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THE IMPACT OF GEOMETRIC SHAPE OF THE LOG WALL CONSTRUCTION ELEMENTS ON THEIR FIRE BEHAVIOUR

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ABSTRACT

The aim of the research was to perform the medium-scale fire tests of two alternate samples of the log wall, using the radiant heat source. The radiant heat source consisted of a ceramic radiation panel with a maximum power of 50.5 $kW \cdot m^{-2}$ and a maximum temperature of 935°C. The samples varied by their geometric shape and the different design of the groove, which was sealed with glass mineral wool. A better result was achieved by a round wood sample with the circular section, which also resisted to high temperatures in the place of the groove and did not start burning with flame. The sample of the squared log elements started to burn with a flame. Temperature measured in the groove was much higher than in the first case.

KEYWORDS: Log wall, groove, radiant heat source, glass mineral wool, medium-scale fire test, fire resistance

INTRODUCTION

Traditional log buildings are made of solid structural elements (timber) vertically stacked on top of each other. The bearing elements of this structure are placed in a horizontal position, where the vertical statics ensure the dimension of the used elements (Gracovský et al. 2015).

According to Zachar et al. (2017), wood is a material characterized by a relatively inhomogeneous anisotropic structure, consisting of a macromolecular substances complex (cellulose, hemicelluloses, lignin and extractives).

Research of behavior of wood and wood based materials in fire has been realised by e. g. Čabalová et al. (2013), Kučera et al. (2012), Leško and Lopušniak (2015), Osvald (2011). Oremusová and Čepec (2012) assessed the ignitability, linear burning rate dependent on the type of wood. Zachar et al. (2012) analysed the following fire properties: flash-ignition temperature, spontaneous ignition temperature, mass burning rate, ignitability of material exposed to a small open flame.

Temperature above 100°C has an influence on the changes in chemical, physical and structural characteristics of wood (Osvald et al. 2017). According to Čabalová et al. (2013), the thermal resistance of the basic buildings components of the wood is different (thermal decomposition of the hemicellulose decompose in a temperature range of 170-240°C, of the cellulose 250-350°C, of the lignin 300-400°C).

According to Kučera et al. (2012), Osvald (2011), Leško and Lopušniak (2015), Vavrušková and Lokaj (2009), char layer is formed on the surface of wood during a fire load. Carbonization process starts at temperatures above 250°C (Kačíková et al. 2011). Under this hardened layer, in the case of a fire, lasting for more than 20 min, the wood at the depth of about 30 mm is affected by high temperature. A part of this layer with a temperature of 200°C represents the pyrolysis layer (Kuklík 2005). However, at a depth of about 30 mm below the charcoal layer, the wood is the same temperature as the ambient temperature (i.e. about 20°C), because wood is a bad heat conductor and very little heat is supplied to the remaining cross section (Kuklík 2005). Štefko et al. (2006) indicate that the thermal conductivity of the charcoal layer (wood charcoal) is about 1/6 of the thermal conductivity of the wood, and therefore the charcoal layer acts as an insulating layer and the decomposition of the wood is much more slower bellow it.

The risk of fire spread from the exposed side to the unexposed in the abovementioned constructions represent the load-bearing joint (groove) that occurs when two masses of the massiv are in contact. It is therefore necessary to use material suitable to this groove, not only from the thermal insulation point of view, but also from the fire safety point of view.

The cladding of the log buildings was composed of a single layer previously, which had both a tiling, bearing and space-forming function (Kolb 2007). Based on the shape of the massive element, Cooper (2000) classified the structure elements of the logs buildings into the groups shown: round logs, ´D´logs, square logs, rectangular logs.

Depending on the chosen profile of the structural element, the grooves of different shapes can be located in the walls of the traditional log building. The round wood itself may be round shape or may have edges trimmed for a stronger joint (Bell and Rand 2006). The longitudinal groove can have the following profiles: rectangular, shallow half shape, letter "W" shape or so-called double sketched shape (Houdek and Koudelka 2011).

