TEMPERATURE DISTRIBUTION IN WOOD FLOORINGS EXPOSED TO FIRE

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Abstract

Wood construction elements are widely used in buildings and they can be used in construction elements such as roofs, floorings, windows and doors. As wood is combustible material, there are lot of fire regulations that should be fulfilled at the design stage of any building project. In Latvia, as in some other countries usage of wood in building constructions is limited. Wood materials are an ecologically friendly material and a renewable resource, and its usage should be promoted.

The paper presents an overview of heat distribution in wood floorings exposed to standard heat fluxes which is different compared to wood members exposed to high heat radiation.

Fire spread and self-ignition investigation on wood floorings is carried out in this research. The results show different kinds of the temperature distribution in the cross section of the wood member cross section depending on heat radiation and location of the temperature measurement point.

Temperature distributions in wood during fire can be completely different in dependence on heat radiation and cross section of the wood member. The wood materials in floorings do not reach the self-ignition temperature during standard heat radiation.

Keywords: wood, fire, heating, combustion, charring.

Introduction

It is well known that wood is a combustible material. Numerous experiments have been carried out in past to understand the wood burning process which is very important to predict the behaviour of wood construction in fire. Pyrolysis of porous char-forming solids, such as wood, exposed to fire is a very complex process. Figure 1 illustrates the major physical and chemical phenomena involved in the pyrolysis of an exposed slab of wood. Under practical conditions of use, wood products always contain a certain percentage of moisture. When exposed to fire, the temperature of the wood will rise to a point when the moisture starts to evaporate. Since the water is adsorbed to the cell walls (at least if the moisture content is below the fiber saturation point, which is approximately 30% by mass), evaporation requires more energy than needed to boil free water and may occur at temperatures exceeding 100 °C. The water vapor partly migrates toward, and escapes through, the exposed surface. A fraction also migrates in the opposite direction, and re-condenses at a location where the temperature is below 100 °C (Konig, 2006; Janssens, 2004).

The dry wood (zone 3) further increases in temperature until the fibers begin to degrade. The thermal degradation starts at around 200–250 °C. In other literature sources it is mentioned that thermal degradation of wood starts at about 170 °C. The volatiles that are generated again travel primarily toward the exposed side, but also partly in the opposite direction. They consist of a combustible mixture of gases, vapors, and tars. A solid carbon char matrix remains. The volume of the char is smaller than the original volume of the wood. This results in the formation of cracks and fissures which greatly affect the heat and mass transfer between the flame and the solid. The combustible volatiles that emerge from the exposed surface mix with ambient air and burn in a luminous flame Janssens (2004).

Wood self-ignition temperatures have been investigated since 1887. Babrauskas has shown that wood self-ignition temperature varies from 204 to 530 °C depending on the heat flux radiation (Babrauskas, 2001; Babrauskas, 2003). Self-ignition time of wood has been investigated in different heat fluxes. A lower heat radiation means a lower temperature and longer time till ignition, but a higher heat radiation means higher temperatures and faster self-ignition of wood Tran and White (1992).

That is the reason why investigations on wood heating process are so significant to predict the behaviour of the wood construction in real fire.

Although wood products are classified as

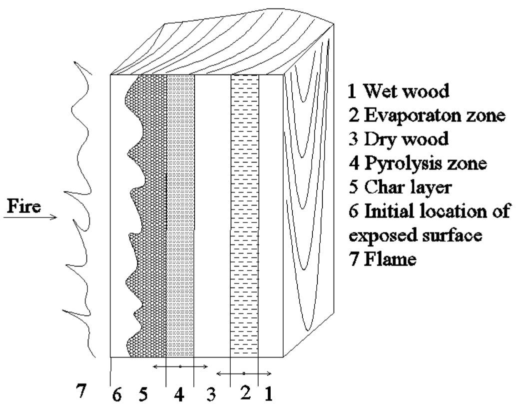

Figure 1. Burning process of wood slab.

combustible materials, a properly designed timber structure has been recognized as performing very well in fire. The reason for it is formation of the char layer on the burning wood member. A thicker char layer means a worse heat transfer in wood member and a longer durability in fire. Also timber cross section dimension is a matter of great importance. Larger dimensions mean higher durability of wood construction in fire. White (2000) has investigated the durability of wood construction in fire. The fire performance of timber is dependent on the charring rate and the loss in strength and modulus of elasticity. The charring rate is more or less constant and depends on the density and moisture content of the wood and heat exposure.

