Meri Cvetkovska[1]

Cvetanka Chifliganec[2]

FIRE SAFETY OF TIMBER STRUCTURES

Abstract: According to the design codes timber buildings have to fullfil defined fire safety requirements. For required duration of fire exposure, the fire safety can be achieved through proper fire design of the structural elements, done either by ensuring residual cross-section to sustain the design loads during fire or by protecting the cross-section with fire protection materials. The fire resistance of unprotected and protected columns and simply supported timber beams exposed to standard fire is analyzed in this paper. The fire resistance is defined with respect to the criteria of usability of the structures in fire conditions, according to Eurocodes.

Key words: Timber beam, timber column, insulation, temperature, fire, char layer

The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

[1] Professor, PhD, St. Cyril and Methodius University, Faculty of Civil Engineering, Partizanski odredi no.24, 1000 Skopje, north Macedonia, cvetkovska@gf.ukim.edu.mk

[2] Assistant, MSc, St. Cyril and Methodius University, Faculty of Civil Engineering, Partizanski odredi no.24, 1000 Skopje, north Macedonia, c.chifliganec@gf.ukim.edu.mk

1. INTROFUCTION

Despite the fact that timber satisfies many of the contemporary building requirements, it has a disadvantage of being combustible when exposed to high temperatures and fire. Consequently timber structures are usualy trated as less safe than structures built of non-combustible materials, such as concrete and masonry. In order to prevent serious consequences, fire as an accidental action has to be taken under consideration in timber structural design. Special parts of the Eurocodes are dedicated to the fire safety of structures and the passive fire protection. In these parts the following essential requirements are defined: load bearing resistance, structural integrity and insulation.

The fire resistance of an element, of a part, or of a whole structure is ability to fulfil the above mentioned requirements for a specified load level, for a specified fire exposure and for a specified period of time [1]. Providing the required fire resistance leads a step closure to ensuring the fire safety of a building structure.

As building technologies and science evolve, the timber fire protection measures are improved and upgraded. The process of making wood more fire resistant usually involves application of surface coatings or impregnation with chemical treatments. The use of rock wool, gypsum plasterboards or other fireboards, as fire-resistant linings, are also common in practice and in same time much cheaper.

In order to determine the fire resistance and the behaviour of unprotected and protected simply supported timber beams exposed to standard fire from the bottom side, three different cases are analyzed. The nonlinear numerical analyses are performed with the specialized program for analysis of structures in fire – SAIR. The results of the thermal and structural analysis are graphically presented and comparison of the results is made.

Columns are elements that also have an important role in providing global stability of the structure. If one of the columns in the structure collapses, then the whole structure is unstable. The factors which could influence the fire resistance of timber columns are: charring rate, charring depth, wood density, moisture content, load capacity, shape and cross-section dimensions, boundary conditions and the model of fire exposure.

The influence of cross-section dimensions and type of isolation on fire resistance of timber columns is analysed in this paper and the difference in fire resistance of protected and unprotected timber columns is defined.

2. BEHAVIOR OF FIRE PROTECTION MATERIALS IN FIRE

Wood: Wood is a complex composite of natural polymers and is generally anisotropic, heterogeneous and porous material. The properties of wood are affected by the moisture content, which, in case of fire, evaporates. This leads to changes of material properties [3]. When exposed to heat caused by fire, the wood goes through a process of thermal breakdown into combustible gases. The pyrolysis is a thermochemical decomposition of a wood at elevated temperatures in the absence of oxygen (or any halogen). It involves the simultaneous change of chemical composition and physical phase, and is irreversible. It usually starts at temperatures of 280 °C to 300 °C. The key contributing factor in timber's fire resistance is the layer of charcoal that is formed on the burning surface during the pyrolysis process. This char layer acts as an insulator protecting the inner core of the timber, making it resistant to heat penetration and thus burns more slowly. The inner uncharred core remains cold and keeps its initial properties, enabling to continue to sustain the load. The progressive conversion of the fire-exposed surfaces to ever-deepening char occurs at definable rates. Since charcoal is produced at a constant rate, the time to failure of timber construction elements can be easily predicted. The rate of conversion to char decreases with increasing of moisture content and density of the timber used. The charring rate is also affected by the permeability of the timber to gaseous or vapor flow. Charring normal to the grain of timber is one-half of that parallel to the grain.

Rock wool: In normal temperature environment, rock wool thermal insulation prevents convection by holding air still in the matrix of the wool. Still air is a good insulator. It also stops radiation and limits the conduction of heat through the body of the insulation. The effectiveness of rock wool in reducing heat transfer depends upon its properties, such as: density, thickness, composition and the fineness of the wool as well as the temperature at which it is used. Due to its non-combustibility rock wool insulation does not spread fire by releasing heat, smoke, or burning droplets. In fire environment it retains integrity and hampers the fire process. The maximum working temperature is about 750°C and melting occurs at 1000°C. Because of all these, the rock wool is used to slow down the heat transfer and protect the flammable constructions or those susceptible to the effects of fire, which results in increased fire resistance of structural elements.

Gypsum plasterboard: Gypsum plasterboard is widely used in building construction. It consists of a gypsum core between two layers of paper and can also contain other materials in small quantities such as glass fibre and vermiculite within the various proprietary products to improve their durability and performance when exposed to high temperatures.

There are three types of gypsum boards: Regular boards, Type X and Type C boards. Regular plasterboards are used as non-fire resistant partitions, while the Type X boards and Type C are used in fire-rated applications.

