FIRE TESTS REPORT n° EFR-20-002989.

Regarding: The characterization of medium exposure cribs

Sponsor: European Commission
Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
GROW C.1 – Circular Economy and Construction
BREY 10/213
Avenue d' Auderghem 45
B-1049 Brussels/Belgium
1. REFERENCES


2. SCOPE

The tests described in this document were part of the European project « Finalization of the European approach to assess the fire performance of facades ». This project aims to develop a method harmonized at European level to assess the fire performance of façade.

A series of tests were carried out in order to evaluate the different configurations of timber cribs according to their characteristics with two types of fire exposure, large and medium exposure.

This test report summarizes the tests carried out on the medium exposure.

The cribs have been installed into a combustion chamber so that the impact of such environment on the fire behaviour was taken into account. To assess the influence of the system on the facade, a portion of non-combustible facade was installed above the combustion chamber.

The test program investigated variations in the main parameters as planned is displayed in the table 1 below. The presented values were only expected target values.

<table>
<thead>
<tr>
<th>Test reference</th>
<th>Fire exposure</th>
<th>Wood species</th>
<th>Surface finish</th>
<th>Wood density [kg/m²]</th>
<th>Moisture content [%]</th>
<th>Stick section</th>
<th>Solid Plate (SP)/ Grating (G)</th>
<th>Chamber volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0*</td>
<td>Medium</td>
<td>Spruce</td>
<td>Sawn</td>
<td>Low</td>
<td>Average</td>
<td>47x47</td>
<td>G</td>
<td>Standard</td>
</tr>
<tr>
<td>M1</td>
<td>Medium</td>
<td>Spruce</td>
<td>Planed</td>
<td>High</td>
<td>Average</td>
<td>47x47</td>
<td>G</td>
<td>Standard</td>
</tr>
<tr>
<td>M2</td>
<td>Medium</td>
<td>Spruce</td>
<td>Planed</td>
<td>Low</td>
<td>Average</td>
<td>47x47</td>
<td>G</td>
<td>Standard</td>
</tr>
<tr>
<td>M3</td>
<td>Medium</td>
<td>Spruce</td>
<td>Sawn</td>
<td>Low</td>
<td>Average</td>
<td>47x47</td>
<td>G</td>
<td>Standard</td>
</tr>
</tbody>
</table>

*A supplementary test was carried out in order to check the test rig.

Table 1. Test program with nominal values.
3. MEDIUM FIRE EXPOSURE

The medium fire exposure scenario was a down-scaled flash-over scenario. This test scenario was represented with:

- A combustion chamber with free internal dimensions of 1000 mm in height, 1000 mm in width and 800 mm in depth. The combustion chamber presented a ventilation system.

- A crib whose nominal dimensions were (517 x 517) mm for the horizontal section and equivalent to a nominal mass of 33 kg in height. The crib was raised by 200 mm above the floor of the combustion chamber thanks to a metal platform.

- The interior of the chamber was covered with ceramic fibre insulation with a thickness of 25 mm and density of 128 kg/m3.

![Picture 1: Sketch of the cross section of the combustion chamber](image1.png)

![Picture 2: Sketch of the elevation view of the combustion chamber](image2.png)
## 4. TESTED PRODUCTS

### Date of arrival:
23 July 2020

<table>
<thead>
<tr>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>RISE Research Institutes Of Sweden</td>
</tr>
<tr>
<td>Brinellgatan 4, HUS 6 G</td>
</tr>
<tr>
<td>SE-504 62 BORÅS</td>
</tr>
<tr>
<td>Sweden</td>
</tr>
</tbody>
</table>

### General description of the product (nominal values)

- **Property**  
  - Stick section  
  - Stick length / number per layer  
  - Total mass of each crib  
  - Species  
  - Surface finish

<table>
<thead>
<tr>
<th>Property</th>
<th>Target value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stick section</td>
<td>(47 ± 2) mm square</td>
</tr>
<tr>
<td>Stick length / number per layer</td>
<td>(517 ± 10) mm / 6 sticks</td>
</tr>
<tr>
<td>Total mass of each crib</td>
<td>(33 ± 1.5) kg</td>
</tr>
<tr>
<td>Species</td>
<td>Spruce (Picea abies)</td>
</tr>
<tr>
<td>Surface finish</td>
<td>Planed and sawn</td>
</tr>
</tbody>
</table>

*The density values given are taken at a moisture content of 12%*

**Table 2: Crib dimensions**
5. INSTALLATION AND ASSEMBLY OF THE TEST SPECIMEN

5.1. ASSEMBLY OF THE TEST SPECIMEN

The cribs were assembled by the laboratory, according to the procedure described below. The wooden sticks were mechanically fixed to each other using pins to prevent the crib from collapsing.

