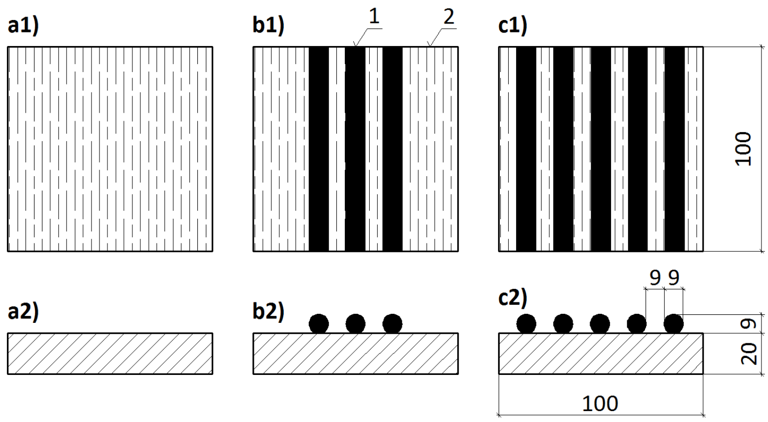
A large number of works (Su et al. 2019) have dealt with the research of critical heat flux, thermal inertia, ignition temperature and charring depth of wood, wood-based materials and synthetic polymers. Significantly less attention was paid to the stated initiation parameters of elements consisting of different materials, e.g. Furst et al. (2021) investigated the fire resistance of textile-reinforced concrete). The influence of the installation of electrical cables in the grooves in the surface of OSB boards has so far been investigated by only one scientific work by Martinka and Stefko et al. (2020). The published results prove a significant influence of the installation of electrical cables in the grooves in the surface of OSB boards on the initiation parameters. In addition, Martinka and Rantuch et al. (2020) investigated the effect of the installation of a power cable (conducting electric current) in the surface of OSB boards on the surface temperature of the board. So far, however, no scientific work has been published examining the effect of electric cable installation (on the surface of wood or wood material) on the initiation parameters of the resulting composition.

The aim of this paper is to determine the effect of the installation of a power cable on the surface of a Norway spruce wood board (*Picea abies* (L.) Karst.) on the initiation parameters (critical heat flux, ignition temperature, thermal response parameter and apparent thermal inertia) of the final composition.

MATERIALS AND METHODS

Norway spruce wood (*Picea abies* (L.) Karst.) samples were examined on the surface of which a CHKE-R J3x1.5, B2ca, s1, d1, a1 power cable (hereinafter only CHKE-R) was installed.

The configuration of the samples is shown in Fig. 1. Physical properties of spruce wood and electric cable samples are in Tabs. 1 and 2. Water content in the Tab. 1 have been determined from mass of wet sample and mass of sample dried at temperature of 103 ± 2°C (to constant mass). Cross-section of the used electric cable is shown in Fig. 2.



1: Electrical cable; 2: Spruce wood board (dimensions in mm).

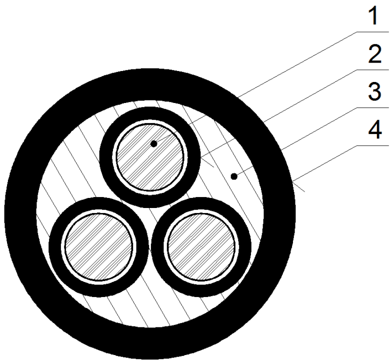
Fig. 1: Configuration of the investigated material composition: a) spruce wood board without electrical cables on the surface, b) spruce wood board with three electrical cables on the surface, c) spruce wood board with five electrical cables on the surface (1 - view from the above and 2 - cross-section).

Tab. 1: Physical properties of spruce wood boards.

Thickness (mm)	20 ± 0.1
Water content (mass %)	8 - 10
Density (kg·m^{-3})	422 ± 22

Tab. 2: Physical and fire properties of CHKE-R electrical cable.

Cable diameter (mm)	9
Number of conductors (-)	3
Conductors cross section (mm^2)	1.5
Conductor material (-)	Copper
Material of conductor insulation (-)	Polyethylene
Sheath material (-)	Polyethylene filled with $Al(OH)_3$ + $Mg(OH)_2$
Rated voltage DC (V)	1000
Rated voltage AC (V)	600
Reaction to fire class (-)	$B2_{ca}$, s1, d1, a1



1: Copper wire; 2: wire insulation (polyethylene copolymer); 3: bedding (polyethylene copolymer filled with $Al(OH)_3 + Mg(OH)_2$); 4: sheath (polyethylene copolymer filled with $Al(OH)_3 + Mg(OH)_2$).