The charring rate of wood has been investigated by a lot of researchers in past and some of the results are described by Schaffer (1967), Hakkarainen et al. (2005), Hietaniemi (2005), Hugi et al. (2007) and White (2000) as well as in the 'Encyclopedia of Materials: science and technology' (2001). Most of all research projects have been done in very high heat fluxes of up to 100 kW m^{-2} and in real fire. The wood charring rate is a very important factor of the behaviour of wood member in fire. Charring rate of wood is dependent on different factors such as wood moisture content, density, heat radiation, dimensions of specimen, grain orientation, and others. In different research projects, wood charring rate has varied from 0.5 to 2 mm min^{-1} Schaffer (1967), Hakkarainen et al. (2005), Hietaniemi (2005), Hugi et al. (2007) and White (2000). The standardized value of charring rate is 0.5-1 mm min^{-1} (European design standards EN 1995-1; 2). The temperature of burning wood surface also is different in low and high heat radiation. Urbas and Parker (1993) have done an experiment on temperature measurements in wood specimens in different heat fluxes. There were about 600 °C surface temperature at 20 kW m^{-2} and about 800 °C in heat fluxes 35, 65 and 80 kW m^{-2}. It is not known what the temperature of wood top surface in low heat radiation is, but it is clear that there can be a big difference of wood behaviour in high heat fluxes.

Rezka and Torero (2006) have investigated the temperature distribution in wood specimens in high heat radiations and included the data into the model of wood burning process. There were different results obtained from temperature measurements in different depth in a wood specimen and it is clear that there is a very big difference between the top surface temperature and the core temperature. Rezka has mentioned that the heating rate of wood in high heat fluxes is different from the heating rate of wood in low heat fluxes. There are some wood burning models developed and lots of research done in wood heating investigations in high temperature radiations.

It is difficult to find the information about the temperature distribution in wood member exposed to low heat radiation for wood products such as floorings. And the main task of this research is to find out the temperature distribution in wood members exposed to low heat radiations. Other aims are to evaluate self-ignition possibilities of wood floorings and fire spread on it.

Materials and Methods

The experiment was carried out in March 2006 in the fire testing laboratory of Forest and wood products research and development institute.

The basic test material was sampled randomly from pine *(Pinus Sylvestris)* sawn timber with cross section dimensions 230x45 mm with initial moisture content 12 – 16%. Five specimens were selected for the experiment.

Sawn timbers were calibrated to constant thickness and were cut in 1050 mm length. The specimens were conditioned in a constant climate (20 °C temperature and 65% relative humidity) for one week.

Each specimen was divided in seven sectors starting at 110 mm distance from FRP (flooring radiant panel) corner with a step of 100 mm. Five holes for thermocouples in different depth were drilled in each sector line (5, 10, 20, 30 and 40 mm from a top surface of the specimen) (see Figure 2).

The moisture content of each board was measured in accordance with standard EN 13183-2:2003 method and the wood moisture content varied from 12 to 16%.

There were 35 thermocouples inserted in each specimen for temperature measurement in different board cross section sectors.

All FRP settings were set up in accordance with standard EN ISO 9239-1:2002, excluding one deviation from the standard. The propane mass flow was increased to reach a little higher heat radiation on a top surface of the specimen. This deviation from the standard method was done with the aim to get a wider temperature range distribution in the specimen.

The test equipment was calibrated before the experiments, and the measurement values are shown in Figure 3.

The maximal heat flux was at temperature 255 °C at thermocouples position line 110 mm from FRP corner and the lowest heat flux was 1.98 kW m^{-2} at temperature 93 °C at thermocouples position line 710 mm.

The duration of each experiment was about 4800 s. The specimen was ignited at the 2600s by inserting a pilot burner and the surface of the specimen started to burn with a flame. The experiments were stopped at about 4800 s when the temperature in wood started to decrease.

Descriptive statistic and regression analyses were used for data statistical analyses.