5.1.1. Form of construction

The nominal crib was constructed with \((517 \pm 10) \, \text{mm} \times (47 \pm 2) \times (47 \pm 2) \, \text{mm}^3\) sticks of spruce with a low and high density and a moisture content of 9.5%. The sticks were placed equidistantly. The sticks were placed such that the first and last surface were in plane with the overall crib outer dimensions.

The crib was made of twelve layers for the low density and nine layers for the high density. Each layer was constituted of six sticks. The layers were build 90° to each other. It was possible to reduce the number of sticks of the top layer such that the total mass was 33 ± 1.5 kg.

In order to avoid the collapse of the crib, at each crossing of sticks between both layers, a nail was introduced to attach both sticks together: The third layer and the fourth layer were both fixed in the same way and in this way consecutively.

The result was six nailed layers for the low density and four nailed layers for the high density. The nailed layers have been superimposed to constitute the final crib.

5.1.2. Preparation of the crib

The crib was positioned on a platform made of steel sections, in such a way that the base of the crib was at \((200 \pm 5) \, \text{mm}\) above the floor of the combustion chamber.

The platform was made in solid steel sections with an opening at the top. It measured 500 mm x 500 mm for the horizontal section and 200 mm in total height. The top was covered with a grating made of steel cells of 35 mm x 40 mm and a height of 30 mm. The platform and the grating are represented in Picture 7.

**Installation of the crib in the combustion chamber**

Firstly, the platform and the grating were installed at the middle of the combustion chamber. The nailed layers were installed by superposition onto the platform.

The front side of the crib was located at \((100 \pm 10) \, \text{mm}\) behind the front side of the test rig. The distance between the crib and the side walls on both sides was the same, 250 mm. See Appendix 2.
5.2. Combustion Chamber

The combustion chamber walls and roof were built with non-combustible aerated concrete blocks and slabs with an apparent density of \((650 \pm 200) \text{ kg/m}^3\). The interior of the chamber was covered with non-combustible fibre insulation with a thickness of 25 mm and density of 128 kg/m3.

The design of the combustion chamber was selected in accordance with the design details specified in table 3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dimension (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of combustion chamber opening (mm)</td>
<td>1000 ± 50</td>
</tr>
<tr>
<td>Height of the combustion chamber (mm)</td>
<td>1000 ± 50</td>
</tr>
<tr>
<td>Width of combustion chamber opening (mm)</td>
<td>1000 ± 50</td>
</tr>
<tr>
<td>Width of combustion chamber (mm)</td>
<td>1000 ± 50</td>
</tr>
<tr>
<td>Depth of combustion chamber (mm)</td>
<td>800 ± 50</td>
</tr>
<tr>
<td>Opening for forced ventilation</td>
<td>Round of 300 mm in diameter</td>
</tr>
<tr>
<td>Combustion Chamber - Picture Reference</td>
<td>Picture 9</td>
</tr>
</tbody>
</table>

**Table 3.** Specification of combustion chambers.

To analyse the interaction between the façade (only main face) and the combustion chamber, a piece of façade was constructed with a height of 1000 mm above the combustion chamber.

This partial façade was built with concrete blocks with an apparent density of \((650 \pm 200) \text{ kg/m}^3\), a thickness of 200 mm. See Appendix 1.

A fan was located upstream to an aerodynamic circuit installed behind the rear wall of the combustion chamber to blow \((400 \pm 40) \text{ m}^3/\text{h}\) fresh air into the chamber. The circuit was connected to a hole of 300 mm of diameter drilled in the rear wall. The centre of the hole was located at a height of 500 mm from the floor of the chamber on the vertical axis of symmetry as represented in Picture 4.