Gypsum is porous and non-homogeneous material which contains chemically combined water (approximately 50% by volume). When gypsum panels are exposed to fire, dehydration reaction occurs at 100ºC to 120ºC [5]. Heat is absorbed when portion of the combined water is driven off as steam i.e. calcination occurs. Thermal energy that converts the water to steam is thus diverted and absorbed, keeping the opposite side of the gypsum panels cool as long as there is crystalline water left to be converted into steam or until the gypsum panel is breached i.e. heat transmission is effectively retarded. In the case of regular gypsum board, as the crystalline water is driven off, the reduction of volume within the gypsum core causes formation of large cracks, thus causing the panel to fail due to structural integrity [6].

In Type X gypsum boards, special glass fibers are intermixed with the gypsum to reinforce the core of the panels. These fibers have the effect of reducing the size of the cracks that form when the water is driven off, thereby extending the length of time the gypsum panels resist fire without failure. Also, there are Type C gypsum boards whose core also contains glass fibers, only in a much higher percent by weight. In addition to the greater amount of glass fiber, the core of the Type C panels can also contain vermiculite, which acts as a shrinkage-compensating additive that expands when exposed to elevated temperatures of a fire. This expansion occurs at roughly the same temperature as the calcination of the gypsum in the core. It allows the core of the Type C panels to remain dimensionally stable in the presence of fire, which in turn allows the panels to remain in place for a longer period of time even after the combined water has been driven off [6].

3. UNPROTECTED AND PROTECTED TIMBER BEAMS IN FIRE

3.1. Description of the problem

In order to determine the impact of fire on protected and unprotected timber beams and their behaviour when exposed to fire, three case studies were analyzed using the program SAFIR [7]. The temperature rise over time was defined with the standard fire curve ISO 834. In all case studies, the simply supported beams were fire exposed on three sides (Figure 1). In Case study 1 an unprotected timber beam was analyzed. In Case study 2 the same timber beam was protected with rock wool on three sides, while in Case study 3 the timber beam was protected with rock wool on the sides and X type gypsum board at the bottom. The cross-sections of the beams used in the examples are presented in Figure 2.

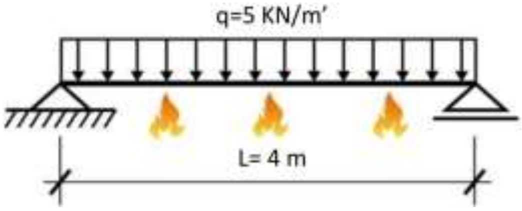


Figure 1- Geometry, support conditions and loads on a simply supported beam

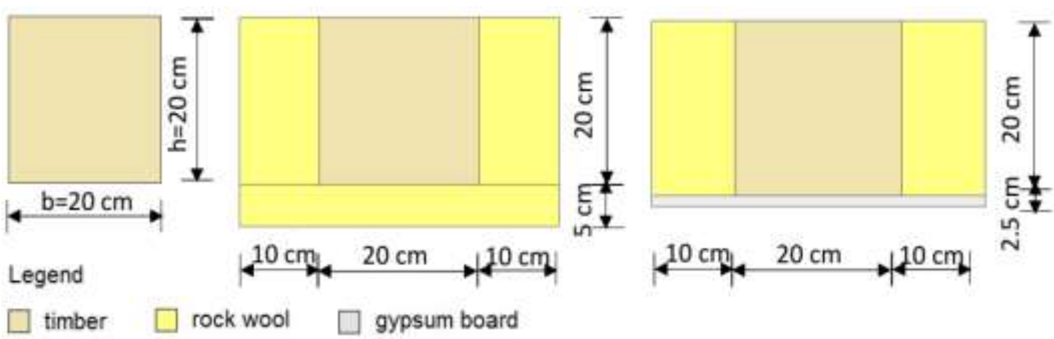


Figure 2- Cross sections of the beams, a) Case study 1, b) Case study 2, c) Case study 3

3.2. Thermal and mechanical properties of materials used in the numerical analysis

The characteristic values of the strength, stiffness and density of the timber class C30 was taken in accordance with the EN 388 [8]. The material was considered with 12% moisture content. The X type gypsum board had a density of 648 kg/m^3 and the rock wool had a density of 160 kg/m^3.

All thermal properties at ambient temperature for the materials used in the analysis are given in Table 1. Temperature dependant thermal conductivity and specific heat for the materials were taken in accordance with the appropriate Eurocodes.

Table 1- Thermal properties used in the numerical analysis

Thermal property	Unit	Timber	Type X gypsum board	Rock wool
λ (20 °C)	[W/mK]	0.12	0.40	0.037
c (20 °C)	[J/kgK]	1530	960	880
ρ (20 °C)	Kg/m^3	425	648	160
α_c	[W/m^2K]	25	25	25
$\alpha_{c,\ cold}$	[W/m^2K]	4	/	/
E		0.8	0.9	0.75

3.3. Thermal analysis

As expected, significant differences in the time-dependant temperature fields in the cross-sections of the unprotected and the protected beams were noticed. The temperature distributions in the cross-sections of all analyzed cases, for the specific moments or for the required fire resistances, given in the regulations, are shown in Figure 3, Figure 4 and Figure 5.

In Case study 1 (Figure 3), the unprotected timber beam reached high temperatures in relatively short time period and at the moment of failure (t_f=37 min) the charring depth in the horizontal direction was d_{char}=30.2 mm and in the vertical direction $h_{cha}r$=30.1 mm. This implies that the charring rates (the ratio of the charring depth to the time of fire exposure) are β_b=0.82 mm/min and β_h=0.81 mm/min, respectively.

