

## CLT CONSTRUCTION PERFORMANCE UNDER THERMAL LOADING

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### ABSTRACT

The paper deals with testing fire resistance of a vertical wooden building construction made of CLT panels subjected to the medium-scale test of the fire resistance. A model test of fire resistance with the ceramic radiation panel as the radiation heat source, with achievable temperature of radiation surface of 935°C at maximum was used. The aim of the experiment was to assess the experiment sample whether it meets the request of the thermal insulation and integrity under thermal loading of the model fire for 30 min. The test resulted in the increase of temperatures on observed thermocouples and assessment of the integrity on the unexposed side of the CLT panel. The construction clearly resisted the effects of the radiation heat during 30 min and maintained the observed criteria of fire resistance. Charred layer of the CLT panel created on the surface of the exposed side in the thickness of 20 mm inhibited the heat transfer into the further layers of construction.

KEYWORDS: Cross-laminated timber (CLT), integrity, thermal insulation, medium-scale test.

### INTRODUCTION

CLT panel is a building material made from several layers of spruce wood which is, according to Wieruszewski and Mazela (2017), distinctive by several positive properties. As stated by Frangi et al. (2009), dried spruce boards are placed across each other and individual layers are glued on the complete surface area. This is the way by Klippel and Frangi (2016) how large-area panels are formed. Its strength properties enable it to be used in structures not only as sheathing panels but as loadbearing construction elements as well. It is still a flammable material from the fire protection point of view. As mentioned by Östman et al. (2018), CLT panel is placed into class of reaction to fire D-s2 or Dfl-sl. Construction made of solely of a CLT panel meets the requirements on the construction element D3. In case of lining such construction by non-flammable material (plaster board) it meets the requirements imposed on the construction element of D2 classification.

By EN 1995-1-2 (2004) standard it is necessary to consider the fact that if the wooden surfaces are exposed to fire effects, the charring process will start. According to Kučera et al. (2012), Leško and Lopusniak (2015), the charred layer is formed on the surface under the thermal loading and thermally insulates the remaining inside layers against the effects of a fire by Wiesner and Bisby (2019). After the top layer of the CLT panel has been charred, it can fall off and then the next layer is exposed to the effects of fire and the process of charring proceeds more rapidly (Klippel et al. 2019). The studies have revealed that the falling off of the charred layer appears earlier especially when the connection of the CLT panel have been provided by a PUR adhesive. This has been mentioned by Dúbravská et al. (2019), McGregor et al. (2012), and Friquin et al. (2010). Behaviour of CLT panel in a fire depends on thickness and the number of layers which the actual building material is made from as mentioned by Klippel et al. (2014), Menis et al. (2018). By Klippel et al. (2014), CLT panels with thicker out layers achieve more positive results as in performance of the material in fire. According to Schmid et al. (2015), CLT panels can be used in a structure without sheathing (so-called unprotected) or with lining (so-called protected). Yet, a non-protected CLT panel of 80 mm thickness is claimed by the producer to have 60-minute fire resistance. During 60-minute loading according to standard temperature curve, the wall shall maintain its load-bearing capacity, integrity, and thermal insulation. The review of Barber and Gerard (2015) mentions the results. Fragiaco et al. (2013) conducted the fire tests on protected and un-protected CLT panels to state the fire resistance. They came to the following results: the time of failure of ranges between 99 min to 110 min for unprotected and protected CLT panels.

As mentioned earlier, the construction is made solely of the CLT panel and it is classified as construction element of D3 class. In case the construction element is covered by a non-combustible material, the construction element falls in to D2 class. Henek et al. (2017) state the following measures: to increase the thickness of the fire lining (fire resistant), to change the kind of lining material or to apply other form of fire protection (fire coating, spray-on, plastering).

## MATERIAL AND METHODS

The main aim of the paper was to assess the fire resistance, namely the criteria of thermal insulation and the integrity of the vertical structure made of CLT panel under thermal loading.

The test sample was made of cross-glued slats without surface treatment. It is a 3-layer panel, whose individual layers were made of spruce wood with a humidity of up to 15%. The panel had the following dimensions - 1000 x 1500 x 80 mm, with the middle layer having a thickness of 40 mm and the outer layers having a thickness of 20 mm. The gluing direction of the slats of the middle layer was vertical, the gluing direction of the slats of the outer layers was horizontal.