Results and Discussion

Five specimens were tested at different heat fluxes and temperatures. The first specimen was ignited by a pilot burner at 1500 s from the beginning of the experiment, but all other specimens were ignited at 2500 s. The experiment can be divided into two stages:

1. specimen heating up by constant heat radiation;
2. specimen heating up by heat radiation during burning process of the specimen surface.

A wood specimen heats up very slowly at different speed, which depends on the heat radiation. Temperatures were measured in one cross section at five different depths from a top surface of the specimen. The temperature difference in the specimen cross section is shown in Figure 4 where non-linear regression analysis is done and equation (1) is expressed as a power function at the top layer of wood at a 5 mm depth and exponential function equation (2) for the temperature calculation at the depth of 30 mm from the top surface of the specimen. Both equations have significant determination coefficients - 0.9629 and 0.9483:

$$T1 = 8.3436 \cdot x^{0.3598} \tag{1}$$

$$T2 = 25.183 \cdot e^{0.0003x} \tag{2}$$

where

$T1$ - wood temperature trend line at a 5 mm depth;

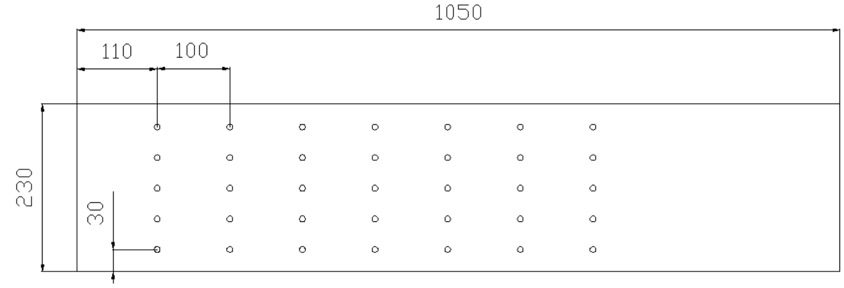

Figure 2. Placement of thermocouples in a specimen.

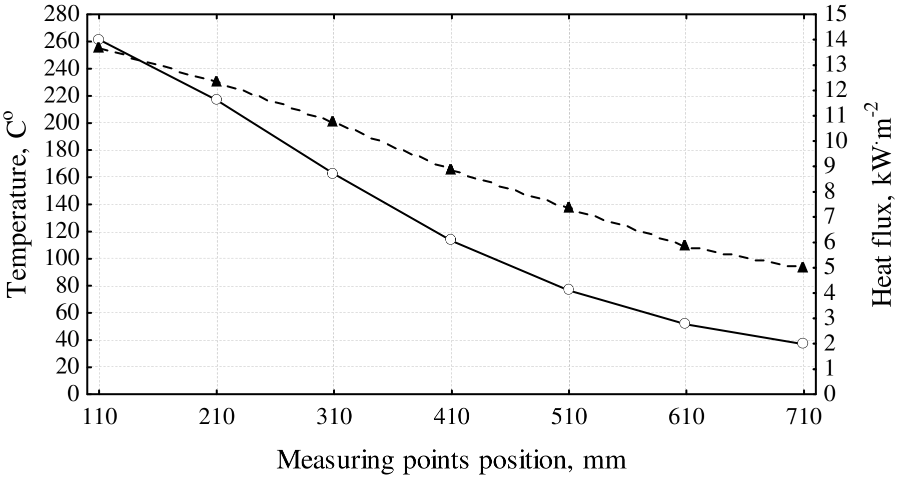

Figure 3. Temperature and heat flux distribution on a specimen surface: ▲ - temperature, ○ - heat flux.

$T2$ - wood temperature trend line at a 30 mm depth.

There were a different situation at the second stage of the experiment, when a specimen ignited by a pilot burner and a top surface of the specimen flashed with flames. The wood specimen starts to heat up much faster and the heat-up function is more linear (see Figure 5 and equations 3 to 5). Top layers of the wood specimen heats up faster that is shown by a trend line equation directional coefficients – 0.082 at a 40 mm depth and 0.529 at a 5 mm depth. A relative time function used for calculations by setting time to zero from the moment of the specimen ignition was:

$$T1 = 46.5984 + 0.0821 \cdot x \tag{3}$$

$$T2 = 114.5497 + 0.2626 \cdot x \tag{4}$$

$$T3 = 158.1642 + 05321 \cdot x \tag{5}$$

where

$T1$ – wood temperature trend line at a 40 mm depth;

$T2$ - wood temperature trend line at a 10 mm depth;

$T3$ - wood temperature trend line at a 5 mm depth.

