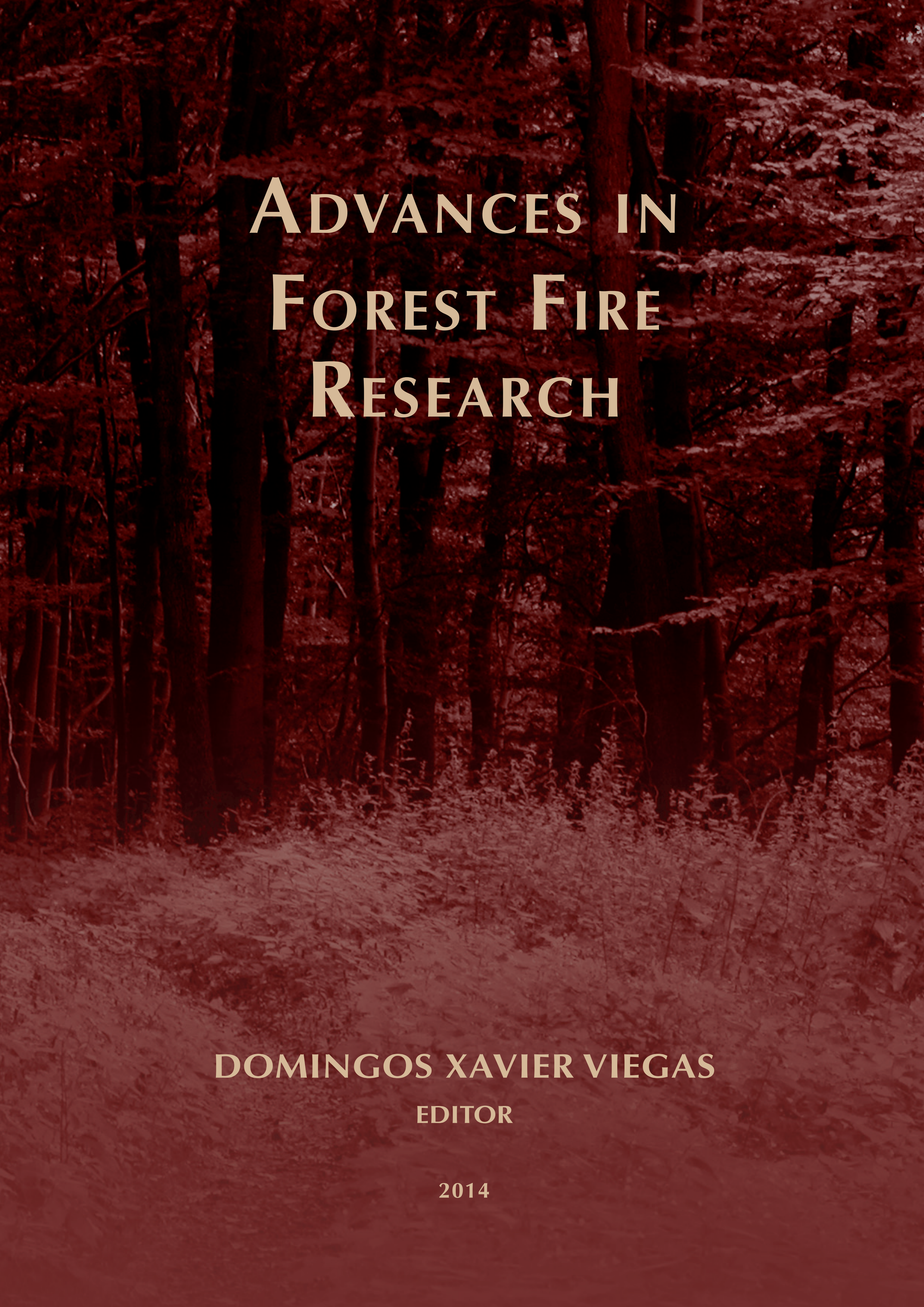

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Wooden buildings in Wildland-Urban Interface areas − flammability of solid woods used in wood-framed construction in Portugal

Valeria Reva[a], João Gomes[b], José J. Costa[b], A. Rui Figueiredo[b]