Fig. 2: Cross-section of CHKE-R electrical cable.

Critical heat flux (CHF), thermal response parameter (TRP) and apparent thermal inertia (ATI) have been computed from time to ignitions measured at heat fluxes of 30, 35, 40, 45 and 50 $kW \cdot m^{-2}$. Temperature of the cone calorimeter heater has been from 862 K (correspond to the heat flux of 30 $kW \cdot m^{-2}$) to 998 K (correspond to the heat flux of 50 $kW \cdot m^{-2}$). Ignition times at the indicated heat fluxes were determined using a cone calorimeter according to ISO 5660-1: 2015. Critical heat flux have been computed according to Lawson and Simms (1952), Mikkola and Wichman (1989), Janssens (1991), Tewarson (1994, 2002), Spearpoint and Quintiere (2001). Lawson and Simms (1952) computed critical heat flux from the dependency of heat flux to ratio of heat flux to ignition time powered to 1/2. Mikkola and Wichman (1989), Tewarson (1994, 2002), Spearpoint and Quintiere (2001) computed critical heat flux from the dependency of ignition time powered to -1 (thermally think materials) or -1/2 (thermally thick materials) on the heat flux. Mikkola and Wichman (1989) computed the final critical heat flux as a sum of computed critical heat fluxes (from dependence of ignition time on the heat flux) with constant value of 3 $kW \cdot m^{-2}$ (this constant covers heat loses during ignition). Spearpoint and Quintiere (2001) computed the final critical heat flux as a ratio of the critical heat flux (from dependence of ignition time on heat flux) and a constant value of 0.76 (this constant covers heat loses during ignition). Janssens (1991) computed the critical heat flux from the dependence of ignition time (powered to -0.547) on the heat flux. According to the cited author, this method is especially suitable for wood and wood based products.

Ignition temperatures were calculated from critical heat fluxes by procedures according to Spearpoint and Quintiere (2001) and Xu et al. (2015).

RESULTS AND DISCUSSION

Dependence of ignition times (powered on -1, -1/2 and -0.547) on heat flux for investigated materials are shown in the Fig. 3 to 5. Dependence of heat flux on ratio of heat flux to time to ignition powered on 1/2 is in the Fig. 6. Critical heat fluxes (calculated from data in Fig. 3 to 6) are in the Tab. 3. Due to the thickness of the spruce wood samples (20 mm), these behave as thermally thick. Therefore, the heat fluxes in Tab. 3 were calculated for assumption that the examined samples were thermally thick materials.

Tab. 3: Critical heat flux for spruce wood boards with installed electrical cables on their surfaces (configuration is according to Fig. 1).

	Critical heat flux (kW·m^{-2})		
Method (-) / Configuration (-)	1st	2nd	3rd
Lawson and Simms (1952)	21	24	21
Mikkola and Wichman (1989)	6.5	17.5	10
Janssens (1991)	7	16	9
Spearpoint and Quintiere (2001)	4.5	19	9
Tewarson (2002)	3.5	14.5	7
Average	8.5 ± 6	18 ± 3	11 ± 5

In the 3rd configuration, for all the examined heat fluxes (30 to 50 kW·m^{-2}), the electric cable installed on the surface was ignited first and the spruce wood was ignited subsequently. The 2nd configuration showed different behaviour: at heat fluxes of 30 and 35 kW·m^{-2} the electric cable was ignited first; at heat fluxes of 40, 45 and 50 kW·m^{-2} spruce wood was ignited first.

The effect of electric cable installed on the surface of the spruce wood board was assessed by one-way analysis of variance (ANOVA) at the significance level of α = 0.05. The calculated values (p = 0.048; F = 3.94 and F_{crit} = 3.89) prove that the installation of an electric cable on the surface of the spruce wood board has a significant effect on the change (increase) of the critical heat flux of the resulting composition. This is because wood and wood-based materials have a lower critical heat flux (higher tendency to initiation) than electric cables. This conclusion is also confirmed by the results of scientific work of Scudamore et al. (1991), Babrauskas (2003), Rantuch et al. (2018a,b). Under the test conditions, an electric cable with a diameter of 9 mm was installed on a spruce board (2nd and 3rd configuration according to Fig. 1). Since the heat flux decreases with the square of the distance, the heat flux incident on the surface of the wood board was thus slightly lower in the 2nd and 3rd configuration than in the 1st configuration. Thus, in the 1st configuration, the highest heat flux fell on the surface of the spruce board, while in the 2nd and 3rd configuration, the higher heat flux irradiates the surface of the electric cables.

