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TEMPERATURE DEVELOPMENT OF SELECTED MATERIALS IN A REDUCED MODEL – EXPERIMENTAL TEST

Jana Müllerová*
Maroš Krajčír**

ABSTRACT

The work is focused on an experimental test of temperature development in a scale model. Various types of combustible materials were used in the test in combination with the spruce wood. The work points to the influence of the fuel source on selected parameters of a fire in an enclosed space. The course of a fire is influenced by various factors. The course of a fire in an enclosed space differs from the course of a fire in an open space. As a part of the overall development of the fire, the temperature of the fire is affected. Therefore, one can state that the parameters affecting the development of an internal fire also have a direct effect on the temperature development. The main goal of this work is to compare different types of materials in terms of the properties they manifest during a fire. The practical part contains the analysis of the materials used in the experiment. Description of the scale model and of the measuring control panel are the content of another part of the work. In the end there is a comparison of the individual temperature curves.

KEYWORDS

combustion, temperature development, fire parameters, combustible materials

* Prof. Jana Müllerová, Ph.D, Academy of the Police Force in Bratislava, Slovakia; correspondence address: Sklabinská 1, 835 17 Bratislava 35, Slovak Republic; email: jana.mullerova@akademiapz.sk

** Maroš Krajčír, Ph.D., Academy of the Police Force in Bratislava, Slovakia

INTRODUCTION

A fire can arise and develop in various ways. It is impossible to describe and predict each specific type of fire development. On the other hand, one can provide a general understanding of how a fire develops in an enclosed space. The development of a fire is mainly influenced by the amount of combustible material and its arrangement in the fire room. Oxygen supply is another important factor. If the room where the fire begins is closed, its intensity gradually decreases, which means that the temperature of the combustion products in the room also decreases.

The fire in buildings and its beginning is similar to the course of a fire in an open space with limited climatic conditions.[1] The burning conditions in the room change rapidly. Due to the evolution of smoke with respect to oxygen consumption, its concentration decreases during combustion, and thus, naturally, the course of combustion in an enclosed space decreases. The interface between the smoke layer and the air gradually decreases towards the floor.[2]

The exchange of gases and heat in the event of a fire in an enclosed space depends on the construction of the building. The number, size and arrangement of the openings have a major influence on the further course of the fire. With a large surface area of openings, there is a high rate of fire spread due to a sufficient supply of atmospheric oxygen. The direction of the movement of the combustion zone is usually towards the openings. Very intensive combustion is related to the large openings, the rate of the development of combustion decomposition products exceeds the rate of oxygen supply, at the same time they mix with each other. Decomposition products escape together with carbon monoxide. Burning is manifested by flames whipping from the openings, which can subsequently cause the fire to spread to the surrounding environment. The course of a fire in an enclosed space depends on the amount and properties of the burning substances and the exchange of gases (size and position of open vents). During the exchange of gases, a large amount of the heat is removed from the combustion chamber.

Fire development is a term by which the gradual growth, the development of fire is meant. As part of the overall development of the fire, the

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1 L.G. Bengtsson, *Enclosure fires*, Karlstad 2001, https://www.msb.se/RibData/Filer/pdf/20782.pdf (accessed: 11.10.2019), p. 123.

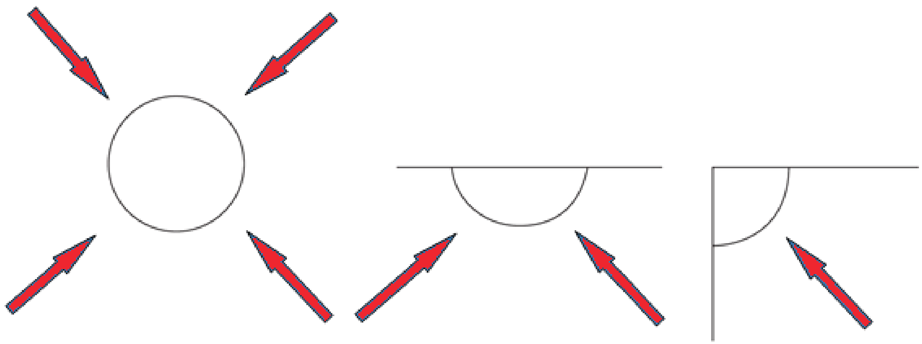
2 M. Kvarčák, *Základy požární ochrany*, Ostrava 2005, p. 78.