[a] *Centre for Forest Fire Research, ADAI-LAETA, Rua Pedro Hispano, 12, PT-3030-289 Coimbra, Portugal, valeria.reva@yahoo.com*
[b] *ADAI-LAETA, Department of Mechanical Engineering, University of Coimbra, Portugal. joao_antonio13@hotmail.com; jose.costa@dem.uc.pt; rui.figueiredo@dem.uc.pt*

Abstract
The problem of forest fires in the wildland-urban interface raises the issue of security of wood-framed constructions. The ability of external wooden walls to resist against fire exposure constitutes the framework of the present study. The flammability of the samples of wooden planks from framing lumber of *Pinus sylvestris*, *Apuleia leiocarpa* and *Pinus pinaster* used in a house construction in Portugal was assessed. The influence of the wood density on time to ignition, position and time of combustion phases (drying, pyrolysis and char combustion), mass loss decay, heat release rate and total heat released was evaluated.

Keywords: *wildland urban interface, flammability, wood-framed construction*

1. Introduction

In the United States of America, Canada, Australia and some countries in Northern Europe, wood-framed houses with up to two floors are the most common type of residential buildings, particularly in rural areas. According to Gustavsson *et al.* (2006), the market share of wood in construction of single-family houses constitutes 90-94% in North America, and 76-85% in Canada. It varies largely in Europe. In Scandinavian countries and Scotland, the share of timber-framed housing is 60-90% (Tykkae *et al.* 2010), while in Central Europe it ranges between 10 and 50% (Richter, 2012). Lowest values (<5%) were registered for Mediterranean countries (Gustavsson *et al.* 2006, Richter 2012). Regarding multi-family (multi-story) residential houses, the use of wood as the main structural material is much lower, with a market share of 2-10% in European countries and 4% in North America (Tykkae *et al.* 2010, Richter 2012).
Low construction costs, durability, thermal comfort, attractive facade, and limitless architectural possibilities of wooden houses encourage the use of wood in construction. The problem of GHG emissions and efficient ways of carbon storage enhances the usefulness of wooden buildings and the benefits of wood as a sustainable building material within the concept of green buildings (Naturally: wood 2011). Satisfactory performance of wood-framed buildings in earthquakes is another positive factor for use of wood in construction (Rainer and Karacabeyli 2000, Ceccotti 2008).
The efforts of industry, research activities, policies and governmental initiatives create the basis for wood-based construction systems, and statistics confirm the increased use of wood in residential and commercial buildings, especially in European countries. Portugal follows this trend, and the construction of wood-framed houses in rural areas is growing. Since 2006, an increase of the number of small enterprises working in wood-building construction sector was verified (Morgado *et al.*, 2011).
The problem of forest fires in the wildland-urban interface (WUI), which is critical in USA, Canada, Australia, Mediterranean countries and Portugal, raises the issue of security of wood-framed constructions, which constitutes the framework of the present study.
Many different types of soft and hard wood with a wide variety of characteristics are available for building construction. Soft and hardwoods are considerably different in flammability properties and combustion (Janssens 1991, Drysdale 2011, Cholin 1997, White and Dietenberger 1999, Van Loo and

Koppejan 2008). Wood type and species influence the combustion process through physical/chemical characteristics such as chemical composition, volatile content, density and porosity. The chemical composition is related with the gross calorific value, emissions and ash-content. Together with the volatile content, it also influences the thermal behaviour of wood. The density, varying within each tree and also significantly between hardwoods and softwoods, is related with the burning time and the total energy released. The porosity influences the burning rate.

Ignitability and heat release rate are determining parameters in the evaluation of fire hazards and combustibility of a material, and are essential for fire safety engineering towards a building design. The objective of the present work was to study the flammability of *Pinus sylvestris*, *Apuleia leiocarpa* and *Pinus pinaster* woods, used in wood-framed construction in Portugal. The influences of the wood density on the time to ignition, the time and duration of the combustion phases (drying, pyrolysis and char combustion), the mass loss decay, the heat release rate and the total heat released were evaluated.

2. Materials and methods

2.1. Wooden material

The samples of wooden planks from framing lumber used in a house construction were provided by the company Exotic House - Casas de Madeira, Lda (http://www.exotic-house.pt/Index.html). In the house under construction where the samples were collected (Figure 1), *A. leiocarpa* wood, imported from Brazil, was used for external walls, and *P. sylvestris* wood, imported from Northern Europe, for internal walls. The response of these wood species to heat flux exposure was compared with that of *P. pinaster* wood, the native species with a great potential for the construction industry.

