Considerations about fire behaviour of an unprotected wood elements according to Romanian Code SR EN 1995-1-2-2004

R Erbașu* and D Țăpușl

1 Department of Civil Engineering, Technical University of Civil Engineering Bucharest, Romania

• ruxi@erbasu.ro

Abstract. Increased interest in wood as construction material has led to the development of research on improving physical and mechanical characteristics of different wood species or various types of processed wood. Since wood construction materials are combustible, it is necessary to improve their fire behavior. This is achieved by treating the surface or the mass of materials using flame retardant substances, which can delay the ignition and can reduce the speed of propagation of fire. Although its benefits: specific weight, thermal conductivity, chemical stability, good vibration and shock absorption, good dimensional stability against temperature, ease of processing, etc., wood has the great disadvantage that it will ignite easily, being a cellulose material.

1. Introduction

According to Romanian Code SR EN 13943 [1], the fire behavior means changing or maintaining physical and chemical properties of a product exposed to fire. The concept includes both the reaction to fire and the fire resistance.

The reaction to fire is defined as the behavior of a material which by its own decomposition, supplies a fire to which is exposed under specified conditions.

The concept of fire resistance is the property of a building element to keep, for a given time interval, the required stability, the tightness and/or the thermal insulation.

The fire tests allow the evaluation of the physical and chemical parameters that characterize the construction and to establish the behavior of the structures and the structural elements at the complex action of fire by estimating measures corresponding to the different limit states of fire resistance.

The theoretical research has been developed in parallel with the experimental research, pursuing the development of calculation models and methods that expand the field of knowledge in this area. The theoretical approach allows the calculation of the behavior in case of fire of large elements and structures, for which experimental tests are difficult to perform. The process of simulation through calculation of the behavior of structures at the action of fire can be a more economical way of investigation.

The essential requirement, “fire safety”, will be fulfilled by taking measures and establishing rules for locating, designing, constructing and operating the buildings, installations and facilities, as well as establishing performance criteria and levels in terms of fire for the respective constructions.

The purpose of this paper is to determine the difference between two approaches in case of fire design: the results obtained through the numerical calculation according Romanian Code SR EN 1995-
1-2-2004 [2] and the series of experimental results obtained after performing two sets of fire resistance tests on one floor and one roof built with glued laminated timber beams [3].

For the analytical modelling the SAP2000 finite element method computer program was used and strength checks were performed at various time intervals, up to failure. The computations respect the provision of Romanian Code SR EN 1995 - 1- 2 - 2004 [2].

2. General presentation of the experiment
Initial set-up data for the experiment [3]:
- wood strength class: GL24; beams section: 140x167x7000 mm;
- permanent load on the roof beam 45 kg/m; permanent load on the floor beams 35 kg/m.

Exposure to fire was made on three sides and a span of 2.50m. 24 thermocouples were installed on the element surface and in the furnace, for measuring the temperature during the test, as shown in the figure below. The wood is not fire proofed.

![Thermocouples positioning](image1)

**Figure 1.** Thermocouples positioning

The temperature/time furnace heating diagrams for both tests are the following:

![Temperature/time diagram](image2)

**Figure 2.** Temperature/time diagram for the two experimental tests
The observations during the experiment described above and that are relevant to this study are the following:

- at time $t = 18$ min, the roof beam has a deflection of $1.00$ cm and the floor beam of $0.5$ cm;
- at time $t = 25$ min, floor beam has a deflection of $1.00$ cm;
- at time $t = 66$ min, both beams show a deflection of $2.00$ cm;
- at time $t = 85$ min, the test is stopped.

The experimental results show that the two beams were subjected to fire for 85 minutes. According to the code SR EN 13501-2 [4], the wooden beams fulfilled the condition of resistance up to 60 minutes, under the conditions of loading to which they were subjected, being framed in the resistance class R60.

3. Calculation of the beams according to SR EN 1995-1 - 2/2004 [2]

According to the obtained information in the roof beam experiment, this was modeled in SAP2000 program, loads being applied on three sides of the beam and strength checks were performed at different time interval, up to failure.