Comparison of the data in Tab. 3 with the data published by Scudamore et al. (1991), Babrauskas (2003), Rantuch 2018a,b shows that the average critical heat flux (in Tab. 3) reaches similar values as the critical heat flux of organic polymers (natural and synthetic) and electrical cables published in most scientific papers.

Ignition temperatures of the examined samples are shown in Tab. 4. As ignition temperatures are calculated from critical heat flux (according to Eqs. 4 and 5), results from the ANOVA show a statistically significant effect of electric cable installation on spruce wood board surface not only on critical heat flux but also on ignition temperatures.

A comparison of the data in Tab. 4 with the data published by Babrauskas (2003) proves that more realistic values of ignition temperatures are provided by the method according to Xu et al. (2015). Ignition temperatures calculated according to Spearpoint and Quintiere (2001) are too high.

Tab. 4: Ignition temperatures of spruce wood boards with installed electrical cables on their surfaces (configuration is according to Fig. 1).

	Ignition temperature (°C)		
Method (-) / Configuration (-)	1st	2nd	3rd
Spearpoint and Quintiere (2001)	544 ± 135	729 ± 29	619 ± 77
Xu et al. (2015)	324 ± 105	475 ± 27	381 ± 65

Thermal response parameter (TRP) is in the Tab. 5 and apparent thermal inertia is in the Tab. 6.

Tab. 5: Thermal response parameters of spruce wood boards with installed electrical cables on their surfaces (configuration is according to Fig. 1).

Configuration (-)	Thermal response parameter ($kW \cdot s^{1/2} \cdot m^{-2}$)
1st	159
2nd	198
3rd	313

Tab. 6: Apparent thermal inertia of spruce wood boards with installed electrical cables on their surfaces (configuration is according to Fig. 1).

	Thermal inertia ($kJ^2 \cdot m^{-4} \cdot K^{-2} \cdot s^{-1}$)		
Method (-) / Configuration (-)	1st	2nd	3rd
Lawson and Simms (1952)	0.20 ± 0.02	0.36 ± 0.01	0.68 ± 0.03
Tewarson and Ogden (1992)	0.11 ± 0.05	0.08 ± 0.01	0.28 ± 0.06

Comparison of TRP in Tab 5 with the results of scientific work of Babrauskas (1992) and Khan et al. (2016) and ASTM E1321-13 (2013) demonstrate that the TRP of the investigated material compositions is comparable to the average TRP of ordinary polymers ($257 \pm 15\ kW \cdot s^{1/2} \cdot m^{-2}$).

The values of thermal inertia (Tab. 6) are comparable with the values ($0.54 \pm 0.38\ kJ^2 \cdot m^{-4} \cdot K^{-2} \cdot s^{-1}$) determined by Spearpoint and Quintiere (2001) for along grain orientation of selected wood species.

Increasing values of TRP (Tab. 5) and thermal inertia (Tab. 6) indicate increasing resistance of the 2nd and 3rd configuration to initiation and flame propagation (compared to the 1st configuration). This conclusion roughly corresponds to the critical heat flux (Tab. 3) and ignition temperature (Tab. 4).

Comparison of the coefficients of determination (R^2) in Fig. 3 to 6, as well as the data in Tab. 3 (critical heat flux above 20 $kW \cdot m^{-2}$ is unrealistic for the investigated compositions) proves that, for wood and wood-based materials (20 mm thick) with installed electric cables on the surface (if the spacing is equal to the diameter of electric cables), the best explanatory value is the dependence of the initiation time raised to -1/2 or -0.547 on the heat flux for the purpose of calculation of the initiation parameters.