Figure 1. Wood-framed house under construction

The density of wood at 12% moisture content for collected wooden planks was 870 kg/m^3 for *A. leiocarpa*, 472 kg/m^3 for *P. sylvestris*, and 582 kg/m^3 for *P. pinaster*.

To protect wood from insect and fungal attack, wooden planks were submitted to chemical treatment. Used for internal walls, low dense *P. sylvestris* wooden planks were treated by substances against insect and fungal attack and impregnation and thixotropic varnishes. Used for external walls, denser *A. leiocarpa* wooden planks were treated only by impregnation and thixotropic varnishes. Flammability of wooden samples with and without chemical treatment was studied.

2.2. Samples preparation

Samples of 60×60×35 mm and 60×60×20 mm were cut from wooden planks (Figure 2). To measure the variation of the temperature inside the wood sample, holes were drilled at 5, 15 and 25 mm from sample surface to fix thermocouples (Figure 3).

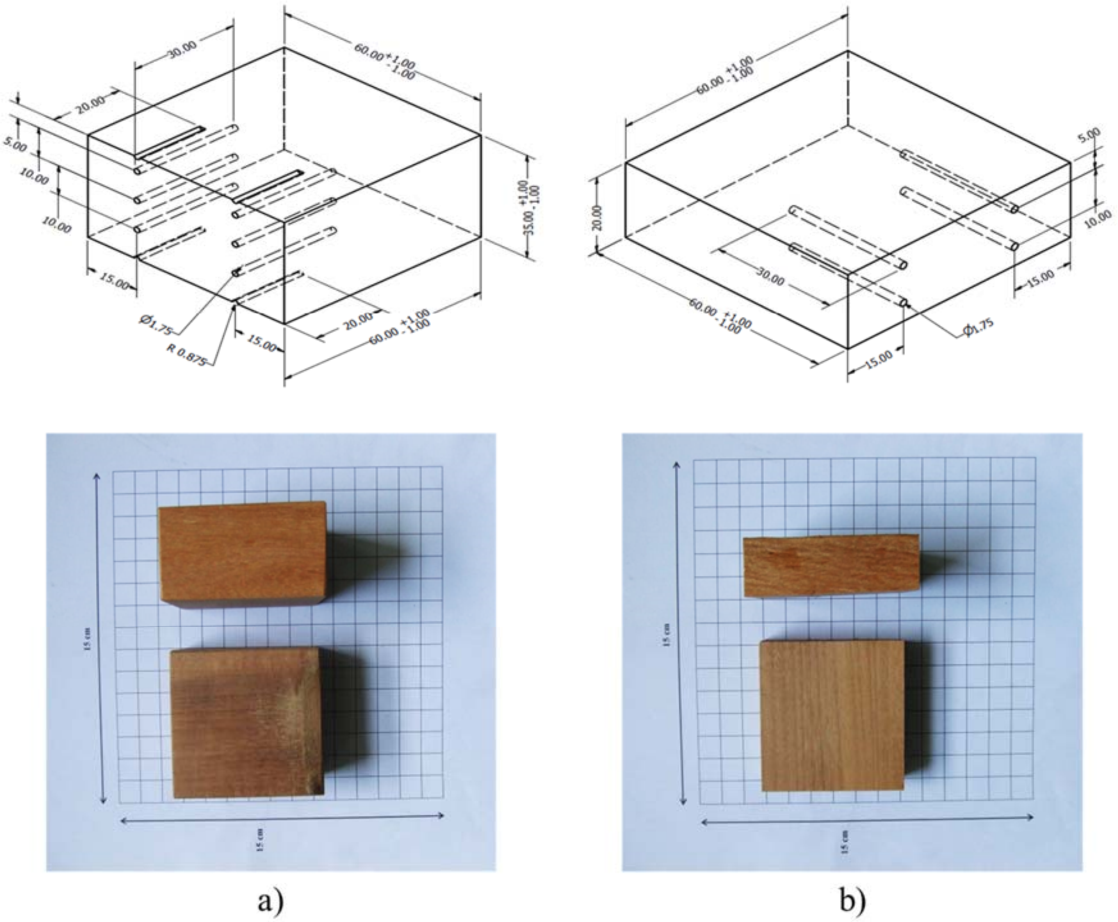

Figure 2. Two types of studied samples: a) 60×60×35 mm; b) 60×60×20 mm. In this figure, samples of Apuleia leiocarpa wood are presented.