In terms of fire protection, one of the most critical locations in a fire dividing structure of the log building is the joints, including the longitudinal groove. In the case of incorrect selection of insulating material or design of the groove, the fire may spread from the exposed side to the unexposed side. Therefore, also the criterion of integrity E and isolation I is largely dependent on the applied filling material (Vaverka et al. 2008).

The longitudinal groove (bearing joint) represents a weakened place of the structure mentioned, quite often occurring in the construction of the external wooden massive wall (Brandejsová et al. 2007). It is most often located along the entire length of the squared or rounded wood.

The intersection of the two logs must be designed to ensure the most advanced and, above all, permanent barrier between the interior and the exterior of the building. Although the logs for the construction of the log building have been chosen very carefully (in order not to show the fibre spinning), after the drying of the round log, some shape changes may occur, resulting in leaks in joints. The material for the coating of all grooves must have thermal insulating properties, both in terms of thermal resistance and air infiltration. At the same time, it must have a shape memory, so it must be able to balance the creep of wood elements (Brandejsová et al. 2007).

According to Houdek and Koudelka (2011), the necessity of the insertion of the longitudinal groove is required especially in constructions that separate the interior from the exterior. This is a requirement for thermal insulation mainly.

In practice, only some of the wide range of insulation materials are used to insulate the longitudinal grooves in the log walls. Mineral insulation can be considered as a representative of classical insulation material. Further, the most used types of materials used to insulate the longitudinal grooves of the log walls are introduced.

MATERIAL AND METHODS

Samples

The subject of the experiment were two samples of the log walls, which varied in the shape of the cross-section of the log elements and thus also in the form and shape of the groove. There was used the glass mineral wool as an insulation material in the grooves of both samples. The dimensions of samples were of 1 x 1 m.

Sample 1: It is a single-shell log spruce structure, made of round logs with diameter of 200 mm, with longitudinal groove filled with the glass mineral wool. The groove was placed at the centre of the log, along its entire length to a depth of 50 cm. After the sample crafting, the groove was sealed by a special heat-resistant sealant, from both sides, that shall lower the flame spread rate in the groove. This is a material with intumescent effect (from 200°C) which protects other layers of materials at a multi-level level (Osvald 2011). Sample 1 during its crafting is shown in Fig. 1.

Fig. 1: Sample 1 with visible groove during its crafting.

Sample 2: It is formed of a log wall made of spruce wood from squared log elements with dimensions of 200 x 200 mm. In this case, the groove was not fed into the log, as in the case of the round logs, but the groove was created naturally, so that a gap was created between each log, using 30 x 200 mm pads, to support each login order to create a space for the placement of the glass mineral wool, i.e. the groove itself. Although the glass mineral wool had a thickness of 40 mm, it was pressed, when the log was applied to it, and this way also the air gap between the logs was filled. For better thermal insulation properties of the construction, wooden rails were used to cover groove, which were sealed with special heat-resistant sealant. In Fig. 2, there is introduced the entire construction of Sample 2.

Fig. 2: View of Sample 2.

Experiment

The principle of the test was to expose the above-mentioned log wall samples to the radiant heat source. This method of thermal loading represents a situation, in which the fire is at a distance from the exposed element, i.e., the flames are not in direct contact with the element exposed.

Twelve thermocouples were used to perform the experiment, which sensed the temperature of both the exposed and unexposed side of the test sample. Since six thermocouples were used for each log wall, three were applied on the exposed and three on unexposed side. The thermocouples were placed into the wood, in the depth of about 50 mm, and into the insulation made from the glass mineral wool, in the depth of 20 mm as well as into the layer of sealant, so that they did not lap over into the insulation in the groove. Position of the thermocouples is shown in Fig. 3.

Fig. 3: Position of thermocouples located on the samples.

