FIRE RESISTANCE OF CELLULAR WOODEN SLABS WITH RECTANGULAR AND CIRCULAR PERFORATIONS

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ABSTRACT

This work presents a numerical and experimental approach in order to predict the thermal behaviour and the performance of typical cellular wooden slabs with rectangular and circular perforations when submitted to fire conditions. For this purpose a 3D numerical model was validated with different experimental tests at real scale obtained in laboratory in four cellular wooden slabs. This study was conducted in accordance with European standard (EN 1365-2, 1999) and using a fire resistance furnace which complies the requirements of European standard (EN 1363-1, 1999). The numerical temperatures show good agreement with experimental results. The numerical model can easily be adjusted for other constructive solutions, to facilitate fire safety tests, in buildings with wooden slabs used in floors or in ceilings applications.

Keywords: Cellular wooden slab, perforation, fire.

INTRODUCTION

Wood is a natural and organic cellular solid material. It is highly anisotropic due to the wood cells shapes and the cell walls orientation. Commercial wood is obtained from two categories of plants, as hardwoods (angiosperms) and softwoods (gymnosperms) (TEMTIS, 2008). There are a wide range of wood applications that demonstrate the strength and stability of the material. Wood offers the innovative and modern design, reliable structures, in a variety of common outdoor and indoor building spaces. Considering the behavior of wood when subjected to the developing fire, wood-based materials will burn and are rated as combustible. But, wood material exhibits many desirable characteristics, whilst the exposed surfaces will ignite when the heat flux becomes great enough, and initially burn fairly vigorously it soon builds up a layer of insulating charcoal. As wood is a poor conductor of heat there is a very low transmission of heat into remaining unburned material, and this has many benefits (TEMTIS, 2008). Wood material when exposed to fire produces a surrounding charring depth layer, with no mechanical resistance, resulting a reduced residual section. In perforated cellular wooden slabs, the perforations size could influence the fire effect over the slab thickness.

In wooden slab with perforations, the shape and the size of perforation can limit the use of these constructive elements in terms of fire resistance. The wooden slab with perforations are typical and very common engineering solutions, used in the ceiling plates to improve the acoustic absorption of compartments. The constructive elements should be design in accordance, to prevent and delay the fire damage effect, allowing that the slab could remain in
service during more time. The perforations increase the slab surface exposed to the fire action, facilitating the penetration of flames and heat flow.

In this work, the main objectives are: present a numerical model validated with experimental tests to predict the time-temperature evolution during a fire scenario using a finite element method with appropriate material properties and boundary conditions; use different constructive solutions of wooden slabs with rectangular and circular perforations; determine the fire resistance in such way that contributes for a safe design in typical perforated wooden slab. The subject of this work is a study in progress according others investigations realized by the authors of this work (Fonseca et al.).

METHODOLOGY AND MATERIALS

In this work, four wooden slabs were considered for analysis. The bottom surface of the slab (perforated side) will be submitted to a fire action. The geometric model of each slab considers three different cellular zones (two cells with different perforations and one cell with no perforation), Fig. 1.

Slab 1 and 2 present in the exposed surface, two types of rectangular perforations (R1=250x20) mm in cell 3, and (R2=50x20) mm in cell 1. Slab 3 and slab 4 present circular perforations with a diameter equal to (d1=20) mm in cell 3, and (d2=10) mm in cell 1, as represented in Fig. 2.

Fig. 1 - Wooden slab with cellular zones.

Fig. 2 - Geometry of wooden slabs: a) slab_1_2 rectangular perforations, b) slab_3_4 circular perforations.

Fig. 3 represents the construction of the four cellular wooden slabs, according the defined dimensions.
INSTRUMENTATION OF THE WOODEN SLABS

In the experimental tests, thermocouples were installed to measure the temperature in different locations and located in the same positions in all slabs, as defined in Fig. 4.

Fig. 4 - Thermocouples positions in wooden slabs.

Fig. 5 shows the instrumentation of the wooden slabs, based on the criteria of (EN 1365-2, 1999) with interest to measuring the temperature in different positions (ceiling plate, beams, metal connectors and cellular zones). Three types of thermocouples were used: single wire for spot measurements $T_{ij}$, copper discs protected with plasterboard for measuring the temperature in the unexposed side, thermocouple wire welded to the connectors $TC_i$ and plate thermocouples $TP_i$ for measuring the temperature within the cellular zones. The acquisition signal of the thermocouples was made with a data acquisition systems HBM (MGC Plus and Spider 8).

Fig. 5 - Thermocouples installation in wooden slabs.
The slabs were tested on fire resistance furnace at Polytechnic Institute of Bragança, Fig. 6. This furnace is equipped with 4 burners running with natural gas, with a total power of 360kW, a working volume of 1m$^3$, prepared to work with any standard fire curve.

Fig. 6 - Test slab in the fire resistance furnace, before, during and after the test.

