Fire safety in perforated wooden slabs: a numerical approach

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Abstract

The main goal of this work is to present a numerical model to assess the fire safety of wooden slabs with rectangular perforations on a ceiling. These typical constructions have good sound absorption, heat insulation and relevant architectonic characteristics. They are used in many civil applications: concert and conference halls, classrooms, nurseries, airports, hotels, shopping, universities, and many other public buildings. These panels are normally installed at a lower level in building constructions to facilitate essential maintenance. Depending on the installation requirement, the perforated wooden slabs could have insulation material inside the cavities. In this work the proposed numerical model could be used for different design constructive solutions. In order to guarantee the fire rating in a typical used perforated wooden slab, a transient thermal analysis with nonlinear material behaviour will be solved using ANSYS program. This study allows for verifying the evolution of the temperature and the char-layer throughout a wooden slab with different rectangular perforations and considering the insulation effect inside the cavities. The developed numerical model allows future studies and simultaneously characterizes the effect of rectangular perforations in wooden slabs to minimize the fire risk. The numerical model can easily be adjusted for other constructive solutions, to facilitate fire safety validation, in buildings with several wooden slab assemblies used in floors or in ceiling applications.
Keywords: perforated wooden slab, fire, numerical study.

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1 Introduction

In this work a perforated wooden slab was exposed to fire. Different types of perforations were considered, simultaneously using an internal fibreboard insulation material. Figure 1 shows applications in floors or ceilings used in buildings.

Figure 1: Wooden applications.

Wood is a natural material and presents advantages due its high strength and stiffness when compared with other materials. The main advantages of wood, relatively to the use of other materials, are: ease of construction and maintenance, pleasant appearance, renewable material and lightweight. The main disadvantage is the high level of combustion when exposed to fire conditions

The fire safety of this type of structures involves prevention, inhibition and detection. This involves appropriate design rules, installation, construction and maintenance of the wood in different applications. If wood is submitted to a sufficient heat flux, a degradation thermal process (pyrolysis) occurs, producing gases accompanied by loss in serviceable cross-section and its mass. The factors which affect the burning behaviour of wood determine the charring rate. These types of factors include: level of radiant heat exposure, char layer formation, moisture content, species and dimensions, as reported by Poon and England [1].

The authors of this work have published different articles in conferences and journals related to this theme [2–6]. They studied different wood species and their behaviour, the evolution of charring rate, using experimental and numerical techniques. In their research activity they usually consider standard fire conditions to improve new design solutions or develop new safety design rules [7–8].

The main objectives of this work are:

- To present a numerical model to predict the evolution of the charring layer during a fire scenario using a finite element method with appropriate material properties and boundary conditions;
- To evaluate the fire performance in a perforated wooden slab, when subjected to nominal ISO834 fire [9];
- To determine the charring layer of two different constructive solutions using a slab with and without insulation material;
- To determine the fire resistance in such way that contributes for a safety design in perforated wooden slab.

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2 Perforated wooden slab

Figure 2 shows the geometric model considered in this work. The model considers a wooden perforated slab (920x1000mm) with three different cellular zones and homogenous thickness (25mm). Different types of rectangular perforations were considered in the bottom layer (4 slots with 250x20mm and six slots with 20x20mm). The top wooden surface is solid (1150x1232mm) with homogenous thickness (18mm). The same geometric model was considered with internal insulation material (MDF) near side by side with perforations, with one overlapping plate (20mm).

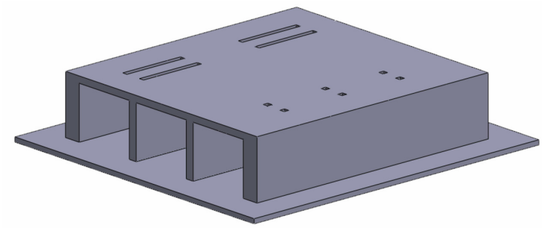

Figure 2: Geometric model.

2.1 Wood thermal properties and numerical model

A 3D finite element (Solid70) with 8 nodes was used for thermal and nonlinear transient analysis. The non-linearity due to the thermal properties dependence will be taken into account in the numerical simulation. The wooden slab (with or without MDF insulation) was exposed to standard fire condition during 1800s at the bottom surface. The temperature of compartment follows the standard fire ISO 834 curve, as represented according the following equation [9]:

$$T = 20 + 345 \log10 (8t+1) \quad (1)$$

where T is the gas temperature in the fire compartment in ºC and t is the time in min.

Wood material when exposed to fire presents a thermal physical degradation. The interface between charred and noncharred wood is the transition phase between black and brown material [10] and is characterized by a threshold value of 300ºC, according Eurocode 5 [11]. Also the thermal properties of wood vary considerably with temperature and should be defined according Annex B of Eurocode 5 [11]. This standard code provides the design values for density, thermal conductivity and specific heat of wood. The density of the spruce wood material was considered equal to 450kg/m^3 at room temperature. Figure 3 shows the thermal material properties used in this work.

