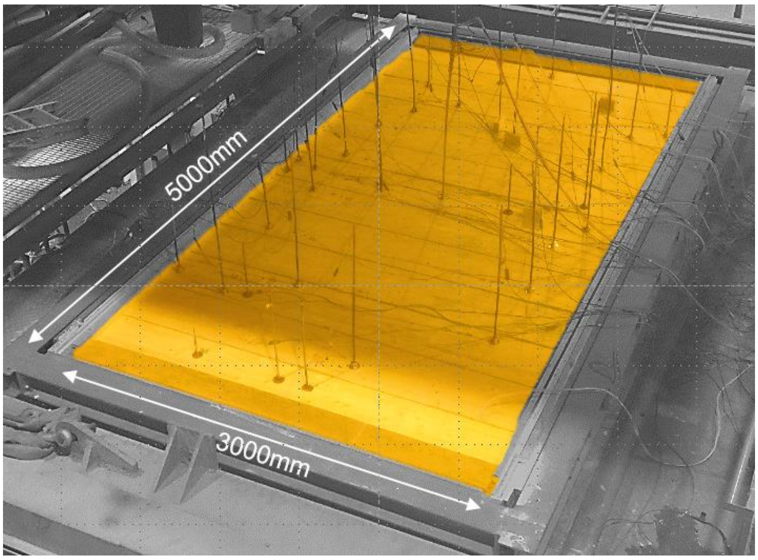
STSM report COST FP1404 "Thermal exposure of combustible products in furnace tests"

Joachim Schmid, ETH Zürich, Switzerland to Rise, Sweden (2017-11-01 to 2017-11-06)



- The purpose of this STSM was the performance of additional measurements exceeding standard fire resistance testing. In conjunction with a large-scale test the charring rate was assessed with two different methods, the gas velocity was estimated and the mass loss determined.
- The charring depth was determined after the test. The measurement of the residual cross-section and the charring depth of timber members after fire exposure respectively is of great importance. However, besides a common understanding about temperature measurements within the solid there is no agreement about the measurement technique. The residual cross-section was measured with a simple device which may be proposed in the future to measure the residual cross-section of timber slabs (e.g. cross-laminated timber). The gas velocity was determined during the test in order to allow a better understanding of the convective heat transfer. This was earlier done only in a model scale test furnace.
- Existing results indicate that the average gas velocity is about 2.5 m/s in a model scale furnace and 1 m/s in the large scale test. The estimation of the residual cross-section was done using a measuring hook, in a grid of 400 mm x 400 mm. The result is a charring rate 0.60 mm/min for the 90min test which was found in literature and confirmed by simulations. The mass loss for the timber specimen during the test was estimated to 14.1 kg/m^3h.
- The test and the actual cooperation has led to further research ideas, applications are planned for 2018.
- Results from the STSM will contribute to a journal paper about the “thermal exposure of combustibles”, the PhD work of the STSM performer and will be discussed in WG2 as standard proposal.
- Confirmation by the host institution of the successful execution of the STSM is attached (Annex 1).

Annex 1 – Confirmation by Host Institution

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Page: 1(1)

Letter of confirmation – STSM at Rise

In the name of the host institution, Research Institutes of Sweden department of fire research, I the undersigned Dr. David Lange confirm the successful execution of the STSM (Short Term Scientific Mission) of Joachim Schmid.

The STSM took place from 2017-11-01 to 2017-11-07. The purpose of the STSM to assist in performing a fire test at the full scale furnace in Borås (Sweden) and evaluate the test data exceeding standard fire testing.

The outcome is a report document which will be a report submitted to COST FP1404 WG1 and WG2.

Yours, sincerely,

RISE, Research institutes of Sweden

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Annex 2 – Scientific Report

Fire safety use of bio-based building products

Thermal exposure of combustible products in furnace tests

Scientific report of STSM at Rise

01.11-06.11.2017

Author:

Joachim Schmid , ETH Zurich (IBK)

Table of Contents

Annex 1 – Confirmation by Host Institution 3
Annex 2 – Scientific Report 1
Fire safety use of bio-based building products 1
Scientific report of STSM at Rise 1
Introduction 3
Overview of performed work 4
Material 4
Installation of the specimen 5
Results and discussions 7
Charring of the solid timber deck plate 7
Gas velocity in furnace tests 11
Mass loss measurements 13
Findings 14
References 15

Introduction

Recently, the thermal exposure of combustibles in general and the applicability of furnace test results when combustibles are tested in particular were questions. At the special sessions organized by COST FP1404 at the World conference on timber engineering in Vienna, 2016 and in several publications it was mentioned that the lower furnace fuel input implicitly proof the different lower thermal input.

