Protection of timber structures – start time of charring and failure time

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External wall with CLT load-bearing core

- Cross-laminated timber (CLT / Xlam)
- Mineral / clay / gypsum board inner lining
- Services void
- Vapour control / airtightness membrane
- Flexible wood fibre insulation between I-joists
- Insulating wood fibre sheathing
- Drained and ventilated cavity
- Horizontal weatherboarding fixed to battens

Fire protection system

Photo source: GreenSpec UK
Charring of initially protected timber structures
Charring of CLT: Adhesive behaviour

Heat-resistant adhesive

Charring depth $d_{char}$ [mm]

<table>
<thead>
<tr>
<th>1st lamella</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd lamella</td>
<td>60</td>
</tr>
<tr>
<td>3rd lamella</td>
<td>90</td>
</tr>
</tbody>
</table>

Time $t$ [min]

Unprotected
Charring of CLT: Adhesive behaviour

Heat-resistant adhesive

Non-heat-resistant adhesive

Charring depth $d_{\text{char}}$ [mm] vs. Time $t$ [min]

- 1st lamella
- 2nd lamella
- 3rd lamella

Unprotected

$\beta_0$
Charring of CLT: Adhesive behaviour

Heat-resistant adhesive

Non-heat-resistant adhesive
Non-heat-resistant adhesive
Falling off of charred lamellas

1:05

1:50
Charring of CLT: Adhesive behaviour

Heat-resistant adhesive

Non-heat-resistant adhesive

Charring depth $d_{\text{char}}$ [mm]

Time $t$ [min]

- 1st lamella
- 2nd lamella
- 3rd lamella

Unprotected

$\beta_0$

$\kappa_3 \beta_0$

$\beta_0$
Charring of CLT: Adhesive behaviour

Heat-resistant adhesive

- 1st lamella
- 2nd lamella
- 3rd lamella

Non-heat-resistant adhesive

- 1st lamella
- 2nd lamella
- 3rd lamella

$\beta_0$, $k_0$, $k_0$, $\beta_0$
Charring of CLT:
Charring phases

Heat-resistant adhesive

Non-heat-resistant adhesive

- Encapsulation phase
- 3rd lamella
- 2nd lamella
- 1st lamella

\[ t_{ch} \text{ Time } t [\text{min}] \]

- Unprotected
- GtF 15, \( t_f = 60 \text{ min} \)
Charring of CLT: Charring phases

Heat-resistant adhesive

Non-heat-resistant adhesive
Charring of CLT:
Charring phases

Heat-resistant adhesive

Non-heat-resistant adhesive

Charring depth $d_{ch}$ [mm]

3rd lamella

2nd lamella

1st lamella

$\beta_0$

$k_2\beta_0$

Time $t$ [min]

$t_{ch}$

$t_f$

Unprotected

-GtF 15, $t_f = 60$ min
Charring of CLT: Charring phases

Heat-resistant adhesive

- 3rd lamella
- 2nd lamella
- 1st lamella

Charring depth $d_{char}$ [mm]

- Encapsulation phase
- Protection phase
- Post-protection phase

Time $t$ [min]

$\beta_0$, $k_0\beta_0$, $k_0\beta_0$

Non-heat-resistant adhesive

- 3rd lamella
- 2nd lamella
- 1st lamella

Charring depth $d_{char}$ [mm]

- Encapsulation phase
- Protection phase
- Post-protection phase

Time $t$ [min]

$\beta_0$, $k_0\beta_0$, $k_0\beta_0$

Unprotected - GtF 15, $t_f = 60$ min
Charring of CLT:
Initially protected

Heat-resistant adhesive

Non-heat-resistant adhesive

Encapsulation phase
Protection phase
Post-protection phase

3rd lamella
2nd lamella
1st lamella

Charring depth $d_{\text{char}}$ [mm]

$t_{ch}$ Time $t$ [min] $t_f$

$\beta_0$

$k_3\beta_0$

Unprotected - GtF 15, $t_f = 60$ min

$\beta_0$

$k_3\beta_0$

$\beta_0$

$k_3\beta_0$

Unprotected - GtF 15, $t_f = 60$ min
$t_{ch} < t < t_f$

$t > t_f$
Gypsum boards

- EN 520

Ca 15 min
Gypsum boards

- EN 520

Ca 15 min

Ca 40 min
Start time of charring behind protection \( t_{ch} \)

- Tested values for specific products
  - EN 13381-7

- K-classes (EN 13501-2, defined times only!)
Model scale test

Start time of charring ($t_{ch}$) and charring rate ($k_2$)
Start time of charring behind protection $t_{ch}$

- Tested values for specific products
  - EN 13381-7
Start time of charring behind protection $t_{ch}$

- Tested values for specific products
  - EN 13381-7

- K-classes (EN 13501-2, strict!)