5.3. Description of the Calorimetric Measurements

The test rig was constituted of a calorimeter hood, connected to an exhaust duct and a gas analysis bay. The hood and exhaust duct collected the combustion gases during the test. The volume flow rate in the exhaust duct was measured to an accuracy of at least ± 5%.

The exhaust duct was equipped with:
- Bi-directional probe. The flow was measured by the bi-directional probe located at the centre line of the duct.
- Pressure transducer with a precision of ± 5 Pa and a range of measurement from 0 Pa to 2000 Pa.
- Two thermocouples. The gas temperature in the immediate vicinity of the probe was measured by two thermocouples with a diameter of 1,6 mm. These thermocouples did not disturb the flow pattern around the bi-directional probe.
- An ambient thermocouple.

The gases taken in the exhaust duct were sent to a gas analyser.

The analyser transmitted the \(O_2\), \(CO_2\) rates as well as the temperatures in the extraction duct directly to software. The analyser recorded the data every second.

In addition, an aerodynamic circuit including a pressure transducer was connected to the air inlet of the combustion chamber.
5.4. Test Program

Before the tests, the ventilation of the exhaust system was regulated at a specific flow rate. The fire test was not started before the ventilation had stabilized. This flow has been chosen in order not to disturb the ambient air speed at 1 m in front of the combustion chamber, which should be less than 3.0 m/s.

A baseline of temperatures, O₂ and CO₂ was recorded during the five first minutes of testing. During the baseline there was no ignition of the system. This baseline verified the initial test conditions, the stability and consistency of the measurements. Initial ambient values were taken into account by the recording additional data.

This data allowed to calculate the parameters as specified in paragraph 6.

Once the baseline was finished, the crib was ignited. The type of ignition was the same for both types of exposure.

According to the assessment method, the fire in the combustion chamber should be extinguished after 22 minutes for the medium exposure. For the present study it was decided to let the crib burning freely until self-extinguishing to determine the behaviour of the crib, it potential impact on the façade and if the extinguishment was required or not.

Before the tests, the air inlet circuit was controlled and the frequency corresponding to a volume flow rate of 400 m³/h was determined. Once this parameter was found, the fan was switched off.

The fuel was made up of seven strips of low density fibreboard who were soaked uniformly in five litres of white spirit for a minimum of five minutes. Each strip having nominal dimensions of 25 mm × 12 mm × 500 mm.

Not more than five minutes before ignition, five strips of soaked fibreboard were inserted into the spaces between the timber sticks in the second layer of the crib allowing approximately 30 mm to project from the front of the crib. The two remaining strips were laid horizontally across the five projected strip ends.

The ignition of the crib was achieved by igniting only the two horizontal strips across their full length.

After four minutes from the ignition, the fresh air blower was switched on and adjusted at the frequency set before the start of the test. The fan was left in operation until the end of the test.

The total duration of the test was 60 min after ignition of the crib.
6. INSTALLATION AND ASSEMBLY OF THE TEST SPECIMEN

6.1. Heat Release Rate Measurements

During the test a series of parameters were calculated to characterize each crib:

- Heat Release Rate (HRR(t)) in kW recorded every second of the test. The HRR(t) value varies as the crib is consumed.

- Time-averaged HRR$_{30s}$ (t) in kW. It was calculated as the average of 30 s between (t - 15) and (t + 15) in order to smooth the disturbances in the measurement.

- The exposure period in seconds.

After the test, the parameters below were calculated:

- The Total Heat Release (THR) with the test time in MJ. The THR is the total heat release of the crib during the exposure period from the lighting until the extinction. It was possible to calculate the Total Heat Release for the duration of the test (60 min) or for the first 22 min period.

- The Heat Release Rate peak in 30 s (HRR$_{peak30s}$) in Kilowatts. It was the maximum value of HRR recorded for the duration of the test from the moment of ignition of the crib. This value was averaged in 30 s in order to remove the possible outliers and smooth the values.

- The time when the HRR$_{peak30s}$ took place in seconds from the start of the ignition (t$_{HRR_{peak30s}}$).

These parameters were calculated by adapting the formulas of the Appendix E of the standard ISO 9705-1:2016.