The test sample was loaded through the radiation panel for 30 min. For the duration of the mid-size test, temperature behaviour was recorded by NiCr-Ni thermocouples with a temperature range from -200 to +1350°C. The specific location of the individual thermocouples in the test sample was as follows (Fig. 1):

- TC1 - located on the exposed side of the sample,
- TC2 - located at the contact of the middle and outer layer at the exposed side,
- TC3 - located at the contact of the middle layer and the outer layer on the unexposed side,
- TC4 - located on the unexposed side.

The test sample was placed at a distance of 200 mm from the radiation panel. This distance corresponded to the radiation intensity of 43.1 kW·m<sup>-2</sup>, the size of the radiation surface was 480 x 280 mm. The radiation surface temperature was about 798°C for the above parameters.

The energy source of the ceramic radiation panel was a propane-butane gas with a constant flow rate.

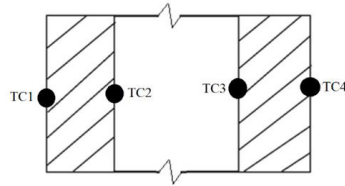


Fig. 1: Location of thermocouples on and in the sample.

### Assessment criteria

In the medium-scale test, we focused on the evaluation of two fire resistance criteria - thermal insulation and the integrity of the test sample. The thermal insulation criterion was evaluated on the basis of the temperature behaviour recorded during the medium-scale test. The temperature increases on the unexposed side of the sample were evaluated with respect to the initial temperature. The maximum temperature increase at any point of the unexposed side was set at 180°C according to EN 13501-2 (2016). The integrity criterion was carried out during the medium-scale test by visual inspection of:

- cracks formation on the unexposed side of the test sample,
- the occurrence of a flame on the unexposed side.

The integrity and flame presence on the unexposed side were monitored during the medium-scale test (every 5 min) and after the medium-scale test. If cracks and gaps were formed on the surface of the unexposed side during fire exposure to the test sample, the scale transfer through the test sample was assessed after the test had been completed. The scale transfer through the test sample was made with a 6 mm diameter measuring device.

## RESULTS AND DISCUSSION

The behaviour of the test sample in the first seconds of the medium-scale test can be compared to the behaviour of spruce wood under fire conditions. As mentioned above (Frangi et al. 2009), the fire behaviour of the CLT panel is characterized by the behaviour of the individual layers of this material. At temperatures of 20°C to 150°C, the wood starts to dry, losing water starting with free water and ending with bound water; at temperatures from 180°C to 250°C the wood is subjected to considerable chemical changes, at temperatures above 250°C the charring process starts accompanied by CO<sub>2</sub> and other pyrolysis products formation (Esteves et al. 2009). Already in the first minute of the medium-scale test, there was a thermal degradation of the test sample, for which a change in colour of the wood is characteristic according to Čabalová et al. (2014), Tereňová et al. (2018). According to Kučerová et al. (2009), Zachar et al. (2017), there is a significant change in especially in the surface layers under the thermal load of wood. This process was accompanied by slight smoke generation. The flame burning occurred during 7<sup>th</sup> min, whose intensity decreased from 10<sup>th</sup> min (Fig. 2). It was flameless combustion after 12<sup>th</sup> min. As stated by Osvald and Gaff (2017), most combustible materials are characterized by burning in two phases: Phase 1 represented by the flame burning of gaseous degradation products, and phase 2 represented by flameless combustion of carbon-rich material residues.



Fig. 2: Flame burning in the 7<sup>th</sup> min.

The TC1 thermocouple was placed on the exposed side. TC1 recorded the heat emitted from the radiation panel, but also the heat that was released from the test sample during the exothermic combustion reaction. The temperature curve is shown in Fig. 3.

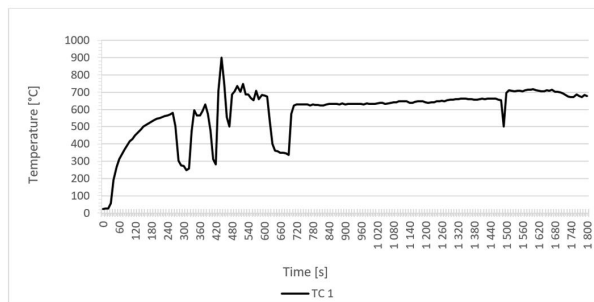


Fig. 3: Temperature development recorded on the exposed side of the test sample.

