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CONTRIBUTION TO THE FIRE RESISTANCE OF WALL/FLOOR ASSEMBLIES WITH GYPSUM PLASTERBOARD

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ABSTRACT

The paper is focused on investigating the fire resistance of wall/floor assemblies with gypsum plasterboard and on the behaviour of timber studs in a wall assembly where timber laths are used for fixing panels. Claddings of gypsum plasterboard and gypsum fibre board are presented in the paper. One full scale fire test of a wall assembly was carried out. Calculation methods for the determination of the starting time of charring of timber stud and the failure starting time are presented. These calculation results are compared with test results and a numerical model. There are a lot of producers of gypsum plasterboards; it is very difficult to prepare a calculation method for each. The calculations of fire resistance according to EN 1995-1-2 2004 are on the safe side.

KEYWORDS: Wall assembly, charring rate, charring depth, gypsum plasterboard, gypsum fibreboard.

INTRODUCTION

Timber wall or floor assemblies are formed by solid timber studs with the axial distance of ca 625 mm and cavities which may be filled, partially or completely, with insulation or may include voids, Fig. 1. The cladding is most often made of gypsum plasterboard, gypsum fibre board, fibre board or particle board. The fire resistance of the whole assembly is most affected by the cladding. In most cases, wall or floor assemblies have cavities filled with insulation. This insulation contributes to the fire resistance, too, as timber studs char only from one side (Buchannan 2000). In Fig. 2, there is a comparison of wall assemblies exposed to fire with insulation (left) and with voids (right) and charring of timber studs.

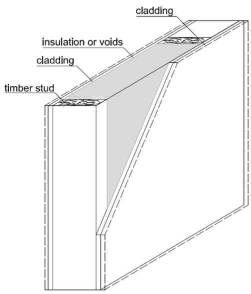


Fig. 1: A timber wall or floor assembly.

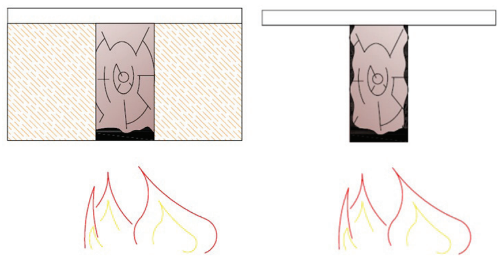


Fig. 2: Charring of studs in a load-bearing wall assembly.

For elements which are protected by the fire shell, the beginning of charring moved until the time tch. The charring of a timber element can occur before the deformation of the fire protection tf, but at a lower charring rate than for the same unprotected element. In Fig. 3, there is an example of the charring depth of an unprotected and protected element where tch is the starting time of charring of protected members and tf is the failure time of the protection.

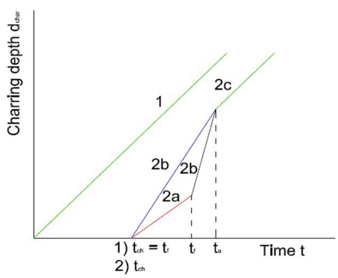


Fig. 3: The evolution of charring depth with time, Curve 1 – unprotected member, Curve 2 – protected member.

Calculation methods

EN 1995-1-2 2004 solves the calculation of the fire resistance of a wall/floor assembly in a simplified way only for certain cladding materials and for the fire resistance of up to 60 minutes. It can be designed as a solution of the fire resistance of the components of a light wall/floor frame and their dependence on various materials to affect the contribution of boards to increasing the fire resistance of the timber structural elements and components. Tab. 1 presents calculation methods to determine the charring starting time t_{ch} and the failure time t_f according to EN 1995-1-2 2004.

Tab. 1: Determination of t_{ch}, t_f according to EN 1995-1-2 2004.