temperature during the fire is also affected. One can therefore assume that the parameters that affect the development of internal fire also have a direct effect on the development of temperatures. The authors will therefore focus on the factors that influence the development of a fire. There are five basic factors that affect the development of internal fire and, consequently, temperature. These are:

- initiation source,
- fuel,
- geometry of space,
- ventilation openings,
- material delimiting the space.

Figure 1 shows the supply of cold air to the fuel during combustion. The circle, the semicircle, and the cut-out from the circle represent the fuel. The horizontal line at the semicircle shows the wall on which the fuel rests. The arrows indicate the direction of air flow into the flame. In the right-hand part of the picture one can see the fuel located in the corner of the room. In this case, the air supply is only possible from one direction. In the middle part of the picture, as already mentioned, one can see the fuel leaning against the wall. In this situation, air supply is possible from several directions. In the latter case, the fuel in the enclosure is situated in such a way that it does not touch nor is in close proximity to the wall. One can see that in this case, the supply of air to the fuel is secured from every side.

Figure 1. The supply of cold air to the fuel during combustion. Left: free burning; middle: burning at the wall; right: burning in the corner.



Source: own elaboration.

Fuel is an integral part of the combustion triangle. The fuel can otherwise be called combustible material. Its decomposition releases heat, light, and combustion products. Fuel is another factor that affects the temperature in a fire in an enclosed space. What is important in this respect is the basic characteristics of the fuel, both chemical and physical. The chemical characteristics considered in this study are: the chemical composition of the fuel, its structure, and the presence of fire retarding compounds. As regards the physical characteristics, the authors are interested in: state, humidity, temperature, thermal conductivity, heat capacity, density, and geometry.

TEMPERATURE DEVELOPMENT OF SELECTED MATERIALS IN A REDUCED MODEL

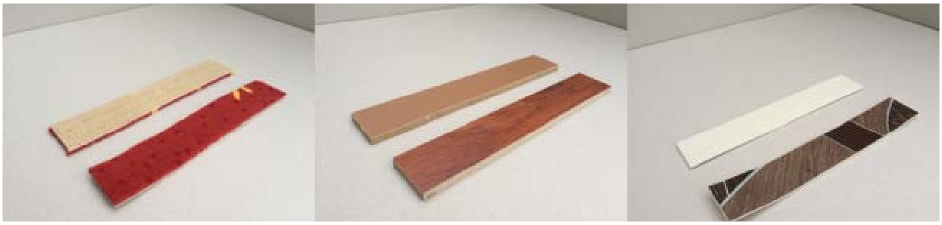
The experimental test is focused on determining the development of fire parameters of the selected material. The fire load in the experimental test is 30 kg/m^2, with 60% being spruce wood and 40% being laminate. It is important to note that this ratio is for the total fire load and is therefore not the same as the weight ratio of the individual materials.

Figure 2. Fuel source – fuel cribs

Source: own elaboration.

Figure 2 shows the materials used in the fire test reduced according to the reduction theory as well as the construction of the fuel package. Each crib was built from planks and was square in cross-section with a shorter side length of each plank 4 cm and a crib length of 24 cm. Laminate planks were of the same dimensions as the wooden ones. It is also necessary to take into account the fuel location, i.e. position. As long as the fuel does not touch the walls, cold air enters the rising flue gas stream from each side. If the fuel is near the wall, this phenomenon is partially limited and this is the main cause of the lower temperature in the room.

Figure 3. Fuel source. Left: polyamide, middle: laminate, right: vinyl



Source: own elaboration.