As noted, TC1 thermocouple deviations occurred at 5<sup>th</sup>, 7<sup>th</sup>, 11<sup>th</sup> and 25<sup>th</sup> min. These were caused by the failure of the TC1 thermocouple mounting and its deflection from the sample surface into the surrounding environment or towards the radiation panel surface. When the mounting failed, the TC1 thermocouple subsequently touched the surface of the radiation surface, which was characterized by temperature of 898.5°C (in 7<sup>th</sup> min).

Temperature development inside the test sample was recorded via two thermocouples (Fig. 4). Thermocouple TC2 was placed 20 mm far from the exposed side and the thermocouple TC3 was placed 60 mm from the exposed side.

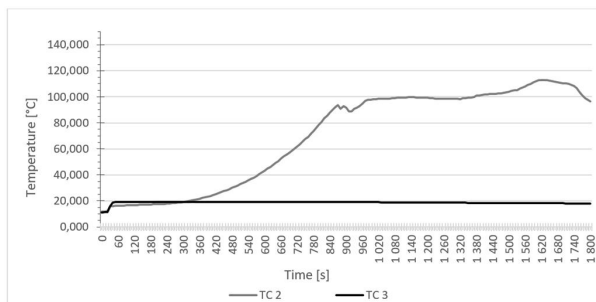


Fig. 4: Temperature development recorded inside the test sample.

A temperature increase at the distance of 20 mm from the exposed side (TC2) occurred in approximately 7<sup>th</sup> min. At this time, flames occurred on the surface of the test sample. This thermocouple was placed between two layers of spruce that were glued with PUR glue. It is assumed that heat released volatile products from the adhesive and thus the pressure between the layers increased. The carbonization of the layer on the exposed side and the pressure between the layers created by heating of PUR glue resulted in falling off of the charred first layer in the 30<sup>th</sup> min of the test.

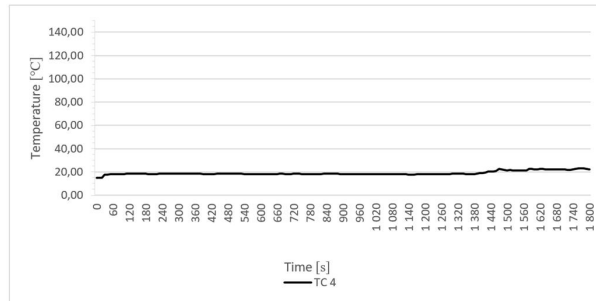


Fig. 5: Temperature development recorded on the unexposed side of the test sample.

During the entire medium-scale test, the thermocouples TC 3 and TC 4 showed no increase in temperature and their temperature ranged around 20°C. The thermocouple TC4 recorded the temperature of 23°C in the 30<sup>th</sup> min. Based on the temperature behaviour showed in Figs. 4 and 5, it was concluded that the very little increase in the temperature was caused by the moderate increase of the ambient temperature.

### Thermal insulation criterion evaluation

The thermal insulation criterion is assessed according to EN 13501-2 (2016) on the basis of the temperature increase at any point of the unexposed side of the sample by maximally 180°C considering the initial temperature measured on the unexposed side of the sample at the beginning of the test. The thermal insulation criterion on all thermocouples is evaluated in this way. The initial temperature of the individual thermocouples placed in the test sample is given in Tab. 1.

Tab. 1: Initial temperature on the individual thermocouples (°C).

Initial temperature at individual thermocouples (°C)			
TC1	TC2	TC3	TC4
25.1	11.9	11.2	15.0

Tab. 2 shows temperature increases considering the initial temperature. As can be seen in Tab. 2 and Fig. 5, there was no temperature increase of 180°C on the unexposed side. Maximum temperature increase on the unexposed side was 8.2°C during the 30<sup>th</sup> min. Maximum temperature increase inside the test sample (20 mm from the exposed side) was 101.1°C in the 27<sup>th</sup> min. Maximum temperature increase inside the test sample (60 mm from the exposed side) was 8.2°C in the 6<sup>th</sup> min.

Tab. 2: Temperature increases considering the initial temperature (°C).