6.1.1.1. Checking equipment response

a) Drift in gas concentration measurement

The drift in both xO$_2$ and xCO$_2$ gas concentration measurements was calculated as the difference between the start values calculated as xO$_2$(30 s...90 s) and xCO$_2$(30 s...90 s) respectively, and the end values obtained by visual recording after a period of at least 60 s, in which no combustion products enter the exhaust duct.

Criteria:

\[
\left| xO_{2,\text{begin}} - xO_{2,\text{end}} \right| \leq 0,02\%
\]

\[
\left| xCO_{2,\text{begin}} - xCO_{2,\text{end}} \right| \leq 0,02\%
\]

where

xO$_2$ is the oxygen concentration in mole fraction;

xCO$_2$ is the carbon dioxide concentration in mole fraction.

b) Exposure period

The cribs were flaming from \( t = t_0 = t_{\text{ignition}} \) (s), until the test was considered as completed (t'). The exposure period was equal to \( t' - t_0 \), i.e. 60 min.
6.1.1.2. Calculation of the heat release rate (HRR) of the crib

a) Calculation of the volume flow of exhaust system, normalized at 298 K, \( V_{298}(t) \)

\[
V_{298}(t) = cA K_f K_p \frac{\Delta p(t)}{T_{ms}(t) R}
\]

where

- \( V_{298}(t) \) is the volume flow of exhaust system, normalized at 298 K, in cubic metres per second
- \( c = (2T_0/\rho_0)^{0.5} = 22.4 \) [K\(^0.5\).m\(^1.5\).kg\(^{-0.5}\)]
- \( A \) is the area of the exhaust duct at the general measurement section, in square metres.
- \( k_f \) is the flow profile factor.
- \( k_r \) is the Reynolds number correction for the bidirectional probe, taken as 1.08.
- \( \Delta p(t) \) is the pressure difference, in Pascals.
- \( T_{ms}(t) \) is the temperature in general measurement section, in Kelvins.

b) Calculation of the oxygen depletion factor

\[
\phi(t) = \frac{[\bar{x}_O_2(30s ... 270s)(1 - x_{CO_2}(t)) - [x_{O_2}(t)(1 - \bar{x}_O_2(30s ... 270s))]}{\bar{x}_O_2(30s ... 270s)(1 - x_{O_2}(t) - x_{CO_2}(t))}
\]

where

- \( \phi(t) \) is the oxygen depletion factor
- \( x_{O_2}(t) \) is the oxygen concentration in mole fraction
- \( x_{CO_2}(t) \) is the carbon dioxide concentration in mole fraction
- \( \bar{x}_O_2(30s ... 270s) \) is the average oxygen concentration in mole fraction measured between 30 s and 270 s after the start of the test
- \( x_{CO_2}(30s ... 270s) \) is the average carbon dioxide concentration in mole fraction measured between 30 s and 270 s after the start of the test

\[\text{c) Calculation of } x_{a,02} \]

\[
x_{a,02} = \bar{x}_O_2(30s ... 270s) \left[ 1 - \frac{H}{100p} \exp \left\{ 23.2 - \frac{3816}{T_{ms}(30s ... 270s)} - 46 \right\} \right]
\]

where

- \( x_{a,02} \) is the ambient mole fraction of oxygen including water vapor;
- \( x_{O_2}(t) \) is the oxygen concentration in mole fraction;
- \( H \) is the relative humidity, in percent;
- \( p \) is the ambient pressure, in pascals;
- \( T_{ms}(t) \) is the temperature in general measurement section, in Kelvins.
d) Calculation of $HRR_{\text{total}}(t)$

$$HRR_{\text{total}}(t) = EV_{298}(t) x_{a,\text{O}_2} \left( \frac{\varphi(t)}{1 + 0.105 \varphi(t)} \right)$$

where

- $HRR_{\text{total}}(t)$ is the total heat release rate of the specimen and the crib, in kilowatts;
- $E$ is the heat release per unit volume of oxygen consumed at 298 K, $E = 17,200$ (in kilojoules per cubic metre);
- $V_{298}(t)$ is the volume flow of the exhaust system, normalized at 298 K, in cubic metres per second;
- $x_{a,\text{O}_2}$ is the ambient mole fraction of the oxygen including water vapour;
- $\varphi(t)$ is the oxygen depletion factor.

e) Calculation of $HRR_{30s}$

$HRR_{30s}(t)$ is the 30 s average of $HRR(t)$

$$HRR_{30s}(t) = \frac{0.5HRR(t-15) + HRR(t-12) + \cdots + HRR(t+12) + 0.5HRR(t+15)}{10}$$

f) Calculation of $THR(t)$, $THR$ during the exposition time and $HRR_{\text{peak30s}}$.