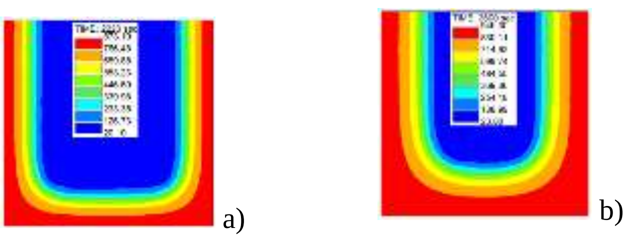
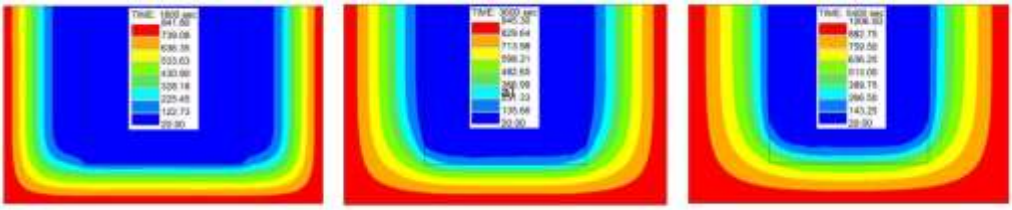
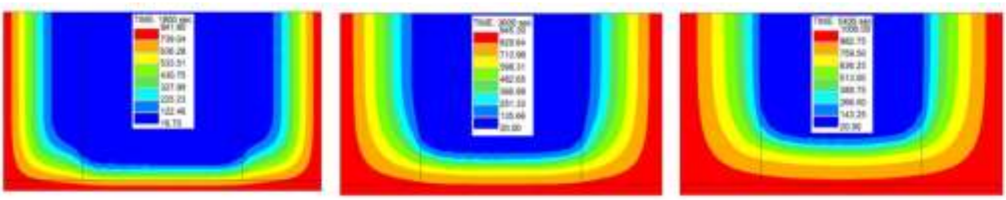


Figure 3- Temperature distribution in the cross-section of Case study 1,
a) $t_{failure}$=37 min b) t=60 min



a) b) c)

Figure 4- Temperature distribution in the cross-section of Case study 2,
a) t=30 min b) t=60 min 2 c) t=90 min



a) b) c)

Figure 5- Temperature distribution in the cross-section of Case study 3
a) t=30 min b) t=60 min 2 c) t=90 min

Charring depth is the distance between the outer surface of the original cross section and the position of the char-line (see Figure 6). The position of the char-line is taken as the position of the 300-degree isotherm.

According to the simplified analytical reduced cross-section method given in Eurocode 5-1-2 [9], the effective charring depth in the cross-section of the unprotected timber beam in Case study 1 can be calculated by using the following relations:

$d_{ef} = \beta_n * t + k_0 * d_0 = 36.6\ mm$

$b_{fi} = b - 2 * d_{ef} = 126.8\ mm$

$h_{fi} = h - d_{ef} = 163.4\ mm$

$A_r = b_{fi} * h_{fi} = 0.020719\ m^2$

$A_r\ (\%A) = 51.8\%$

where: $\beta n = 0.8\ mm/min$ is the design notional charring rate under Standard fire exposure.

- $t=37\ min$ is the time of fire exposure
- $k_0=1$ is for fire exposure t>20 min
- $d_0=7\ mm$ is the zero strength layer
- A_r is the area of the reduced cross section

It can be seen that the charring rates calculated analytically and numerically match.

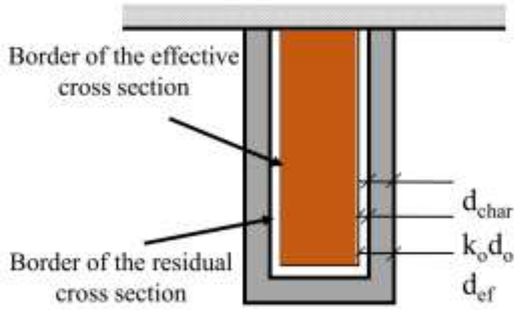


Figure 6 - Definition of the residual and the effective cross-section

In case of protected timber beams, i.e. Case study 2 and Case study 3, the moment when charring process starts is delayed (Figure 4 c and Figure 5 a) and only the numerical results are presented.

At 30 minutes of fire exposure, the whole cross-section of the timber beam in Case study 2 is cold (Figure 4a). At the same time, the timber beam in Case study 3 has 10 mm charring depth in the vertical direction of the cross-section while the sides of the section remain unheated because of the positive influence of the rock wool insulation (Figure 5a). At time t=37 min the cross-section of Case study 1 is significantly heated and has charring depth of 30 mm in both directions (Figure 3a).

The rock wool insulation shows far better results in the fire protection of the timber beam, in comparison to the Type X gypsum board. After one hour of fire exposure the cross-section of the beam in Case study 2 remains cold, that is not a case with the beam in Case study 3 which has a charring depth of 30 mm in the vertical direction (Figure 4b and Figure 5b). Figure 3b shows that after one hour of fire exposure the unprotected beam has a highly reduced cross-section.

3.4. Structural analysis

The timber beam protected with rock wool (Case study 2) has reached higher fire resistance (time to failure) in comparison to the timber beam protected with Type X gypsum boards (Case study 3). Both beams satisfy the required fire resistance of 60 minutes, but the beam in Case study 2 has by far favourable cross-section temperature distribution compared to the one in Case study 3 (Figure 4b and Figure 5b).