Claddings	t_{ch}	t_f
one layer of gypsum plasterboard of type A, F or H according to EN 520 2009 -place with joints with unfilled gaps with a width of more than 2 mm	$2.8\ h_p - 14$ $2.8\ h_p - 23$	t_{ch}; or with respect to pull-out failure of fasteners: $t_f = t_{ch} + \frac{l_f - l_{a,\min} - h_p}{k_s \cdot k_2 \cdot k_n \cdot k_j \cdot \beta_0}$

where: h_p - the thickness of the panel, in mm. (For claddings consisting of two layers of gypsum plasterboard of type A or H h_p - the thickness of the outer layer and 50 % of the thickness of the inner layer. For claddings consisting of two layers of gypsum plasterboard of type F, h_p - taken as the thickness of the outer layer and 80 % of the thickness of the inner layer.)

It is possible to determine the load-bearing function by a calculation method based on the component additive method (CAM) given in Eurocode 5 (Part 1-2) 2004. The fire resistance, especially the protection time $t_{prot,I}$ (Tab. 2), is, therefore, considered as the sum of the contributions of different layers. This method is applicable and offers more precise solutions for a greater variety of materials (Östman et al. 2010).

$$t_{prot,i} = (t_{prot,0,i} \bullet k_{pos,exp,i} \bullet k_{pos,unexp,i} + \Delta t_i) \bullet k_{j,i} \quad (1)$$

where: $t_{prot,0,i}$ - basic protection value of layer i (the order of layers from the fire exposed side) (min),

$k_{pos,exp,I}$, $k_{pos,unexp,i}$ - position coefficient that takes into account the influence of layers preceding the layer considered,

Δt_i - correction time for layers protected by Type F gypsum plasterboards as well as gypsum fibreboards (min),

$k_{j,i}$ - joint coefficient.

Tab. 2: Determination of tprot,0,i, kpos,exp,i, kpos,unexp,i, Δti, kj,I for gypsum plasterboard and gypsum fibre board according to CAM.

$t_{prot,0,i}$	$k_{pos,exp,i}$	$k_{pos,unexp,i}$	Δt_i	$k_{j,i}$
$30 \cdot \left(\frac{h_i}{15}\right)^{1.4}$	$1 - 0.6 \cdot \frac{\sum t_{prot.i-1}}{t_{pro.0,i}}$ for $\sum t_{prot.i-1} \leq \frac{t_{prot.0,i}}{2}$ $0.5 \cdot \frac{t_{prot.0,i}}{\sum t_{prot.i-1}}$ for $\sum t_{prot.i-1} > \frac{t_{prot.0,i}}{2}$	1.0 1) $0.5 \cdot h_i^{0,15}$ 2)	**Floor assemblies** $0.06 \cdot t_{prot.i-1} + 1.1 \cdot t_{prot.0,i} - 5.0$ for $t_{prot.0,i} < 8$ min $0.1 \cdot t_{prot.i-1} - 0.035 \cdot t_{prot.0,i} + 1.2$ for $t_{prot.0,i} \geq 8$ min **Wall assemblies** $0.03 \cdot t_{prot.i-1} + 0.9 \cdot t_{prot.0,i} - 2.3$ for $t_{prot.0,i} < 12$ min $0.22 \cdot t_{prot.i-1} - 0.1 \cdot t_{prot.0,i} + 4.7$ for $t_{prot.0,I} \geq 12$ min	Joints with a width of less than 2 mm or more than 2 mm with filled gaps: 0.8 3) 1.0 4) No joint: 1.0

1) For layers backed by claddings made of gypsum or timber.

2) For layers backed by insulation.

3) Layer backed by a void cavity.

4) Layer backed by battens or panels or structural members or insulation.

The most accurate way of determining the load-bearing function, especially the charring starting time of timber elements tch and the failure time of the protection tf is by fire tests. In Tab. 3, 4, there are some simple calculation methods designed by Östman et al. (2010) and Just et al. (2010).

Tab. 3: Determination of tch for gypsum plasterboard on the basis of results of fire tests.

