Effect of Finger Joint Direction on Wood Ignition in Façade Elements

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ABSTRACT

Statistics show that the number of façade fires has been relatively large in the past few years. The surprising fact is that even in modern high-rise buildings, which are covered with non-flammable façade elements and equipped with high-quality fire-fighting equipment, we have recorded a relatively large number of fires spreading along the façades. They do not have disastrous consequences but they damage buildings, endanger people during evacuation and make the situation more difficult for fire-fighters. Many scientific studies refer to cladding and its functions. Besides its aesthetic function, it serves as thermal, acoustic as well as fire insulation. Building façades are threatened in three ways – by a direct flame from a burning element in front of the building itself, by a fire from the interior of the building, or by a heat radiation source coming from a neighboring building on fire. The choice of material and its application onto the building is important for the fire safety of façades. A wooden spruce façade containing two types of finger joints has been chosen for the experiment and the effect of the joint type using the selected evaluation criteria has been observed. Parts of the façade have been used for the experiment. Samples of 20 x 60 x 250 mm have been made, 15 pieces per each section. A thermal radiator of 1000 W, acted as the heat source, simulating the conditions of thermal radiation coming from a neighboring building. Weight loss and burning rate are the evaluation criteria. The experiment results are represented graphically. The experiment shows that the direction of the finger joints has an impact on the evaluation criteria as well as on the penetration of radiation heat into other parts of the structure thus increasing the probability of its ignition from the radiation heat source.

KEYWORDS: Finger joint, wood ignition, façade elements.

INTRODUCTION

Fire, according to the Slovak legislation [5], is each type of undesirable burning damaging a person´s property, the environment or causing the death or injury of a natural person or an animal; fire is also defined as undesirable burning when a person´s property, the environment and the lives or health of natural persons or animals are at risk. Burning and fire are two phenomena which cannot be considered identical.

In general, burning and fire are intentional and desirable processes with a particular use, burning in the desired time and space and using specified materials – fuel. The energy, which is obtained, is utilized. Fire represents unwanted burning, in unwanted space and time. All materials affected by the fire become fuel [3, 7]. Fire is characterized by several chemical and physical phenomena that are related to each other. According to civil engineers and security experts, it is the cladding which is at fault in the case of a fire. Cladding has various functions and it is, in many cases, made from highly flammable materials [2, 8]. The application of flammable materials (e.g. wood) for cladding has lately been preferred by designers and architects [4, 6, 11]. Their projects and designs require

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further measures to be implemented to prevent a fire. These measures aim to prevent the uncontrolled spread of a fire on the surface or in the cavities. If these measures are implemented, wood can be used without lowering any safety levels in terms of fire protection. These measures can be divided into several categories [3]:

- Material solutions;
- Design solutions;
- Certification;
- Legal solutions in the field of fire protection.

The problem arises with the addition of thermal insulation to buildings using flammable material as well as from an increased demand for wood from an aesthetic and functional point of view. In many countries, special attention is paid to wooden cladding of façades and strict criteria and conditions have been set out for such cladding. In general, it is based on fire scenarios of potential ignition and the subsequent fire of a façade which are shown in Fig. 1 [11].

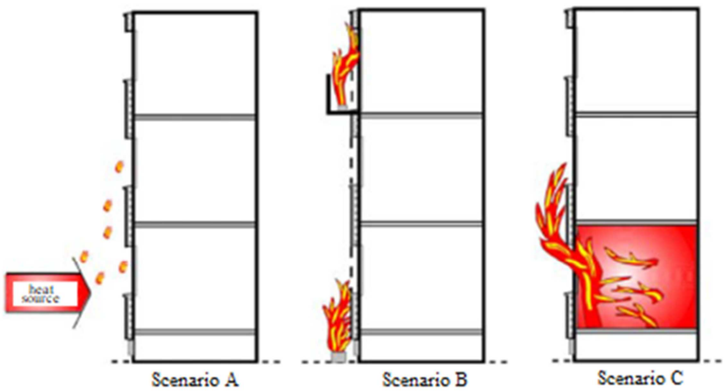


Fig. 1. Fire scenarios for façade fires [11].