The unprotected timber beam has a fire resistance of tf=37 min. Besides the benefit to the thermal distribution in the timber cross-section, the contribution of the rock wool to the structural fire performance of the beam is confirmed too.

The cold cross-section in Case study 2 results with prolongation of the load-bearing resistance of the beam and smaller mid-span vertical displacements (Figure 7). The vertical mid-span displacements of the analysed beams (Δy) are presented in Table 2.

Table 2- Vertical displacements at mid-span of the beams, for different case studies

Type of cross section	Δy [cm]	Time [min]
Case study 1	3.72	37
Case study 2	1.37	60
Case study 3	2.15	60

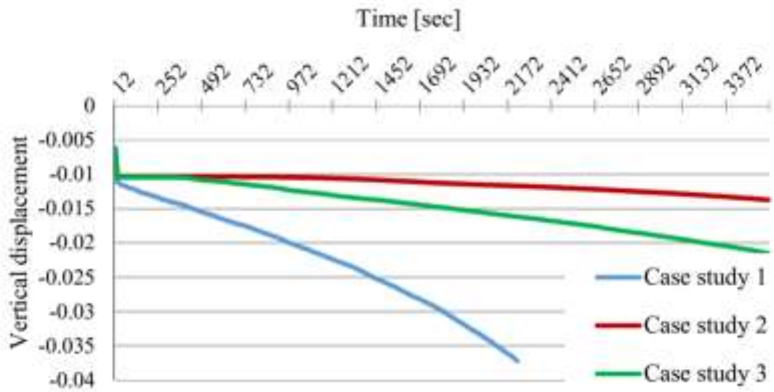


Figure 7- Time and temperature dependent vertical displacements at beams mid-span

4. UNPROTECTED AND PROTECTED TIMBER COLUMNS IN FIRE

4.1. Unprotected timber columns in fire

For defining the influence of the cross section dimensions on the fire resistance of the columns, the following unprotected columns were analyzed: cross-section dimensions 16x16, 17x17, 18x18, 20x20, 22x22, 24x24 and 26x26cm, height H=3m, pin ended on both sides, subjected to axial loading and exposed to Standard fire ISO 834 from all four sides. The timber type C 24 with specific density γd=600 kg/m^3 was used for all columns.

The column's cross section geometry is presented in Figure 8.

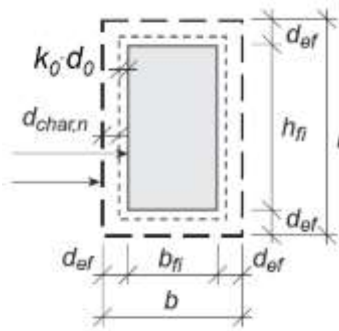


Figure 8 - Geometry of column's cross section

The timber columns were analysed for the following classes of fire resistance: R30, R45, and R60. The simplified analytical reduced cross-section method, given in Eurocode 5-1-2 [9], was used for the analysis.

The design compressive strength of the column in fire, $f_{c,0,d,fi}$, is reduced in time as a result of the increased buckling effect due to the reduced cross section dimensions of the column by forming the char layer. In same time the design compressive stress in fire, $\sigma_{d,fi}$, is increased as a result of the reduced cross section dimensions.

The moment when the design compressive strength in fire, $f_{c,0,d,fi}$, is equal to the design compressive stress in fire, $\sigma_{d,fi}$, represents the fire resistance of the column. For the column with cross section dimensions 16x16 cm the fire resistance is 33 min. (Figure 9), concequently this column satisfies the criteria for R30 class of fire resistance.

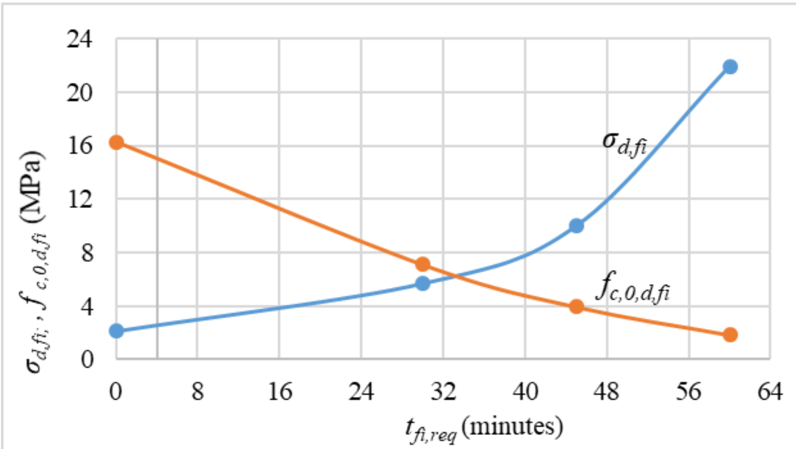


Figure 9. Fire resistance of unprotected column with cross section dimensions 16x16cm, hight H=3m, pin ended on both sides

The results for all other unprotected columns are presented in Table 3 and in Figure 10.

Based on the analyticaly achieved results, it can be concluded that in case of constant axial force the fire resistance of the unprotected timber column increases proportionaly to the increase of the cross section dimensions. The reason for this fact is the constant charring rate of the timber.

