STSM report COST FP1404

- The purpose of the STSM reported here was to collect data and literature in the field of fire testing of timber members and structures with focus on non-standard fire exposures.
- A comprehensive literature review was performed, the result is presented in a report (in the Annex 2).
- The main results are a list of relevant literature where data is presented which can be used to develop calculation models for non-standard fire exposure of timber members.
- It is aimed for a cooperation between all members of the COST FP1404 WG2 TG “natural fire design”. The TG members are identified and further steps will be discussed within this TG.
- Publications for the students PhD work will partly base on the outcomes of this STSM.
- The confirmation of ETH, the host of this STSM, is attached (Annex 1).

Annex 1 – Confirmation by the host institution

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

2015-11-26

Letter of Confirmation

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

The STSM took place between 2015-10-08 and 2015-10-28. 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.

Professor Andrea Frangi

Annex 2 – Scientific report
Literature review on non-standard fire tests

Report by Joachim Schmid

1 List of aberrations

AST	Adiabatic Surface Temperature
CLT	Cross laminated timber
COST	European Cooperation in Science and Technology
iBMB	Institute of Building Materials, Concrete Construction and Fire Protection, Brunswick, Germany
RCSM	Reduced cross-section method

2 Summary - Scientific tests and test programs with non-standard fire curves

Table 1. Overview of non-standard fire exposure tests.

Reference	Tests	Outcome
(Hakkarainen, n.d.*)*	Protected and unprotected room fires	Plume ignition risks fire spread to upper levels; limited protection may have no effect.
(J. König et al. 1997)	Model scale furnace tests	Temperature measurements later used to develop a design model (J. König and Walleij 2000) implemented in the Annex B of Eurocode for fire design of timber. Charring continued in the decay phase even for low temperatures.
(Fornather, Jochen and Bergmeister 2000; Fornather and Bergmeister 2001)	Model scale furnace tests	Linear charring rate of Eurocode 5 was approved for standard fire exposure; non-linear charring was observed for parametric fire curves.
(Frangi, Andrea, Bochicchio, and Lauriola 2008)	CLT building fire tests (initially protected)	The CLT building system allows safe firefighting.
(Leikanger Friquin 2010)	CLT members (furnace)	The total fire load consists of the fire load in the room and the char layer (iterative process).
(McGregor 2013)	CLT room fire tests (initially protected and unprotected)	Gypsum plasterboards in natural fires don't show earlier failure than in standard fire tests. Detailed charring report.
(Hopkin, 2010)	König (furnace) and with timber frame assemblies (furnace)	Modified material properties for temperatures higher than 500°C.
(Frangi and Fontana 2005)	Hotel modules (exterior)	Burn out seem to be unlikely for unsprinklered wooden compartments.
(Lange et al. 2015)	Beams exposed to standard and non-standard fire tests	A comprehensive statistical evaluation of the charring rate and a corresponding zero-strength layer considerable deviating from the Eurocode model (RCSM).
(Roy 2015)	Ad hoc tests with radiant heat panel exposed CLT specimens	Air flow and surface heat flux limits for sustaining combustion.

3 Introduction

The literature review in this study focuses on the available information regarding non-standard fire design and testing of timber structures, timber members and wood-based products. General information about non-standard fire design is available in many references and is not repeated here. Literature addressing combustibility in tests and theoretical thoughts are summarized here to follow up the conclusions which might have impact on this study.

This report is a STSM (Short Term Scientific Mission) report of the COST Action FP1404, Fire Safe Use of Bio-Based Building Products during the first of four years lifetime. During the first year the goals are to collect knowledge in different topics related to the four available Working Groups. This should allow further identification of knowledge gaps and allow coordinated further research performed ideally in close cooperation of the participating countries.

3.1 Fire design according to European standards

The Eurocode is a series of European standards (EN standards) to overcome national borders with respect to design procedures for buildings. The first drafting was done during the 80s and 90s based on a public procurement Directive in 1971 [Joint research centre, https://ec.europa.eu/jrc/].