The total heat release of the specimen $THR(t)$, the total heat release of the crib during the exposure period of the crib, and the $HRR_{\text{peak30s}}$ were calculated as follows:

$$THR(t_a) = \frac{1}{1000} \sum_{\text{Ignition time (s)}}^{t_a} (\max[HRR(t), 0])$$

The time the duration of the ignition of the crib is $t_{\text{final}}(s) - t_{\text{ignition}}(s)$.

$$THR_{\text{Exposure time}} = \frac{1}{1000} \sum_{\text{Ignition time (s)}}^{t_{\text{final}}} (\max[HRR(t), 0])$$

The peak of $HRR$ averaged in 30s:

$$HRR_{\text{peak30s}} = \max[(HRR(t)_{30s})_{\text{Ignition time (s)}}^{\text{Final time (s)}}]$$

where

- $THR(t_a)$ is the total heat release of the specimen during the period $t_a$ in Megajoules;
- $HRR(t)$ is the heat release rate of the specimen, in kilowatts;
- $THR_{\text{Exposure time}}$ is the total heat release of the specimen during the ignition period in Megajoules.
- $\max[x, y]$ is the maximum of two values $x$ and $y$. 
6.2. **Temperature Measurements**

In front of the combustion chamber, three plate thermometers and three gas (Inconel) thermocouples Ø 1.5 mm were positioned at a distance of 1 m of the front side of the timber crib. The first plate was placed into the vertical axis of symmetry of the chamber, the other ones were placed 340 mm to the right and left of the first. See Picture 8.

In the surface of the façade, on the vertical axis of symmetry, three plate thermometers and three Inconel thermocouples were installed. The first plate thermometer was placed at 1000 mm from the floor of the construction chamber, the other ones were installed at a distance of 500 mm and 1000 mm from the first one. See Picture 9.

Under the ceiling of the combustion chamber were placed three plate thermometers and three Inconel thermocouples. They were positioned on the horizontal projection of the diagonal of the crib. The first was placed at the middle of the diagonal, the other ones at the ends of the diagonal. See Picture 10.

The plate thermometers were oriented so that their metal side faces to the crib and were designed according to EN 1363-1.

For all configurations, the Inconel thermocouples were placed very close to the plate thermometers.

In each position, the external thermocouples were placed within a tolerance of ± 10 mm with respect to the locations given in Appendix 5.

6.3. **Determination of the Heat Flux Measured by Plate Thermometers**

The incident heat flux was estimated from the plate thermometers measurements according to the formula given below:

\[
q^{\text{inc}}_\text{inc} = \sigma T^4 \text{PT} + \frac{(h + K_{PT})(T_{PT} - T_\infty) + C_{PT} \frac{dT_{PT}}{dt}}{\varepsilon_{PT}}
\]

\[
q^{\text{stor}}_\text{PT} = C_{PT} \left( \frac{dT_{PT}}{dT} \right)
\]

Where:

- \( q^{\text{inc}}_\text{inc} \) is the incident radiation heat flux.
- \( q^{\text{stor}}_\text{PT} \) is the rate of heat being stored in the plate.
- \( \sigma \) is the Stefan-Boltzmann constant and it is considered as \( 5.670373 \times 10^{-8} \) Js m\(^{-2}\) K\(^{-4}\).
- \( T_{PT} \) is the temperature of the metal sheet of the plate thermometer.
- \( h \) is the convective heat transfer coefficient, it is assumed to be 25 W/m\(^2\)K.
- \( K_{PT} \) is the heat transfer coefficient due to a heat loss of the plate thermometer, found to be equal to 8 W/m\(^2\) K.
- \( T_\infty \) is the adjacent gas temperature.
- \( C_{PT} \) is the heat storage lumped heat capacity, considered as 4200 J/m\(^2\)K for an ISO/EN standard thermometer.
- \( dT_{PT} \) is the temperature difference between two consecutive temperature recordings with an interval \( \Delta T = 1 \) s
- \( \varepsilon_{PT} \) is the emissivity and it is considered as 0.8
6.4 Mass Loss

A weighing load cell platform with an accuracy of \(\pm 0.01\) kg was used to measure continuously the mass loss of the timber crib throughout the fuel source combustion period.