Scenario A

The fire spreads from the neighboring buildings onto another building. For a larger cladding the fire risk is limited to an ignition risk assessment when the façade is exposed to a radiant heat source. If the buildings are close to each other, the analysis can be extended - including contact with flame and the flare-up of materials is being observed. This scenario also takes into consideration the spread of the fire from a neighboring building onto other neighboring buildings. For flammable façades, we need to take into consideration the heat from the burning façade - if the façade ignites - as well as radiant heat from cavities and flames coming from the vents on the façade of the neighboring building. Fire protection legislation for this fire scenario also deals with the issue of the distance between the adjacent buildings.

Scenario B

The fire spreads from an external source adjoining the façade (not a neighboring building) e.g. vehicle on fire, litter bin, and so on. A balcony fire might also fall into this category.

Scenario C

A vertical fire spreads through the vents from a fully developed fire inside the building. There is at least one vent on the façade.

Several authors [9, 12] monitored the effect of the construction itself - its surface, smoothness etc. (see Fig. 2), however, the types of joint elements used within the structure have not been monitored yet.

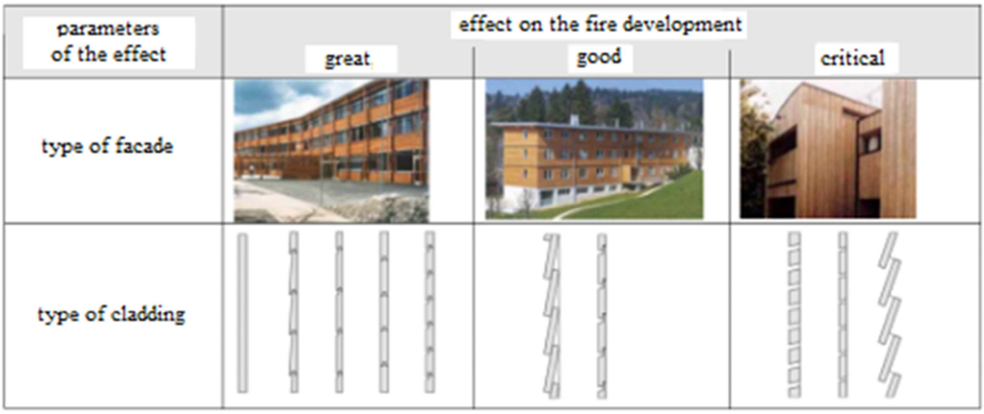


Fig. 2. Examples of parameters affecting fire behavior of multi-story façades [12].

THE EXPERIMENT

The wood of Norway spruce (Picea abies (L) Karst.) was selected for the test. It is the second most widely used wood in Slovakia and the most important one from an economic point of view. Spruce is light, soft, elastic, easy to chop, easy to stain but more difficult to impregnate. The wood is free of defects and typically has symmetric and narrow annual growth rings (1 to 4 mm) with summerwood ratio in the annual ring ranging from 5 to 20 %. Primarily, it is used as construction lumber for above-ground structures. The wood is also used for residential roof structures, farm buildings as well as other special buildings. Spruce lumber is a part of frame constructions of panels for wooden buildings. Spruce wood is easy to dry, it is not prone to shriveling or crinkling [1, 10, 13].

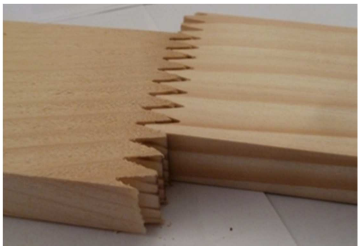
A wooden façade made from spruce and one type of finger joint in two directions were chosen for the experiment. The effect of the finger joint direction in façade elements on the selected evaluation criteria has been observed. The control sample was jointless (compact). The type of joint and its direction is shown in Fig. 3.

Fragments of the façade were used for the experiment - samples of 20 x 60 x 250 mm, 15 pieces per each section (including the control samples). A thermal radiator of 1000 W is used as the heat source simulating the conditions of scenario A – a fire coming from a neighboring building.

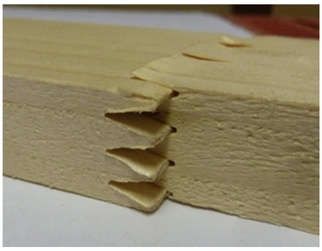
The test method is not standard; however, it is flexible and suitable for testing not only different types of finger joints but also different types of wood and wood treatment methods - wood of different age classes, retarding treatment or other aesthetic adjustments of façades and their effect on ignition and the burning process. It is possible to change the delivery of the thermal radiator, or to replace the radiant heat source with a flame heat source. The power output of 1000 W as well as the distance of the sample from the source were, after carrying out some preliminary experiments, set to the values given above to prevent the sample from burning down – partially or completely. Thanks to these parameters, it is possible to observe whether the direction of the finger joint influences the ignition and burning of the sample that constitutes a part of the façade.