The possibility for performance based design (PBD) was included for the fire design of buildings in the codes (part 1-2) for design of steel, concrete, timber and masonry structures [EN 1993-1-2, EN 1994-1-2, EN 1995-1-2, EN 1996-1-2]. The European approach incorporated the fire design in the material design standards. Although a European approach exists, the national regulation and traditions respectively give large differences in the fire curves. The national different view on the use of the fire curves was content of a previous COST Action, C26, Urban Habitat Constructions under Catastrophic Events(Mazzolani 2010). A survey showed that the definition of the fire loads vary significantly. Limitations exist using fire load densities, localized fire but also the parametric temperature-time curves. Further, an approval for the usage might be needed, the range of documentation differs as well as a certification process for designers might be required.

3.2 Fire testing

Fire resistance tests for testing the separation function or load-bearing resistance is done in Europe using the standards series EN 1363 for the general requirements. Nominal time temperature curves are specified defining temperature-time fire curves depending on the time only. In part EN 1363-1 three different curves are given, see Figure 1.

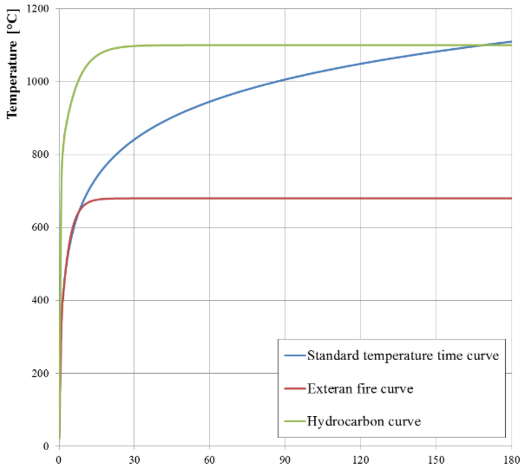

Figure 1. Different nominal fire curves specified in EN 1363-1.

Together with the plate thermometer [Wickström, EN 1363-1] the fire curves shown in Figure 1 are a tool to compare structural elements and assemblies with each other.

Apart from the nominal fire curves design fire curves exist. In general they consider the specific boundary conditions of the compartment to predict the fire development within the specific compartment. The lack of a general agreement on fire curves (see even Capture 0) does in general imply deviating boundary conditions for fire tests performed in mainly nationally performed projects dealing with non-standard fire design.

4 Available research investigating the effect of non-standard fire curves

4.1 General

In this chapter only research is included where tests have been performed to investigate the effect of non-standard fires on timber members. Fire tests on combustible facades (external fire curves) as are not considered in the following.

4.2 Wood construction behaviour in natural/parametric fires, SWE, 1995(J. König et al. 1997)

Loaded fire tests are performed with timber studs exposed to different fire curves. Temperature measurements at different positions are recorded. Data was used to develop a design model for predicting the thermal response as well the mechanical behaviour in standard fire (J. König and Walleij 2000). Applied protection in the tests led to a delayed temperature rise in the timber cross-sections, thus resulting in different fire exposures of the assembly (chosen fire curve) and the timber member (depending on the applied fire protection).

4.3 Model scale fire tests to investigate the charring rate in different fire behaviours by Fornather et al., AT, 2001 (Fornather, Jochen and Bergmeister 2000; Fornather and Bergmeister 2001)

Model scale tests were performed with timber using the standard fire exposure, a slow heating curve and a parametric fire design curves. The authors presents a charring rate and temperature gradients observed. In addition the furnace pressure was varied as well as the temperature control devices. To measure the temperature inside the wood samples, tube thermocouples were used (∅ 0.5 mm), further a new technique was developed to measure the residual cross section with drill samples. This technique allowed the measurement of the moisture distribution in the residual cross-section. Increased pressure had an influence on charring when gaps were close to the measurement points, the usage of a PT to control the furnace did not change the charring depth results. The authors conclude that the standard-fire results in the most extreme charring and that the use of parametric curves does not lead automatically to smaller timber cross-section. Solid timber showed slightly higher charring rates (ca. 10%) than glulam timber. The orientation of the annual rings was recorded but no correlation between the orientation and the charring rate was observed.