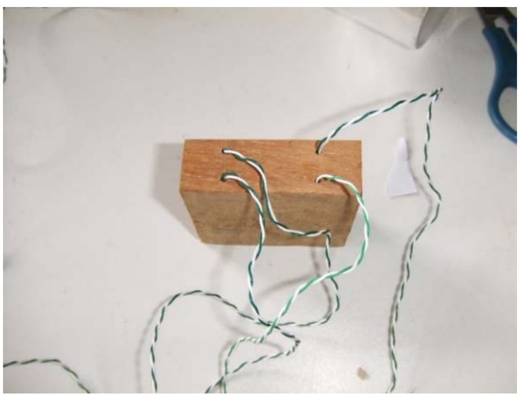

Figure 3. Apuleia leiocarpa wood sample with thermocouples fixed inside

2.3. Flammability test

Flammability tests were performed in a cone calorimeter (Figure 4) at a constant heat flux of 16kW/m^2. At least three replicates of each sample types were made. Samples were laterally wrapped in a single layer of aluminium foil and placed in horizontal orientation on calcium silicate support. A fuel sample was permanently radiated and an ignition source (pilot flame) provided. During the test, the sample mass was continuously measured using an AND FXi3000 electronic balance and the time variation of the temperature inside the wood samples was measured and registered using thermocouples, fixed inside and on the sample surface and connected to a PICO TC-08 data logger. Mean values of the studied parameters are reported.

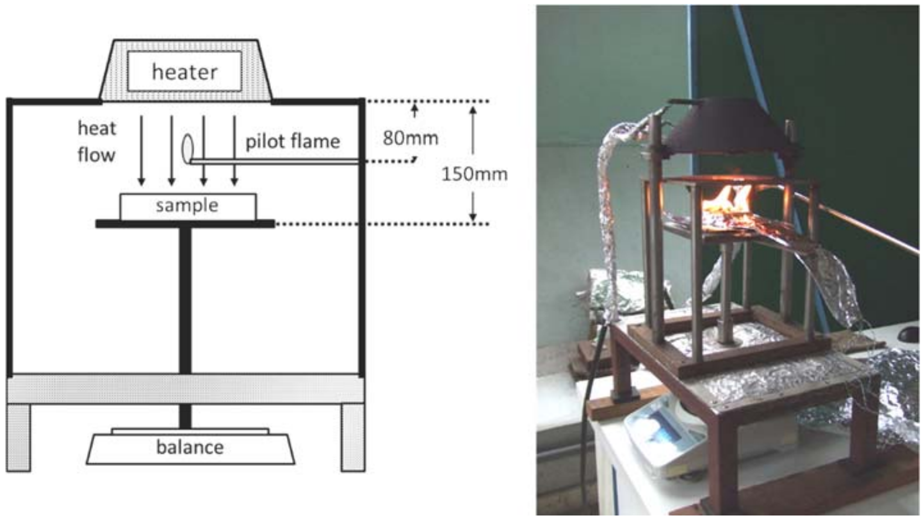

Figure 4. Sketch of cone calorimeter and experimental set-up for the flammability test

The heat release rate (HHR) was evaluated using the equation:

$$HRR = \dot{m} \times NCV$$

where $\dot{m} = -dm/dt$ is the mass loss rate and *NCV* is a net (or low) calorific value. Values of the *NCV* referred by Telmo and Lousada (2011) were assumed. For *P. pinaster*, the *NCV* was of 16.936 MJ/kg. For *P. sylvestris* and *A. leiocarpa*, mean values for softwoods (16.423 MJ/kg) and hardwoods (16.030 MJ/kg) were taken as a reference.

The total energy released was evaluated by:

$$q = \int_0^{t_f} \dot{q}\, dt = (m_i - m_f) \cdot NCV$$

where t_f is the time when the test was complete (flameout); $\dot{q}$ is the heat release rate; and m_i and m_f are the initial and final masses of the sample, respectively.