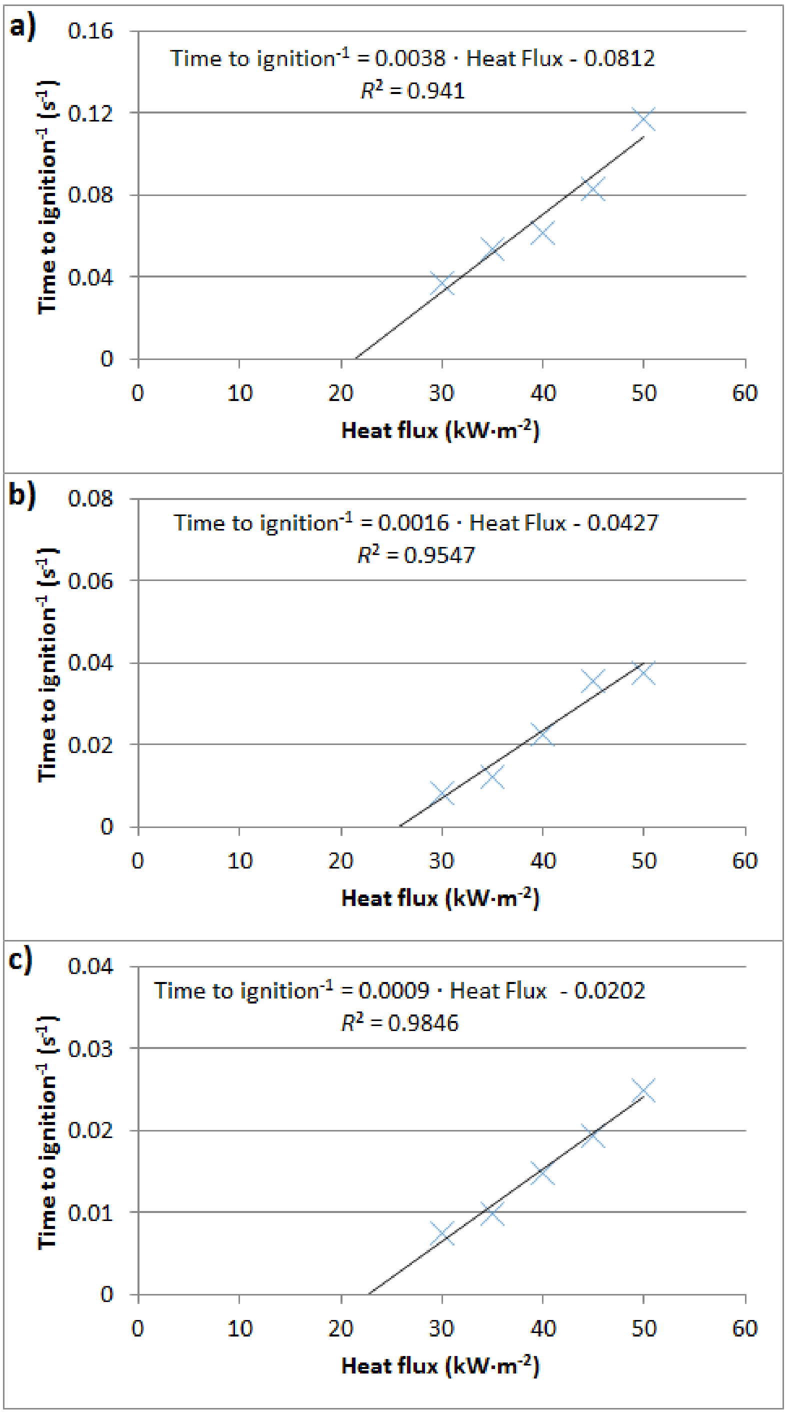


Fig. 3: Dependence of ignition time^{-1} on heat flux for three configurations of spruce wood board and electrical cable a) configuration according to Fig. 1a; b) configuration according to Fig. 1b; c) configuration according to Fig. 1c (assumption of thermally thin material).