4.4 Full-scale tests with initially unprotected and protected timber construction, FIN, 2002 (Hakkarainen, n.d.)

Full scale room fire tests with initially protected and different building assemblies (light and heavy timber construction) were performed. The fire compartment was about the size of an ISO room fire compartment with one opening only (“ISO 9705:1993 - Fire Tests -- Full-Scale Room Test for Surface Products” 2015). Temperature measurements (gas temperature (Leikanger Friquin 2010)) gave low maximum temperatures for the heavy timber constructions (lower than predicted by parametric fire curves for the compartment) while it was between 1000 and 1200°C for sufficiently protected constructions independent on the construction (light and heavy timber-).
It is concluded that the insufficient availability of oxygen in comparison to the production of pyrolysis gases kept the maximum temperature low for heavy timber members. However the plume ignited leaving the compartment which may accelerate vertical fire spread on the façade if done in practice.

4.5 Full scale tests on wooden modular hotels, 2005, CH (Frangi and Fontana 2005)

Full scale fire tests on wooden modular hotel compartments (area ca. 3 m x 6.5 m x 3 m; light frame timber construction) were performed to investigate the efficiency of different fire safety concepts. Fire growth and spread due to combustible and non-combustible surfaces was compared. A calculated total fire load density of about 365 MJ/m^2 was specified for the non-combustible surface modules and about 2.5 times higher for modules with combustible wall and ceiling linings. With the tests it was proven that the sprinkler system was capable to compensate the influence of a combustible structure on the fire safety. When the sprinkler system was not in use, flash over occurred at about 4 min (combustible linings) and about 6.5 min (non-combustible linings). As observed in (Hakkarainen, n.d.) the external burning out of the window was much more severe than for the modules with non-combustible linings. Due to lower temperature measurements in the rear of the modules the authors assumes lower oxygen content in this area. Temperatures exceeded those of the ISO 834 standard fire (“ISO 834-1:1999 - Fire-Resistance Tests -- Elements of Building Construction -- Part 1: General Requirements” 2015). No significant differences of the room temperature was measured in compartments with or without combustible linings. Simulations with commercial software to predict the fire development deviated significantly from the measured temperature. The authors see the reason for that in the failure (fall-off) of the gypsum plasterboards. One test allowed complete burnout, however, further information is not given.

4.6 Natural full-scale fire test on a 3 storey CLT timber building, IT, 2008 (Frangi, Andrea, Bochicchio, and Lauriola 2008)

The authors conducted a natural fire test of a CLT building. The charring depths was determined using a mesh of 300 mm after the tests and resulted in 5 to 10 mm charring. Intervention of the fire brigade terminated the fire after the partial failure of the fire protection system (gypsum plasterboards). Room temperature measurements are available in several positions (TC and PT). Further pressure was measured and gas analysed.

4.7 Fire tests on heavy timber elements, NOR, 2010 (Leikanger Friquin 2010)

An extensive literature review specifies properties influencing the charring rate of large timber elements. Characteristics affecting the charring behaviour are (i) density, (ii) moisture content, (iii) chemical composition, (iv) grain orientation, (v) permeability, (vi) scale effect, (vii) char contraction and (viii) char oxidation and external factors such as (ix) thermal exposure, (x) oxygen concentration and (xi) opening factor. The documented change of these characteristics found in other studies are collected in tables specifying the source. The overall ranges are given in this report in Table 2.

Table 2. Material characteristics affecting the charring rate as documented in (Leikanger Friquin 2010).