3. Results and discussion

3.1. Time to ignition

Figure 5 shows the results of time to ignition (t_i) measurements for *A. leiocarpa*, *P. sylvestris*, and *P. pinaster* wood samples, with and without chemical treatment. Characterized by highest density (870 kg/m^3), *A. leiocarpa* wood has longest time to ignition (t_i = 66 s) as compared with *P. pinaster* (582 kg/m^3, t_i = 28 s) and *P. sylvestris* (472 kg/m^3, t_i = 24 s) woods. Despite the small difference in density, denser *P. pinaster* wood took a longer time to ignition than less dense *P. sylvestris* wood. Chemical treatment reduced time to ignition by 23% for *P. sylvestris* wood (24 s for non-treated and 18 s for treated wood) and 27% for *A. leiocarpa* (66 s for non-treated and 48 s for treated wood).

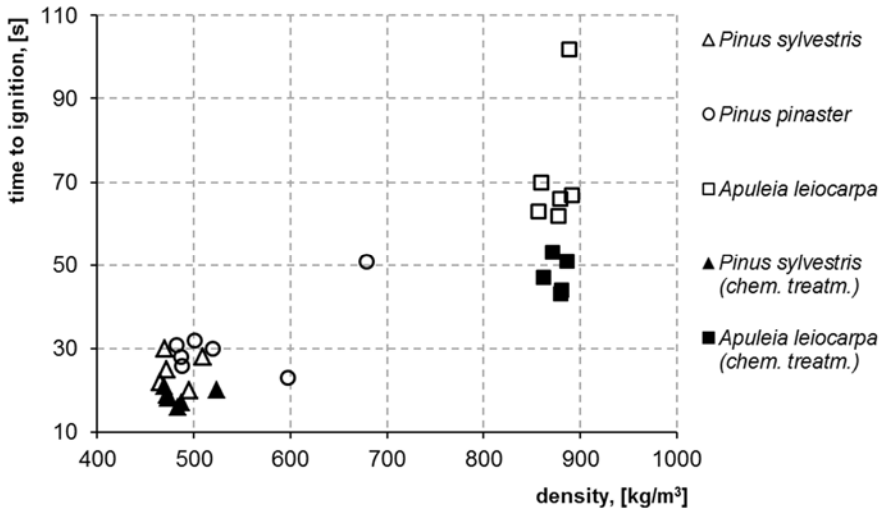

Figure 5 –Influences of density of wood and of chemical treatment on the time to ignition

3.2. Temperature variation

Figure 6 shows time-temperature curves for the surface and interior parts of the samples (at 5, 15 and 25 mm from the surface) for *P. sylvestris* and *A. leiocarpa* wood samples. The effect of wood density on the temperature variation, where higher density corresponds to lower temperature for all depth levels, was observed. The difference in the registered temperatures is greater on the sample surface and at a 5 mm depth, which may be explained by time to ignition, which is shorter for less dense *P. sylvestris* wood. Smaller and similar differences of temperature for *P. sylvestris* and *A. leiocarpa* wood were observed at 15 and 25 mm depths.

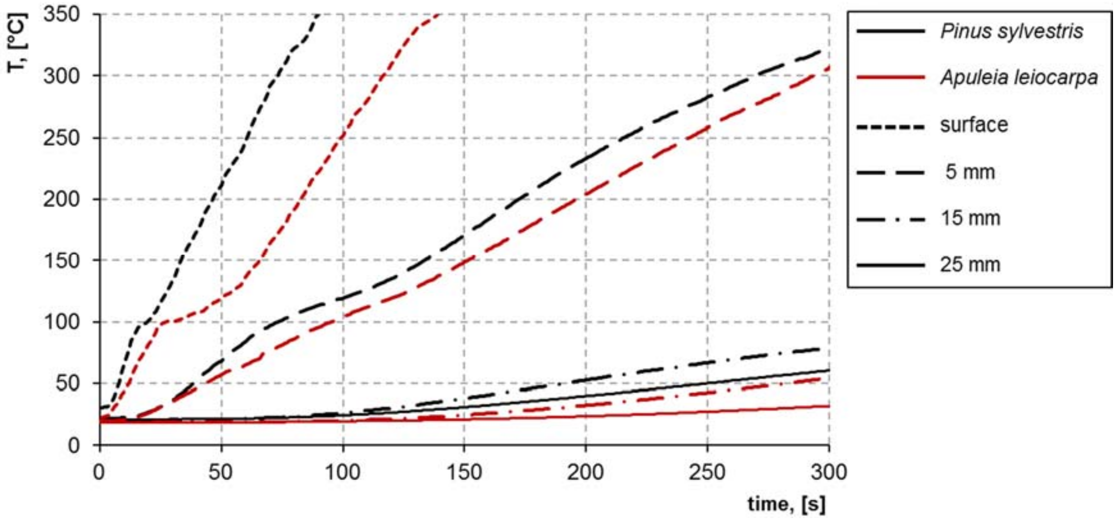

Figure 6. Temperature variation on the surface and inside the sample for Pinus sylvestris and Apuleia leiocarpa woods