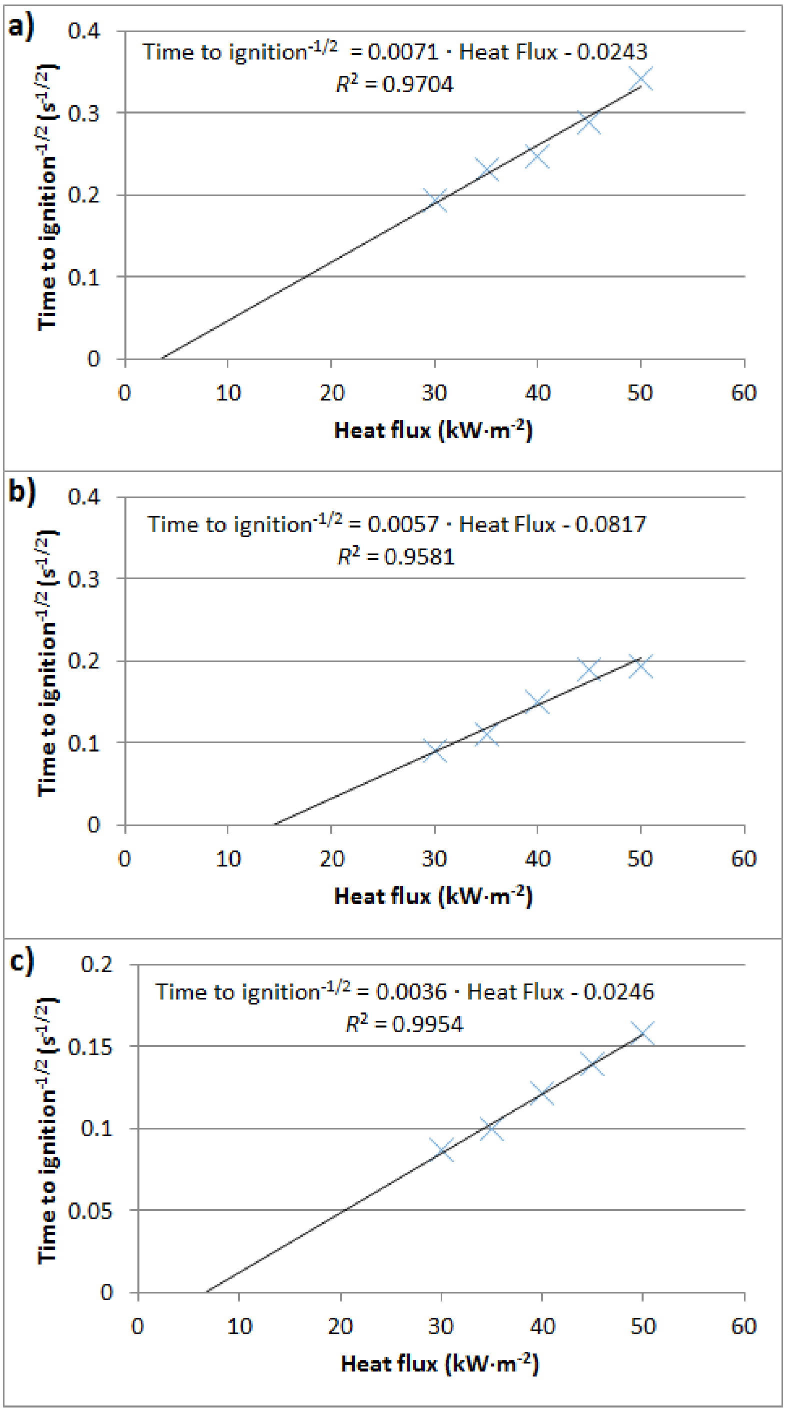


Fig. 4: Dependence of ignition time$^{-1/2}$ on heat flux for three configurations of spruce wood board and electrical cable a) configuration according to Fig. 1a; b) configuration according to Fig. 1b; c) configuration according to Fig. 1c (assumption of thermally thick material).