The thermal radiator is warmed up, - after reaching the given temperature, the samples are exposed to heat for 10 minutes. Fig. 4 shows the direction of the thermal radiator and the sample. The sample is placed 40 mm below the lower edge of the thermal radiator.

The reason for doing so is a follow-up evaluation of the experiment, which is not the subject of this article. The whole surface of the sample was exposed to the heat of the thermal radiator. The finger joint is located in the center of the sample. The apparatus is shown in Fig. 4.



(a)



(b)

Fig. 3. Finger joint: (a) vertical; (b) horizontal.

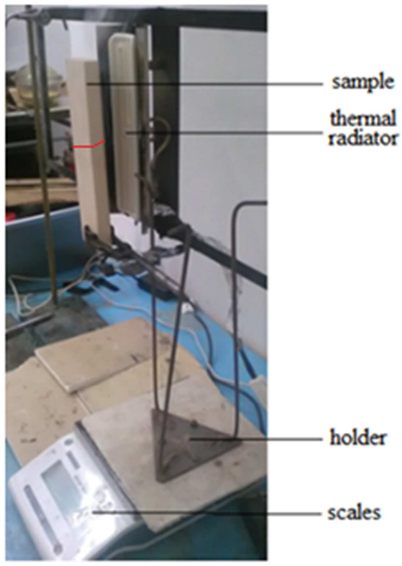


Fig. 4. The apparatus – exposure of samples to radiant heat.

Weight loss and burning rate are the evaluation criteria. Weight loss was calculated according to the following Eq. (1),

$$\delta_m(\tau) = \frac{\Delta m}{m(\tau)} 100 = \frac{m(\tau) - m(\tau + \Delta\tau)}{m(\tau)} 100 \; (\%), \tag{1}$$

where $\delta_m(\tau)$ is the relative weight loss at a time τ, %, $m(\tau)$ is the sample weight at a time τ, g, $m(\tau+\Delta\tau)$ is the sample weight at a time $\tau + \Delta\tau$, g, Δm is the weight difference, g.

Relative burning rate will be determined according to the relation Eq. (2) and Eq. (3),

$$v_r = \left| \frac{\partial \delta_m}{\partial \tau} \right| (\%/\mathrm{s}), \tag{2}$$

or numerically

$$v_r = \frac{|\delta_m(\tau) - \delta_m(\tau + \Delta\tau)|}{\Delta\tau} \; (\%/\mathrm{s}), \tag{3}$$

where v_r is the relative burning rate, %/s, $\delta_m(\tau)$ is the relative weight loss at a time τ, %, $\delta_m(\tau+\Delta\tau)$ is the relative loss of weight at a time $\tau + \Delta\tau$, %, and $\Delta\tau$ is the time interval where the weights are being subtracted, s.

EVALUATION AND DISCUSSION

The experiment confirmed that the finger joint direction has an impact on the evaluation criteria and therefore on the penetration of radiant heat into other parts of the structure. This means that the finger joint direction affects the possibility of ignition from a heat source. When evaluating the experiment, it is necessary to point out that special attention has been paid to the homogeneity of all samples: their density (360 ± 10 kg/m^3), moisture level (12 ± 2 %) and the quality of woodworking. The term homogeneity is understood as a selection of samples according to their density in the given interval, keeping the samples air-conditioned, since the density and moisture level of the samples could influence the experiment results and the finger joint direction does not need to manifest itself if not selected properly. These factors could have had an impact on the experiment results. This is why the samples were homogenized so that the impact of the type of finger joint and its direction would be the most clearly manifested. Photographic documentation was not done throughout the tests. The continuous burning rate and the change in weight were the only parameters recorded during the test, at 10 second intervals.

As we can see from Fig. 5, the effect of the finger joint direction manifests itself from the very first minutes of the experiment. From the very first minute (which is relatively early), an increase in weight loss for the vertical finger joint samples was observed. In the second minute of the experiment, this increase is noticeable, and it is rising throughout the whole experiment.