	Characteristic	Investigated range (all studies)	Max. change
(i)	Density	343kg/m^3 to 691 kg/m^3	28%
-	Hardwood vs. softwood	Different species	54%
(ii)	Moisture content	0% to 21%	31%
(iii)	Chemical composition	Klason lignin 19.8% to 37.1%	29%
(iv)	Grain orientation		
(v)	Permeability	Penetration depth of chemical treatment (3 to 47 mm) and oxygen permeability index (9.76 to 10.75)	52%
(vii)	Char contraction[1)]	0.784 to 0.862 and 0.594 to 0.703	12%
	External heat flux	17.8kW/m^2 to 75kw/m^2	104%
(x)	Oxygen content	4% to 10%	8%
(xi)	Opening factor	0.04 to 0.12 m$^{-1/2}$	45%
[1)] The factor describes the ratio of the charring depth and the char layer depth.			

Three laboratory experiments on large cross-laminated timber panels exposed to three different temperature-time curves were performed as part of this research. It was found that the charring rate is affected by the growth rate of the fire and the maximum temperature but showing a wide scatter.

4.8 Fire tests with protected and unprotected CLT elements, CAN, 2012 (McGregor 2013)

The author performed a series of five tests in a room slightly larger than the ISO room. The HRR was recorded as well as room temperatures (TC trees, one PT) and charring rates. TC (tube -) were used to measure the temperatures within the CLT elements to follow the char line, thus the TCs were installed perpendicular to the isotherms. Tests were performed initially protected (gypsum plasterboards) as well as unprotected. Adhesive failure was observed (delamination) in some cases which influenced to the overall fire development. The tests were terminated as a burn-out was not expected following the temperature development in the compartment. A special test procedure was used to determine the contribution of the CLT to the fire development and the heat release rate respectively. During the growth phase the PT showed higher temperature than the average temperature of the TC trees, see Figure 2.

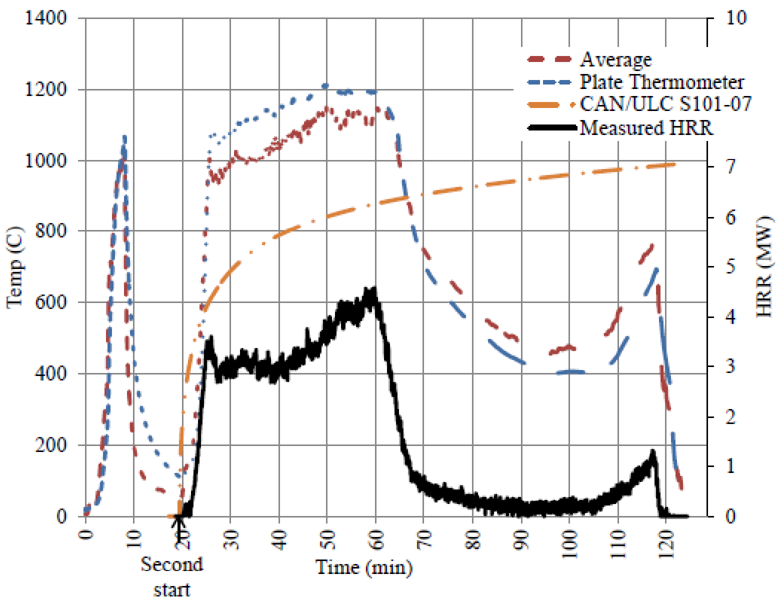

Figure 2. Time-temperature fire curves and HRR of tests presented in (McGregor 2013).

During tests, delamination of wall member layers resulted in a rise of the temperature in the decay phase. After the test the char was removed and the residual cross-section measured to estimate the charring depth. As observed by other authors (Hakkarainen, n.d.), the room temperature dropped in the flashover phase.

