STSM report COST FP1404

Antonio Totaro, From University of Naples "Federico II" to ETH Zurich (21.06-18.07.2018)

- The purpose of this STSM is to analyse the temperature measurements by wire and sheathed thermocouples. This work shows how the inlaid wire thermocouples installed parallel to the isotherm records the best temperatures in respect to the sheathed thermocouples installed perpendicular to the isotherm from the unexposed side.
- The investigation of temperature measurement with different setups were performed by production of two specimens equipped with inlaid wire thermocouples parallel to the isotherm and sheathed insulated thermocouple installed perpendicular to the isotherm in boreholes from the unexposed side. A third specimen was produced to analyse the charring of wood. The third specimen was equipped only with inlaid wire thermocouples parallel to the isotherm. Specimens were exposed to a constant heat flux. In the end, test data were analysed.
- The different temperature measurement setups recorded different temperatures. The sheathed insulated thermocouples underestimated temperature measurements due to the heat leakages. The inlaid wire thermocouples parallel to the isotherm recorded the best temperature.
- The student Antonio Totaro will continue the collaboration with the Institute of Structural Engineering (IBK) at ETH Zürich, contributing to the progress of the fire tests field as exchange student. The topic of this work will be used as proposal for research in fields of:
    - Cross Laminated Timber;
    - Compartment fire;
    - Charring evaluation.
- The STSM work will be object of possible publication in "Fire and Material" journal. Moreover, the work will be presented for the final conference of COST Action FP1404 the 1st October in Switzerland.
- The confirmation of the successful execution is attached in Annex 1.

Annex 1 – Confirmation by Host Institution

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

2018-08-10

Letter of Confirmation

In the name of the host institution, ETH Zurich, Department of Civil, Environmental and Geomatics Engineering (D-BAUG), Institute of Structural Engineering (IBK) the undersigned, Professor Andrea Frangi confirms the successful execution of the STSM by Antonio Totaro within the COST Action FP1404.

The STSM took place between 2018-06-21 and 2018-07-18. The purpose of the STSM was to collect data and literature of timber members exposed non-standard fire tests. The collection is content of a separate Scientific Report to be submitted to the COST Action FP1404 representatives.

ETH Zürich
IBK – Timber Structures

Prof. Dr. Andrea Frangi

Annex 2 – Scientific Report

Fire safety use of bio-based building products

TEMPERATURE MEASUREMENTS IN WOOD SPECIMENS

Scientific report of STSM at ETH Zürich

21.06-18.07.2018

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Introduction

The EN 1995-1-2[1] defines the 300°C isotherm as the borderline between the char-layer and the residual cross-section. 300°C is the temperature where wood loses its stiffness and strength. Thus, the investigation of the 300°C isotherm rate is important to define the residual loadbearing capacity of timber members after a fire. The most common temperature probes are thermocouples. Several types and designs of thermocouples are available in the market; which can be installed in various possibilities.

In this work, the investigation of the charring has been performed on three Solid Timber Panels (STP) made of spruce timber. Two specimens have been equipped with inlaid wires (1.2x0.9 mm) and sheathed thermocouples (ø1.5 mm and 3.0 mm). Wires were installed parallel to the isotherm while the sheathed thermocouples were installed perpendicular to the isotherm drilled from the back side.

Two specimens have been produced to investigate the temperature measurements recorded by different measurement setups. One specimen has been performed to compare the charring with different test parameters.

Overview of performed work

Specimens

Spruce from region of Zurich was used to produce the specimens. The wooden boards were stored in a climate room at 20°C and 65% of ambient humidity. These conditions allowed getting 12% of moisture content in the wood [2]. The boards came from the same tree in such a way to have similar physical properties; thereby a high degree of combustion was achieved.