The issue of thermal exposure in furnace tests was subsequently investigated by Schmid et al. (Schmid et al., 2017) but several issues remain unanswered. Among others, the use of the heat flux sensor in furnace tests and the assessment of the charring rate and depth respectively. The heat flux sensor measures a temperature gradient from its surface to the water cooled body. Many experts assume that the heat flux measured by a heat flux sensor, e.g. Schmidt-Boelter-type, is the incident radiant heat flux. However, the sensor is sensitive to radiation and convection whereby it is difficult to estimate the convection part. Schmid et al. (Schmid et al, 2017) showed that the convection may exceed 20% of the measured value. The convective heat transfer is depending on the difference between the gas- and the surface temperature and the convective heat transfer coefficient which varies depending on the gas flow condition. In the first part of this study, the gas flow in the large scale furnace is measured and documented.

Overview of performed work

A large scale fire resistance test in a furnace was performed at Rise on 2nd of November 2017. A combustible specimen with 15 m2 surface was fire exposed to standard fire for 90 min. The furnace was controlled by plate thermometers to follow the standard EN/ISO temperature-time curve (CEN, 2012).

Material

The test specimen's initially unprotected surface was about 5000 mm x3000 mm in thirteen individual sections and was placed in a metal frame of H200 profiles. The depth of the specimen was 139 mm. The individual elements were bonded with Melamine Urea Formaldehyde adhesive (MUF) and had standing lamellae, i.e. bond lines in the direction of the heat flux. The elements were glulam beams 400 mm x 139mm and a length of 2910 mm. At delivery, all beams delivered, i.e. 14 beam elements, had a mass of 1051 kg. Using the specified geometry, the density was estimated to 464 kg/m^3. On the day of the test, the moisture content of the spare element was estimated to 12% (±0.2%) with a resistance meter at about 1 mm depth. Heating a part of the spare beam to 105°C, the moisture content was estimated to 12.8%. The total mass of the specimen assembled out of 13 elements was determined using the density to 975.9 kg, see Figure 1.

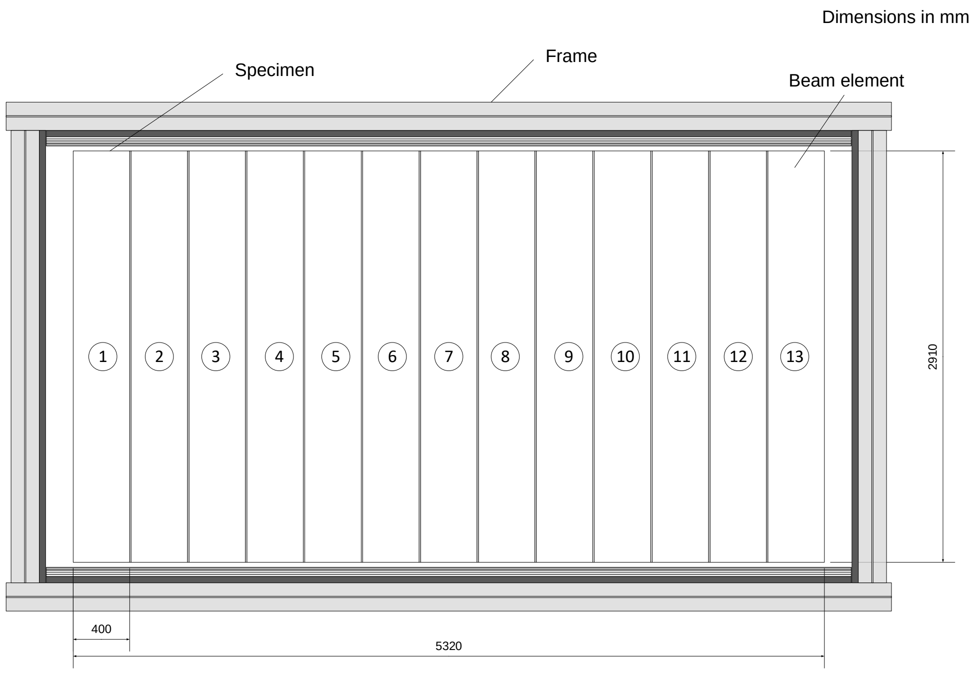


Figure 1: Test specimen assembled out of beam elements and the metal frame with fitting layers.

Installation of the specimen

The specimen was installed in a HEB 200 metal frame with fitting elements made from a layer mineral fibre board PROMATEC (20 mm), three layer gypsum plasterboards (each 15 mm) and a wooden joist (45 mm). The specimen was supported using angle sections (70 mm x 70 mm x 8 mm) on each of the long sides of the frame. The total mass of the frame was estimated to 1255.5 kg. Using the estimated mass of the specimen and the frame, the total mass (excluding the instrumentation) can be specified to 2233.8 kg (or 21.9 kN). While several beams were equipped with thermocouples (wire thermocouples drilled with channels in parallel to the isotherms), further, the specimen was equipped with plate thermometers to measure the homogeneity of the temperature field in the furnace. For quick extinguishing with water after termination of the test (90 min) the specimen was installed in a metal frame, see Figure 2.