The temperature distribution in a wood specimen during all experiments is shown in

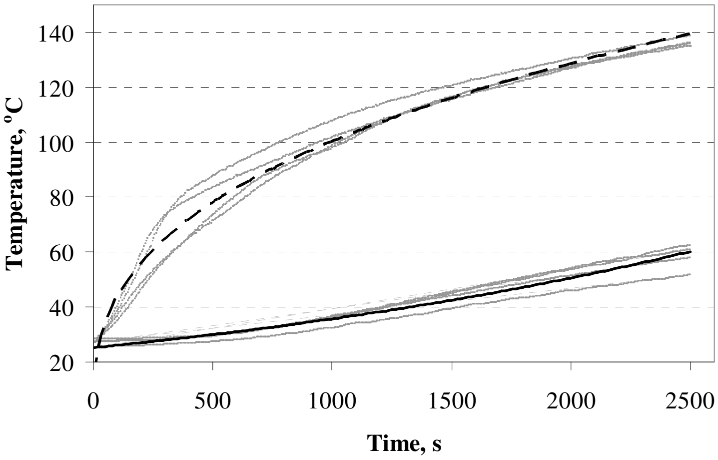

Figure 4. Wood heating up trend at a 5 mm and 30 mm depth from the top surface exposed to the 14 kW m^{-2} heat flux:
- - - - 5 mm depth, — 30 mm depth.

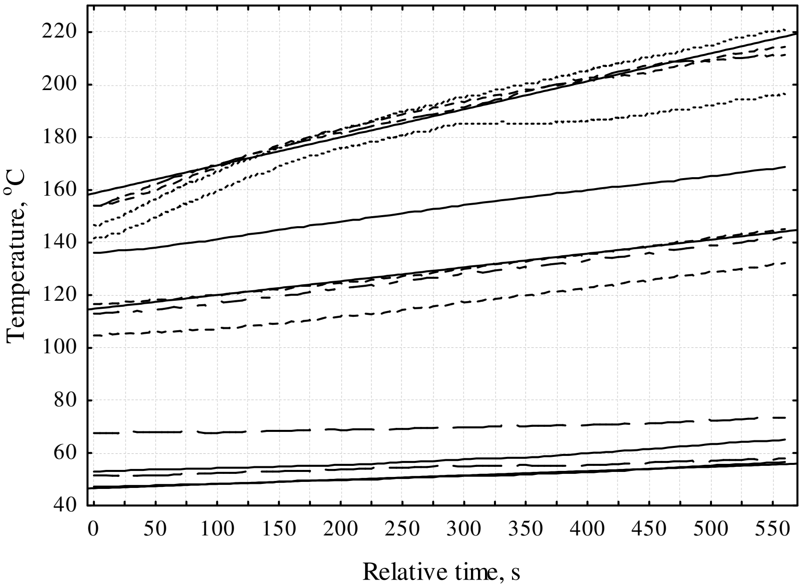

Figure 5. Wood heating up trend at a 40, 10 and 5 mm depth to the 14 kW m^{-2} heat flux after specimen ignition.

Figure 6. The top temperature curve is at 110 mm distance from FRP corner and the lowest curve is at 710 mm from FRP corner. The wood temperature is dependent on the heat radiation on a specimen surface, and this difference is very significant. There is also a very big difference between the temperature measurements at a 5 mm depth from the top surface and at a 40 mm depth. The temperature in a wood member cross section differs more than three times comparing the top surface to the bottom surface.