Claddings	Wall assemblies		Floor assemblies	
Type A, F, one layer	$1.5 \cdot h_p - 7$ or $1.8 \cdot h_p - 7$	9 mm $\leq h_p \leq$ 18 mm	$1.5 \cdot h_p - 7$ or $1.8 \cdot h_p - 7$	9 mm $\leq h_p \leq$ 18 mm
	25.5	$h_p >$ 18 mm	25.5	$h_p >$ 18 mm
Type F, two layers Type F + Type A two layers	min ($2.1 \cdot h_{p,tot} - 7$; $1.6 \cdot h_p + 13$)	25 mm $\leq h_{p,tot} \leq$ 31 mm 9 mm $\leq h_p \leq$ 18 mm	min ($2.1 \cdot h_{p,tot} - 7$; $4.5 \cdot h_p - 14$)	25 mm $\leq h_{p,tot} \leq$ 31 mm 9 mm $\leq h_p \leq$ 18 mm
Type A, two layer	min ($2.1 \cdot h_{p,tot} - 7$; $1.6 \cdot h_p + 13$)	18 mm $\leq h_{p,tot} \leq$ 31 mm 9 mm $\leq h_p \leq$ 18 mm	min ($2.1 \cdot h_{p,tot} - 7$; $1.6 \cdot h_p + 11$)	18 mm $\leq h_{p,tot} \leq$ 31 mm 9 mm $\leq h_p \leq$ 18 mm

where: h_p - the thickness of the outer board and $h_{p,tot}$ - the total board thickness.

Tab. 4: Determination of tf for gypsum plasterboard on the basis of results of fire tests.

Claddings	Wall assemblies		Floor assemblies	
Type F, one layer	$4.5 \cdot h_p - 24$	9 mm $\leq h_p \leq$ 18 mm	$h_p + 10$	12.5 mm $\leq h_p \leq$ 16 mm
	57	$h_p >$ 18 mm	26	$h_p >$ 16 mm
Type F, two layers	$4.5 \cdot h_{p,tot} - 40$	25 mm $\leq h_{p,tot} \leq$ 31 mm	2hp,tot-3	25 mm $\leq h_{p,tot} \leq$ 31 mm
	100 (84)	$h_{p,tot} >$ 31 mm	59	$h_{p,tot} >$ 31 mm
Type F (outer) + Type A (inner)	81	$h_p \geq$ 15 mm (thickness of 1st layer) $h_{p,tot} \geq$ 27 mm	50	$h_p \geq$ 15 mm (thickness of 1st layer)
Type A, one layer	$1.9 \cdot h_p - 7$	9 mm $\leq h_p \leq$ 15 mm	$1{,}8 h_p - 7$	12.5 mm $\leq h_p \leq$ 15 mm
	21.5	$h_p >$ 15 mm	20	$h_p >$ 15 mm
Type A, two layers	$2.1 \cdot h_{p,tot} - 14$	25 mm $\leq h_{p,tot} \leq$ 30 mm	No data available	
	49	$h_{p,tot} >$ 30 mm		
Type A, three layers	55	$h_{p,tot} \geq$ 37.5 mm		
GF, one layer	$2.4 \cdot h_p - 4$	10 mm $\leq h_p \leq$ 12.5 mm		

where: h_p - the thickness of the outer board and $h_{p,tot}$- the total board thickness

Heat transfer

Heat transfer by the construction is calculated using the heat-dependent coefficients according to EN 1991-1-2 2002. Thermal actions are defined by the net heat flux h_{net} (W.m^{-2}) to the surface of the member. On fire exposed surfaces the net heat flux h_{net} should be determined by considering the heat transfer by convection and radiation.