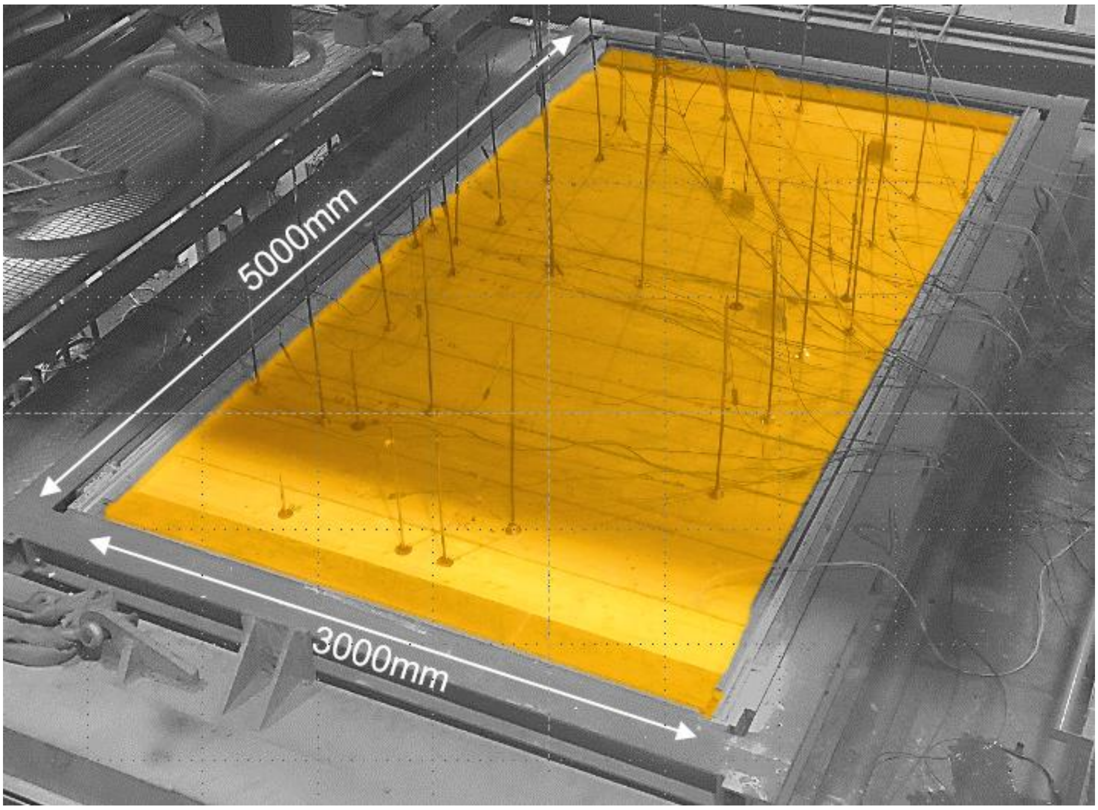


Figure 2: Test specimen installed on the horizontal full scale furnace at the fire lab of Rise.

To estimate the gas velocity in the furnace, four probes (Pitot tubes) were installed at different positions as shown in Figure 3.