As the radiant heat source, there was used a ceramic radiation panel with dimensions of 480 mm x 280 mm, which energy source was the propane-butane gas with a constant flow. The log samples were placed at the centre of the radiation panel at the distance of 200 mm from the radiation source (Fig. 4), which power was of 43.1 $kW \cdot m^{-2}$ at this distance. The samples were exposed to radiation panel for 45 min.

Based on the temperatures measured and the changes observed in the samples during the experiment, the impact of the cross-sectional shape of the log elements on the sealing of the groove, when subjected to radiant heat source thermal loading was evaluated.

Fig. 4: Position of sample in front of the ceramic radiant panel.

RESULTS

The first subject of the experiment was the Sample 1 (round log sample). During the test, after 10 min, the degradation at the surface of the wood was quite evident and a white layer of charcoal began to appear, which was gradually growing. The sample did not show signs of flaring during the entire duration of the test, thus the burning was still flameless with considerable smoke formation. During the thermal loading of the sample (30 min), the grooves resisted burning and also the deformation was not very pronounced. However, after 31 min, there was a considerable deformation of the log wall at the place of grooves, as well as the disruption of the sealant layer on the exposed side of the groove, as seen in Fig. 5. The temperature course recorded by the T5 thermocouple, placed in the sealant layer (see Fig. 6), was affected by the disruption of the groove integrity in this case, while in the case of square log, there was recorded continuous temperature course by the T5 thermocouple at the same time.However, it should be emphasised that despite the disruption of the integrity of Sample 1in the groove, the glass mineral wool remained almost intact, exhibiting remarkably high temperatures at the end of the experiment (T6 = 380°C).

Fig. 5: Detail of the groove sealing disruption after 31 min of thermal loading.

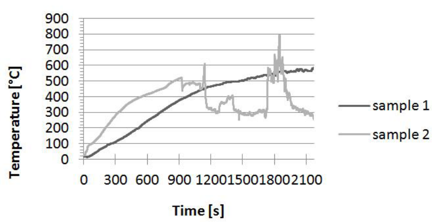

Fig. 6: Temperature course in sealant layer on T5 thermocouple under sample thermal.

In Tab. 1, there are introduced the temperatures measured on individual thermocouples and in Fig. 7, there is introduced the round log wall during the testing (after 10 min, 30 min) and after the testing. Position of the individual thermocouples mentioned in Tab. 1:

Tab. 1: Temperatures measured on the Sample 1.

Time/min	5	10	15	20	25	30	35	40	45
T0/°C	17.5	17.3	16.6	17.4	17.0	17.1	17.0	16.7	17.3
T1/°C	12.5	70.3	60.0	55.0	69.0	90.0	130.0	150.0	130.0
T2/°C	14.5	14.0	13.5	13.0	14.5	13.5	13.0	12.5	13.8
T3/°C	15.0	14.5	14.5	15.9	18.5	23.1	28.0	35.0	50.0
T4/°C	40.5	82.3	120.8	162.7	242.0	397.0	490.0	540.0	603.0
T5/°C	45.9	150.0	303.0	416.3	480.8	410.0	550.0	590.0	520.0
T6/°C	86.5	118.0	80.0	84.0	90.0	110.0	170.0	260.0	380.0

T0 – Measurement of ambient air temperature; T1 – Measurement of temperature in the groove insulation on the unexposed side; T2 – Measurement of temperature in the wood on the unexposed side; T3 – Measurement of temperature in the sealant layer on the unexposed side; T4 – Measurement of temperature in the wood on the exposed side; T5 – Measurement of temperature in the sealant layer on the exposed side; T6 – Measurement of temperature in the groove insulation on the exposed side.

Fig. 7: Testing the Sample 1 a) after 10 min, b) after 30 min, c) after the testing.