The model had floor dimensions 1400 mm × 1300 mm and height 750 mm (internal dimensions). The inner walls of the model were covered with 5 cm thick mineral wool (Figure 4). The material was determined by applying the basic relationships of the reduced scale. The mineral wool was attached to a 1.25 cm thick gypsum board built into a metal frame (3 mm thick and 30 mm wide).

The mineral wool was sealed to the plasterboard using glue for thermal insulation systems. The outer walls were anchored with screws placed at 15 cm intervals. During the tests, the material was directly exposed to the hot gas fire.

The values of the monitored parameters were recorded by a measuring panel of the ALMEMO 5690-1 type with a K-type thermocouple (Figure 4). There are 15 thermocouples inside the space. The thermocouple and compensation cable were connected to the ALMEMO 5690-1 control panel. Temperature registration was performed at 2-second intervals.

Figure 4. Measurement panel and small-scale dwelling model for the measuring of temperature development of the selected materials

Source: own elaboration.

Six fuel cribs were placed in the interior (Figure 4). In experiments, a gas burner, a container for flammable substances, or a fuel bundle of wood is most commonly used. The choice of fuel depends on the required maximum temperature compared to the actual fire. It then reaches approximately the same temperature, heat flux and other properties of the model in full. Wood fuel packages are constructed according the scaling method of "dimensionless groups," well explained by Heskestad[3] and Karlsson & Quintiere.[4] The heat flow rate is controlled by the number and dimensions of the cribs and the gaps between them as stated by Mullerova & Krajcir.[5]

FIRE EXPERIMENTS AND RESULTS

The construction of the small-scale objects was made in accordance to the pictures captured above. Three fire tests focused on the temperature development were held with different materials inside. The first test involved laminate cribs, the second test – polyamide, and the third – vinyl material. Temperature curve shown in Figures 5, 6, and 7 describe the development of the fire intensity. The duration of the fire is on the horizontal axis while the vertical axis represents the temperature of the gases accumulated under the ceiling. The curve represents the average fire temperature values taken out of three sensors placed directly under the ceiling. As the figures below show, extremely fast temperature increase was measured in the first phase after fire initiation in the models with polyamide (Figure 6) and vinyl inside (Figure 7). The growth of the temperature inside the laminate model was a little bit lighter compared to the rest of two materials tested. On the other hand, the model with the laminate cribs inside reached the highest temperature in its top approaching 1000 °C, while in polyamide it was over 900 °C. Vinyl reached its top temperature around 930 °C. It is interesting that laminate temperature was the highest after 100 minutes of the test. It was still 500°C, while models with polyamide had 250°C and vinyl only 70 °C after the same period. The difference is visible in Figure 8.

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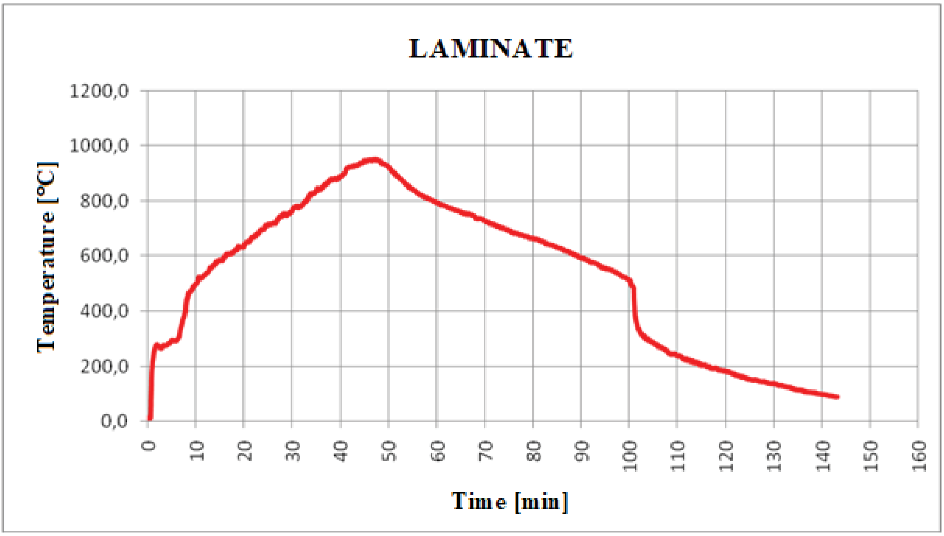
[3] G. Heskestad, *Modelling of enclosure fires*, "Combustion Institute Symposium on Combustion" 1973, no. 14, http://libgen.org/scimag/?s=Modeling+of+enclosure+fi-res.+&journal-id=&v=&i=&p=&redirect=1 (accessed: 11.10.2019), p. 1025.