Theory of heat transfer – non-stationary heat conduction

The calculation of temperature fields is based on the Fourier´s partial differential equation of non-stationary heat conduction, which can be expressed in the differential form:

For one-dimensional heat conduction:

$$\frac{\Delta T}{\Delta t} = a \frac{\Delta^2 T}{\Delta x^2} \tag{2}$$

For two-dimensional heat conduction:

$$\frac{\Delta T}{\Delta t} = a\left(\frac{\Delta^2 T}{\Delta x^2} + \frac{\Delta^2 T}{\Delta y^2}\right) \qquad (3)$$

where: ΔT - increase in temperature (°C),
Δt - increase in time (s),
Δx - thickness of the layer in the direction of the x axis (m),
Δy - thickness of the layer in the direction of the y axis (m),
a- coefficient of thermal conductivity ($m^2 . s^{-1}$).

The coefficient of thermal conductivity a can be expressed as:

$$a = \frac{\lambda}{c\rho} \qquad (4)$$

where: λ - thermal conductivity ($W . m^{-1}K^{-1}$),
c - specific heat ($J. kg^{-1}K^{-1}$),
ρ - density ($kg . m^{-3}$).

It is necessary to have a good understanding of the values which characterize the heat transfer and the thermal parameters of insulating materials and materials filling the timber frame for a correct numerical solution. These are ρ, λ, c. These parameters are variable with temperature; hence there is the need to know their values depending on the temperature (Karpaš 1984).

MATERIAL AND METHODS

Fire test of a wall assembly

The fire test of a load-bearing wall assembly was carried out in the fire test laboratory according to the EN 1365-1 2012 European standard for 65 minutes' fire exposure. The wall dimensions were 3.0 (depth) x 3.0 (height) x 0.190 (thickness) m. The dimensions of timber studs were 60/120 mm. The cladding was made with gypsum plasterboard (Rigistabil DFRIEH2) stiffened by glass fibres from both sides, with a thickness of 15 mm. The gaps between the timbers studs were completely filled by rock wool (Woodsil). In Fig. 4, the composition of the test specimen and the placement of the thermocouples can be seen.

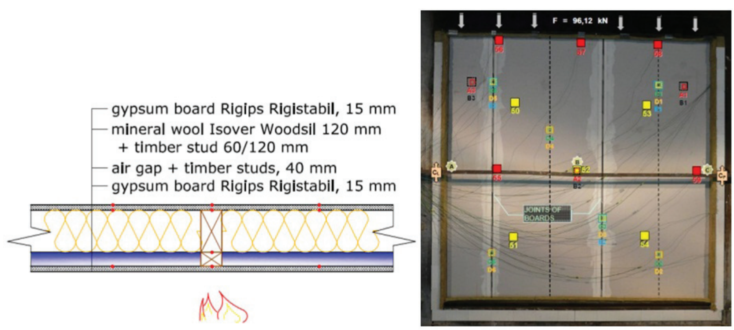


Fig. 4: The composition of the test specimen and the placement of thermocouples (left), as seen from the unheated side of the wall (right).

A1 ÷ A3: *Thermocouples under the 1st layer of gypsum plasterboard on the heated side,*
B1 ÷ B3: *Thermocouples under the 1st layer of gypsum plasterboard on the unheated side,*
C1 ÷ C6: *Thermocouples under the 1st layer of gypsum plasterboard on the heated side on timber studs,*
D1 ÷ D6: *Thermocouples between load-bearing timber studs (60/160 mm) and timber studs (40/60 mm);*
E1 ÷ E3: *Thermocouples under the 1st layer of gypsum plasterboard on the unheated side on timber studs.*

After the fire test: The gypsum plasterboard did not fail and remained in the same place throughout the fire test (Fig. 5). Fig. 5 (left) shows the furnace in the 65th minutes there is a joint of boards and rising flames from timber laths. Timber laths totally charred throughout the fire test at places where they were anchored to the timber studs and carried out the insulation function (the timber studs were not directly exposed to the fire).

Fig. 5: The furnace in 65th minute (left) and the wall assembly after the fire test (right).

Calculation of tch, tf, dchar,n according to EN 1995-1-2 2004

It is assumed that the charring of timber studs started at the same time as the start of the charring of timber laths. The charring of timber laths is very rapid due to the charring start from three sides (gap voids). Timber laths are not included in this calculation.

