COST Action FP1404
Fire Safe Use of Bio-Based Building Products

Book of abstracts of COST FP 1404 MC and WG meeting:
"Dissemination, standardization and implementation of novel improvements"

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Dear experts,

The meeting in Prague represents a mile-stone of the COST Action FP1404, Fire Safe Use of Bio-Based Building Products. In the last two years, 13 task groups and about 150 documents have been created, and the programme was supported by the EU with about 150,000€.

Researchers sometimes consider COST Actions as a network of travellers rather than active experts. As chair and vice chair of this Action we also had this concern at the beginning, but at this point in time we can report on very active groups which have created not only a range of useful outputs but also a platform for stimulating exchange of information and creative energy, which has been acknowledged by several experts so far. However, without individual commitment and team work, possibilities for this inspiring environment are limited. We do hope that you have found your task group within this COST Action that gives you vitality to make your business area and your country to push the borders for sustainable bio-based building materials while ensuring the fire safety of these exciting new buildings.

The meeting in Prague attracted about 60 experts from all over the world including Canada and Japan. Presentations were given on national challenges and state-of-the-art in fire safe use of bio-based building products of countries that recently joined the Action. Highly specialized contributions were also delivered on firefighting and experiences of tests with combustible materials.

Together with the WG4 leaders, we collected the abstracts within this book to provide the experts with information on different areas. We hope you will continue to work with us for the next two years and contribute to the success of this Action.

This book contains proceedings of the annual COST Actions meeting in Prague and includes 17 abstracts from different themes covering the topics of technical working groups of the COST action FP1404 and 1 abstract covering the report from the training school held at the University of Edinburgh, UK, 2016. This book of abstracts has been subdivided into following themes:

WG1 - Contribution of bio-based materials to the fire development
WG2 - Structural Elements made of bio-based building materials and detailing
WG3 - Regulations for fire safety of bio-based building materials
WG4 - Dissemination

Dest Regards,

Joachim Schmid, chair of FP1404
Massimo Fragiacomo, vice-chair of FP1404
Tomaž Hozjan and David Lange, WG4 Leaders
Working Group 1
Contribution of bio-based materials to the fire development
Smouldering behaviour of bio-based building materials

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Keywords: pyrolysis, oxidation, timber, hemp, cellulosic materials

Smouldering combustion is the slow, low temperature flameless form of combustion sustained by the heat evolved from the heterogeneous oxidation of solid fuels [1]. Typically smouldering has not been considered a substantial risk to constriction materials however, the adoption of cellulose-based materials requires that the risks posed by smouldering are explicitly addressed. This presentation will briefly discuss the process of smouldering combustion, some of the unique challenges associated with bio-based building materials and highlight some work underway to develop mitigation strategies. The talk will discuss the implications of smouldering on timber construction and hemp-based insulation materials [2]. Work underway at the University of Edinburgh at TWU (UK) to investigate the ability of novel, silica-based nanoparticles to reduce the risk of smouldering will also be presented. An overview of recent regulatory developments [3] will be given and areas of emerging risk discussed.

References:


State-of-the-art about how real fires may be influenced by structure

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Keywords: timber, natural fire, literature review, SOA

Following summary gives an overview of fire tests, research studies and fire incidents where bio based building materials (BBBM) have been involved with respect to observations and results about the potential contribution of bio based building materials to the fire scenario.

This documentation aims to help in understanding the influence of BBBM in each stage of the fire and to an overall fire safety.

This knowledge is needed to quantify the risk in using BBBM and in order to add or develop passive and/or active measures to guarantee fire safe buildings.

The potential influences can be summarised as follows and are derived from the table below:

- the presence of BBBM increase the smoke production rate and most dominant in under-ventilated scenarios or smouldering fires the production of toxic gases, in particularly in the early stage of fire,
- combustible linings can lower the time to flash over,
- the presence of combustible linings can increase the fire severity and heat release, but does not necessarily lead to increased peak temperatures in fully developed fires, the influence is less pronounced if only the ceiling or a single wall is unprotected,
- the contribution of combustible linings can postpone the decay of fire, however self-extinguishment may also possible even combustible linings are present
- multiple flash overs may cause if delamination of unprotected CLT or falling down of a protection lining occur,
- intense flaming combustion outside the windows may occur in ventilation controlled compartment fires
- a threat for rapid fire spread and large fire incidents within the erecting phase of building exist, in particular for light timber frame structure when protective lining is not in place