NUMERICAL MODEL OF THE WOODEN SLABS

The finite element method was used for thermal transient analysis running with Ansys program. Each wooden slab was exposed to fire, at the bottom surface, during 900s for rectangular and circular perforations, respectively. At the exposed surface and internal cavities the temperature follows real heating curves obtained during experimental tests. The convection coefficient is taken equal to 25W/m$^2$K (EN1991-1-2, 2002) inside cavities and in the exposed surface. At the unexposed surface the room temperature is applied (16°C or 20°C, dependent of slab) and the value of convection is equal to 4 W/m$^2$K. The surface emissivity is taken constant and equal to 1,0 for exposed side and internal cavities (EN1991-1-2, 2002). Fig. 7 shows the mesh and the boundary conditions used in all numerical simulations.

Fig. 7 - Numerical model for each wooden slab.

Each wooden slab was exposed to fire, at the bottom surface, during 900s for both rectangular and circular perforations, respectively. Temperature in the exposed surface follows the real furnace heating curves (T$forno$ for Slab_1_2 and Slab_3_4), as represented in Fig. 7 and 8. The furnace was switch off between 450-500s and the front door opened near of 900s. The temperatures of the internal cavities follow curves based on data obtained during each slab test by mean of plate thermocouples (T$Pi$, i=1,3 for Slab_1_2 and Slab_3_4).
The total area of each perforation type is compared for cell 1 and 3, as represented in Table 1. Cell 1 has a similar open space between slabs with rectangular or circular perforations. Cell 3 with circular perforations represents 50% open space in comparison to the rectangular perforations. The temperature measurements of plate thermocouple TPi within the cellular zones was affected in proportion to with the open space.

The non-linearity due to the thermal material properties dependence will be taken into account in the numerical simulation. The density of the ceiling wood is equal to 450 kg/m$^3$ and the density of the floor board and beams equals 480 kg/m$^3$. The thermal properties of wood vary considerably with temperature and should be applied according Eurocode 5 (EN 1995-1-2, 2003). This standard code provides the wood design values for density ratio, thermal conductivity and specific heat.

### DISCUSSION OF RESULTS

During the real fire test exposure, the insulation criteria were verified, in both wooden slabs, since the temperature rise on the unexposed surface did not exceed 180ºC on any of the disc thermocouples or 140ºC in average with respect to the initial average temperature, defined according to the European standard for fire resistance tests (EN 1365-2, 1999). The integrity criteria was also verified during experimental tests using the cotton ignition test, where no flame appearance occurred during the wooden slabs testing (EN 1365-2, 1999).

The figures below (Fig. 9 a) to e)) show the time-temperature evolution from experimental real fire exposure (Ti_exp) and the corresponding numerical results (Ti_num) for each typical slab (slab_1_2 and slab_3_4). As regards, the time-temperature numerical simulation results are in agreement and with the same behaviour with the experimental results. Some discrepancies between experimental and numerical results may be justified due to different level of moisture in slabs and also to the relative position of thermocouples, slightly located away with respect to the numerical nodal positions. In general, good agreement was found between both results.

The nodal positions in the border of the rectangular and circular slots (T33 and T34, T35 and T36, cell 3 and cell 1, respectively) have higher values of temperatures when compared with all inside nodal positions which remain at lower temperatures (T24 and T25, cell 3 and cell 1, respectively).

Comparing cell 3 and cell 1, the rectangular perforations enable a faster heating process with higher temperatures compared to the circular perforations. Attending to the table 1, the circular perforation type for cell 1 or 3 has almost the same open space in slab_3_4, which permits to conclude a similar temperature evolution (T24 and T25) inside the cell. In slab_1_2 the temperature inside cell 3 is higher when compared with cell 1, which agrees with the
calculated open space between R1 and R2. In cell 3 and 1 the temperature increases until switch off the furnace (450-500s) and decreases after this time.

The other results in cell 2, on beam and unexposed surface have similar behaviour between the wooden slabs. During all test time the temperatures are below 100°C, with an almost constant behaviour and slight increase.

Fig. 9 - Time-temperature history for each wooden slab (slab_1_2 and slab_3_4): a) on cell 3, b) on cell 2, c) on cell 1, d) on beams, e) at unexposed surface.
CONCLUSIONS

Wood material when exposed to fire presents a thermal physical degradation. The evolution of the temperature inside the cellular zones was characterized and the shape and size of perforations could be compared with the unperforated cell. The size of the perforation is responsible for different temperature evolution. The damage effect of fire is higher in the slab with larger perforations, as expected. The perforated wooden slabs reach a temperature almost twice the unperforated, justified by the temperature recorded within the cavities. To the same time test, the temperature of the unperforated cellular zone did not exceed 100°C, while in the cavities with openings this value is higher. This study allows to verify the evolution of the temperature throughout a fire resistance test of a wooden slab. This type of analysis and tests are important in safety and structural design because it determines how quickly the cross-section size decreases to a critical level at high temperatures.

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REFERENCES


