



Book of Abstracts of the
International Fire Safety
Symposium 2015

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**cib - International Council for Research and
Innovation in Building Construction**
UC - University of Coimbra
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Editors:

João Paulo C. Rodrigues
George V. Hadjisophocleous
Luís M. Laim
Hélder D. Craveiro

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PREFACE

On behalf of the Organising and Scientific committees, as well as the CIB W-14 Commission on Fire Safety it is our pleasure to welcome you to the International Fire Safety Symposium - IFireSS 2015, which is organised by the CIB's Commission W14-Fire Safety, ALBRASCI and University of Coimbra. The Symposium aims to contribute to the exchange of ideas and knowledge in the area of Fire Safety and assist in planning future research activities in this area.

CIB W14-Fire Safety is a Working Commission of CIB (International Council for Research and Innovation in Building & Construction) and its main objectives are:

- To create an ongoing research and innovation focus for the development of a comprehensive, coherent, rational and empirical basis for a safe and sustainable built environment, which includes fire science and engineering practices and design methodologies;
- To promote the acceptance of Fire Science and Engineering Practices, Procedures and Design Methodologies worldwide, and to encourage their use in Building and Fire Safety Legislation, Codes, Regulations and Standards;
- To provide technical input, from a Fire Science and Engineering Perspective, to other relevant CIB Working Commissions and Task Groups;
- To facilitate the transfer of state-of-the-art Fire Science and Engineering Technology at international level;
- To encourage capacity building for Fire Science and Engineering worldwide.

The Luso-Brazilian Association for Fire Safety (ALBRASCI) was established recently by Portuguese and Brazilian specialists in the area of Fire Safety to create a platform for the development of Fire Safety in Portugal and Brazil.

The University of Coimbra (UC) is a reference in higher education and research in Portugal, due to the quality of the courses taught and to the advances achieved in pure and applied research in various areas of knowledge. UC is also well-known around the World due to the research and training in Fire Safety with an MSc and PhD in the area.

The Symposium has participants from researchers around the world and covers a wide variety of research areas including: Structural Fire Safety; Mechanical and Thermal Properties of Materials; Fire Chemistry, Physics and Combustion; Fire Reaction; Fire Safety in Vehicles and Tunnels; Fire Risk Assessment; Smoke Control Systems; Firefighting and Evacuation; and Fire Regulations, Standardization and Construction Trends.

Joao Paulo C Rodrigues
President of the Organizing Committee

George Hadjisophocleous
President of the Scientific Committee

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FIRE RESISTANCE OF WOODEN CELLULAR SLABS WITH RECTANGULAR PERFORATIONS

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Keywords: Wooden slab, perforations, charring layer.

1. INTRODUCTION

This paper presents a numerical approach with finite element method in order to predict both the behaviour and the performance of the wooden slabs with rectangular perforations under fire exposure. These typical constructions have good sound absorption, thermal insulation and relevant architectonic features, they are used in many civil engineering applications as: concert and conference halls, classrooms, nurseries, airports, hotels, shopping, universities, and many other private and public buildings. These slabs are normally installed at lower level in building constructions essentially due to an easy maintenance requisite. Depending on the installation requirement, the perforated wooden slabs could have an additional insulation material inside the cavities [1]. The proposed numerical model could be applied to different design constructive slab solutions. For this purpose a 3D numerical simulation was conducted with particular attention to the wood thermal properties variation with temperature [2]. The numerical results were compared with those obtained experimentally in laboratory, for two wooden slabs. The fire resistance (performance criteria related to the insulation (I) and integrity (E)) was evaluated, as

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well as the effect of rectangular perforations into the residual cross section of the slab. This study was conducted in accordance with European Standard EN 1365-2 [3] and using a fire resistance furnace which complies the requirements of EN 1363-1 [4] in the experimental test.

2. METHODOLOGY

Figure 1 shows the geometric model considered in this work and the mesh used in numerical simulation. The model considers a wooden slab with three different cellular zones and with different rectangular perforations in the bottom layer (slab 1 and slab 2).

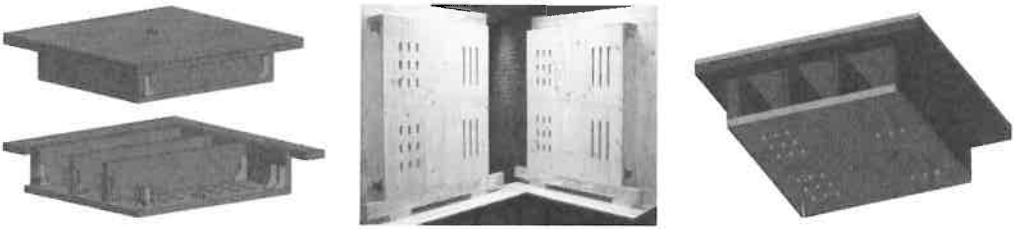


Figure 1: Geometry of wooden slabs and numerical model.

A 3D finite element (Solid70) with 8 nodes was used for nonlinear transient thermal analysis, using Ansys software. Each wooden slab was exposed to fire, at the bottom surface, during 1500s and 950s, respectively. At the exposed surface and internal cellular cavities the compartment temperature follows real experimental curves, based on data obtained during test slabs by means of plate thermocouples. The convection coefficient was taken equal to $25\text{W/m}^2\text{K}$ [5] inside cavities and in the exposed surface. In the unexposed surface the ambient temperature was kept constant (20°C) and the value of convection coefficient was considered equal to $4\text{W/m}^2\text{K}$ [4]. The surface emissivity is taken constant and equal to 1,0 for the exposed surfaces and internal cavities [5].