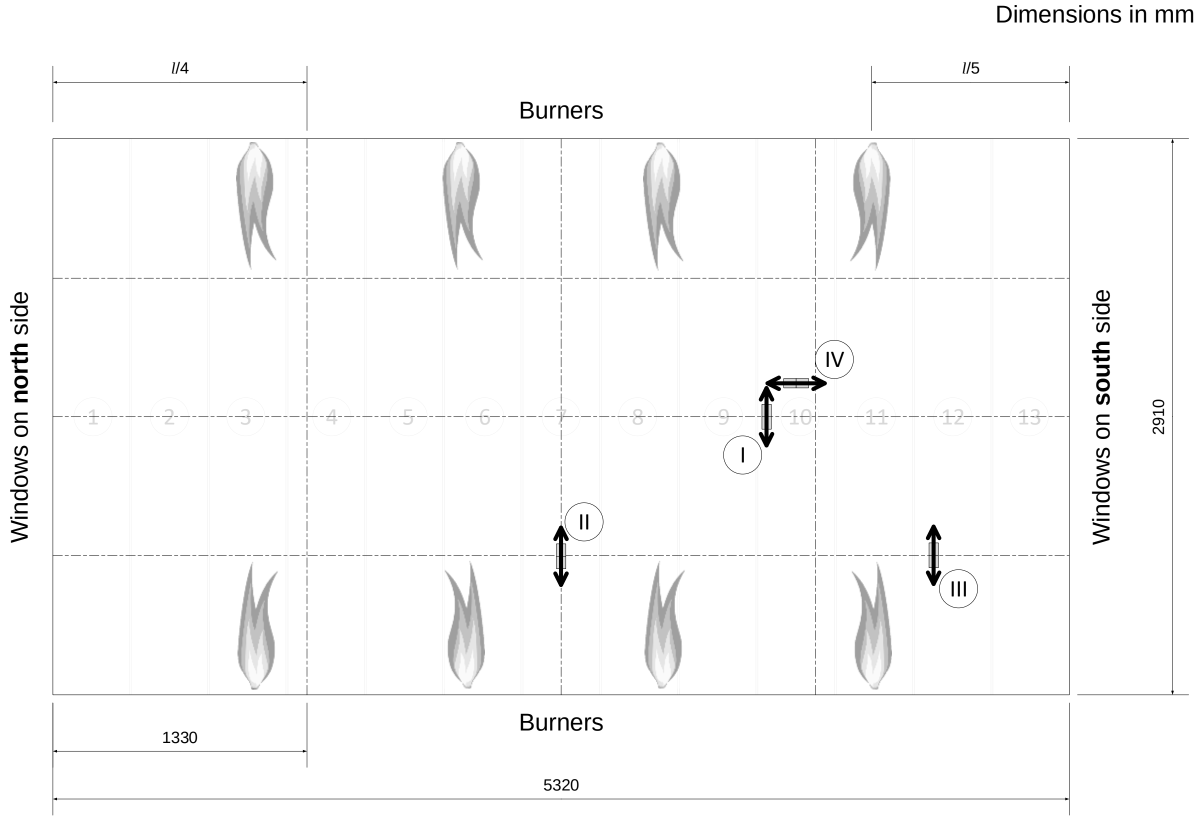


Figure 3: Pitot tubes I to IV and burner location in the specimen.

The Pitot tubes I, II and III were in the direction of the burners while the Pitot tube IV was installed in the cross direction but close to the Pitot tube I to detect the gas movement in both directions. Further, at the tubes a small thermocouple was installed in order to detect the gas temperature for further use.

Results and discussions

Charring of the solid timber deck plate

The charring rate was assessed using two different methods. Commonly, the charring depth was estimated measuring the residual cross section. Taking into account the original cross section depth $h_{20} = 139$ mm the charring depth was determined. Subsequently, the charring rate was estimated assuming a linear charring rate over the time of fire exposure:

$$\beta_i = \frac{d_{char}}{t_{test}} = \frac{h_{20} - h_{res}}{t_{test}} = \frac{139 - h_{res}}{90}$$

Firstly, a special meter made from a pipe section with a diameter of 8 mm and a hook at one end of the meter. The meter had markers every 5 mm and the residual depth was measured with a resolution of 2.5 mm. The meter was inserted in hand drilled holes (D=17 mm). Details about the measurement technique are given in Figure 4.

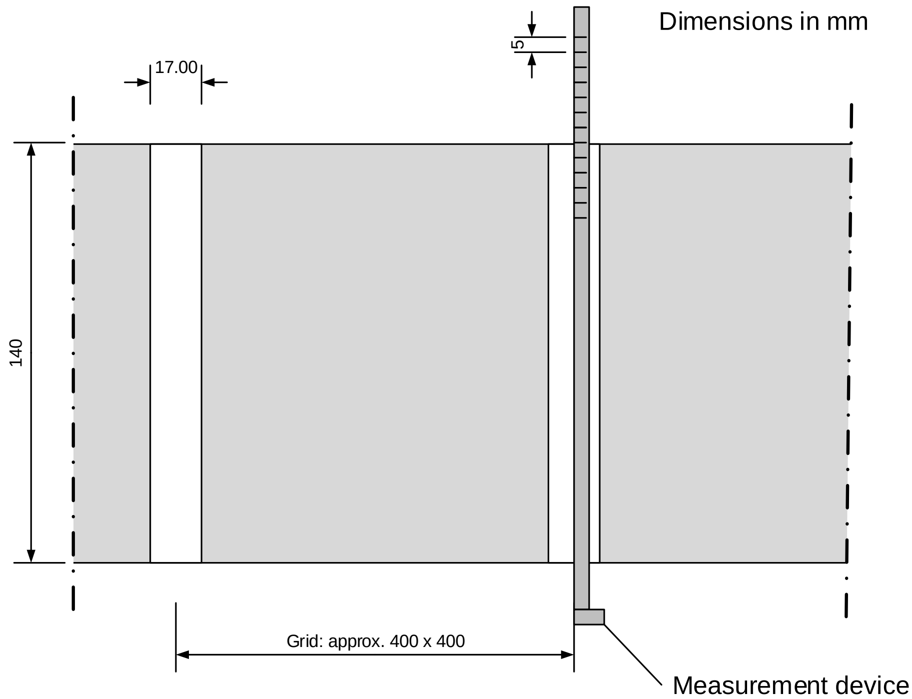


Figure 4: Measurement of the residual cross section. Vertical channels were drilled along the centre line.