[4] B. Karlsson, J.G. Quintiere, *Enclosure fire dynamics*, London 1999, p. 45.

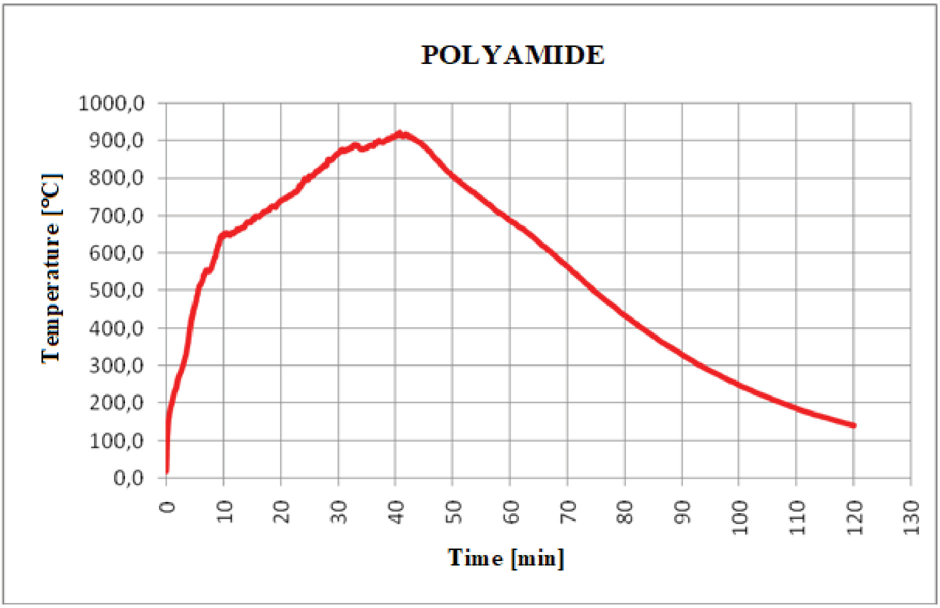
[5] J. Mullerova, M. Krajcir, *Effect of fuel source on enclosure fire parameters*, [in:] *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM 2018 (18)*, Albena 2018, p. 327.

FIGURE 5. TEMPERATURE DEVELOPMENT DURING THE FIRE EXPERIMENT WITH THE *LAMINATE* CRIBS



Source: own elaboration.

FIGURE 6. TEMPERATURE DEVELOPMENT DURING THE FIRE EXPERIMENT WITH THE *POLYAMIDE* CRIBS



Source: own elaboration.

Figure 7. Temperature development during the fire experiment with the *vinyl* cribs