At the beginning of the experiment with Sample 2, there was also observed a change in the colour of the surface of the wood from dark brown to black, spreading across the edge of the logs. The signs of cracking and charring began to appear a little earlier than in the case of a log wall made of round logs, i.e. after 2 min. At about half of the 3rd min, a spark was visible on the surface of the sample. After 11 min, the edgeof the lower log was ignited on the exposed area of the wall (see Fig. 8 a), while the flame was spreading rapidly from the edge gradually over the entire area of the sample exposed area (see Fig. 8b). At the 15thmin, the flames began to recede and the smoke production intensity increased. At the 25thmin, the protection rail was destroyed as well as the sealant layers in the groove (Fig. 9).

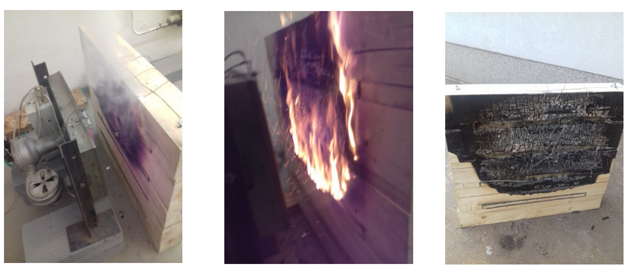

Fig. 8: Testing the Sample 2 a) after 10 min, b) after 30 min, c) after the testing.

Fig. 9: Deformation of the protection rail before it is completely falling out.

At the 30th min, the protection rail completely felt out and there was an increase in the temperature in the insulation and subsequent accumulation of the combustion gases in the groove. At the 35th min, there was a flame extinguishing at the bottom of the wall. There occurred the sudden destruction of the lower log caused by a crack which grown due to the high temperature and the log was ripped along its entire length. From a safety point of view, therefore, the experiment was terminated prematurely at 36th min. But, we still expect that the structure should with stand the fire effects during the 45-min, despite the high temperature in the insulation layerof the groove at the 35th min of the test (T6 = 514°C).

In Tab. 2, there are introduced the temperatures measured on the thermocouples located on the Sample 2. Fig. 9 shows a sample during and after the test Fig. 10 and Fig. 11 show the graphical representation of the temperature measured on the individual thermocouples of both samples.

Tab. 2: Temperatures measured on the Sample 2.

Time/min	5	10	15	20	25	30	35
T0/°C	14.5	15.0	15.5	17.0	16.5	17.0	17.2
T1/°C	23.2	55.5	72.0	73.8	160.0	190.0	230.0
T2/°C	14.8	15.0	13.5	13.5	14.0	13.7	14.0
T3/°C	13.5	14.5	15.0	16.5	16.8	17.0	17.5
T4/°C	285.0	250.0	150.0	270.0	330.0	390.0	405.0
T5/°C	150.0	350.0	480.0	325.0	290.0	310.0	254.0
T6/°C	80.0	124.5	280.0	525.0	680.0	669.0	514.0

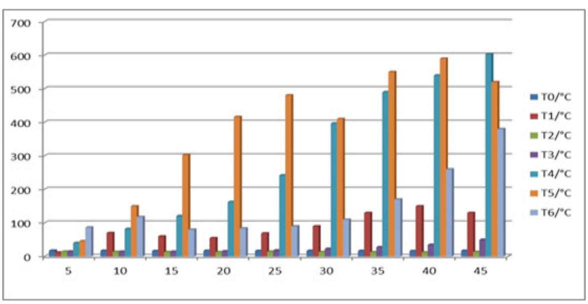

Fig. 10: Temperatures measured by the thermocouples located on the Sample 1.

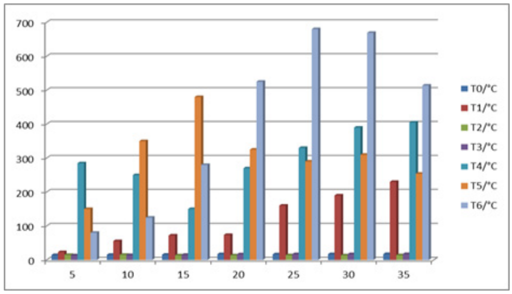

Fig. 11: Temperatures measured by the thermocouples located on the Sample 2.