The charring starting time t_{ch} of the timber member (Tab. 1):

t_{ch} = 2.8 • h_p = 2.8 • 15 - 14 = 28 min

The failure time of the cladding with respect to the pull-out failure of screws is calculated as (Tab. 1):

$$t_f = t_{ch} + \frac{l_f - l_{a,\min} - h_p}{k_s \cdot k_2 \cdot k_n \cdot k_j \cdot \beta_0} = 28 + \frac{50 - 10 - 15}{1.1 \cdot 0.94 \cdot 1.5 \cdot 1.0 \cdot 0.65} = 52.8 \,\text{min}$$

where: k_s = 1.1 (-)- the cross-section factor; k_2 is the insulation factor,
k_n = 1.5 (-) - a factor for converting the irregular residual cross-section into a notional rectangular cross-section,
β_0= 0.65 (mm.min^{-1}) - the one-dimensional design charring rate.
k_2 = 1.05 – 0.0073•hp = 1.05 – 0.0073 • 15 = 0.9405

For the calculation of the charring rate of a timber stud (60/120 mm), charring from only one side is assumed (cavities are completely filled by mineral wool).

$$\beta_n = k_s \cdot k_2 \cdot k_n \cdot \beta_0 \quad \text{for} \quad t_{ch} \le t \le t_f \tag{5}$$

$$\beta_n = k_s \cdot k_3 \cdot k_n \cdot \beta_0 \quad \text{for} \quad t \ge t_f \tag{6}$$

where: $k_3 = 0.036 \cdot t_f + 1 = 0.036 \cdot 52.8 + 1 = 2.9$ *(-)* - the post-protection factor.

The charring depth obtained by calculation in the 65th minute (the irregular cross-section is replaced by an equivalent rectangular cross-section) – strength and stiffness properties using the reduced properties method (EN 1995-1-2 2004) is:

$$d_{char,0} = (t_f - t_{ch}) \cdot k_2 \cdot k_s \cdot k_n \cdot \beta_0 + (t - t_f) \cdot k_3 \cdot k_s \cdot k_n \cdot \beta_0 = \text{ mm}$$

In the graph (Fig. 6), there is the dependence of the charring depth on time for a protected and unprotected member. It is assumed that when the charring depth of a protected member reached the charring depth of the same unprotected member, the charring rate decreased to the nominal charring rate.

The charring depth obtained by calculation in the 65th minute (the irregular cross-section is replaced by an equivalent rectangular cross-section) – strength and stiffness properties using the reduced cross-section method described by König (2009) is:

$d_{ef} = d_{char,n} + d_0$

$d_0 = 21.5 + 0.1 \cdot h = 21.5 + 0.1 \cdot 120 = 33.5\ mm$

$d_{ef} = 51.99 + 33.5 = 85.5\ mm$

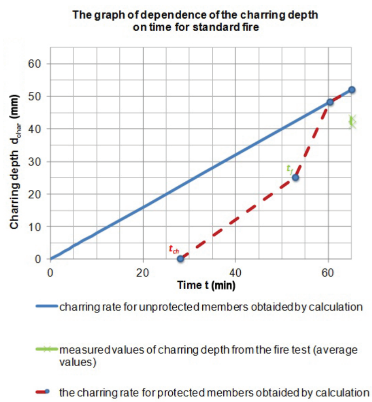


Fig. 6: The graph of the charring depth dependence on time, comparison between calculation and the fire test.