4.9 Loaded large-scale fire tests on glulam beams (Lange et al. 2015)

A comprehensive comparison of the effect of standard an non-standard fire exposure on the load-bearing capacity of glulam beams was recently performed by Lange et al. (Lange et al. 2015). A novel test set-up allowing simultaneously testing of eight beams with different loads was presented. Further, a comprehensive analysis on the charring rate including the scatter of this important factor was conducted. Further the so called zero-strength layer (depth to take into account the effect of heat on the reduction of strength and stiffness) was investigated for the tested fire exposures. The calculation was performed using backwards calculation according to a proposed methodology (Schmid, Just, et al. 2014).

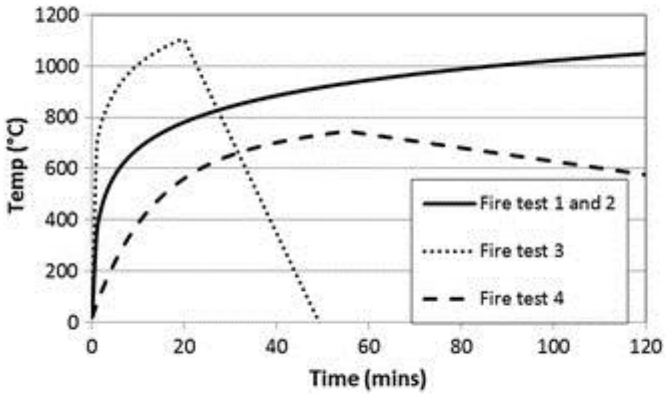

Figure 3. Time-temperature fire curves of tests presented in (Lange et al. 2015).

As fire exposure parametric fire curves were chosen. Tests 1 (unloaded) and 2 are close to the ISO 834 standard fire exposure also specified in EN 1363-1. Other tests assumed a “short hot fire” (test 3) and a “long cool fire” (test 4). Test results showed a notional charring rate for the standard fire exposure of about 0.8 mm/min (mean) and an increased charring rate of about 1.1 mm/min for the “short hot fire”. The zero-strength layer was found to be slightly higher than double the value given in Eurocode 5 (7 mm) for the standard fire and the “long cool fire” and slightly higher than 7 mm for the “short hot fire”.

4.10 Fire tests to investigate the charring behaviour during the decay phase (Kinjo and Yusa 2014)

Fire tests following the standard fire exposure but with focus on the decay phase were performed by the authors. One reference test, two unloaded tests, two tests with load application after and two loaded fire tests were performed with Japanese larch glulam beams. It was found that charring was close to zero when the burners were turned off after one hour ISO 834 (“ISO 834-1:1999 - Fire-Resistance Tests -- Elements of Building Construction -- Part 1: General Requirements” 2015) fire exposure, independent of the ventilation conditions in the furnace. Corresponding zero strength layers were considerable higher than specified in Eurocode 5(“DIN EN 1995-1-2:2010-12 - Beuth.de” 2015). Conducted material tests could not explain the observed losses in load-bearing capacity.

4.11 Fire tests on unloaded glulam beams (Mansson et al. 2015)

As continuation of the study described in Section 4.9 fire tests in a mini furnace were performed. The fire exposures were equal to those of (Lange et al. 2015). Different from full-scale tests the furnace temperature was controlled using a shielded thermocouple. Charring rates were analysed for the three fire exposures, however subdivided in the different phases. Depending on the observed phase the results show significant deviation of the notional charring rate of 0.7 mm/min given in (“DIN EN 1995-1-2:2010-12 - Beuth.de” 2015).

Table 3. Measured charring rates in different phases of the fire exposures (Lange et al. 2015).

Notional charring rate (mm/min)	fire curve	Phases	total exposure duration
1.0	Standard fire		60 minutes
0.8	Standard fire		90 minutes
0.9	Short hot	including cooling phase	60 minutes
2.0	Short hot	Heating phase only	25 minutes
0.6	Long-cool	including cooling phase	120 minutes
0.9	Long-cool	Heating phase only	60 minutes

4.12 Tests with a radiation panel to evaluate the self-extinguishing ability of fires (Roy 2015)

Although no fire resistance tests according to a traditional understanding were performed in the study results may contain significant information. The author conducted tests to investigate burn out of solid timber construction in bench tests (cone calorimeter). Burning of untreated massive timber member after flash over is described in a flaming combustion phase followed by smouldering combustion phase which ends in self-extinguishment under certain boundary conditions.