DISCUSSION

The results of the experiments showed that the effect of the radiant heat in designing and sealing the grooves was better in the case of the log wall made of round logs. After disruption the integrity of the groove, the thermal insulation, despite high temperatures, was well resistant to the effect of thermal loading during the entire experiment. When comparing the temperature on the thermocouple in the thermal insulation layer on the exposed side, a temperature of 170°C was recorded at the 35th min. In the case of log wall made of the square log, the temperature of 514°C was recorded. An important difference in the results of the experiment was flame burning, that occurred in the experiment with the log wall made of square logs. The reason for the flame formation was the geometry of the surface of the sample and its edges, along which the flame spread rapidly and easily. This caused the falling out of the protection rail and more intense increase in the temperatures in the insulation layer. It is also necessary to mention the excellent thermal insulation properties of wood and the structures made of it, which was also evident from the values of the temperatures measured on the unexposed side of the log walls, which had a temperature measured in the wood layer comparable to the ambient temperature. In accordance to the temperatures measured in the sealant layer on the unexposed side of the groove, we can assume that both log walls would maintain the integrity criterion E and thermal insulation I for 45 min, according to EN 13 501-2 (2010).

Tereňová and Jochim (2005) studied the fire resistance of a block house, too. The construction made of square logs was subjected to the experiment. They achieved similar results. At the 30th min, temperature of the surface was of 497.6°C. At this moment, there occurred a flame that was spreading across the surface. During the test, the temperature inside the construction did not increase. Tereňová and Jochim (2005) confirmed this fact by the values of the temperature measured on two thermocouples (location of the first thermocouple – into the longitudinal groove, location of the second thermocouple – between cuts and thermal insulation).

Osvald (2011) assassed the construction of round logs with mineral insulation. At the 20th min, the sample was charring. At the 31th min, the flame burning occurred, that receded after few minutes. After this model test, the entire log construction was tested in certified testing laboratory. According to Osvald (2011), the final fire resistatnce of this construction was of 180 min.

A similar experimental study was also performed by Wakefield et al. (2009). Authors assessed the solid timber external wall under simulated bushfire attack. The samples were made from the white cypress round logs and in different variations (the sample #8 – without surface conditioning, the sample #2 – coated with intumescent paint, sample #3 – two layers of coatings, sample #6 – with a small section to emulate decking board). Wakefield et al. (2009) summarized the performance criteria: formation of through gaps greater than 3 mm, sustained flaming for 10 s on the non-fire side, flaming on the fire-exposed surface at the end of the 60 min test period, radiant heat flux of 365 mm from the non-fire side exceeding 15 $kW \cdot m^{-2}$, mean and maximum temperature rises greater than 140°C and 180°C, radiant heat flux 250 mm from the specimen, greater than 3 $kW \cdot m^{-2}$ between 20 and 60 min, mean and maximum temperature of internal (unexposed) faces exceed 250°C and 300°C respectively between 20 and 60 min after commencement of test. At the 49th, there was ignition of the sample #4. At the 52^{th}, there was ignition of the sample #8. Sample #4 and sample #8 were significant charring. The exposed surface temperature of the sample #4 was of 641°C. There was no ignition of the sample #2, because the sample was coated with intumescent painting. According to Wakefield et al. (2009), all samples except the sample #6 passed the criteria.

CONCLUSIONS

The experiment proved that the geometric shape of the material influences the possibility of ignition, the rate and intensity of the burning process. According to Osvald (1997), the dimensions, mainly thickness, length, diameter, edges (their number), rounding angles, and other parameters of geometric shape determine the resistance of the wood element to ignition. This was confirmed also in the case of samples tested. While, the log wall made of square logs, used also in groove (protection rails), ignited relatively in a short time, resulting in a higher increase in the temperature inside the groove. The experiment also confirmed that the design and material used for groove, as well as its shape, quality thermal insulation and quality sealing from the outer side of the groove, have significant effect on achieving the required fire resistance at the place of the groove.

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