Calculation of tch, tf according to CAM

The protection time of type F gypsum plasterboard (Tab. 2):

$t_{prot.0.1} = 30 \cdot (h_1/15)^{1.2} = 30 \cdot (15/15)^{1.2} = 30\ min$

$k_{pos.exp.1} = 1.0$

$k_{pos.unexp.1} = 0.5 \cdot h_i^{0.21} = 0.5 \cdot 150.21 = 0.883$

$\Delta t_1 = 0$

$k_{j.1} = 0.8$

$t_{prot.1} = (t_{prot.0.1} \cdot k_{pos.exp.1} \cdot k_{pos.unexp.1} + \Delta t_1) \cdot k_{j.1} = (30 \cdot 1 \cdot 0.883 + 0) \cdot 0.8 = 21.19\ min$

The charring start of a timber stud:

$t_{ch} = t_{prot.1} = 21.19\ min$

Calculation of tch, tf according to fire tests

$t_{ch} = 1.8 \cdot h_p - 7 = 1.8 \cdot 15 - 7 = 20\ min$ (Östman et al. 2010)

$t_{ch} = 1.5 \cdot h_p - 7 = 1.5 \cdot 15 - 7 = 15.5\ min$ (Just 2010)

$t_{ch} = 30 \cdot (h_p / h_{p.ref})^{1.2} = 30 \cdot (15/15)^{1.2} = 30\ min$ (Frangi et al. 2008);

where: $h_{p.ref}$ - reference depth of gypsum plasterboard equaling 15 mm.
$t_f = 4.5 \cdot h_p - 24 = 4.5 \cdot 15 - 24 = 43.5\ min$

Numerical calculation

A part of a light timber wall assembly exposed to fire from one side was modelled. This model was performed using ANSYS Workbench, solved in thermal analysis (Transient thermal).

Material properties for wood at elevated temperatures were taken from the Eurocode 5 (EN 1995-1-2 2004), for gypsum board filled by glass fibre they were determined based on testing and based on available research results, and for gas they were taken from other authors (Hejduk 2009). Specific heat and thermal conductivity values are presented in Fig. 7. The result of this numerical calculation should provide the time when the temperature of the timber member reaches 300°C, this is the temperature at which timber begins to char. The thicknesses of each layer and the dimensions of timber studs were identical with the fire test. The failure of timber laths is not included in this model. Such results give better values, including only heat transfer.

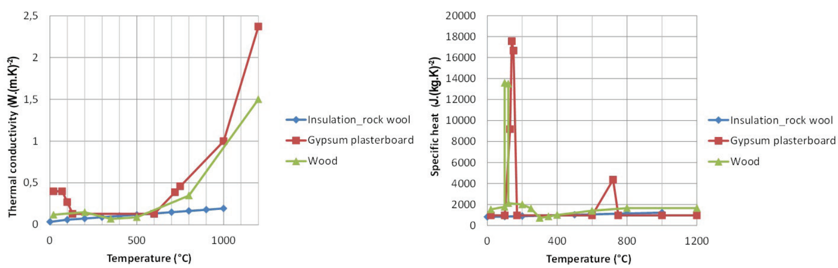


Fig. 7: Thermal conductivity and specific heat for gypsum plasterboard, timber and gas.

The thermal load of the wall assembly was modelled by a fire for 65 minutes using the standard temperature-time curve. In Fig. 8, the heat transfer in the 30th and 65th minute can be seen. The comparison of the numerical model and the fire test results are in the next graphs (Fig. 9).

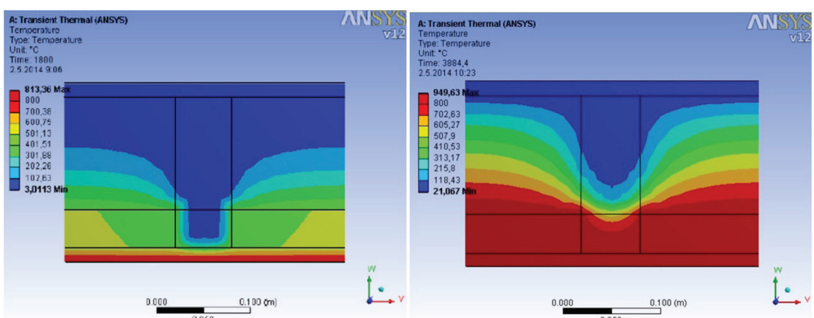


Fig. 8: The heat transfer in 30th (left) and 60th (right) minute.