![Beam static scheme](image)

**Figure 3.** Beam static scheme

Beam section: $b = 140$ mm, $h = 167$ mm, span = 7.00 m

Taking into account the ISO 834 [4] time-temperature curve the model temperatures were determined:

$$T = 345 \log_{10}(8t + 1) + T_0(\degree C)$$ (1)

$$T = 20\degree C$$ (2)

where

- $T$ - hot gas temperature in the furnace fire test, in the vicinity of the element exposed to fire
- $T_0$ - during fire exposure (min)

![Temperature Time Curve - ISO 834](image)

**Figure 4.** Temperature Time Curve - ISO 834 [4]

Fire design was performed using the reduced cross section method, according to SR EN 1995 – 1-2 – 2004 [2].

For this computation method the duration of fire resistance depends on the resilience of non charring section.
Calculation of the design bearing capacity with reduced cross-section beam $M_{rd,r}$.

\[ M_{rd,r} = W_r f_{d,fi} \]  
\[ f_{d,fi} = k_{mod,fi} \frac{f_{20}}{\gamma_{M,fi}} \]  
\[ f_{20} = k_f f_k \]  
\[ f_{d,fi} = k_{mod,fi} \frac{k_{ff} f_k}{\gamma_{M,fi}} \]

where

- $f_{d,fi}$ - value of the resistance to fire;
- $k_{mod,fi}$ - fire-factor modification;
- $f_{20}$ - 20% fractile resistance at normal temperature;
- $f_k$ - resistance characteristic value;
- $\gamma_{M,fi}$ - partial safety coefficient of wood to fire action.

\[ W_r = \frac{b_r h_r^2}{6} \]

$W_r$ - strength modulus of the non-charring section

$b_r$ - width of cross section

$h_r$ - depth of cross section

The fire resistance checks were made for different time intervals from $t = 18$ min to $t = 85$ min, according to the experimental data.

The SAP 2000 analysis led to the design sectional moments $M_{Ed,fi}$ for the considered time intervals.

| Time (min) | Beam Section | Sup Temp (°C) | Inf Temp (°C) | $f_{max}$ (mm) | $M_{rd,r}$ (kNm) | $M_{Ed,fi}$ (kNm) | Check |
|------------|---------------|---------------|---------------|----------------|-----------------|-----------------|--------|
| 18         | 102.2         | 148.1         | 20            | 766            | 8.29            | 10.31           | 5.65   | ok    |
| 20         | 98            | 146           | 20            | 781            | 8.916           | 9.61            | 5.58   | ok    |
| 25         | 91            | 142.5         | 20            | 815            | 10              | 8.50            | 5.47   | ok    |
| 30         | 84            | 139           | 20            | 842            | 11.345          | 7.47            | 5.27   | ok    |
| 35         | 77            | 135.5         | 20            | 865            | 12.6            | 6.50            | 5.01   | ok    |
| 40         | 70            | 132           | 20            | 885            | 13.96           | 5.61            | 4.69   | ok    |
| 45         | 63            | 128.5         | 20            | 902            | 15.33           | 4.79            | 4.32   | ok    |
| 50         | 56            | 125           | 20            | 918            | 16.7            | 4.03            | 3.92   | ok    |
| 55         | 49            | 121.5         | 20            | 932            | 18.1            | 3.33            | 3.48   | Beam fails |
| 60         | 42            | 118           | 20            | 945            | 19.5            | 2.69            | 3.02   | Beam fails |
| 66         | 33.6          | 113.8         | 20            | 960            | 21              | 2.00            | 2.46   | Beam fails |
| 70         | 28            | 111           | 20            | 968            | 21.9            | 1.59            | 2.08   | Beam fails |
| 75         | 21            | 107.5         | 20            | 979            | 21.57           | 1.12            | 1.62   | Beam fails |
| 80         | 14            | 104           | 20            | 988            | 22              | 0.70            | 1.17   | Beam fails |
| 85         | 7             | 100.5         | 20            | 997            | 22.78           | 0.33            | 0.74   | Beam fails |

Thus, it appears from the above calculation that the beam fulfils the resistance conditions up to time $t = 50$ min, 10 minutes earlier than in the experimental case, this showing the fact that the analytical computational offers a safety interval to cover the unpredicted risks that may appear in case of real service conditions.

According to the Code SR EN 13501-2 [4], there will be a different framing of the wooden beams in fire resistance classes: R30 – for the analytical computational and R60 for the experimental case.
Following the previous example, the floor beam was modelled in SAP2000, according to information from the experiment and checked until failure.