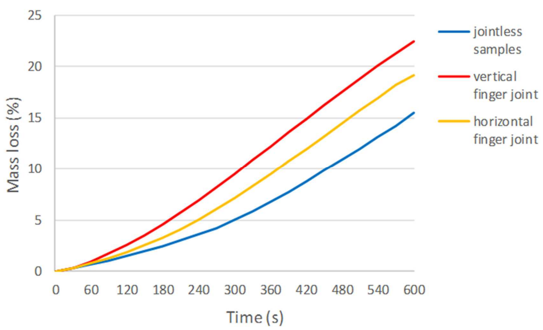


Fig. 5. The course of weight loss for a test sample and the effect of finger joint direction on weight loss.

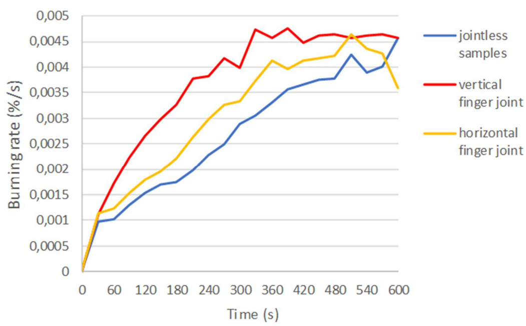


Fig. 6. Burning rate course of a control sample and the effect of finger joint direction on burning rate.

There is a constant difference between the joint-less samples as well as between the finger joint ones. The final weight losses are as follows: jointless samples 15.51 %, horizontal finger joint samples 19.13 % and vertical finger joint samples 22.47 %. For the horizontal finger joint sample, the difference is 3.98 % compared to the control sample, for the vertical finger joint one it is 7.32 %, and there is a difference of 3.34 % when comparing the two types of finger joints.

When assessing the second evaluation criterion (burning rate) we can come to similar conclusions as for weight loss. An increase in the burning rate can be observed immediately after the first minute of the experiment (see Fig. 6). The burning rate (for the control samples as well as the finger joint samples) gradually increases due to the exposure to the heat source. The increase in the burning rate is much more abrupt for the finger joint samples compared to the control samples. As it is obvious from Fig. 6, the burning rate is influenced by the finger joint direction; it is more intense for the vertical finger joints than the horizontal ones. In the case of vertical finger joints, the most intense burning rate was reached at the 330th second of the experiment and at the 510th second of the experiment for the horizontal finger joint. The burning rate for the control samples was recorded at the end of the experiment at the 600th second.

The peak values of the evaluation criteria are stated in Table 1. In addition to the basic ones, it also includes the time necessary to achieve the burning rate peak and the ratio of these two variables (maximum burning rate and the time when this value was reached). This table clearly shows the effect of finger joint direction on the evaluation criteria. The differences in the values were caused by two factors: a weak heat source and a very short time interval. In case of fire (a more intense heat source and a longer time of exposure), these disparities will certainly be higher.

The a/b ratio has been chosen as an auxiliary indicator. It is an indicator that is used during some tests to determine the fire protection properties of wood. If the maximum burning rate is reached in the first "minutes" (at the beginning of the experiment), the material has a negative assessment for fire protection purposes compared to the same burning rate value reached in the middle or at the end of the experiment. (e.g. burning rate of 10 is achieved at the 1st , 5th and 10th minute of the experiment then the ratio is 10, 2, 1. The lower the ratio (a/b) is, the better the assessment of the material (finger joint) is.

Table 1. Peak value of the evaluation criteria

Evaluation criteria (peak value)	Type of construction		
	Jointless samples	Vertical finger joint	Horizontal finger joint
Mass loss (%)	15.51	19.13	22.47
a Burning rate (%/s)	0.004375	0.004638	0.004776
b Time max. burning rate (s)	600	510	420
Ratio **a/b**$*10^6$	7.29	9.09	11.4

The burning rate has decreased/stabilized for the finger joints samples. For the vertical finger joints, this happens in approximately the 420th second of the experiment and approximately in the 540th second of the experiment for the horizontal finger joints. This slowdown in the burning rate can be a result of a charred layer being created directly inside the joint and functioning as an “insulator”.

The charred layer slows down the burning rate, however, the degradation of the finger joint (for both types of joints – see Fig. 7 and Fig. 8) and the material continues even if the process has slowed down.

Fig. 7. Charred layer – vertical finger joints.