The scale was located under the floor of the combustion chamber. The scale was protected with a silicate panel positioned between the top and the floor of the chamber.

The weighing data was continuously saved every 10 s. The dimensions of the scale were greater than the size of the cribs and less than the size of the combustion chamber.

The instantaneous rate of mass loss was calculated with the recorded data according to the formula given below:

\[
v_{\text{inst}} = \frac{\Delta m (kg)}{\Delta t (s)}
\]

where

- \(\Delta m\) is the difference between two weightings in kg.
- \(\Delta t\) is the time difference between the two weightings.

The smoothing of the data was carried out according to the method of Savitzky-Golay. The results are given in Appendix 10.

6.5 Measurement and Control of Inlet Fresh Air Flow

A calibrated orifice plate was installed downstream to the fan, inserted in the fresh gases blowing circuit.

Differential pressure from the orifice plate was measured during the test.

The volumetric flow inside the orifice plate was calculated in respect of EN 5167-2 standard.
7. ENVIRONMENTAL CONDITIONS

7.1. AMBIENT AIR VELOCITY
The horizontal component of the ambient air speed was less than 3 m/s before the commencement of the test.

Several measures were done with the anemometer located at a distance of 1 m horizontally away from the exposed face, and at the same height as the upper edge of the combustion chamber.

The ambient air speed was measured at intervals of 1 minute during 15 minutes before the commencement of the test, and none of these 15 values had exceed the speed limit.

These measurements were carried out under the same ventilation conditions as the ones used during the test.

7.2. AMBIENT TEMPERATURE
The ambient temperature prior to testing was comprised between +5°C and + 35°C.

This measure was taken with an ambient thermometer located at a distance of between 1 m and 3 m horizontally away from the unexposed face, and between 1 m and 3 m above the ground.

This measurement was performed not later than 5 min before the commencement of the test.

8. TESTS

8.1. CONDITIONING
The wood of the cribs was received in a state with a moisture content of 12.5%. They were stored in a covered and closed area at ambient temperature.

In order to maintain the humidity, the wood was shipped packaged with waterproof protection. This protection was conserved until the construction of the cribs.

Once the cribs were made, they were repacked up to the test date. However, the cribs lost a part of their moisture content and reached 9.5% before testing.

8.2. TESTING

8.2.1. Before the test
- Before every test, a 100 kW propane burner working was performed to verify the correct facility response.
- The extraction rate of the hood was started and stabilized at the target value.
- The ambient air velocity was controlled.
- The ambient temperature was controlled.

8.2.2. Test

The timing device used for this test had an accuracy of ± 5 s/h.

<table>
<thead>
<tr>
<th>Time (in minutes)</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Start of timing and insert fibreboard ignition strip into crib. Begin data logging and audio-visual recording equipment.</td>
</tr>
<tr>
<td>5</td>
<td>Ignition of the timber crib</td>
</tr>
<tr>
<td>9</td>
<td>Addition of air to the combustion chamber via a fan unit</td>
</tr>
<tr>
<td>65</td>
<td>Termination of test</td>
</tr>
</tbody>
</table>

Table 4 – Time scale.
9. RESULTS

Three official tests identified M1, M2, M3 were done with spruce wood and a moisture content of 9.5%. The minimum and maximum densities were tested. The surface finish of wood sticks for M1 and M2 was planned, for the M3 it was sawn.

In order to check the test rig, a supplementary test was performed. It was identified as “M0” and had similar characteristics with the crib identified “M3”.

Tests have been performed on 04 November 2020 and 05 November 2020.

Curves are given in Appendix 7.