The inaccuracy of the measurements was estimated to be ± 1.25 mm for the residual cross section depth which would result in an accuracy of the charring rate of less than ± 0.15 mm/min considering a linear charring rate as suggested by Eurocode (CEN,

2004) and a fire exposure of 90 min. The charring rate was assessed by means of the measured charring depths at five positons equally distributed along the centre axis of the thirteen 400 mm wide deck sections. With this approach a mesh of about 400 mm x 400 mm was covered. The measured residual depth varied ± 10 mm and resulted in a mean charring rate of $\beta_{mean} = 0.60$ mm/min.

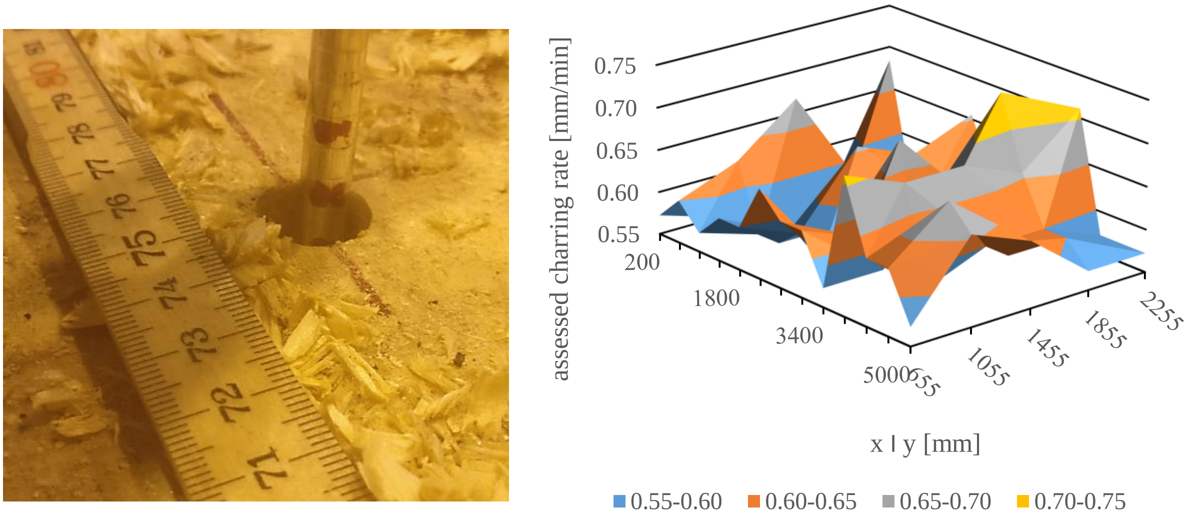
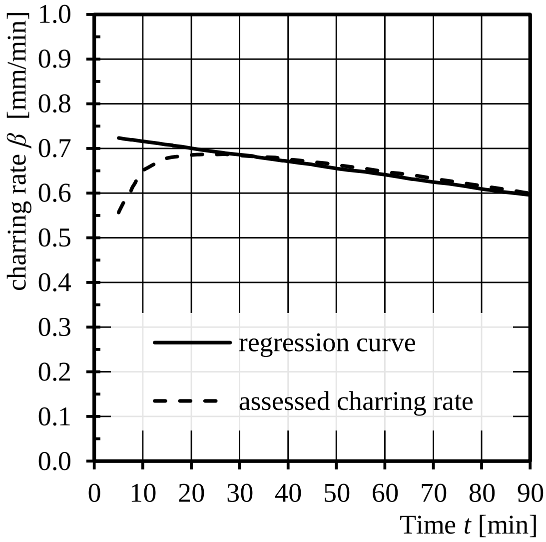


Figure 5: Measurement device (left). Assessed charring rates using the special made meter (right).

This value is the same value assessed by König et al. (König et al., 1999) for 90 min standard fire exposure. König et al. found that the charring rate is 0.70 mm/min at 20 min and decreases to 0.60 mm/min at 90 min. Subsequently 0.65 mm/min were specified as one dimensional charring rate in the fire part of Eurocode 5, EN 1995-1-2 (CEN, 2004). The value of 0.60 mm/min at 90 min is in good agreement with simulation results when the thermal properties of Eurocode 5 (CEN, 2004) are used, see Figure 7.



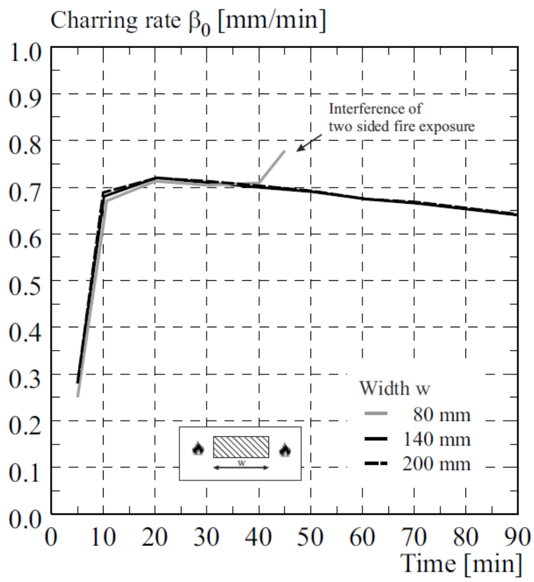


Figure 6: Measurement device (left). Assessed charring rates using the special made meter (right).