Table 2. Check of the floor beam from $t = 0$ to $t = 85\text{min}$.

| Time (min) | $b_r$ (mm) | $h_r$ (mm) | Sup Temp ($^\circ\text{C}$) | Inf Temp ($^\circ\text{C}$) | $f_{\text{max}}$ (mm) | $M_{\text{Ed,fi}}$ (kNm) | $M_{\text{Ed,fi}}$ (kNm) | Check       |
|-----------|------------|------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------------|
| 18        | 102.2      | 148.1      | 20              | 766             | 8.22            | 10.31           | 5.48            | ok          |
| 20        | 98         | 146        | 20              | 781             | 8.84            | 9.61            | 5.42            | ok          |
| 25        | 91         | 142.5      | 20              | 815             | 10              | 8.50            | 5.31            | ok          |
| 30        | 84         | 139        | 20              | 842             | 11.27           | 7.47            | 5.13            | ok          |
| 35        | 77         | 135.5      | 20              | 865             | 11.29           | 6.50            | 4.87            | ok          |
| 40        | 70         | 132        | 20              | 885             | 13.91           | 5.61            | 4.56            | ok          |
| 45        | 63         | 128.5      | 20              | 902             | 15.3            | 4.79            | 4.2             | ok          |
| 50        | 56         | 125        | 20              | 918             | 16.7            | 4.03            | 3.8             | ok          |
| 55        | 56         | 125        | 20              | 932             | 18.1            | 3.33            | 3.36            | Beam fails  |
| 60        | 42         | 118        | 20              | 945             | 19.62           | 2.69            | 2.92            | Beam fails  |
| 65        | 33.6       | 113.8      | 20              | 960             | 21.27           | 2.00            | 2.36            | Beam fails  |
| 70        | 28         | 111        | 20              | 968             | 22.2            | 1.59            | 1.99            | Beam fails  |
| 75        | 21         | 107.5      | 20              | 979             | 23.15           | 1.12            | 1.53            | Beam fails  |
| 80        | 14         | 104        | 20              | 988             | 23.17           | 0.70            | 1.08            | Beam fails  |
| 85        | 7          | 100.5      | 20              | 997             | 23.2            | 0.33            | 0.66            | Beam fails  |

As in the case of roof beams, the results of the experimental test and the analytical calculation obtained for the floor beam are maintained: the beam is framed in the class of resistance R60 – according to experimental tests and in the resistance class R30 by the analytical calculations.
4. Fireproofing of wood
The process of improving the fire behavior of combustible materials is called fireproofing. The fire retardant does not exclude the ignition and combustion of the material, but it gives an improved fire behavior over a certain period of time.

Improvement of the fire behavior of wood elements can be done by protecting the surfaces of the elements with: (i) fireproof cladding, made by using one or more layers of wood-based panels, a layer of gypsum or clay shale fibers, (ii) flame retardant substances applied to the surface (heat-foaming paints) or in the mass of the element.

According to SR EN 1995-1-2 [2] computations, when using protection made of wood panels a minimum of 13.3 mm of timber panel or plywood is necessary to delay the charring starting time with 15 min meaning that one 15 mm thickness protective panel of wood is sufficient to offer satisfying fireproothing.

Considering the flame retardant variant with the gypsum coating, in order to delay the charring initiation time by 15 minutes, a minimum of 11 mm gypsum board panel is needed.

5. Conclusions
Although its benefits: specific gravity, thermal conductivity, chemical stability, good vibration and shock absorption, good dimensional stability against temperature, ease of processing, etc., wood has the great disadvantage that it will easily ignite, being a cellulosic material.

Wood, even if is a combustible material, performs well in terms of structural resistance to fire. As explained in this study, when exposed to fire wood retains its strength for a longer period of time.

In this study, one aims to achieve the comparison between the results of the fire tests performed on two beams of glued laminated timber and the results of the analytical calculation, performed according to the Codes in force in Romania in compliance with the experimental conditions.

By comparing the results obtained from the experiments with those obtained by the analytical calculation, on the unprotected structural elements, it resulted that, regarding the fire resistance, the analytical calculation leads to more restrictive results, compared to the experimental approach.

Fireproofing is one of the requirements for fire safety that lead to improving the fire resistance of a building.

References
[1] SR EN ISO 13943 2011 Fire security. Vocabulary
[2] SR EN 1995-1-2 2004 Design of timber structures. General - Structural fire
[3] Test report no. 931 2005 S.C. GLULAM S.A.
[4] SR EN 13501-2 2010 Fire classification of products and building element