9.1. CHARACTERISTICS

<table>
<thead>
<tr>
<th>Test reference</th>
<th>Wood species</th>
<th>Surface finish</th>
<th>Average wood density [kg/m³]</th>
<th>Wood density range [kg/m³]</th>
<th>Moisture content [%]*</th>
<th>Test date</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0</td>
<td>Spruce</td>
<td>Sawn</td>
<td>390</td>
<td>325 - 417</td>
<td>9.5</td>
<td>04 November 2020</td>
</tr>
<tr>
<td>M1</td>
<td>Spruce</td>
<td>Planed</td>
<td>542</td>
<td>529 - 575</td>
<td>9.5</td>
<td>05 November 2020</td>
</tr>
<tr>
<td>M2</td>
<td>Spruce</td>
<td>Planed</td>
<td>413</td>
<td>343 - 451</td>
<td>9.5</td>
<td>05 November 2020</td>
</tr>
<tr>
<td>M3</td>
<td>Spruce</td>
<td>Sawn</td>
<td>389</td>
<td>370 - 396</td>
<td>9.5</td>
<td>04 November 2020</td>
</tr>
</tbody>
</table>

*Values at the day of the test.

Table 9. Test program for medium fire exposure with actual measured values.
Table 10. Density distribution of each crib.

The pictures are shown in Appendix 6.

9.2. RESULTS

<table>
<thead>
<tr>
<th>Test reference</th>
<th>HRRmax (kW)</th>
<th>tRHRmax (s)</th>
<th>THRTot (MJ)</th>
<th>Heat flux max front crib (kW/m²)</th>
<th>Heat flux max façade (kW/m²)</th>
<th>MLR peak inst (g/s)</th>
<th>tMLR peak (s)</th>
<th>Total mass lost (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0</td>
<td>518</td>
<td>259</td>
<td>526</td>
<td>18</td>
<td>59</td>
<td>78</td>
<td>290</td>
<td>99.4</td>
</tr>
<tr>
<td>M1</td>
<td>325</td>
<td>273</td>
<td>519</td>
<td>12</td>
<td>37</td>
<td>31</td>
<td>170</td>
<td>99.0</td>
</tr>
<tr>
<td>M2</td>
<td>501</td>
<td>281</td>
<td>528</td>
<td>18</td>
<td>61</td>
<td>94</td>
<td>410</td>
<td>98.9</td>
</tr>
<tr>
<td>M3</td>
<td>506</td>
<td>278</td>
<td>525</td>
<td>16</td>
<td>61</td>
<td>47</td>
<td>230</td>
<td>99.0</td>
</tr>
</tbody>
</table>
**Table 1. Test results.**

<table>
<thead>
<tr>
<th>Mass loss</th>
<th>MLR peak Savitzky-Golay (g/s)</th>
<th>t&lt;sub&gt;MLR peak&lt;/sub&gt; (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>51</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>280</td>
<td></td>
</tr>
<tr>
<td>62</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>340</td>
<td></td>
</tr>
</tbody>
</table>

*Time after ignition of the crib*
9.3. OBSERVATIONS
For the test observations and to have a precise idea of the behaviour of the crib, it was taken as $t = 0$ the
ignition time of the crib

9.3.1. During the test

Test M0
- Ignition of the crib at $t = 0$ s
- Flames start to come out of the combustion chamber at $t = 39$ s.
- The first parts of the crib begin to fall at $t = 9$ min 34 s.
- The crib collapse in its entirety at $t = 18$ min 39 s.

Test M1
- Ignition of the crib at $t = 0$ s
- After the ignition of the crib, the flames attack the wood sticks positioned above the ignition sticks.
- Flames start to come out of the combustion chamber at $t = 51$ s.
- The first parts of the crib begin to fall at $t = 5$ min 42 s.
- The first row of wood sticks begins to burn at $t = 17$ min 5 s.
- The first row is ignited totally at $t = 20$ min 31 s.
- Flames no longer come out of the combustion chamber at $t = 24$ min 24 s
- A large part of the crib falls at $t = 28$ min 12 s
- The crib collapse in its entirety at $t = 32$ min 41 s.

Test M2
- Ignition of the crib at $t = 0$ s
- Flames start to come out of the combustion chamber at $t = 30$ s.
- The first parts of the crib begin to fall at $t = 3$ min 12 s.
- The large parts of the crib begin to fall at $t = 14$ min 18 s.
- The façade of the crib falls at $t = 21$ min 4 s.