Figure 7: Simulated charring rates (Klippel, 2014).

In addition to the approach to measure the charring rate through drilled holes presented above with the results shown in Figure 5, the charring rate was assessed using the measurements with a standard meter (metal angle) with a resolution of 1 mm at the free edge of the single strips. Individual results shown in Figure 8 result in a mean charring rate of $\beta_{mean} = 0.68$ mm/min. This value is 13% higher than the value resulting from the centre measurements presented above. The reason for this is that the stone wool insulation strips led to a certain corner rounding due to the heat flux through the mineral wool strips (stone wool with approx. density of 25 kg/m^3) in between the deck elements. The total mass of the mineral wool (13 strips) was estimated to 2.4 kg and of the measurement devices (plate thermometers and pitot tubes) installed in the specimen to 25.5 kg.

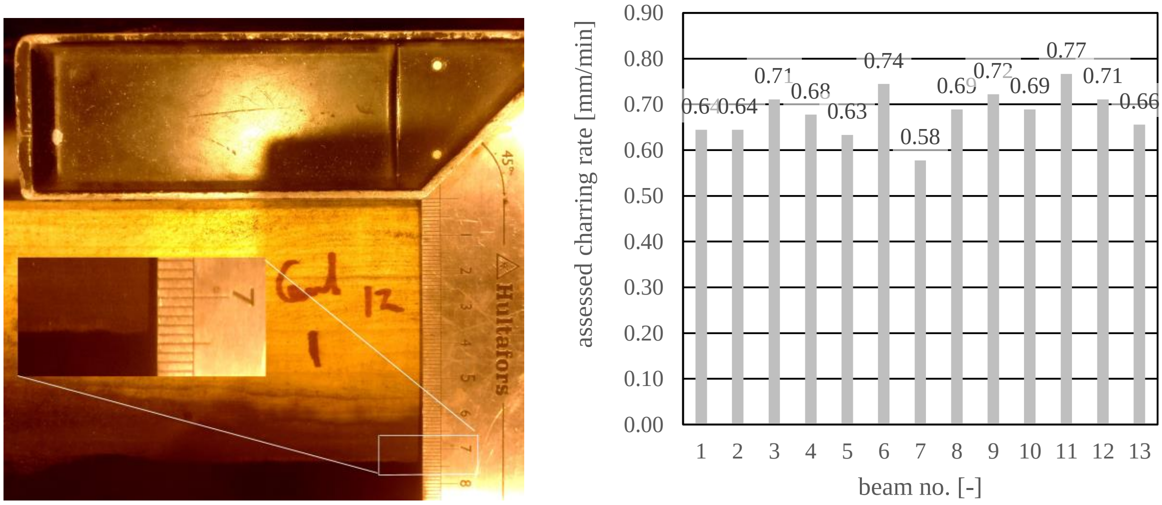


Figure 8: Measurement device (left). Assessed charring rates on the element sides using the metal angle (right).

The measurement technique to assess the charring depth and rate respectively of both methods was compared along the centre line (position $x = 1455$ mm). It was found that the charring rate is $\beta_{mean} = 0.68$ mm/min and $\beta_{mean} = 0.61$ mm/min respectively, see Figure 9.

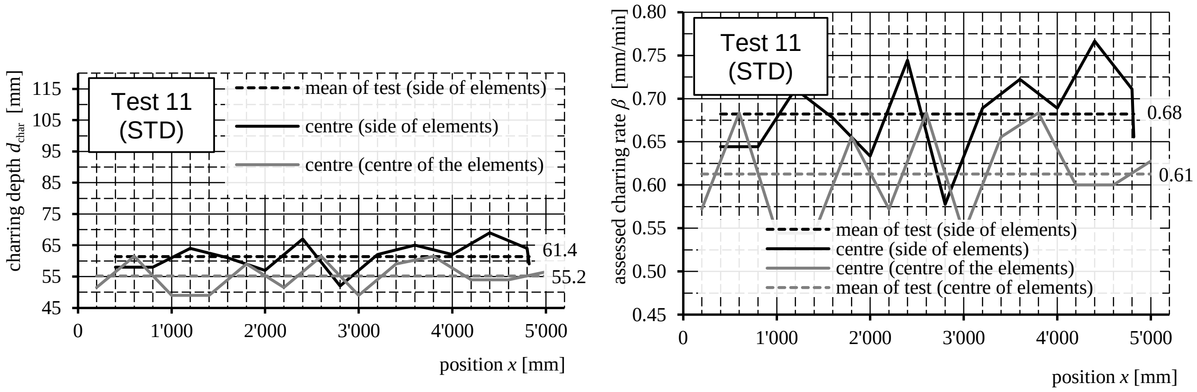


Figure 9: Assessment of the charring depth (left) and rate (right) using both measurement techniques.