Table 3. Fire resistance of unprotected columns with hight H=3m, as function of the cross section dimensions

Cross section dimensions (cm)	16x16	17x17	18x18	20x20	22x22	24x24
Fire resistance (minutes)	33	39	46	59	70	82

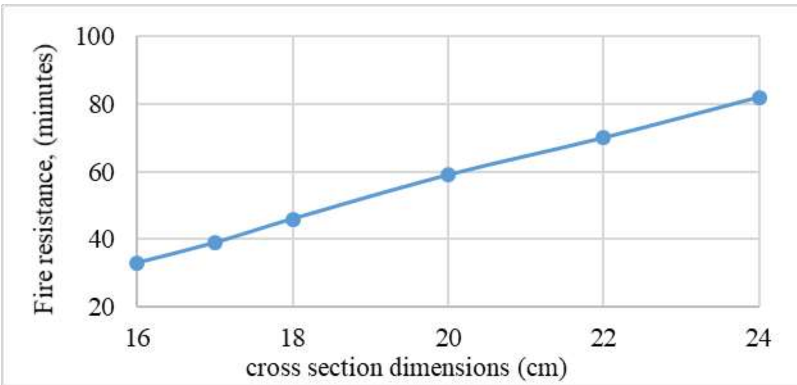


Figure 10 - Fire resistance of unprotected columns as funcion of the cross section dimensions

4.2. Protected timber columns in fire

The other topic of this research is the influence of the thermal protection on the fire resistance of timber columns. The influence of two different types of thermal protection was analyzed: wood-based panels and one or two layers of gypsum plasterboard. Dimensions of the analyzed columns are: 16x16,18x18 and 20x20cm.

In case of thermal protection with one layer of gypsum plasterboard with thickness hp=18mm, the charring process is delayed according to the equation given in Eurocode 5-1-2 [9]:

$$t_{ch} = 2{,}8 * h_p - 14 = 2{,}8 * 18 - 14 = 36{,}4\, min$$

In case of R30 class of fire resistance, the time of fire exposure is less than the time when charring starts ($t_{fi,req} < t_{ch}$), the protection layer doesn't fall off during the time of fire exposure and the effective thickness of the char layer consists only the pyrolysis layer:

$$k_0 = \frac{30}{36{,}4} = 0{,}824 \Rightarrow d_{ef} = d_{char,n} + k_0 * d_0 = 0 + 0{,}824 * 7 = 5{,}768mm$$

In such case the residual cross section is sufficient to sustain the axial load.

For higher classes of fire resistance, when the $t_{fi,req} > t_{ch}$, the protection layer falls off at moment t_{ch} and the charring process starts with double valye of the charring rate till the moment when the char layer will reach 2.5 cm. After this moment the charring rate will have the initial value.

In case of two layers of gypsum plasterboard the charring is postponed for:

$$t_{ch} = 2{,}8 * (h_{p1} + \frac{1}{2} * h_{p2}) - 14 = 2{,}8 * (18 + \frac{1}{2} * 18) - 14 = 61{,}6\, min$$

Fire resistance of a timber column 16x16 cm, protected by two layers of plasterboard, is presented in Figure 11. In this case the charring process starts after 61.6 min of fire exposure and after this moment the design compressive strength in fire, $f_{c,0,d,fi}$, is rapidly reduced, while the design compressive stress in fire, $\sigma_{d,fi}$, is rapidly increased.

The charring rate of wood-based panel is: $\beta_0 = 0{,}9\, mm/min$. In case the timber column is protected by one layer of wood-based panel with thickness hp=20 mm, the charring process is delayed for 22 minutes:

$$t_{ch} = \frac{h_p}{\beta_0} = \frac{20}{0{,}9} = 22{,}22 min$$

The fire resistance of a timber column with dimensions 16x16 cm, protected by one layer of wood-based panel, is presented in Figure 12. The results for all other protected columns are presented in Table 4 and Figure 13.

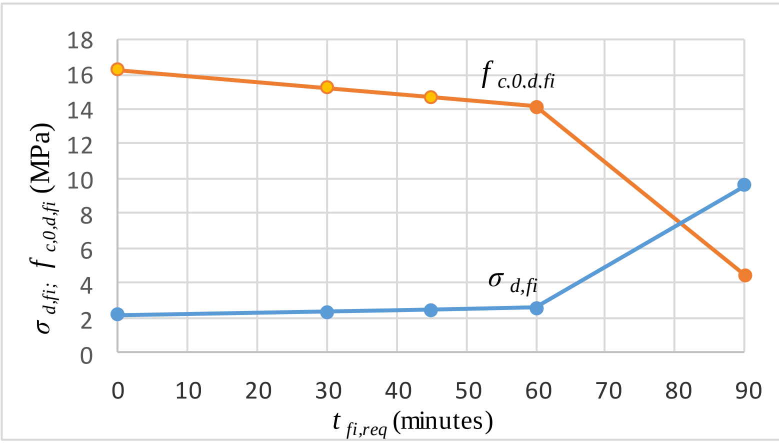


Figure 11 - Fire resistance of column with cross section dimensions 16x16cm, hight H=3m, pin ended on both sides, protected by two layers of gypsum plasterboard

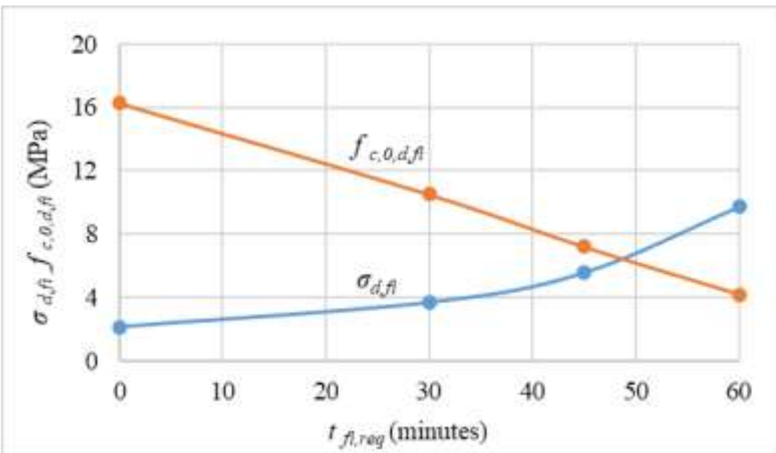


Figure 12- Fire resistance of column with cross section dimensions 16x16cm, hight H=3m, pin ended on both sides, protected by one layers of wood-based panel