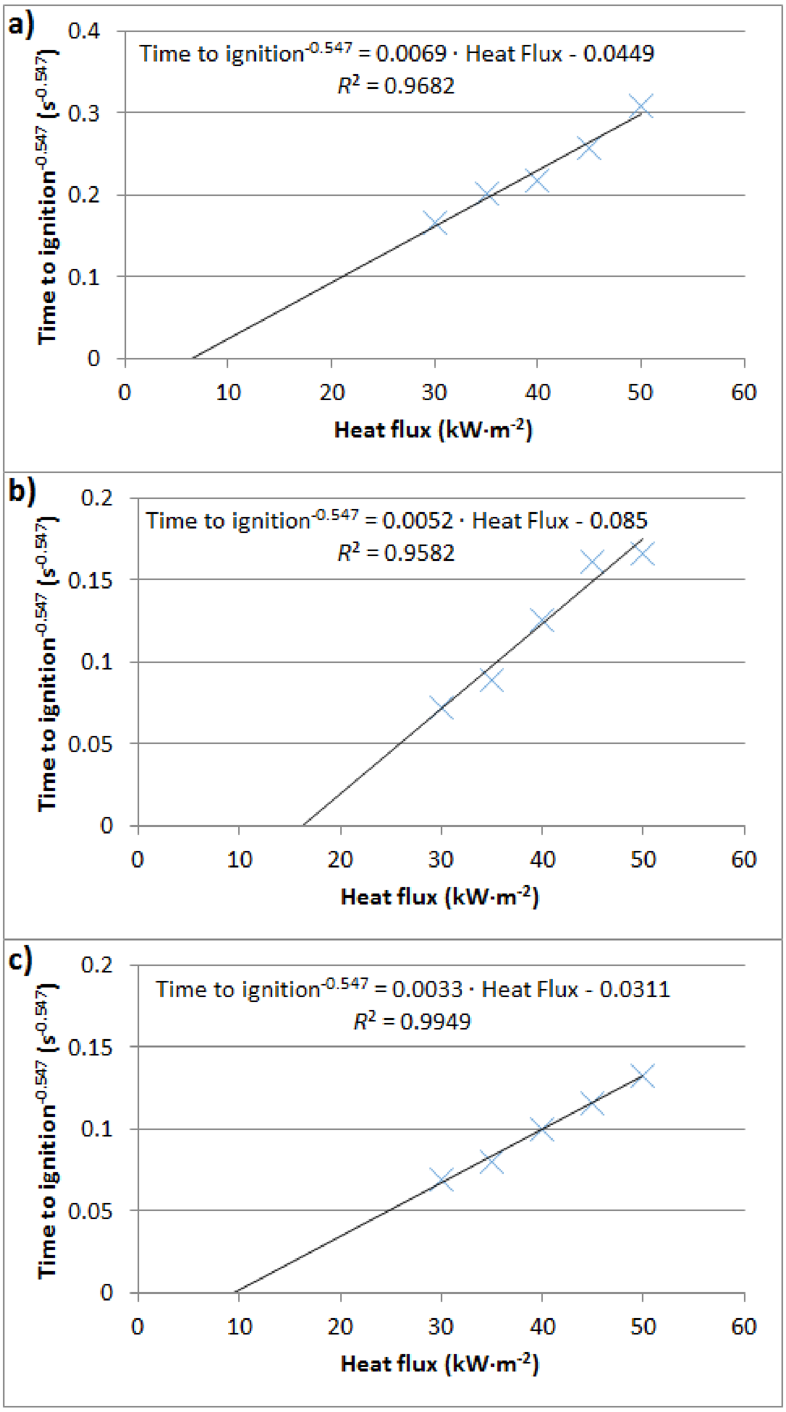


Fig. 5: Dependence of ignition time$^{-0.547}$ on heat flux for three configurations of spruce wood board and electrical cable a) configuration according to Fig. 1a; b) configuration according to Fig. 1b; c) configuration according to Fig. 1c (assumption of thermally thick material, calculation procedure is according to Janssens 1991).