Test M3
- Ignition of the crib at $t = 0$ s
- Flames start to come out of the combustion chamber at $t = 50$ s.
- The first parts of the crib begin to fall at $t = 4$ min 27 s.
- Large part of the crib falls at $t = 17$ min.
- The crib collapse in its entirety at $t = 23$ min 22 s.
9.4. CONCLUSION

<table>
<thead>
<tr>
<th>Test</th>
<th>Heat production</th>
<th>Mass lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>N°</td>
<td>HRR₃₀₅ max (kW)</td>
<td>t₉₉₅ max (s)</td>
</tr>
<tr>
<td>0</td>
<td>518</td>
<td>259</td>
</tr>
<tr>
<td>1</td>
<td>325</td>
<td>273</td>
</tr>
<tr>
<td>2</td>
<td>501</td>
<td>281</td>
</tr>
<tr>
<td>3</td>
<td>506</td>
<td>278</td>
</tr>
</tbody>
</table>

*the reference time is t = 0 equal to the moment of ignition of the crib

Table 12. Results for large fire exposure.

<table>
<thead>
<tr>
<th>Mass loss</th>
<th>MLR peak Savitzky-Golay (g/s)</th>
<th>t MLR peak * (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>51,2</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>29,4</td>
<td>280</td>
<td></td>
</tr>
<tr>
<td>62,2</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>42,3</td>
<td>220</td>
<td></td>
</tr>
</tbody>
</table>

Les Avenières Veyrins-Thuellin, on March 2021
APPENDIX 1 - DRAWINGS OF THE TEST ARRANGEMENT – MEDIUM EXPOSURE CRIB TEST
Picture 3 - Principle scheme for the crib test
APPENDIX 2 – WOOD CRIB AND PLATFORM

<table>
<thead>
<tr>
<th>Key</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Masonry</td>
<td></td>
</tr>
<tr>
<td>2 Wood crib</td>
<td></td>
</tr>
<tr>
<td>3 Fireproof blanket</td>
<td></td>
</tr>
<tr>
<td>4 Additional air</td>
<td></td>
</tr>
<tr>
<td>5 Top opening of the combustion chamber</td>
<td></td>
</tr>
<tr>
<td>6 Grating (thickness 30 mm)</td>
<td></td>
</tr>
</tbody>
</table>

**Picture 4.** Wood crib installation.

**Picture 5.** Crib geometry of the medium exposure cribs, M1 at the left and M2-M3 at the right.
**Picture 6.** Detail of the positioning of the ignition sticks

**Picture 7.** Dimensions of the crib platform
APPENDIX 3 – PLATE THERMOMETERS LOCATIONS

Picture 8. Horizontal position of plate thermometers in the front of the chamber.

Picture 9. Position of plate thermometers in the façade above the chamber.
**Picture 10.** Horizontal position of plate thermometers in the ceiling of the chamber.
APPENDIX 4 – PICTURES DURING AND AFTER THE TEST

- Test M0
○ Test M1
Test M2
Test M3
APPENDIX 7 – HEAT RELEASE RESULTS – HRR$_{30s}$

<table>
<thead>
<tr>
<th>Test</th>
<th>HRR$_{30s}$ (KW)</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX 8 – TEMPERATURE RESULTS AND HEAT FLUXES ESTIMATION

- FRONT OF THE CRIB
  - Test M0
Test M1

Thermocouples Inconel Front Chamber

Plates Temperatures - Front chamber
Test M2
Test M3
o FACADE
  o Test M0
Test M1

Thermocouples Inconel - Facade

Facade Temperatures - Plates
Test M2

Thermocouples Inconel - Facade

Facade Temperatures - Plates
Test M3

Thermocouples Inconel - Facade

Facade Temperatures - Plates
○ CHAMBER
  ○ Test M0
Test M2

M2 - Thermocouples Inconel Chamber

M2 - Chamber Temperatures - Plates
Test M3

M3 - Thermocouples Inconel Chamber

M3 - Chamber Temperatures - Plutes
APPENDIX 10 – MASS LOSS RESULTS

- Test M0

- Test M1
- **Test M2**

![Graph](image)

- **Test M3**

![Graph](image)