Table 4- Comparison of fire resistance of unprotected and protected columns as function of the cross section dimensions and type of protection

Cross section dimensions (cm)	Fire resistance (minutes)			
	unprotected	Protected by one layer of wood-based panel	Protected by one layer of gypsum plasterboard	Protected by two layers of gypsum plasterboard
16x16	33	48	55	81
18x18	36	53	65	91
20x20	59	64	76	102

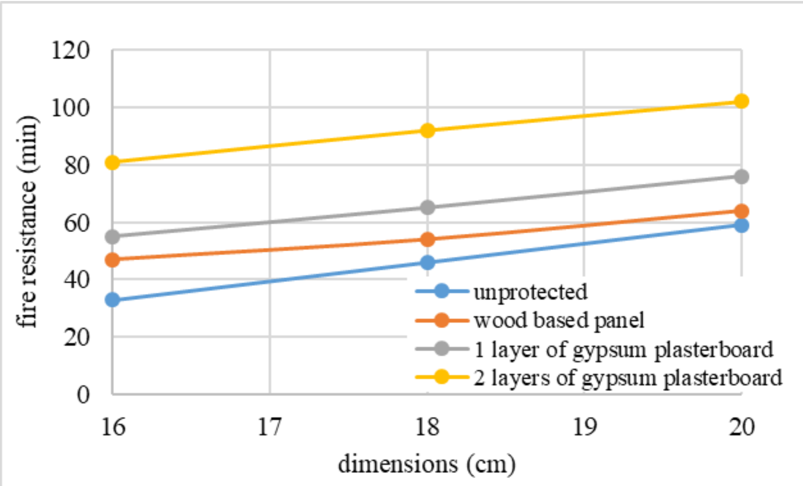


Figure 13 - Fire resistance of protected timber columns with different cross section dimensions, as funcion of the type of the protection

5. FIRE RESISTANCE OF TIMBER BASED FLOOR STRUCTURES

The timber floor is widely used in traditional and rural buildings, but the high combustibility of the wood results in low fire resistance of this type of floors. Wood can be protected by fire protective claddings, other protection materials or by other structural members and nowadays a special attention is paid to this problem.

One of the possible solutions for increasing the fire resistance of wooden floor structures is the composite timber-concrete floor assembly made of timber girders and reinforced concrete slab, while the cavities are field with mineral or rock wool. Two types of floor structures, timber-concrete composite floor structure TCCFS and traditional timber floor structure TFS, for two different fire scenarios, are analysed in this paper.

The cross sections and the dimensions of the two different types of simply supported floor structures with span L=5m were defined according to the current standards and are presented on Figure 14. Material properties at room temperatures are given in Table 5. The temperature dependent physical and mechanical properties of the siliceous aggregate concrete (compressive strength fc=30Mpa) and the reinforcement (yield strength fy=400Mpa) were assumed according to EN 1992-1-2. For standard fire exposure, values of thermal conductivity, specific heat and the ratio of density of softwood were taken as given in EN 1995-1-2.

The thermal conductivity values of the char layer are apparent values rather than measured values of charcoal, in order to take into account increased heat transfer due to shrinkage cracks above 500°C and the consumption of the char layer at about 1000°C (Figure 15). Cracks in the charcoal increase heat transfer due to radiation and convection. The computer program SAFIR does not take into account these effects.

Each type of floor structure was analyzed for two different types of ceiling: lime cement mortar 2cm or gypsum plasterboard 2cm, and for two different positions of the fire action, at the top and at the bottom side of the floor:

Case 1: TFS with ceiling made of lime cement mortar, fire at the top side

Case 2: TFS with ceiling made of gypsum plasterboard, fire at the bottom side

Case 3: TFS with ceiling made of lime cement mortar, fire at the bottom side

Case 4: TCCFS with ceiling made of gypsum plasterboard, fire at the bottom side

Case 5: TCCFS with ceiling made of lime cement mortar, fire at the bottom side

Case 6: TCCFS with ceiling made of lime cement mortar, fire at the top side.