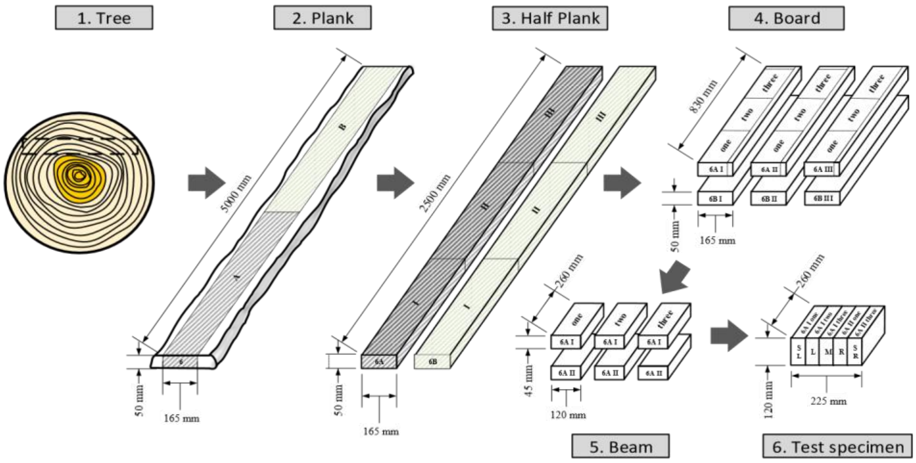

Figure 1: Scheme of the specimen production.

Boards were cut in beams with dimension of 260 mm x 120 mm x 45 mm (see Figure 1). The best five beams were selected to produce the specimen and the worst, with more defects, was discarded (see Figure 2). After the thermocouple installations in beams, they were attached with one-component adhesive. In the end, when the adhesive was cured, an aluminium tape was attached around the specimen (see Figure 2).

Figure 2: The beams of the specimen TS02

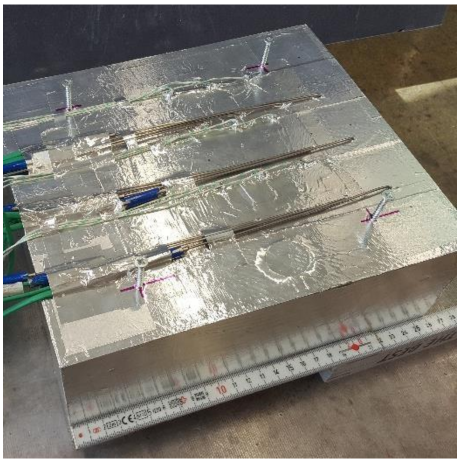

Figure 3: Aluminium tape around the specimen

Temperature Measurements

Temperatures were measured using two different thermocouples *design*: wire and sheathed. Both thermocouples were type K (Chromel-Alumel) which are the most common in fire tests.

The wire thermocouples need of a hot junction to allow the temperature measurement. In one side of the wire the metal wires were twisted without welding. Welding can be applied to guarantee electrical contact during the fire test, but it may increase the dimension of the hot junction and may lead to difficulties inserting the thermocouple in a borehole. Thus, the extremities were only twisted and cut as short as possible, i.e. 2 to 3 mm, to measure the temperature in a short area. According to the VDI-VDE 3511-4 [3] an incorrect installation of the thermocouples in a body with poor thermal conduction like wood disturbs the temperature distribution. For this reason, the thermocouples shall be fitted in such a way that the heat input from the body to be measured to the temperature sensor is considerably greater than the thermal leakage via the sensor wires. The solution was to embed the wire thermocouple parallel to the isotherm. The embedded length depends on the diameter of the wire. In EN 1363-1 [4] a minimal length of 50 mm is suggested.

To satisfy the suggestion mentioned above, thermocouples were installed from the side of the beam as shown in Figure 4. The hot junction of the thermocouples was installed in the middle of the beams at 22.5 mm depth. Wires were installed in the boreholes with 1.6 mm diameter, paying attention the heat insulation. The latter was pushed in the borehole together with the conductor wires.