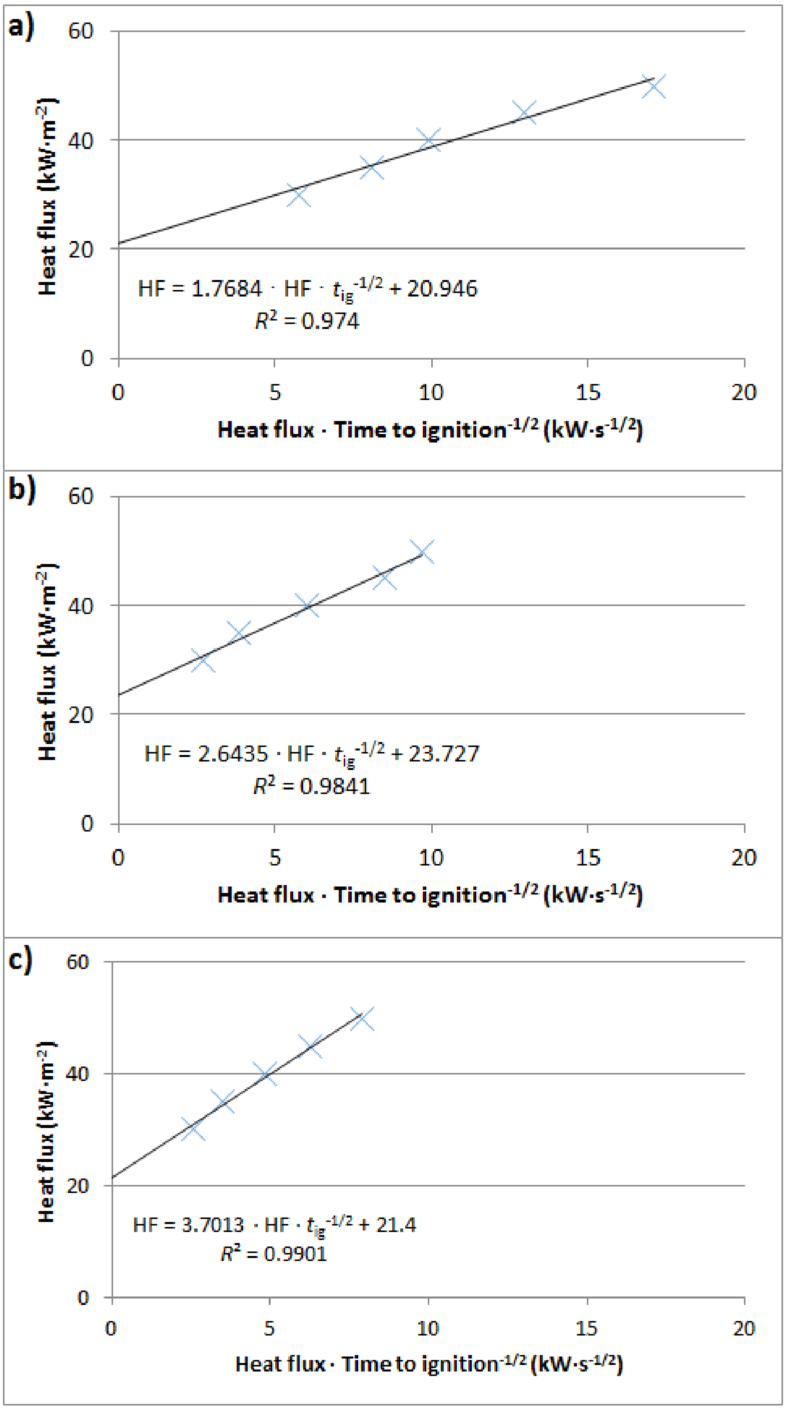


Fig. 6: Dependence of heat flux on ratio of heat flux to time to ignition (powered on 1/2) for three configurations of spruce wood board and electrical cable a) configuration according to Fig. 1a; b) configuration according to Fig. 1b; c) configuration according to Fig. 1c (HF denote heat flux and t_{ig} denote time to ignition, calculation procedure is according to Lawson and Simms 1952).

CONCLUSIONS

This paper deals with the influence of installation of power electric cable (reaction to fire class B_{2ca}, s_1, d_1, a_1), installed on the surface of a spruce wood board, on the initiation parameters (critical heat flux, apparent thermal inertia, ignition temperature and thermal response parameter). The data obtained show that the installation of an electric cable on the surface of a spruce wood board will significantly increase the critical heat flux (from 8.5 ± 6 $kW \cdot m^{-2}$ to 18 ± 3 $kW \cdot m^{-2}$), ignition temperature (from 324 ± 105°C to 475 ± 27°C) thermal response parameter (from 159 $kW \cdot s^{1/2} \cdot m^{-2}$ to 313 $kW \cdot s^{1/2} \cdot m^{-2}$) and apparent thermal inertia (from 0.20 ± 0.02 $kJ^2 \cdot m^{-4} \cdot K^{-2} \cdot s^{-1}$ to 0.68 ± 0.03 0.02 $kJ^2 \cdot m^{-4} \cdot K^{-2} \cdot s^{-1}$). These values prove that the installation of electrical cables on the surface of wood and wood-based materials must be taken into account when evaluating the initiation parameters of the resulting material compositions. The recorded increase is so significant that it must be considered in modelling the flame spread over the surface (the key parameter for modelling flame spread is apparent thermal inertia) or modelling the development of fire in fire compartments with the presence of wooden elements with electric cables installed on their surface.