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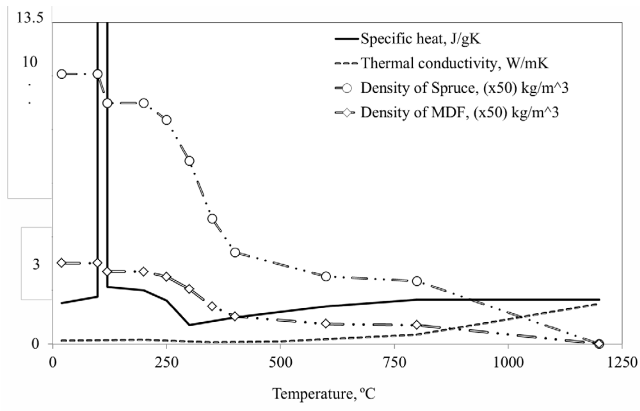

Figure 3: Thermal properties.

Medium density fibreboard (MDF) was applied in the wooden slab using the properties of ISO 10456 [12]. Two MDF panels were used in the numerical model. The density was considered equal to 151.2 kg/m^3 and for this reason (below 550 kg/m^3) is considered ultra-light MDF [13]. The thermal conductivity was considered equal to 0.05 W/mK and the specific heat equal to 1700 J/kgK, at room temperature and at elevated temperature.

The effect of fire in building structures [14] is considered using the appropriate boundary conditions due to convective heat flux (αc=25W/m^{2o}K in exposed surface and αc=9W/m^{2o}K in perforated zone) and radiative heat flux (ε=1).

Figure 4 represents the finite element model used for the numerical approach and all applied boundary conditions.

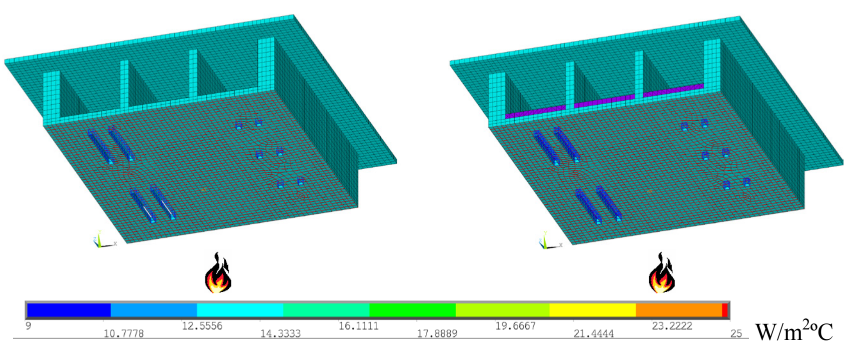

Figure 4: Numerical model and boundary conditions.

2.2 Numerical results

The numerical results for different time instants are represented in figure 5. Different images represent the temperatures in wooden slab with and without insulation material (MDF). Also a residual cross-section with the charring layer formation is presented with incidence of the perforated slab zones. This effect is presented with a grey colour. The charring depth depends on the time of fire exposure and also depends of the insulation material. The charring depth is the distance between the outer surface of the initial member and the position of the char-line, defined by the threshold value of 300ºC isotherm [11]. The calculation of the charring rate under standard fire exposure is the relation between the charring depth in mm and the time of fire exposure in min. This relation (β) is calculated for each model when bottom surface is carbonized and is presented in mm/min near of the slab models. Eurocode 5 [11] proposes a value equal to 0.9 mm/min as a design value for wood panelling.