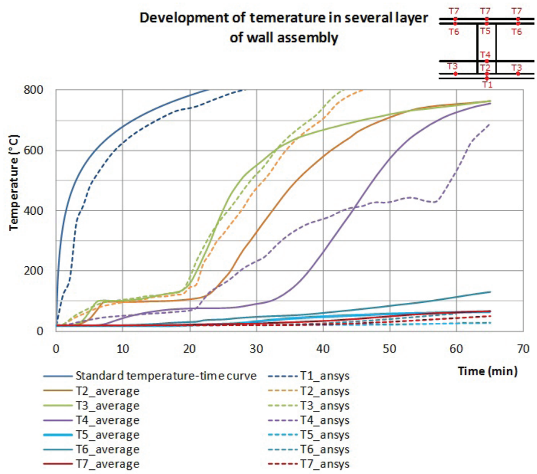
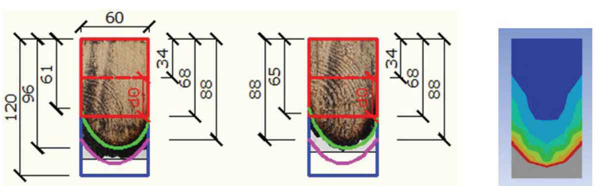


Fig. 9: The comparison of the numerical model with the fire test results.

In Fig. 10, there are pictures of timber studs cut up after the fire test. It shows the comparison between the calculation (red line), the numerical model (pink line) and the real (green line) charring depth. It is obvious that the numerical model cannot include the damage or disappearance of timber laths. In the calculation according to EN 1995-1-2 2004, timber laths are not included, the results are more conservative, red dashed line represents the reduced cross-section method according to König (2009).



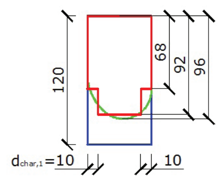


Fig. 10: Timber studs after the fire test: the calculated charring depth is drawn by a red line (dashed line – reduced cross-section method (König 2009), solid line - calculation according to EN 1995-1-2 2004), real charring depth is highlighted by a green line, the blue line outlines the original stud profile, the pink line is the profile with a temperature of 300°C from the numerical model.

Fig. 11: The comparison of charring depths of the fire test result and rectangular models.

In the case that the timber laths do not fall off before their total charring, a new method applying a rectangular model can be used (Fig. 11). All the time during the fire test (from t_{ch}), the load bearing timber studs charred normally (according to the charring rate in Fig. 6 – red line) in the corner, $d_{char.1}$ (Fig. 11) is determined according to fire test. The timber laths charred after 30 minutes. For the next 35 minutes, the timber studs charredat the notional charring rate (β_n).

RESULTS AND DISCUSSION

On the basis of the calculation, Tab.5 was compiled. It records:

- charring starting time of protected members (t_{ch}) – charring start of timber laths;
- failure time of the protection (t_f);
- charring rate under standard fire exposure (β_n);
- charring depth (d_{char}).

Tab. 5: The comparison of measured and calculated values (tch, tf, β_n, dchar).

	t_{ch} (min)	t_f (min)	β_n (mm.min^{-2})	$d_{char,n}$ (mm)
EN 1995-1-2 2004	28	52.8	1st phrase: 1.009 2nd phrase: 3.11 3rd phrase: 0.8	51.99*
Calculation according to CAM	21.19			
Fire tests (Östman et al. 2010; Just et al. 2010)	20 15.5 30	43.5		
Numerical model	24.1	-	1.114	**
Fire test	29	not reached	1.277	average: 43
Rectangular models	28 – at the edges 38 – at the centre	-	1st phrase: 1.009 2nd phrase: 3.11 3rd phrase: 0.8	Fig. 11

* Timber laths (40/60 mm) are not included to the calculation, they were exposed to fire for 65 minutes.