However, several projects in recent years have shown, that considering these potential influences adequate within the design process fire safety will be reached even if bio based building products are used. A further detailed description about measures to exclude and compensate these potential influences will be part of further publications within the COST action FP1404.
<table>
<thead>
<tr>
<th>Country (Date)</th>
<th>References</th>
<th>Type of fire (real/ fire test)</th>
<th>Real Fire</th>
<th>Full Scale fire test</th>
<th>Potential contribution of BBBM to fire behaviour</th>
</tr>
</thead>
</table>
| SE            | Karlsson et al. (1992) | Analysis of 24 fire tests with different lining materials | ✔️ | ✔️ | for combustible linings compartment temperatures under the ceiling in pre flash over fires can be determined by multiply following equation by factor 2  
\[ \Delta T = 0.5 \left( \frac{Q}{A_s H_{N1}} \right)^{0.7} \] |
| USA           | Tewarson (2002) | ASTM E2058 fire propagation apparatus tests with respect of combustion efficiency and toxic hazard of materials | ✔️ | ✔️ | under ventilated combustion (equivalence ration >1) result in excessive production of toxic gases e.g. CO |
ISO 9705 room: wall + ceiling (125s), wall only (163s), ceiling only (400s) |
no contribution of combustible linings in sprinklered compartment |
### Wooden Modular Hotels

“wooden modular hotels” with different linings (pre- and post-flashover)

### Post Flashover:

- Rapid flashover, combustible linings increased fire plume outside the window, no significant temp. differences
- Rear ventilated caps in combustible façade will contribute to an increased fire spread

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Authors</th>
<th>Description</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPN</td>
<td>2000</td>
<td>Kagiya et al. (2002)</td>
<td>Fire of a large glulam gymnasium</td>
<td>✔</td>
</tr>
<tr>
<td>FI</td>
<td>2002</td>
<td>Hakkarainen (2002)</td>
<td>Four compartment fire tests with different linings</td>
<td>✔</td>
</tr>
<tr>
<td>GER</td>
<td>2004</td>
<td>Hegemann (2004)</td>
<td>Full scale test to evaluate the influence of combustible linings</td>
<td>✔</td>
</tr>
<tr>
<td>UK</td>
<td>2006</td>
<td>Schneider et al. (2007)</td>
<td>Fire in Beaufort Park building site of a large timber frame building</td>
<td>✔</td>
</tr>
<tr>
<td>JPN</td>
<td>2006</td>
<td>Frangi et al. (2008)</td>
<td>Full scale fire tests of compartment fires</td>
<td>✔ ✔</td>
</tr>
<tr>
<td>GER</td>
<td>2006</td>
<td>Winter et al. (2009)</td>
<td>Full scale fire tests to</td>
<td>✔ ✔</td>
</tr>
</tbody>
</table>


- Flashover in a large enclosure


- No increase in compartment temperature
- Release of additional pyrolysis gases and increased fire plume (heat flux) in front the façade
- Extension of the phase of the fully developed fire (delay of the decay phase)


- Extended fire duration and larger fire plume outside the window within the compartment with combustible linings


- Fire protection lining and separating elements only partly finished - allowed a rapid fire spread, size of the fire uncontrollable for fire service


- Excessive burning outside window after lining failed


- Continuous gaps and voids in contact with combustible materials promoted the spread of fire
<table>
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<tr>
<th>Country</th>
<th>Authors</th>
<th>Description</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT (2010)</td>
<td>Feuerwehr Salzburg (2010)</td>
<td>Fire in 3 storey timber frame apartment building &quot;Brand Stabauergasse Salzburg&quot;</td>
<td>• fire spread via eave within an unseparated roof structure • Smoldering fires within void cavities</td>
</tr>
<tr>
<td>CAN (2011)</td>
<td>Sherlock et al. (2011)</td>
<td>Fire in the “Remy” housing project in Richmond Canada, timber frame structure with 81 units under construction</td>
<td>• rapid fire spread, buildings were fully engulfed by flames when fire service arrived • wood contributed to the severity of the fire (citation chief of fire &amp; rescue service)</td>
</tr>
<tr>
<td>JPN (2011-2013)</td>
<td>Hasemi et al. (2014) Suzuki et al. (2016)</td>
<td>Fire tests of a 3-storey wooden school building (3 tests)</td>
<td>• rapid fire spread by ejected flame • severe heating to structural timber elements • charring rate of timber column in natural fire</td>
</tr>
<tr>
<td>JPN (2011-)</td>
<td>Watanabe et al. (2015) Naruse et al. (2015)</td>
<td>Full scale fire tests of compartment fires</td>
<td>• floor area, opening, location and surface area of wood</td>
</tr>
<tr>
<td>AUS (2011)</td>
<td>England et al. (2011)</td>
<td>Literature review, risk</td>
<td>• no difference in the fire tests between compartments with lined steel and timber</td>
</tr>
<tr>
<td>Country</td>
<td>Authors/Source</td>
<td>Title</td>
<td>Key Findings</td>
</tr>
<tr>
<td>---------</td>
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</tr>
</tbody>
</table>
| SE (2013) | Östman and Stehn, SP Rapport 2014:07 | Fires in a residential timber building | • fire growth via cavity of walls after initial fire
| CAN (2012) | McGregor (2013) | Fire tests in protected and unprotected CLT compartments | • initially unprotected CLT or when protective lining failed - panels contributed to the fire intensity (heat release) and duration
• increased fire growth rates, with reduced time to flash over for unprotected CLT compartment tests
• extended fire duration, delay of decay and “second flash over” if delamination of layers occurred |
| Literature review (Multi-Countries) | Brandon and Östman (2016) | Summary of several full scale fire tests of compartment fires | • opening, fire source and types of interior linings |
References