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REFERENCES

1. ASTM E1321-13, 2013: Standard test method for determining material ignition and flame spread properties.
2. Babrauskas, V., 1992: The cone calorimeter. In: Heat release in fires (eds. Babrauskas, V., Grayson, S.J.). Pp 61-92, Elsevier Publishing Company, London.
3. Babrauskas, V., 2003: Ignition handbook. Fire Science Publishers. Issaquah, 1128 pp.
4. Delichatsios, M.A., Panagiotou, Th., Kiley, F., 1991: The use of time to ignition data for characterizing the thermal inertia and the minimum (critical) heat flux for ignition or pyrolysis. Combustion and Flame 84(3-4): 323-332.
5. 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(1): 87-100.
6. Furst, R., Vlach, T., Pokorny, M., Mozer, V., 2021: Study of behavior of textile-reinforced concrete with epoxy resin matrix in fire. Fire and Technology 14: 22.
7. ISO 5660-1:2015, 2015: Reaction to fire tests. Heat release, smoke production and mass loss rate. Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement).

8. Janssens, M.L., 1991: A thermal model for piloted ignition of wood including variable thermophysical properties. In: Fire Safety Science – proceedings of the third international symposium (eds. Cox, D., Langford, B.). Pp 167-176, International Association for Fire Safety Science, London.
9. Khan, M.M., Tewarson, A., Chaos, M., 2016: Combustion characteristics of materials and generation of fire products. In: SFPE Handbook of Fire Protection Engineering (ed. Hurley, M.J.). Pp 1143-1232, Springer. New York.
10. Lawson, D.I., Simms, D.L., 1952: The ignition of wood by radiation. British Journal of Applied Physics 3(9): 288-292.
11. Martinka J., Rantuch P., Stefko T., Wachter I., 2020: Electric cables installed in OSB boards surfaces and their temperature. In: Wood and Fire Safety (eds. Osvaldova, L., Markert, F., Zelinka, S.). Pp 426-431, Springer. Cham.
12. Martinka, J., Stefko, T., Wachter, I., Rantuch, P., 2020: Impact of electrical cables embedded into oriented strand board on critical heat flux. Wood Research 65(2): 257-270.
13. Mikkola E., Wichman, I.S., 1989: On the thermal ignition of combustible materials. Fire and Materials 14(3): 87-96.
14. Patel, P., Hull, T.R., Stec, A.A., Lyon, R.E., 2011: Influence of physical properties on polymerflammability in the cone calorimeter. Polymers Advanced Technologies 22(1): 1100-1107.
15. Rantuch, P., Štefko, T., Martinka, J., 2018a: Critical heat flux determination of electric cable insulation. Research papers Faculty of Materials Science and Technology Slovak University of Technology in Trnava 26(42): 11-20.
16. Rantuch, P., Štefko, T., Martinka, J., Wachter, I., Kobetičová, H., 2018b: Impact of initiator placement on ignition of the vertically positioned electrical cable. In: SGEM Proceedings of the 18th International Multidisciplinary Scientific GeoConference Nano, Bio and Green - Technologies for a Sustainable Future. Pp 419-426, STEF 92 Technology. Vienna.
17. Scudamore, M.J., Briggs, P.J., Prager, F.H., 1991: Cone calorimetry—a review of tests carried out on plastics for the association of plastic manufacturers in Europe. Fire and Materials 15(2): 65-84.
18. 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.
19. Su, H.C., Tung, S.F., Tzeng, C.T., Lai, C.M., 2019: Variation in the charring depth of wood studs inside wood-frame walls with time in a fire. Wood Research 64(3): 449-460.
20. Tewarson, A., 1994: Flammability parameters of materials: ignition, combustion, and fire propagation. Journal of Fire Sciences 12(4): 329-356.
21. Tewarson, A., 2002: Generation of heat and chemical compounds in fires. In: The SFPE Handbook of Fire Protection Engineering (ed. DiNenno PJ). Pp 618-697, National Fire Protection Association. Quincy.
22. Tewarson, A., Ogden, S.D. 1992: Fire behavior of polymethylmethacrylate. Combustion and Flame 89(3-4): 237-259.

23. Vandlickova, M., Markova, I., Osvaldova, L.M., Gaspercova, S., Svetlik, J., Vraniak, J., 2020: Tropical wood dusts - granulometry, morfology and ignition temperature. Applied Sciences 10(21): 1-15.
24. 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(1): 416-427.
25. Zachar, M., Mitterova, I., Xu, Q., Majlingova, A., Cong, J., Galla S., 2012: Determination of fire and burning properties of spruce wood. Drvna Industrija 63(3): 217-223.

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