The effect of chemical treatment on the temperature variation on the surface of the sample is more notable for *P. sylvestris* wood (Figure 7). The difference between surface time-temperature curves for non-treated and treated *P. sylvestris* wood is higher as compared with *A. leiocarpa* wood, which may be related to the more complex chemical treatment applied to *P. sylvestris* wooden planks.

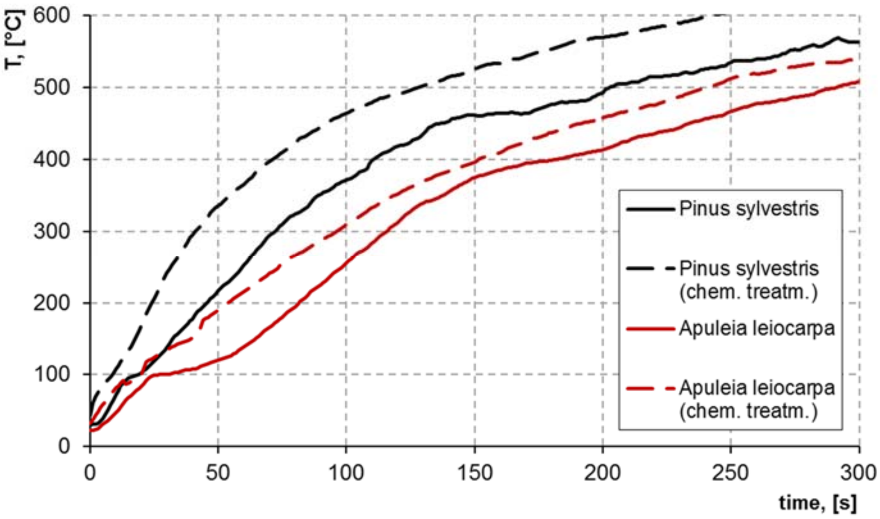

Figure 7. Temperature variation on the surface of the sample for Pinus sylvestris and Apuleia leiocarpa woods, with and without chemical treatment

3.3. Mass loss rate, heat release rate and total energy released

The mass loss ($\Delta m = m_f - m_i$), the heat release rate, HRR, and the total energy released (q) increase with increasing density of the wood. Figure 8 shows the mass loss rate and HRR curves for the studied wood species. Due to the greater time to ignition, the mass loss rate for *A. leiocarpa* wood starts growing later than for *P. sylvestris* and *P. pinaster* woods (Figure 8a). The highest maximum value of mass loss rate (0.051 g/s) was obtained for *A. leiocarpa* wood. Similar and lower values were found for *P. sylvestris* and *P. pinaster* wood (0.047 and 0.045 g/s, respectively). As the gross and net calorific values are lower for hardwoods than for softwoods, the difference in positioning of HRR curves as compared mass loss rate curves will decrease. Figure 8b shows that the HRR curve obtained for *A. leiocarpa* wood is less distant from HHR curves for *P. sylvestris* and *P. pinaster* wood. The maximum values of HRR are 214 kW/m^2 for *P. sylvestris*, 213 kW/m^2 for *P. pinaster* and 228 kW/m^2 for *A. leiocarpa* woods. The values of mass loss Δm and of the total energy released are 28.37 g and 10.53 MJ/kg for *P. sylvestris*, 32.28 g and 10.79 MJ/kg for *P. pinaster*, and 54.26 g and 12.12 MJ/kg for *A. leiocarpa*, respectively.