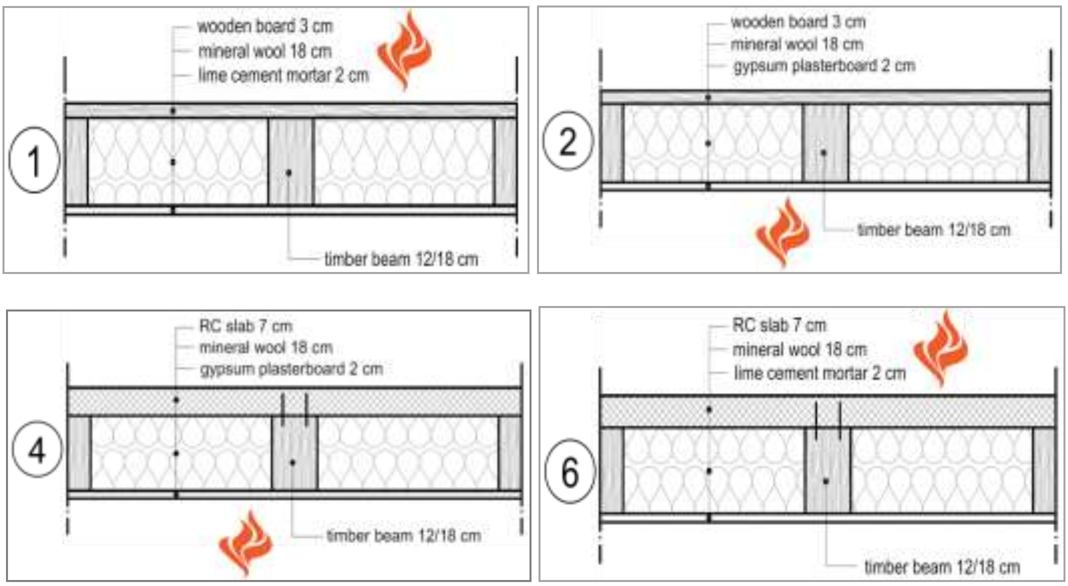


Figure 14 - The cross sections and the dimensions of the two different types of simply supported floor structures with specified position of the fire action

Table 5 - Material properties of composite materials at room temperatures

Material properties		Concrete	Wood	Gypsum	mortar	Miner. wool
specific mass	kg/m^3	2400	450	900	1850	150
water percentage	%	8	4	4	8	2
convection coeff. on hot side	W/m^{2}K	25	25	25	25	25
convection coeff. on cold side	W/m^{2}K	9	9	9	9	9
relative emissivity	-	0,8	0,8	0,85	0,8	0,85
specific Heat	J/kgK	900*	1530*	1090	400	150
thermal conductivity	W/mK	1,6*	0,12*	0,21	0,87	0,035

* The values for the specific heat and the thermal conductivity of concrete and wood are temperature dependent and only the initial values are given (T=20°C). Reductions of the values at higher temperatures are as it is recommended in EN 1992-1-2 and EN 1995-1-2.

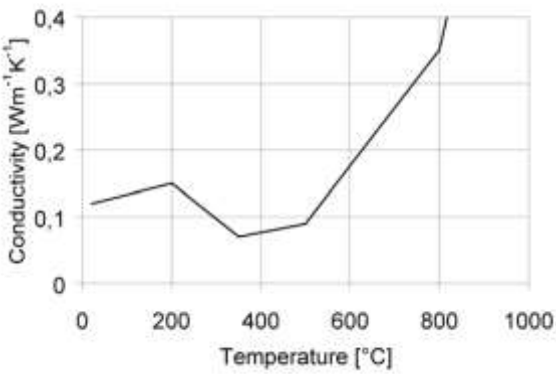


Figure 15- Temperature-thermal conductivity relationship for wood and the char layer, according to EN 1995-1-2

Numerically achieved results for the temperature distribution in the cross section of timber-concrete composite floor structure with gypsum plasterboard ceiling, for different position of the fire, are presented on Figure 16.

The analysis presented in this paper show that from all six cases, the timber-concrete composite floor structure with ceiling made of gypsum plasterboard and exposed to fire from the bottom side has the best performance (Figure 17). The gypsum plasterboard ceiling and the rock wool infill have an insulating function and provide lower temperatures in the cross section of the floor assembly (Figure 16a). When the fire is from the top side of the thin concrete slab (d=7cm), in short time period the temperature penetrates dipper into the concrete slab (Figure 16b), the slab loses the bearing capacity and becomes a dead load for the timber girder, therefore the whole structure collapses. When the load coefficient q_{fi}/q_u is increased, the fire resistance is decreased, but not proportionally to the value of the load coefficient, and this effect is mostly stressed in Case 5.

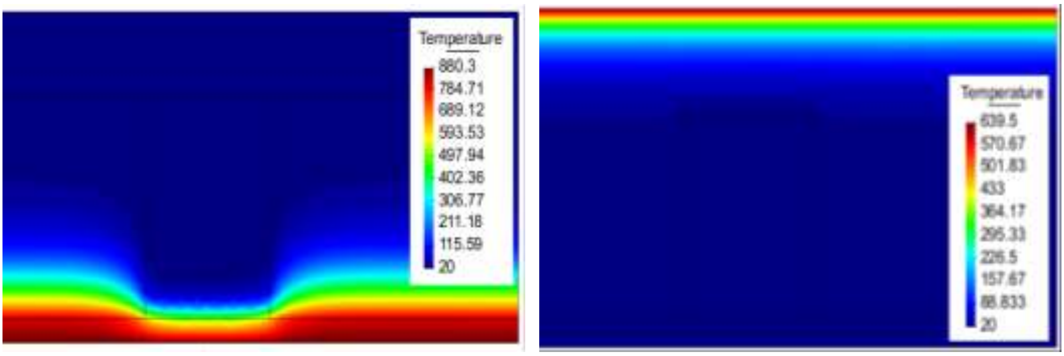


Figure 16 - Temperature distribution in the cross section of timber-concrete composite floor structure with gypsum plasterboard ceiling, at the moment of failure (when q_{fi}/q_u= 0.8)
a) case 4-fire from the bottom side, t=2410 sec.; b) case 6-fire from the top side, t=1080 sec.

The timber floor structure (Case 1, 2 and 3) has much lower fire resistance that the timber-concrete composite floor structure. It is more expressed when the load coefficient q_{fi}/q_u has expected values (less than 0.5). When fire is from the top side the char layer protects the timber girder from burning (low value of the thermal conductivity, Figure 15) and the girder keeps his original dimensions for a longer period than in case when the fire is from the bottom side.