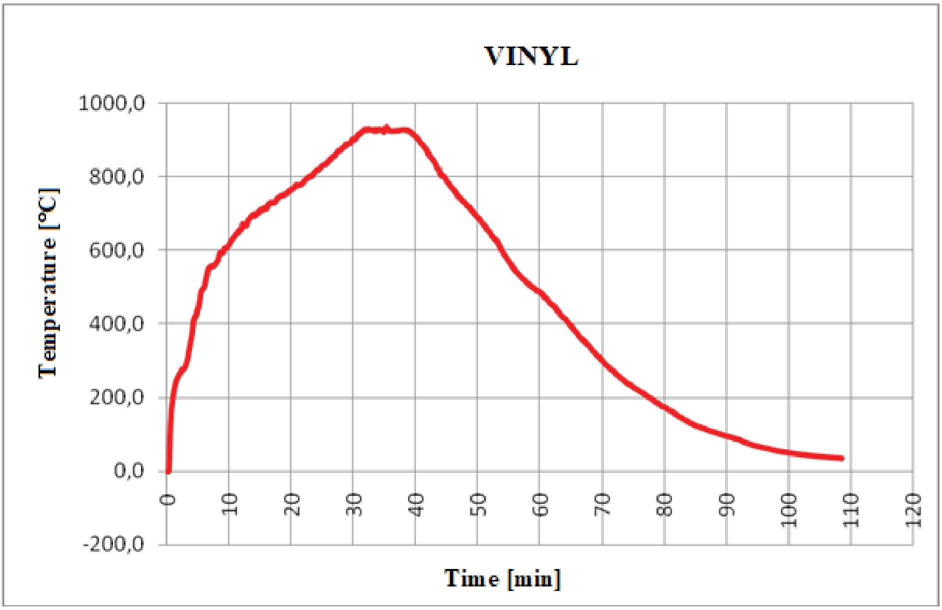


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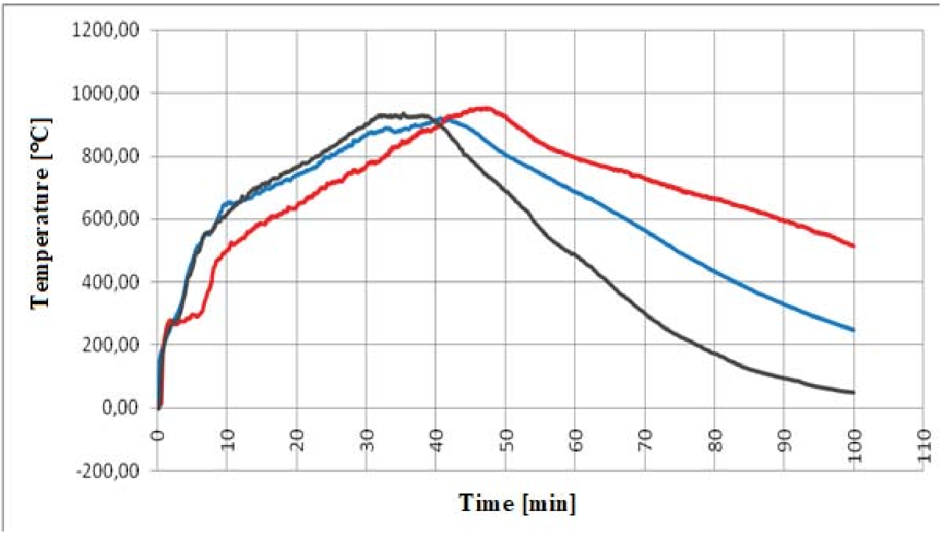
Figure 8. Comparison of temperature development during fire. Red: laminate; blue: polyamide; black: vinyl



Source: own elaboration.

CONCLUSION

Dwelling or compartment fires, due to their specific properties, pose a significant risk not only to residents but also to firefighters. When measuring its parameters using a reduced small-scale model, it is essential to emphasize that the results obtained are equivalent to those obtained when measuring in full. It is incorrect to assume that reducing the model in the ratio will also cause a reduction in the amount of fuel in the same ratio. In experimental fire tests, it is necessary to correctly evaluate the obtained results and conclusions.

The current test was focused on burning material consisting mainly of wood with a fire load of 30 kg/m^2. These conditions are characteristic of the office space. This test can be understood as a simulation of an office fire. There are various types of offices, therefore also the conditions of inner fire in such environment differ. The specificity of an interior is conditioned by many factors such as the amount of material, the geometry of the space, the number and size of openings, the properties of the structure etc. It can be stated the temperature curve of a given fire will not be equivalent to another fire, but it will fit a similar trend. Furthermore, one can say that the models on a reduced scale have a great but insufficiently used potential for obtaining input data in modern computer programs that simulate fires in a full-scale.

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