In the experiments where CLT specimens were exposed to a heat flux created by a radiant heat panel up to 75 kW/m2. The temperature measurements within a CLT compartment during a fire test (McGregor 2013) were transferred to heat flux loads used in bench tests, see Figure 4.

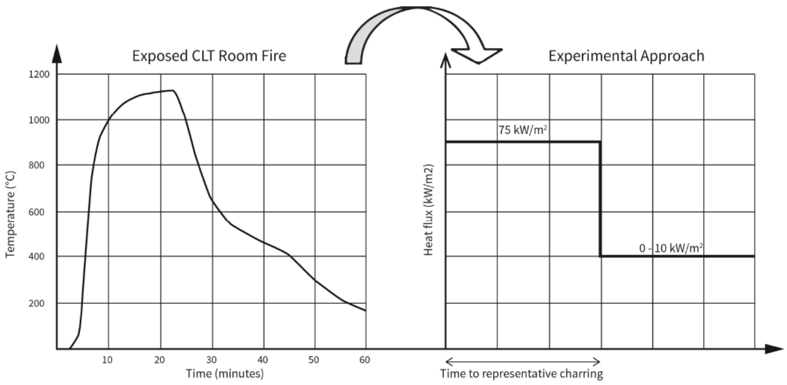

Figure 4. Temperature load of fire tests converted to heat flux to the surface loads (Roy 2015).

The temperature inside the specimen, on the surface, the loss of mass and heat release rate was measured.

A second test series modelled design fires. It was calculated that a heat flux to the surface of 250 kW/m2 would appear in these fires; the authors chose a HRR of 63 kW for the tests considering the size of the ad-hoc test set-up (compartment 50 cm x 50 cm x 50 cm). In this tests CLT samples were mounted on different sides of the compartment. A threshold heat flux to the surface of 6 kW/m2 (at 0,5m/s air flow) is specified as limit for self-extinguishing.

5 Models for non-standard fire tests

5.1 General

Models to describe the performance of timber structures exposed to non-standard fires are either of very general nature or specialized for a type of application, e.g. light weight timber frame walls. Below some examples are given.

Charring rates for both nominal- (standard-) and parametric fire developments can be found in EN 1995-1-2 (“DIN EN 1995-1-2:2010-12 - Beuth.de” 2015). Besides the charring, the change of material characteristics such as strength and stiffness of the residual, partly heated, cross-section has to be taken into account deriving the load-bearing capacity.

General FEM software needs the thermal conductivity, the density and the heat capacity as function of the material temperature for thermal modelling. Data is available in literature, e.g. (Hurley et al. 2016) or specialized on timber structures in (Ostman et al. 2010). It should be noted that the range of direct measurements is limited by the measurement equipment influencing the application range.

The material properties of timber exposed to fire in Eurocode 5 (“DIN EN 1995-1-2:2010-12 - Beuth.de” 2015) are considered as effective material properties as the effect of fire on the material is considered using the change of the characteristics density, thermal conductivity and heat capacity only; effects as mass transfer due to the movement of e.g. water are not considered (Jürgen König 2005). The effective material properties are developed by backwards calculation based on temperature measurements in fire resistance tests of initially protected and initially unprotected timber members (Schmid, König, and Just 2012). Due to the fact that the properties were fitted to specific fire exposures these effective material properties may not allow general application to other fire exposures (Jürgen König 2006).

5.2 Approach by König, Modification of the gas temperature (Jürgen König 2006)

König (Jürgen König 2006) states the need to consider the different boundary conditions in the fully developed fire after flash-over and in the decay phase to predict the heating of timber members. König observed higher temperatures in the char layer compared to the decreasing gas temperature in the decay phase. Thus, he proposes to take this effect into account by means of an increased effective gas temperature to consider glowing combustion. The latter has been modelled by Fredlund (Fredlund 1988), however there is no information about a successful re-application of the model.