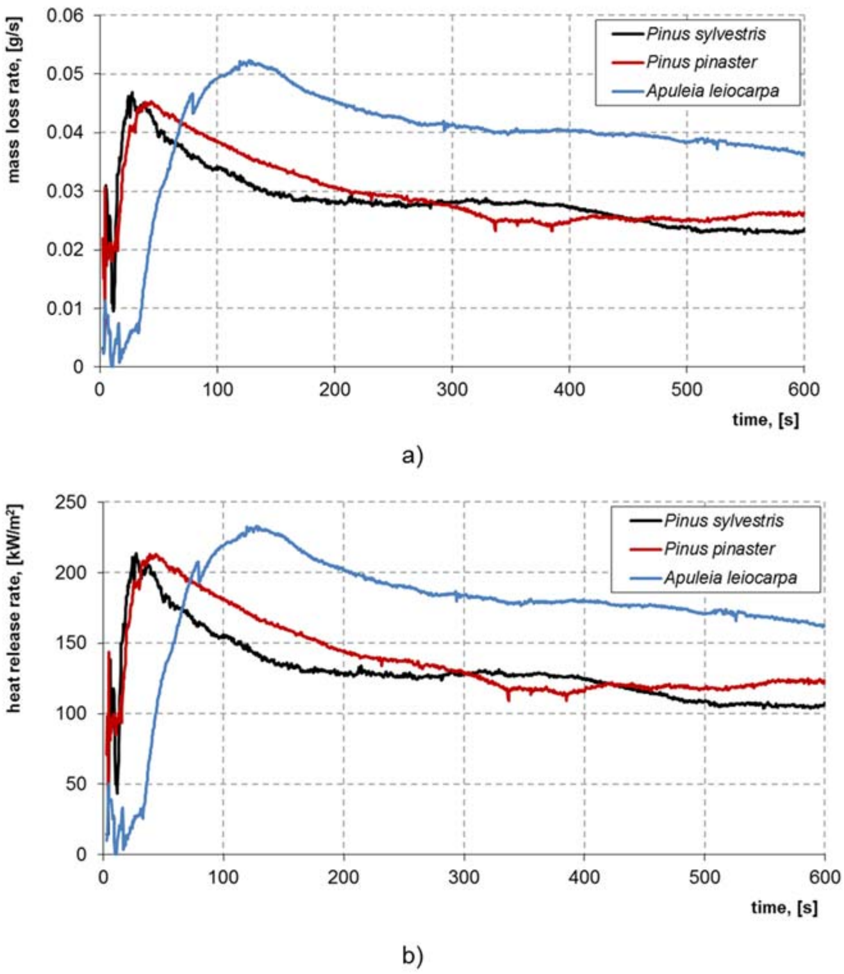

Figure 8. Mass loss rate (a) and heat release rate (b) for Pinus sylvestris, Pinus pinaster and Apuleia leiocarpa woods

4. Conclusions

Most hardwoods have a higher density than softwoods and, consequently, are more resistant to fire than softwoods. The use of hardwood for external walls in wood-framed buildings increases the resistance of these constructions to fire exposure. Flammability parameters such as time to ignition, mass loss, heat release rate, temperature of ignition and variation of temperature inside the wooden samples of one hardwood (*Apuleia leiocarpa*) and two softwood species (*Pinus sylvestris* and *Pinus pinaster*) used in construction of wood-framed buildings in Portugal were studied. Under a constant heat flux of 16kW/m^2, the time to ignition of *A. leiocarpa* wood (hardwood) was more than twice longer as compared with two softwood species (*P. sylvestris* and *P. pinaster*) and, consequently, a slower temperature rise on the wooden sample surface was verified. However, *A. leiocarpa* wood showed higher peak values of the mass loss and heat release rates, i.e. higher fire intensity, when ignition occurs. Higher mass loss rate also results on higher quantity of toxic gases resulting from combustion. The use of chemical treatments shortens the time to ignition, an effect that was more pronounced in the case of *A. leiocarpa* wood than with *P. sylvestris* wood. On the other hand, resistance of denser hardwood to insect and fungal attack allows moderate chemical treatment usage, which positively leads to lower temperatures on the surface of the wooden samples after ignition. Inside the wood samples, the temperature tends to present similar variations in softwoods and in hardwoods as the depth increases. Thus, for any wood type, the thickness of the wooden planks used in the building envelope construction may be an important parameter to control the temperature rise at the inner surface of the external walls, in case of intense heat fluxes in the outside, and thus prevent ignition of flammable materials inside the construction.

5. Acknowledgments

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