3. CONCLUSIONS

During the fire exposure, the insulation (I) criterion was verified, in both wooden slabs, since the temperature on the unexposed surface did not increase either: a) the average temperature above the initial average temperature by more than 140°C or b) temperature at any location by more than 180°C above the initial average temperature [3]. The integrity (E) criterion was also verified during experimental tests using the cotton pad ignition test where no flame appearance occurred during the wooden slabs testing [3]. The temperature evolution was compared with experimental (T_{exp}) results, in particular different nodal positions (T_{num}) during 1500s and

950s. Figure 2 presents the temperature evolution in locations near the rectangular perforations for each slab. The numerical results are in good accordance with experimental results. Figure 3 shows the temperature field at the end of fire exposure for each slab, being the charred layer represented in grey colour. The criterion to determine the charred layer was applied to the last time step and was compared with the experimental record obtained in each slab, allowing to evaluate the residual cross section and the influence of different perforations on the fire performance of wooden cellular slabs.

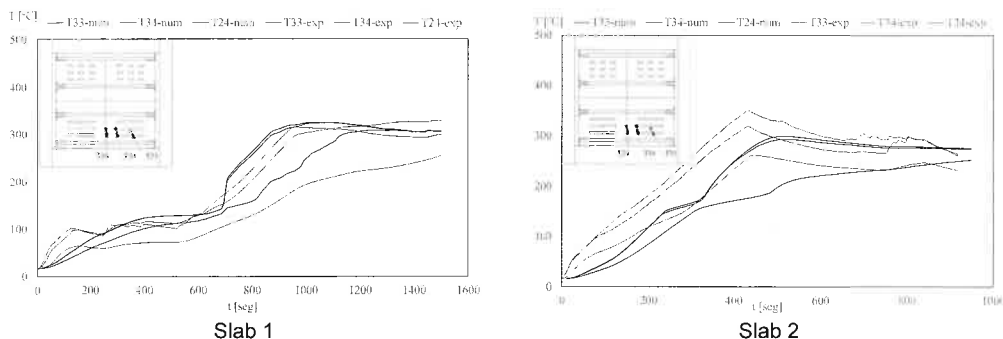


Figure 2: Temperature history in nodal positions compared with thermocouples.

The assessment of the charred layer allowed to verify that the cavity without perforations presents the lowest values of charring rate, while the cavity with large perforations presents higher temperatures values.



Figure 3: Temperature and charring rate results.

Table 1 presents a summary of the residual cross-sections and charring rates in different cavities of the slabs, according to the location identified in figure 4. At the end of fire exposure, cells without perforations did not exceed 100°C at the ceiling level, while cells with perforations presented more than three times this value. Also, the charring rate value relationship between the perforated and non-perforated layers is almost double, which is justified by the temperatures recorded within the cellular cavities of each slab. Results demonstrate the importance of the study in these type of structures and the evaluation of the fire performance.

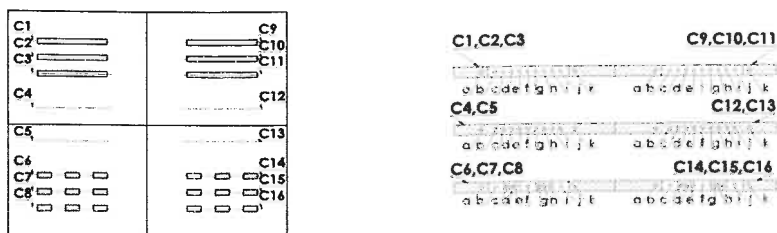


Figure 4: Cross-sections locations for charring rate measure.

Table 1: Average measured charring rate.

	Numerical charring rate	Experimental charring rate
Slab 1	C1, C2, C3, C9, C10, C11 - 1,3mm/min	1,2mm/min
	C4, C5, C12, C13 - 1,0mm/min	0,65mm/min
	C6, C7, C8, C14, C15, C16 - 1,4mm/min	1,0mm/min
Slab 2	C1, C2, C3, C9, C10, C11 - 1,3mm/min	1,4mm/min
	C4, C5, C12, C13 - 0,7mm/min	0,8mm/min
	C6, C7, C8, C14, C15, C16 - 1,2mm/min	1,0mm/min

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5. REFERENCES

- [1] Fonseca E.M.M., Couto D., Piloto P.A.G. - *Fire safety in perforated wooden slabs: a numerical approach*, 5 Int. Conf. Safety and Security Eng., Vol.134, 2013, p.577-584.
- [2] CEN, EN1995-1-2 - *Eurocode 5: Design of timber structures - Part 1-2: Structural fire design*, Brussels, 2003.
- [3] CEN, EN1365-2 - *Fire resistance tests for loadbearing elements. Part 2: Floors and roofs*, Brussels, 1999.
- [4] CEN, EN1363-1 - *Fire resistance tests - Part 1, General requirements*, Brussels, 1999.
- [5] CEN, EN1991-1-2 - *Eurocode 1: Actions on Structures, Part 1-2: General actions - Actions on Structures Exposed to Fire*, Brussels, 2002.