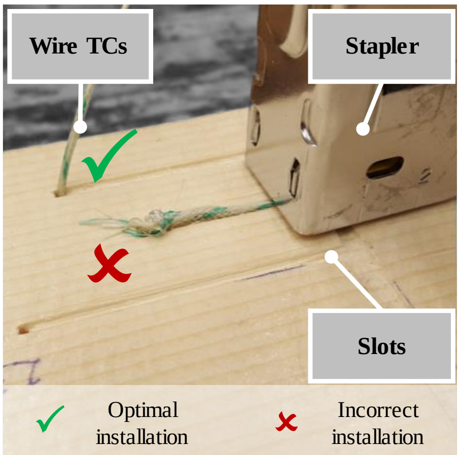

Figure 3: Installation of the wire thermocouples (TCs) in specimen TS03.

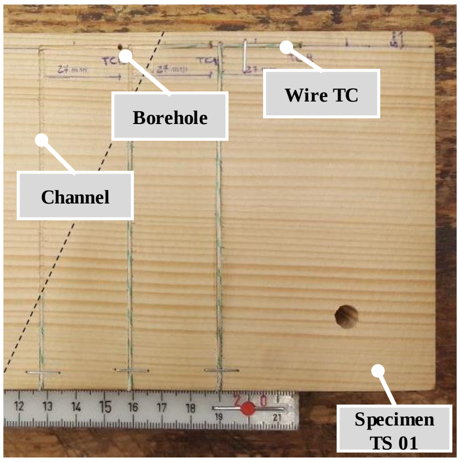

Figure 4: Installation of the inlaid wire thermocouples (TCs) in the specimen TS01.

The length of the boreholes was not enough to install the wire thermocouples in the isotherm for 50 mm. Thus, milled channels 1.5 mm width, at least 27 mm length, on side of the beams were made to extend the installation in the isotherm. At the end, the wire thermocouples were inserted and fixed by staple.

The sheathed thermocouples were installed in the boreholes perpendicular to the isotherm. The boreholes were drilled by drill bit 150 mm long because the beams were 120 mm height. This means that slightly errors during drilling can happened and lead to a significant error when drilled perpendicular to the isotherm. The long and thin drill bits can bend easily during the drilling, especially at the beginning. Thus, the issue was reduced using a bench drill, increasing the speed of the driller and pushing the drill bit very slow.

The installation of the thermocouples in the boreholes could be divided in *loose* and *tight*. It depended whether the borehole dimeter was greater or equal to the thermocouple diameter. The wire thermocouples were installed in loose boreholes because they have too much friction and too few stability to be pushed in a tight boreholes. The sheathed thermocouples were installed in three different length (see *Figure 6*) of the tight part at the tip of the thermocouples: 5 mm, 50 mm and 100 mm.

Figure 6: Installation of insulated tube thermocouples in boreholes.

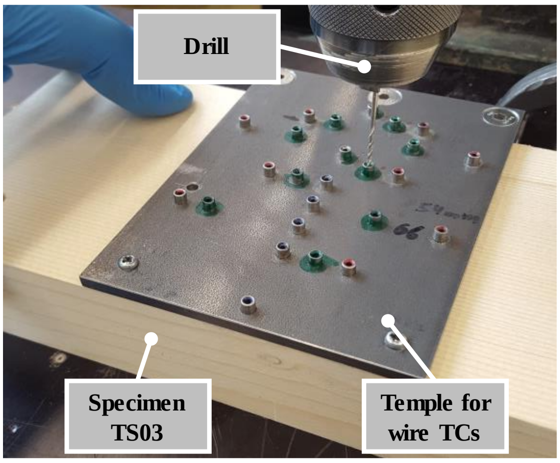

Figure 7: Drilling of boreholes to install the wire thermocouples (TCs).

In the specimens TS01 and TS02, where the insulated tube thermocouples were installed, also wire thermocouples were installed to compare the measurements. All thermocouples were installed with 15 mm distance to each others to minimize the effect of locally varying charring rates, but to keep a distance that also limits the influence from one thermocouple to the other. In the specimen TS03 only wire thermocouples were installed which were located in middle part of the beam as shown in *Figure 7*. The template allowed to drill boreholes at the same position in every beam. The thermocouples were designated, as described in [5].