5.3 Approach by Hopkin, Modification of the material characteristics (Hopkin et al. 2011)

Another approach was published by Hopkin et al. The approach addresses the limitations of the Eurocode 5 model for non-standard fire exposure. The authors aimed for effective material properties for timber which can be used in commercial FEM software. These effective properties of timber were developed for the char layer in the heating phase. Further the application of such effective properties in the cooling phase are discussed here.

5.4 Comparison between experimental results, analytical methods and numerical analysis (Salminen 2015)

The paper focuses on the prediction of the residual cross-section for non-standard fire exposure. The author used studies with documented non-standard fire tests (Hakkarainen, n.d.; J. König et al. 1997; Kinjo and Yusa 2014). For calculation of the continuous charring observed during the decay phase in fire resistance tests (J. König et al. 1997) a not further specified heat flux at the timber surface in contact with the fire compartment was taken into account by simulations. The author found a good agreement between calculations of the charring behaviour during the heating phase by means of modified material properties for wood as proposed by other authors (Hopkin et al. 2011).

5.5 Connection between tests of different scales

Test results and test documentation is available for three different kind of tests. These can be grouped in (i) fire resistance tests in standard testing furnaces following non-standard fire curves, (ii) bench tests with samples exposed to a defined incident heat flux to a specimen's surface (e.g. cone-calorimeter tests) and (iii) room fire tests which are performed in outdoors or indoors.

Babrauskas (Babrauskas 2005) compared results from fire resistance tests to standard fires with bench tests and constant incident heat fluxes and room fire tests. He found ranges between 0.5 mm/min and 0.8 mm/min for typical densities for fire exposures up to 30 and 60 minutes. Further he presents results of bench tests with charring rates up to about 100 mm/min for about 3000 kW/m^2 (brief exposures). Babrauskas reported a strong dependency of the effect of the time period (typically 15 to 45 minutes) for cone calorimeter tests. Babrauskas approach to connect the bench tests with the fire resistance tests uses documented heat flux measurements in furnaces. Babrauskas specifies the average heat flux for the first 60 minutes of fire exposure which is about between 70 and 100 kW/m^2. d

6 Models for wood burning

There are numerous studies on the behaviour of the material wood in fire. General models are based on the Fourier equation and were adopted using constant or temperature depending material properties by different authors. Pyrolysis models presented in the past (Lizhong et al. 2007; M Shearpoint and Quintiere 2000; Lautenberger and Fernandez-Pello 2009) base on the fundamentals of the mathematical decomposition model for wood presented by Kung (Kung 1972). Kungs model is based on the Arrhenius decomposition reaction and results in parabolic partial differential equations with specified boundary conditions. Kung solved the equations numerically aware of the limited knowledge regarding the material properties.

Lautenberger et al. see limitations in TGA test environments due to the unrealistic penetration of the ambient air into the samples (Lautenberger and Fernandez-Pello 2009). This might explain why TGA developed char models need significant calibration factors.

One limitations of the pyrolysis models may be the limited time these models are verified, often up to 10 minutes only, as well as the constant heat flux exposures.

7 Conclusions and suggestions for further investigations

Recently a comprehensive document with suggestions for further investigations was published(Buchanan, Ostman, and Frangi 2014). This section focuses on the needs with respect to simulation techniques in connection to the data collection, fire testing.

In general the techniques of temperature measurements are poorly described in fire test reports and documentation. Reporting fire tests, documents often specify a room temperature, however, it remains unclear which kind of temperature was measured, e.g. if the gas temperature has been measured by means of small thermocouples or if an AST was measured.