For expected values of the load coefficient (q_{fi}/q_u less than 0.5) and for the same fire scenario, the fire resistance of the timber concrete composite floor structure is almost twice higher than the fire resistance of the timber floor structure.

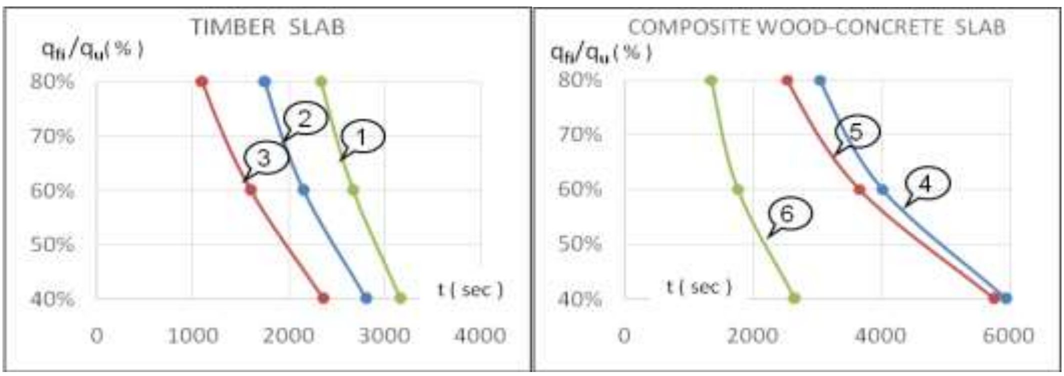


Figure 17 - The effect of the intensity of the permanent action and the position of the ISO 834 standard fire on the fire resistance of the two types of simply supported floor structures

6. CONCLUSIONS

The acceptable fire performance of unprotected timber elements should be attributed to the charring effect of the wood. The char layer acts as an insulator and protects the core of the wood section. For the required duration of fire exposure, unprotected beams and columns may withstand the design loads only if proper dimensions of the cross-section are used.

Fire exposed beams protected with gypsum fireboards at the bottom show improved fire resistance, but best results are achieved when the protection material from bottom side is rock wool. The improved fire resistance and the reduced deflections of the fire protected beams should be attributed to the positive effect of the insulation materials on the temperature distribution in the cross-sections of the beams.

In practice, if there are no architectural requirements for visibility of timber elements, floor and roof structures are constructed as in Case study 3 and the rock wool is used only for satisfying the energy efficiency requirements. The results obtained in this study show that a layer of rock wool from the bottom side of the structure (not only as an infill) will significantly improve the fire resistance of the whole structure.

The timber-concrete composite floor structures have higher fire resistance than timber floor structures. In case of timber-concrete composite floor structures better fire scenario is fire from the bottom side of the structure. In case of timber floor structure better fire scenari is fire from the top side.

In case of timber columns, the following conclusions can be made:

- By increasing the timber column cross section dimensions, the fire resistance is proportionally increased;
- Fire resistance of timber column increases when the column is protected by some type of thermal isolation;
- In case the timber column is protected by two layers of gypsum plasterboard, the fire resistance increases twice.

The general conclusion is that a fire safety plan with all fire safety measures has to be prepared for the timber structures and careful planning and detailing of the structural elements to be conducted.

7. REFERENCES

[1] Committee of European Normalisation (CEN), EN-1991-1-2-2002, Eurocode 1: Actions on Structures, Part 1-2: General actions - Actions on Structures Exposed to Fire. CEN, Brussels, (1991-2002).

[2] Canadian wood council, Fire Safety in Residential Buildings, Building Performance No. 2

[3] Tabaddor M., Modelling The Thermal and Structural Behaviour of Wood Beams in a Fire Environment, Underwriters Laboratories Inc, (2013)

[4] Schaffer, E. L. Structural fire design: Wood, Forest Products Laboratory, Madison, (1984).

[5] Keerthan P., Mahendran M., Numerical studies of gypsum plasterboard panels under standard fire conditions. Fire Safety Journal, 53(Oct) (2012), pp. 105-119.

[6] https://www.usg.com, Accessed: 2016-09-15

[7] Franssen J.-M, SAFIR: A Thermal/Structural Program Modelling Structures under Fire, Engineering Journal, A.I.S.C., Vol. 42 No. 3 (2005), pp. 143-158.

[8] Committee of European Normalisation (CEN), CSN EN 338 Structural timber - Strength classes, CEN, (2009).

[9] Committee of European Normalisation (CEN), EN 1995-1-2 (2004): Eurocode 5: Design of timber structures - Part 1-2: General - Structural fire design, CEN, Brussels, (2004).

TEST FOR THE PARTICIPANTS

According to the lectures on **Fire safety of timber structures**, anwer the following questions:

1. Main disadvantage of timber is:

   ____

2. Factors that influence the burning speed of wood.

   ____

3. Why the char layer slows down the burning of wood?

   ____

4. According to EC5, part 1-2, list the methods for calculating the fire resistance of timber elements.

   ____

   ____

5. Parameters that influence the fire resistance of timber elements are:

   ____

   ____

6. How the fire resistance of timber elements may be improved?

   ____

   ____

7. Why the gypsum plasterboard may be used for protection of timber elements?

   ____

   ____

8. Why the rock wool may be used for protection of timber elements?

   ____

   ____

Novi Sad, 24.4.2019

Prof. Dr Meri Cvetkovska