- Generic values
  - EN 1995-1-2:2004

- EN 1995-1-2:2022 (coming soon)

- Sum of protection times
### Calculations

**Fire protection system**

- $T_{prot} = 270\,^\circ C$
- $T_{ch} = 300\,^\circ C$

**Initially protected CLT**

- $t_{prot} = \sum t_{prot,\,cladding}$

**Equation**

\[
t_{prot,i} = (t_{prot,0,i} \cdot k_{pos,\,exp,i} \cdot k_{pos,\,unexp,i} + \Delta t_i) \cdot k_{j,i}
\]

<table>
<thead>
<tr>
<th>No</th>
<th>Material</th>
<th>Protection time $t_{prot,i}$</th>
<th>Sum of protection times</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gypsum plaster-board type F (GtF)</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>Gypsum plaster-board type F (GtF)</td>
<td>11.3</td>
<td>41.3</td>
</tr>
<tr>
<td>3</td>
<td>Stone wool (SW)</td>
<td>28.7</td>
<td>69.9</td>
</tr>
<tr>
<td>4</td>
<td>CLT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Expression**

\[
t_{ch} = \min \left\{ \sum t_{prot} \right\}
\]
Start time of charring
Mineral wool vs wood substrate

\[ t_{\text{prot}} = t_{\text{prot,0}} \times k_{\text{pos,unexp}} \]

\[ k_{\text{pos,unexp}} = 1 \]

\[ k_{\text{pos,unexp}} < 1 \]
Failure of the cladding

Mechanical degradation

Pull-out of fasteners
Failure time of fire protection system

$ t_f $
Failure time of fire protection system $t_f$

- Tested values for specific products
  - **EN 13381-7:2019**
  - EN 1363, 1364, 1365 series

Controlled by TC-s
Visual observations
EN 13381-7:2019

Full scale test of a floor

Key
1. timber joist
2. decking
3. furnace
4. load
5. insulation fitting part
6. fire protection board
7. cavity insulation
8. outer joist (example: cut)
9. fire protection board (fitting part)
10. outer joist (example: half width)
11. spreader beam

a) Top elevation

b) End elevation

Key for diagram:
- 1: timber joist
- 2: decking
- 3: furnace
- 4: load
- 5: insulation fitting part
- 6: fire protection board
- 7: cavity insulation
- 8: outer joist (example: cut)
- 9: fire protection board (fitting part)
- 10: outer joist (example: half width)
- 11: spreader beam

Diagram notes:
- 8: inner wall
- 9: outer wall
- 10: support beam
- 11: spreader beam
Temperature and charring measurements

Centre distance of termocouples 300 mm

Failure time of protection

Key
1 charring specimen I
2 charring specimen II
3 charring specimen III
4 fire protection system including joints
C centre distance
h_p thickness of the fire protection system
h_D thickness of the Decking
A thermocouple group A: behind the fire protection system more than 200 mm away from any joint
B thermocouple group B: behind the fire protection system behind joints (for fire protection systems including joints)
C thermocouple group C: Centric between two loaded joists or studs
Temperature and charring measurements

The failure time:
- Maximum temperature at TC A and TC B; TC C deviates less than 50K from the mean furnace temperature
- Observations detect loss of stickability in total more than 0,25 m²

Key:
1. Charring specimen I
2. Charring specimen II
3. Charring specimen III

Failure time of protection
Failure time of fire protection system $t_f$

- Tested values for specific products
  - EN 13381-7:2019
  - EN 1363, 1364, 1365 series

- Generic values
  - COST FP1404 documents (2018)
  - EN 1995-1-2:2022 (coming soon)
Just et al. (2018)
Improved fire design models for Timber Frame Assemblies - Guidance document N 217-07

Ostman et al. (2010)

https://costfp1404.ethz.ch/publications.html
Failure times of gypsum plasterboards

Draft EN 1995-1-2:2022

Table 5.9 – Failure time of the fire protection system due to mechanical degradation

<table>
<thead>
<tr>
<th>Panel(s)</th>
<th>Walls</th>
<th>Floors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$t_f$ [min]</td>
<td>$h_p$ [mm]</td>
</tr>
<tr>
<td>Gypsum plasterboards Type F (EN 520), one layer</td>
<td>$4.9 \cdot h_p - 30$ (0.1)</td>
<td>$9 \leq h_p \leq 18$</td>
</tr>
<tr>
<td></td>
<td>58</td>
<td>$h_p &gt; 18$</td>
</tr>
<tr>
<td>Gypsum plasterboards Type F (EN 520), two layers</td>
<td>$1.6 \cdot h_p + 18$ (0.3)</td>
<td>$25 \leq h_p \leq 31$</td>
</tr>
<tr>
<td></td>
<td>68</td>
<td>$h_p &gt; 31$</td>
</tr>
<tr>
<td>Gypsum fibreboards (EN 15283-2)</td>
<td>Values to be included in the second draft if available.</td>
<td></td>
</tr>
</tbody>
</table>

where:

- $t_f$ is the failure time of the fire protection system due to mechanical degradation, in min;
- $h_p$ is the thickness of the fire protection system; in mm.

For gypsum plasterboards, Type A

$$t_f = t_{ch}$$
Analysis of the database

- Full scale fire test reports
- Held at RISE Research Institutes of Sweden
- 470 full scale test reports

K.Kraudok. Master thesis at TUT
COST documents
Effect of substrate

Gypsum plasterboards on insulation

Gypsum plasterboards on CLT structures
Effect of fastening on failure time

- Studs or beam spacing
- Spacing of fasteners
- Quality of mounting

Gypsum plasterboard, Type F 15 mm

120 min
Effect of fastening

Model scale tests
GtF 15 on CLT
Summary

• Different charring phases for initially protected structures depending on properties of protection system.
• Substrate and fastening can influence start time of charring and failure time significantly.
• Start time of charring and failure time can be determined by EN 13381-7
• Generic values on start time of charring calculated according to Separating Function Method
THANK YOU FOR YOUR ATTENTION!

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