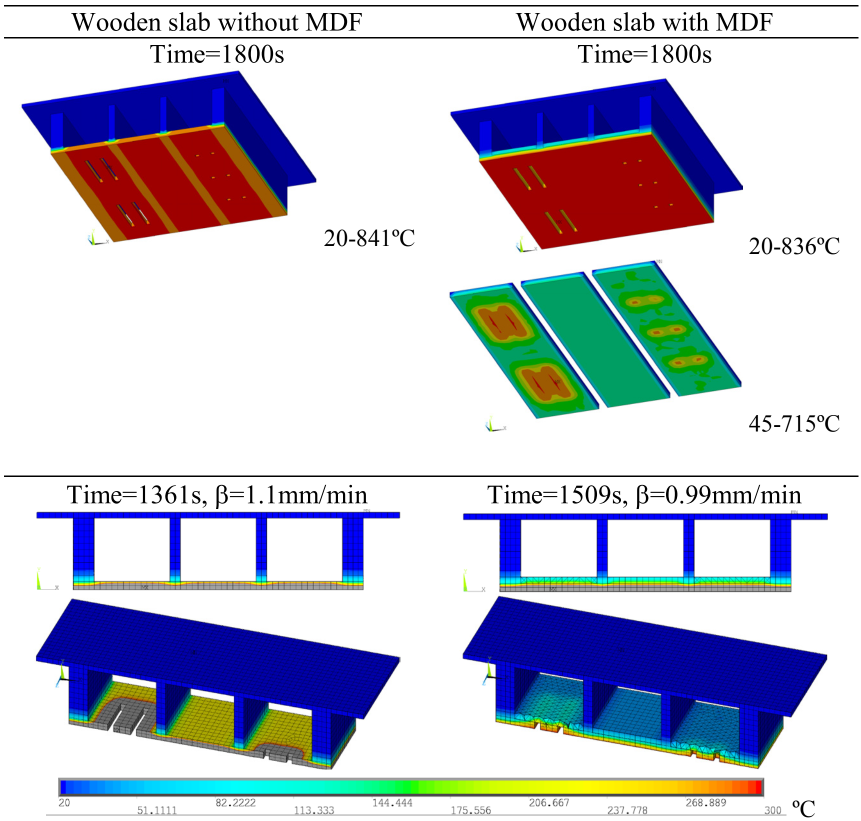

Figure 5: Results of temperature and charring rate.

As represented in figure 5, the damage effect of fire is higher in the wooden slab with higher perforated zones. The rectangular perforation facilitates the heating process when compared with the squared perforation. The cellular zone without perforations presents less damage. The charring rate is higher in wooden slab without MDF and for a time equal to 1361s reaches the start of carbonization. When the wooden slab has a MDF panel the carbonization has a delay equal to 148s.

The time temperature evolution was also compared, in particular different nodal positions during 30 minutes, as represented in figure 6. All positions are compared between the two different models in different curves, figure 7. The standard fire ISO 834 curve is represented [9].

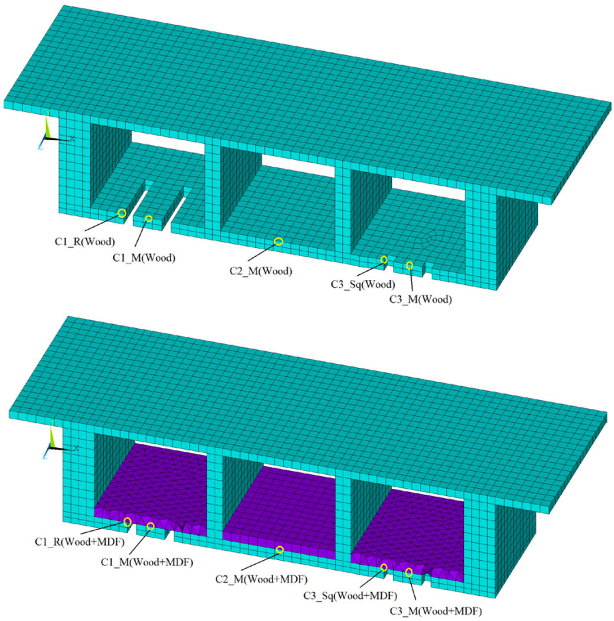

Figure 6: Nodal positions for time history.

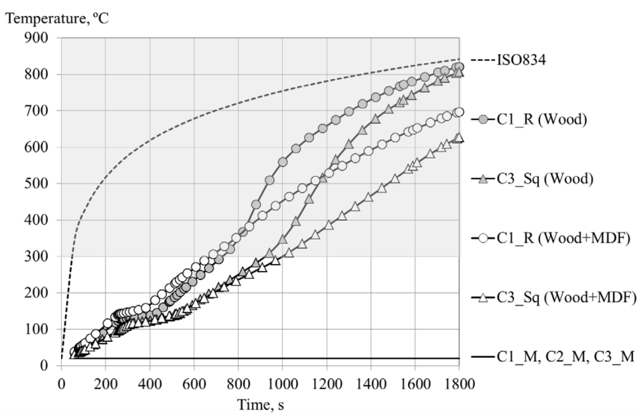

Figure 7: Time-temperature history in nodal positions.

The nodal positions in the border of the rectangular and square slots have higher values of temperatures when compared with all other nodal positions which remain at lower temperatures. The rectangle perforation facilitates a faster heating process with higher temperatures compared to the square perforation. Comparing the rectangular perforation in two different wooden slabs it is notorious a delay during all fire exposure when the cellular zone has a plate of MDF insulation. The same conclusion is obtained for squared perforation. At the end of simulation, 1800s, a difference of 100ºC exists for rectangular perforation slots and a difference of 200ºC for squared perforation slots.

3 Conclusions

In wooden slab with perforations, the type and the size of perforation can limit the use of these constructive elements in terms of fire resistance. The constructive elements should be chosen before, to prevent and delay the damage effect, allowing that the slab could remain in service during more time. This study allows verifying the evolution of the temperature and the char-layer throughout a wooden slab and verifying the influence of the use of MDF. In the future developments in this area should consider the experimental validation in typical wooden slab with perforations using a fire resistance furnace with imposed standard and natural fire conditions.

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