Tests

The specimens were exposed to a constant incident radiation heat flux (non-standard fire exposure). The aluminium tape attached to all sides, except the exposed side, prevented the increase of the charring. On the side, moreover, to simulate the one-dimensional combustion, insulation was installed around the specimen.

Table 1: Test parameters

Specimen	Exposure level [kW/m^2]	Test time [min]
TS01	50 (⚡)	20
TS02	50 (⚡)	35
TS03	75 (⚡⚡)	40

The specimens were subjected to a controlled incident radiation. The Table 1 gives more information about the test parameters.

Results

In *Figure 8*, *Figure 9* and *Figure 10* the temperature measurements of the tests performed are shown. The legend of the plots is given in *Figure 11*. The black dotted line represents the average surface temperature (two K-t-i-0.2/1.5/*-*). The test times were different for the particular test.

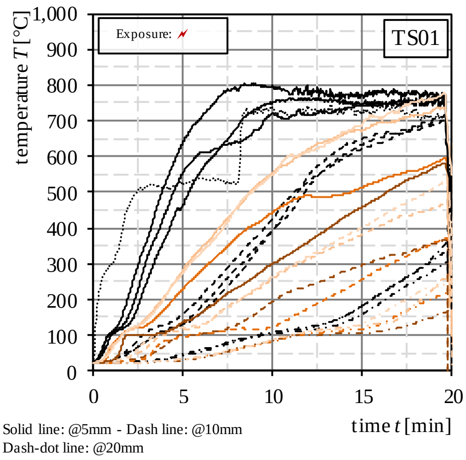

Figure 8: Temperature time relationship in the specimen TS01; legend see Figure 11.

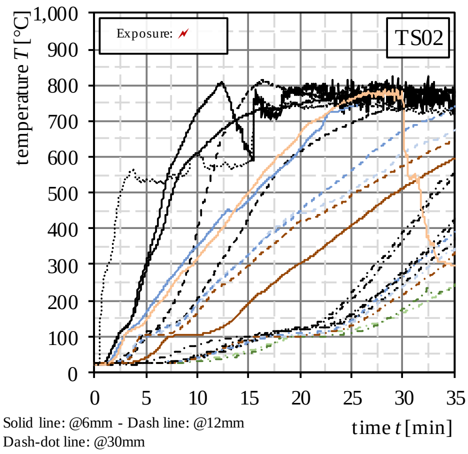

Figure 9: Temperature time relationship in the specimen TS02; legend see Figure 11.

The temperature trends show higher values for inlaid wire thermocouples installed parallel to the isotherm, while thermocouples installed perpendicular to the isotherm show different trends in function of the measurement setups. An installation error was possible among the thermocouples installed at the same depth, as well as the charring of specimens was not perfectly homogeneous. However, these reasons do not justify the significantly different temperature measurements.

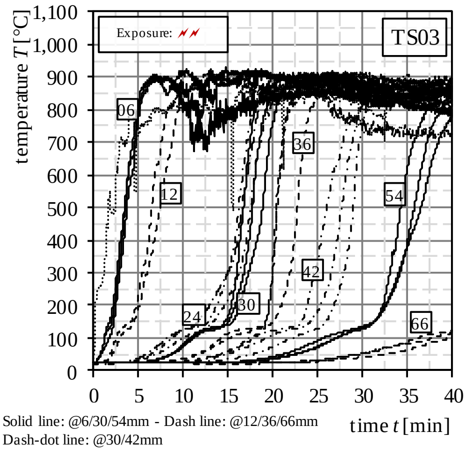

Figure 10: Temperature time relationship in the specimen TS03; legend see Figure 11.

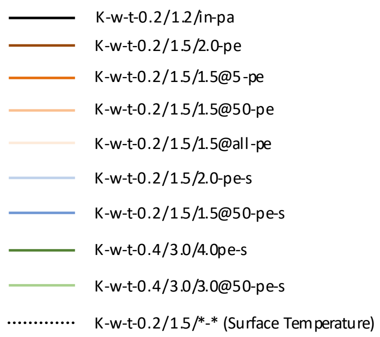

Figure 11: Legend of Figure 8, Figure 9 and Figure 10.