** Damaged or falling off non-load bearing timber laths (40/60 mm) were not included.

The wall/floor assemblies have voids between insulating and claddings in many cases. These voids serve for example for electrical installation. For fixing claddings are used timber non load-bearing laths. The laths contribute to the fire resistant whole construction as well. According to Eurocode 5 (part 1-2) 2004 the laths charred after 30 minutes. Charring of load-bearing timber stud performs differently on edges (fire exposure after reached time t_{ch}) and on the centre (fire exposure after the laths charred). It is necessary to including different charring of timber stud to the calculation. The depth $d_{char,1}$ 10 mm (Fig. 11) was determined according to fire test.

CONCLUSIONS

The behaviour of gypsum plasterboard under fire is influenced by its composition. The special type of gypsum plasterboard studied in this paper was strengthened by glass fibres. The charring starting time of timber studs is very accurately determined according to EN 1995-1-2 2004. A problem arises in determining the charring depth and the charring rate in individual phases. This paper presents some calculation methods for determining the charring depth. It could be better to use new rectangular methods for timber studs which are protected by timber laths (these laths carry the boards and the void gap serves for the distribution system).Increasing charring goes on in the corner while the centre of the studs chars normally. The main parameters for determining the load-bearing function of a wall/floor assembly (t_{ch}, t_f, β_n, d_{char}) were determined.

The behaviour of wood under fire is a very predictable phenomenon. Using simplified computational methods we can determine the separating and the load-bearing function of structures. In many cases, according to Eurocode 5 (part 1-2) 2004, it is very difficult or nearly impossible to determine the charring starting time of timber elements under the fire protection and the failure time of the cladding. Section 5 of the current version of Eurocode 5 (par 1-2) 2004 may be extensively improved by adding design rules based on the reduced cross-section method for wall and floor assemblies. To this end, it is necessary to perform fire tests and develop more precise computational methods.

ACKNOWLEDGMENT

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REFERENCES

1. Buchanan, A.H., 2000: Fire performance of timber construction. Progress in Structural Engineering and Materials 2(3): 278-289.
2. EN 1992-1-2, 2007: Eurocode 2: Design of concrete structures – Part 1-2: General rules – Structural fire design.
3. EN 1995-1-1, 2005: Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings.
4. EN 1995-1-2, 2005: Eurocode 5: Design of timber structures – Part 1-2: General – Structural fire design.
5. EN 1365-1, 2012: Fire resistence tests for load bering elements - Part 1: Walls.
6. Frangi, A., Schleifer, V., Fontana, M., Hugi, E., 2008: Fire performance of gypsum plaster boards, structures in fire. Proceedings of the fifth International Conference Structures in Fire : SiF 2008, Nanyang Technological University, Singapore, 28-30 May, 2008. Pp 619-631, ISBN: 978-981-08-0767-2.
7. Hejduk, P., 2009: Fire resistance of light timber-framed walls. Thesis, CTU in Prague. (Požární odolnost stěn lehkých dřevěných skeletů.) Thesis, ČVUT v Praze. (in Czech).
8. Just, A., Schmid, J., König, J., 2010: Failure times of gypsum boards, structures in fire. Pp 593-601, ISBN: 978-1-60595-027-3.
9. Just, A., 2010: Post protection behaviour of wooden wall and floor construction completely filled with glass wool. SP Report : 28, Stockholm.
10. Karpaš, J., 1984: Technical guideline for calculation of fire resistance of steel construction, Building Research Institute, Prague. (Směrnice pro výpočet požární odolnosti ocelových konstrukcí. Výzkumný ústav pozemních staveb), Praha. (in Czech)
11. König, J., 2009: The educed cross-section method for light timber frame members. SP Report: 46, Stockholm.
12. Östman, B., Mikkola, E., Stein, R., Frangi, A., König, J., Dhima, D., Hakkarainen, T., Bregulla, J., 2010: Fire safety in timber buildings. Technical guideline for Europe, 210 pp., SP Technical Research Institute of Sweden, SP Report: 19, ISBN 978-91-86319-60-1.

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