Gas velocity in furnace tests

Information about gas velocity in fires is rare. Limited data are available from compartment tests and fire tests. Performed measurements indicate that velocities of up to 6 m/s and 15 m/s respectively (Schmid et al., 2017) seem to be reasonable.

To estimate the gas velocity in fire environments a pitot tube presented originally by McCaffrey et al. 1974 was used.

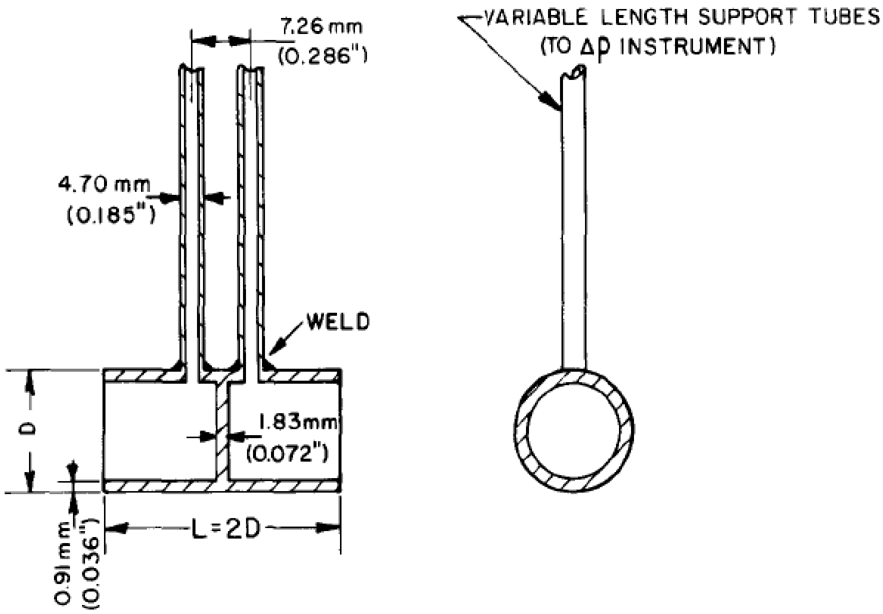


Figure 10: Pitot tube type used in the furnace test (image by McCaffrey et al., 1976).

Recently, in recent fire resistance tests, measurements of the gas velocity were performed in a model scale furnace (inner measurements about 1000 mm x 800 mm x 1000 mm) when a Cross-Laminated Timber (CLT) floor element was tested. The velocity was determined to be variable between 4 m/s and -2 m/s in the direction of the burners which were situated on one side of the furnace, see Figure 11.

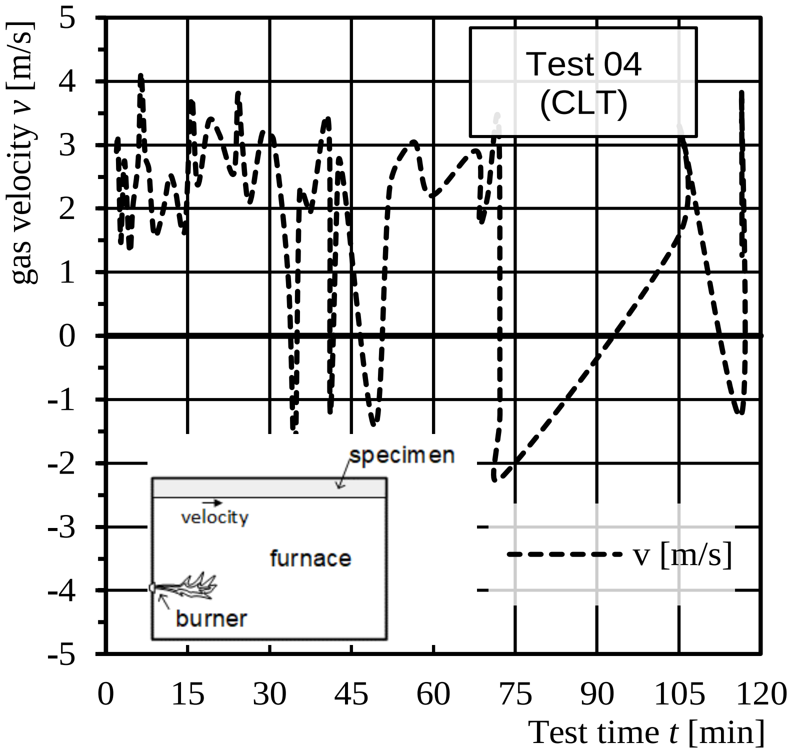


Figure 11: Determined gas velocities in the model scale furnace of VKF, Switzerland (formerly EMPA).