To define which measurement setup recoded the correct temperature, the measurement of the residual cross-section can be used as reference. The EN 1995-1-2 [1] defines the borderline between the char layer and the residual cross-section should as the position of the 300-degree isotherm. The time when 300°C were detected by thermocouples were used to draw the plots shown in Figure *12* and Figure *13*.

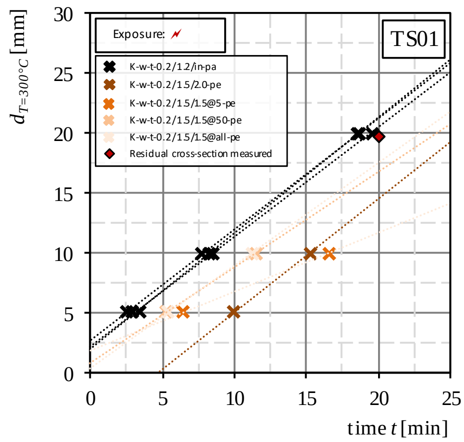

Figure 12: Char-line depth-time relationship of the specimen TS01.

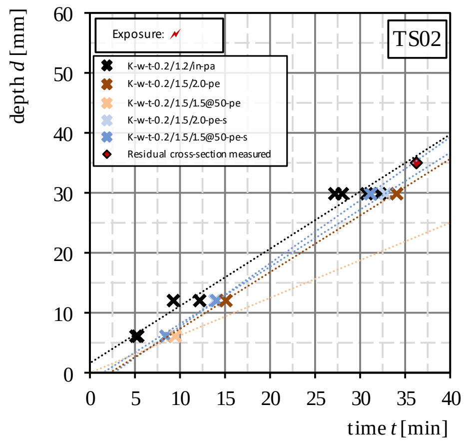

Figure 13: Char-line depth-time relationship of the specimen TS02.

The trend lines were determined to analyse the envelop of the char-line. The residual cross-section (red rhombus symbol) was measured after that char layer was brushed-out. The results of the specimen TS02 were rejected as considered as not reliable because the heat went through the sides of the specimen burning the plastic sheath of the thermocouples compromising measurements.

As explained before, two thermocouples K-t-i-0.2/1.5/*-* recorded the surface temperature. When the thermal exposure test started, the panel heated the surface specimen. Water in the specimen evaporated producing steam and the pyrolysis started producing flammable gases. The typical trend of surface temperature is clearly visible in Figure *8*: temperature increased until a plateau at ca. 4min and then, when the specimen burned with flame, they increased immediately to a new higher plateau at ca. 8min. The surface temperature was lower than temperature inside the specimen. This is considered as incorrect because the surface was directly exposed to the radiation. Thermocouples K-t-i-0.2/1.5/*-* recorded a lower temperature due to the influence of the air ambient temperature. The measurement error growths with increase of the temperature difference between surface temperature and the ambient temperature.

Conclusions

The first important step in fire safety engineering is the correct evaluation of the temperature to describe the charring of timber and the temperature profile in the virgin wood. Wood is a material with a low thermal conductivity ($\lambda_{20°C} \approx 0.10\ W/mK$) and an incorrect installation of the thermocouples can lead to an incorrect temperature measurement. Installing in the same specimen more temperature measurement setups the most reliable measurements were recorded by inlaid wire thermocouples parallel to the isotherms. The other installation setups underestimated the temperatures. The thermocouples installed perpendicular to the isotherm, transferred the heat away from the hot junction due to the thermal leakages of the thermocouple and the cool air the surrounding.

Acknowledgments

The Author would like to express his gratitude to my supervisor Joachim Schmid for his continuous support of my study, for his patience, motivation, enthusiasm, and immense knowledge. A special thanks goes to Prof. Dr. Andrea Frangi for giving me the possibility to contribute to the project “Natural Fire Exposure of Timber Structures” and the COST FP1404 for give me the possibility to perform the STSM and join to the final conference in Switzerland.

References

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