During the experiment, the specimen did not ignite itself and at 2500 s was ignited by a pilot burner. The fire spread on pine wood floorings

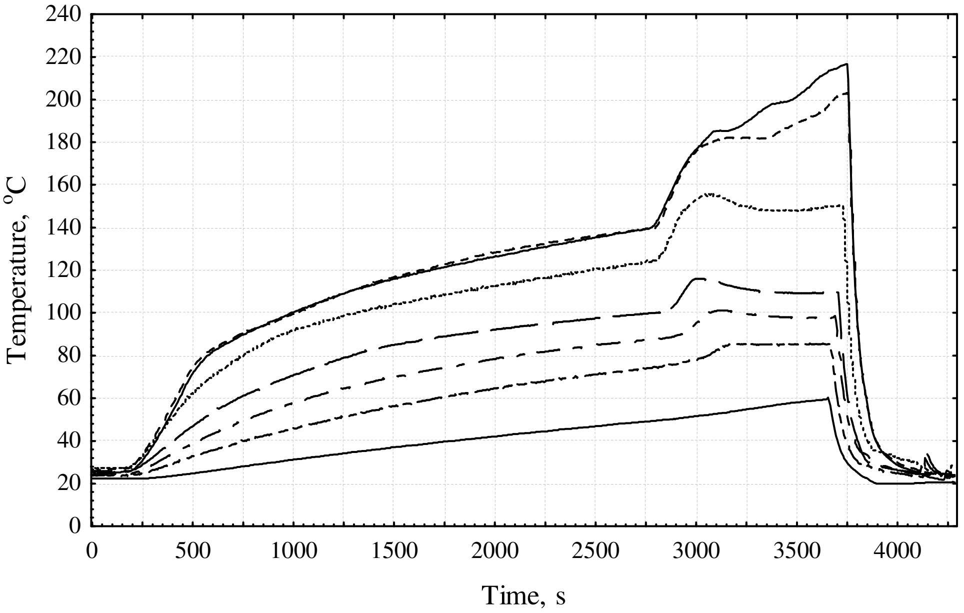

Figure 6. Temperature distributions in a wood specimen at a 5 mm depth from the top surface during the experiment in 7 different heat fluxes.

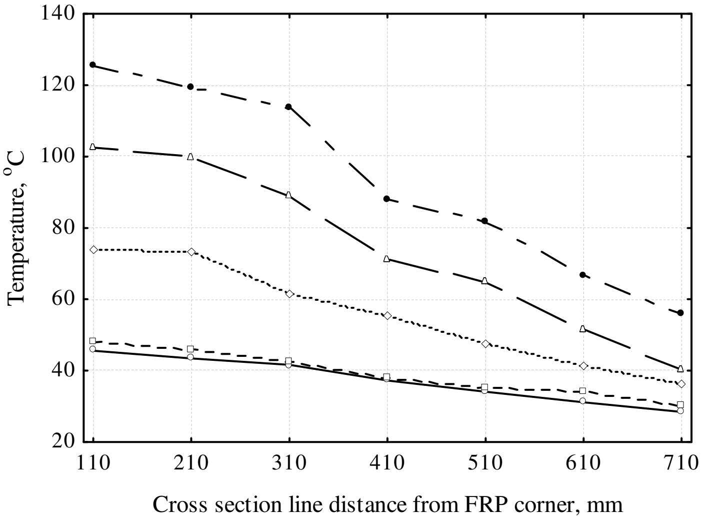

Figure 7. Temperature distributions in 7 cross sections of a specimen at different depth at 2000th s from the beginning of the experiment.

was about 700 mm. The fire spread would have been less if the specimen had been tested in accordance with the standard, because the pilot burner should be activated at the beginning of the test when the wood specimen is comparably cool. The temperature profile in the wood member cross section at one time moment is shown in Figure 7. If the wood is exposed to higher heat radiations, then temperature distribution is wider. In lower heat fluxes temperature distribution in the wood cross section is smaller. The heat flux values and temperatures are shown in Figure 3.

Conclusions

As floorings get a comparably small heat radiation of up to 14 kW m^{-2}, the heating up process of wood is much slower than of wood construction elements used in walls and roofs. There is still a significant difference in temperature distribution in wood member cross section. During the 4000 s from the beginning of the experiment, the inside temperature of the specimen did not reach the self-ignition temperature, which means that wood floorings are not the critical construction elements in buildings. The temperature distribution curves in wood are completely different in dependence on the heat radiation and the cross section of the wood member.

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