Evaluation of the actual full-scale test shows that the full-scale furnace environment is less severe when it comes to the gas velocity, see Figure 12.

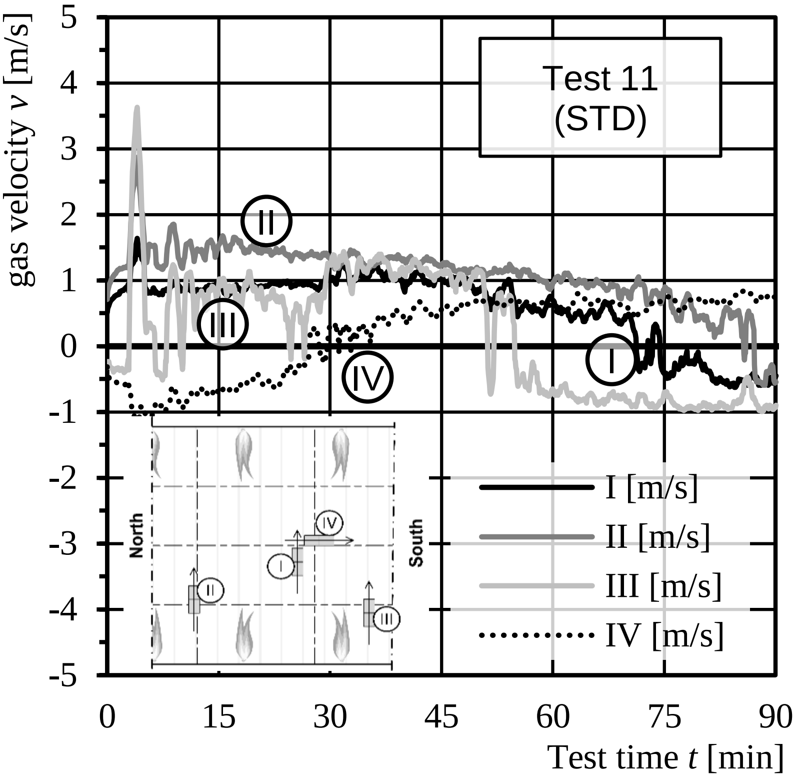


Figure 12: Determined gas velocities in the full scale furnace of Rise, Sweden (formerly SP).

To estimate the furnace gas velocity the actual air pressure at the time of the fire test (99.8 kPa) and the expansion of the heated air was taken into account.

Mass loss measurements

Information about the mass loss is considered as standard for bench scale tests as when using the cone calorimeter (ISO, 2002). For fire resistance tests, this procedure is still new and was recently presented by Klippel et al., 2017. As for tests with structural timber members, the reference moisture condition was considered as the equilibrium moisture content of 12%. Klippel et al. (2017) used a solid timber deck with a density of 430 kg/m^3 as reference resulting in a mass loss rate in standard fire resistance tests per hour of 15.4 kg/m^2. This value is proposed by ETH as comparative value for solid timber to describe no significant falling off (loss of stickability) of charred parts of the member. The validity of this value is implicitly given by the available fire test data and is up to 120 min.

Using the measured mass of the elements delivered to the full scale test and the geometry of this beams, the mass of the timber specimen containing of 13 elements was estimated to 976 kg before the tests. After the 90 min test, the mass of the elements with removed char coal was 592 kg resulting in a mass loss of 25.4 kg/m^2. With respect to the reference density a conversion factor of 0.93 can be calculated resulting in an hourly mass loss of 15.7 kg/m^2. It should be considered that this value cannot be compared with the value proposed by ETH as the char coal is not included in the calculated value. Considering the char coal mass loss of 1.7kg/m^{2}h the standardized mass loss per hour can be estimated to 14.1 kg/m^{2}h. It is not clear if the slightly lower value for the mass loss in the full scale test (about 10% difference) is due to the different densities (about 8% difference) or due to the gas velocities (250%) inducing a higher reaction rate between the available oxygen and the char coal. Another reason for the difference could be the increased charring along the edges of the specimen which are less significant in the full scale test compared to the model scale test.

Findings

It was found that the charring rate of plate elements should be measured in the undisturbed area, a grid of 400 mm x 400mm seems to be appropriate. The value of 0.60 mm/min agrees well with tests from literature and simulations in literature and is slightly lower than rules of Eurocode 5.

The gas velocity was estimated to be lower in the full scale test performed (about 1 m/s) than in a previous model scale tests (about 2.5 m/s).

The mass loss rate in the full scale test was about 14.1 kg/m^{2}h which is slightly lower than in the model scale test with 15.4 kg/m^{2}h.

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