Time (min)	Temperature increases from the initial temperature (°C)			
	TC1	TC2	TC3	TC4
1	286.7	4.3	7.9	3.1
2	423.4	5.0	8.0	3.4
3	503.8	5.4	8.2	3.5
4	541.0	6.0	8.2	3.4
5	248.9	7.3	8.1	3.4
10	657.1	31.4	8.0	3.3
15	603.9	79.8	7.9	3.3
20	615.4	87.3	7.4	3.0
25	672.2	92.0	7.1	6.3
30	653.4	84.7	6.9	8.2
Max. increase	728.5	101.1	8.2	8.2

Comparing the temperature increases on TC1 and TC2 in the 30th min the difference is 568.7°C. The distance between these two thermocouples is 20 mm. On the surface of the test sample made from three layers of spruce wood the charred layer was formed adding its insulation capacity. Based on the above mentioned, it can be stated that the test sample m CLT panel fulfilled the thermal insulation criterion.

The integrity criterion was assessed on the basis of visual inspection. Formation of cracks or presence of flame on the unexposed side was checked in regular intervals. During the medium-scale test and after the test, no cracks were formed. The transfer of the measuring device was not applicable. The test sample made of CLT panel satisfied the integrity criterion (Fig. 6)



Fig. 6: Unexposed side of the test sample after the medium-scale test.

Frangi et al. (2008) also investigated the performance of CLT with no weight load in fire conditions. The test sample was 84 mm thick (3 x 28 mm). The individual layers were glued by PUR adhesive. The authors state the charring rate as 0.6 to 0.68 mm·min<sup>-1</sup> and the char layer depth as 26.5 mm after 39<sup>th</sup> min. The fire test was finished after 39<sup>th</sup> min before the outer layer of the CLT panel was completely charred.

CLT panel performance during a fire was studied by Schmid et al. (2015). The authors carried out several tests (model test, medium-scale test, and large scale test). Various makes of test samples (protected and unprotected surfaces of a CLT panel) were tested. In the medium-scale test, the test samples were tested in a vertical furnace. The test samples with dimensions of 600 mm x full height x 95 mm were placed into the frame and mounted in the down part. The thermocouples were placed into three areas (750 mm from the upper edge of the test sample, in

the middle of the sample and in 750 mm from the bottom edge of the test sample). In every area three thermocouples were placed – 9.5 mm, 28.5 mm and 47.5 mm from the exposed side. During the test, also the loadbearing capacity was assessed therefore they were loaded by even weight load of 83.3 kN·m<sup>-1</sup>; 166.7 kN·m<sup>-1</sup> and 250.0 kN·m<sup>-1</sup>. Schmid et al. (2015) state that all test samples maintained integrity and insulation during the whole course of the test. The test was finished at the time when there was a load-bearing failure due to the sample deformation. The duration of the medium-scale test was, therefore, different for each sample depending on the weight load. For the test load of 83.3 kN·m<sup>-1</sup>, the test duration time was 96 min. For the test load of 166.7 kN·m<sup>-1</sup>, the test duration time was 59 min. For the test load of 250 kN·m<sup>-1</sup>, the test duration time was 48 min.

## CONCLUSIONS

The medium-scale test was aimed at investigating the behavior of the structure made of the CLT panel under thermal loading. Despite the CLT panel classification in D-s2, d0 class according to the reaction to fire classification, a construction made of this material can achieve favourable results. When exposed to fire, a charred layer is formed on the exposed side, which generally slows down the process of thermal degradation of the rest cross-section. Based on the temperature curves monitored on the places between the individual layers of CLT panel, the conclusion that the panel clearly resisted to the radiation heat (the effects of model fire) for 30 min while it maintained the criterion of thermal insulation and integrity. Due to the charred layer which had a retarding effect, the degrading of the of the next layer of the CLT panel did not occur which was confirmed by the maximal temperature of 115°C measured by the thermocouple TC2 in the 27th min of test (Fig. 4 in 16420th second). That was also the reason why the integrity was not breached which means permanent flaming did not occur on the unexposed side and no cracks or openings which would exceed the determined limits on the unexposed side of the sample.

The described positive test results are comparable to the earlier mentioned results presented by research of foreign authors (Frangi et al. 2008). At the same time they show that the constructions of CLT panels represent a suitable and prospective material for the construction of modern multi-storey wooden buildings in the Slovak Republic.

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