Temperature measurements within the timber sections are rarely included in the documentation. While the diameter of the TC seem to have little influence on the temperature measurement, the direction of the hole (parallel or orthogonally to the isotherms) and the design of the hot junction (e.g. welded or by means of metal connectors) may influence the result. The diameter of the bore hole may influence the measurement due to convention in the void for larger diameters but the diameter itself affects the connection of the temperature measurement point to the position in the cross-section.

It seems that not only the migration of mass seem to be a major problem but also the change of the depth of the solid itself. It is unclear how the phenomenon of char contraction(White 2015) can be addressed at the moment which prevents the successful application of FEM.

In several discussions (CIB W18, INTER) the Eurocode 5 material properties in the fire part are questioned. These effective properties are used for modelling in commercial Ongoing research investigating the effect of non-standard fire curves

8.1 General

As the timber industry expects advantages designing timber structures exposed to non-standard fires, e.g. considering specific, lower fire load densities (e.g. in hotels), very ambition projects are ongoing at the moment. However, available studies are a result of earlier initiatives which contributed to the topic but did not result in a general valid approach for the structural timber design.

8.2 UK initiatives

At The University of Edinburgh a new testing methodology based on heat radiant panel ("H-TRIS) has been pushed forward recently (Maluk et al. 2012). Originally developed for concrete structures it has been applied to timber members such as CLT. Advantages of the testing methodology are specified as increased reliability and lower testing time and costs. However, the testing procedure has to be adjusted corresponding to a fire test.

8.3 CH initiatives

Specialized on combining models at ambient temperature with fire design the strength of ETH initiatives are the simulation of fire tests covering the scatter of the material. A general weakness of all fire tests is the poor description of the material properties of the tested timber member (Schmid, Klippel, et al. 2014). An accurate prediction of the load bearing capacity is needed to evaluate the influence of heat on the change of material characteristics in the residual cross-section (Schmid, Just, et al. 2014). Combining the prediction model for timber members based on comprehensive material investigations (Fink 2014) with thermal simulations the number of cost and money consuming fire tests may be minimized. In one project the fife percentile value of the material timber in the fire situation is under investigation. The variation of the source material will be considered. The approach was already used to compare the influence of finger-joints in glulam with other defects in standard fire (Klippel 2014).

8.4 SE initiatives

Investigations in Sweden have traditionally focused on the end-user application of the results. Aim of studies have been easy-to-use models in Eurocode 5 ("DIN EN 1995-1-2:2010-12 - Beuth.de" 2015). The actual design procedure is the RCSM using an effective residual cross-section. However, recent analysis of a comprehensive collection of standard fire tests question the procedure (Schmid, Klippel, et al. 2014). Full-scale testing of load-bearing elements showed expected deviations in case of non-standard fire exposure (Lange et al. 2015). At the moment, the charring rate for different fire exposures are under investigation. A COST Action (COST Action FP1404) was initiated to coordinate further research with respect to structural members (WG2) where a Task Group on non-standard fires was started. The reliability of timber structures is one focus of actual research.

8.5 GER initiatives

Recent investigations at TUM compare different fire design procedures as well as modelling of the response of timber members in different fire scenarios. The studies undertaken showed that the different national regulations may lead to different design fires which may result in different testing condition. Thus the comparison of test results may be very complex. While the parametric fire curves are usually accepted in UK and Scandinavia, other countries (e.g. Germany) use a considerable different temperature drop rate in the decay phase. The present differences do not allow the development of simple effective material properties. (Werther 2016)

8.6 SLO initiatives

Simulation techniques were recently developed to consider charring and heating of the timber member including mass flow. For the thermal analysis Fourier partial differential equation are used. The scatter of the material properties (density, thermal conductivity and moisture coefficient) are considered using a probabilistic approach. The outcome will be presented at among others WCTE 2016. (Pečenko 2016)

9 Acknowledgements

The author expresses acknowledgements to COST supporting this literature study in the framework of an STSM which was performed at ETH Zurich, the host institute which provided the working environment as well as the Swedish research fund “FORMAS” providing financial funding to investigate natural fires and timber structures.

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