Fig. 8. Charred layer – horizontal finger joints.

Carbonization sets in sooner for horizontal finger joint samples - it covers a larger surface but it does not have such an important impact. It just brings about a constant charring rate in a relatively long period of time. In the case of horizontal finger joints, a steeper decrease in the burning rate can be observed as a consequence of a layer of compact wood coming after the charred layer and representing an “obstacle” preventing heat transfer from advancing.

PSPP software was used to calculate the descriptive properties of the statistical data where the group called "finger joints - width" is labeled as VFJ and the group HFJ is short for "finger joints - thickness". Weight loss was the only parameter subject to the statistical evaluation (see Table 2 and Fig. 9).

Table 2. Outputs of descriptive statistics

	N	Mean	S.E. Mean	Std. Dev.	Variance	Kurtosis
VFJ	15	21.44	0.31	1.31	1.72	-1.10
HFJ	15	19.15	0.20	0.77	0.59	-0.19

	S.E. Kurt.	Skewness	S.E. Skew	Range	Min	Max	Sum
VFJ	1.12	0.36	0.58	4.06	19.73	23.78	321.65
HFJ	1.12	0.05	0.58	2.81	17.63	20.44	287.23

Valid cases ′15; cases with missing values (s) = 0

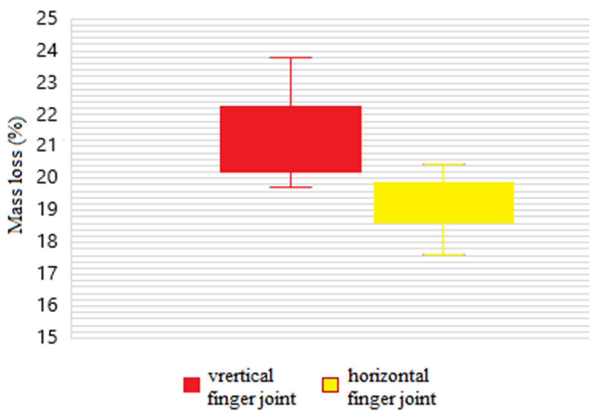


Fig. 9. Box plot for the given groups.

The statistical data show that the weight loss was greater for VFJ samples compared to HFJ samples. VFJ samples showed a larger variability as evidenced by a higher standard deviation (SD) = 1.31 compared to the second group where the SD = 0.77. Maximum and minimum weight losses ranged almost in the same intervals for both groups. In general, they were slightly above and below the median values. Kurtosis for the VHJ group reached -1.10. It indicates that the values in the population deviate from the normal distribution in the population and the minus indicates that the distribution is shallower i.e. the values in the population are lower or higher than the mean. On the other hand, kurtosis for the HFJ group was significantly lower, i.e. -0.19, so most data were close to the mean. As for skewness, both VFJ and HFJ samples reach values very close to 0 (0.36 and 0.05), therefore the data in the population are distributed normally.

CONCLUSION

A relatively simple experiment confirmed that attention needs to be paid not only to façades and cladding material but also to the type of joint used. The evaluation criteria confirmed different behavior patterns of finger joints made from spruce wood and the fact that the finger joint direction affects the test results. In order to evaluate the selected evaluation criteria, a heat source with a lower intensity has been chosen. The wood did not even ignite, which was the aim of the experiment. Despite this fact, the evaluation criteria confirm that the finger joint direction has an impact on the heat transfer through the joint. We should bear this fact in mind in practice. It is recommended that the finger joint made from a flammable material is protected by a fireproof material or coating from the other side to prevent the rapid ignition of the reverse side of the façade where, in the case of a vented type of a façade, it may result in the very rapid spread of the fire along the façade.

The maximum burning rate for the vertical finger joints is achieved since the joint creates a direct heat bridge (free of obstacles) at a length of 220 mm. Although the joint is glued, radiant heat breaks through that length/surface of 4400 mm^2 more easily than in the case of horizontal finger joint creating an obstacle by its own teeth.

It is necessary to pay attention to other types of joints, e.g. metal fasteners, too. Metal fasteners may conduct heat faster than the surrounding material or its joint. As the experiment proved, the form of the joint may influence the spread and the speed of fire. Therefore, we also recommend, by means of a simple test, to test the other types of joints that are commonly applied onto façades. Attention should be paid to glued joints as well as the materials which form the load-bearing structure to which the elements of the façade are fixed.

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