BBC: (2015), “University of Nottingham laboratory fire caused by electrical fault, says report”


Bregulla J., Mackay S., Matthews S.: (2010), “Fire safety on timber frame sites during construction”, 11th World Conference on Timber Engineering (WCTE), Riva del Garda, Italy

Bullock M, Lennon T, Enjily V.: “TF2000 Stair Fire Test Summary Report”, University Manchester
http://www.mace.manchester.ac.uk/project/research/structures/strucfire /CaseStudy/Timber/stair.htm

http://www.mace.manchester.ac.uk/project/research/structures/strucfire /CaseStudy/Timber/default.htm


England P., Matthew E.: (2011), “Extension of the Concession which allows timber frame construction in class 2 buildings to include class 3 buildings”, Forest & Wood Products Australia, Melbourne, Australia


Frangi A., Bochicchio G., Ceccotti A. & Lauriola M.P.: (2008), “Natural Full-Scale Fire Test on a 3 Storey XLam Timber Building”, World Conference on Timber Engineering (WCTE), Miyazaki, Japan


McGregor C.J.: (2013) “Contribution of cross-laminated timber panels to room fires”. Master thesis at Department of Civil and Environmental Engineering Carleton University - Ottawa-Carleton Institute of Civil and Environmental Engineering, Ottawa, Ontario, Canada

Naruse T., Kagiya K., Suzuki J., Yasui N. & Hasemi Y., (2015), Experimental Study of Time to Onset of Flashover in Classroom Size Compartment, Proceedings of Asia-Oceania Symposium of Fire Science and Technology (AOSFST), Tsukuba, Japan


Sherlock T., Kane L.: (2011), VANCOUVER SUN


Update on recent activities in WG1 – TG1: “Reaction to fire performance and input parameters for simulation purposes”

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Keywords: bio-based, material properties, temperature dependence, fire testing

A short presentation of the scope of “WG1 – TG1: Reaction to fire performance and input parameters for simulation purposes”, as well as the current and future research activities performed in the frame of WG1 – TG1 is given below.

1. Aim of WG1-TG1 “Reaction to fire performance and input parameters for simulation purposes”

It is well established that the thermal and structural behaviour of a bio-based construction material exposed to fire is significantly affected by the values of its material properties, which are commonly varied with increasing temperature. For instance, the thermal behaviour of a material exposed to a high temperature environment is practically determined by three main physical parameters, namely heat conductivity (c.f. Figure 1), density and specific heat capacity. On the other hand, the mechanical behaviour of a load-bearing timber element in a case of fire is significantly affected by the way its main mechanical properties (tensile strength, compressive strength, shear strength, modulus of elasticity) are varied with temperature (c.f. Figure 2).

*Figure 1. Temperature-thermal conductivity relationship for wood and the char layer [1].*

*Figure 2. Reduction factor for strength parallel to grain of softwood [1].*
A distinctive feature of bio-based construction materials is that they are essentially combustible materials. Therefore, when exposed to a high temperature environment, a range of physical phenomena, such as pyrolysis, charring and combustion, may occur. The rate of these phenomena is determined by the values of relevant material properties and the manner in which they vary with temperature. For instance, the charring behaviour of timber can be affected by a range of physical parameters, the most important of which are density, moisture content and permeability.

In order to perform accurate numerical simulations of the thermal and structural behaviour of bio-based materials exposed to fire, a comprehensive knowledge of the manner in which the aforementioned material properties vary with temperature is required. However, there are scarce relevant reports in the open literature; also, the reported property values show considerable scatter. As a result, the thermo-mechanical behaviour of bio-based construction materials exposed to fire is still an active research area, focusing not only on the effects of temperature-dependent material properties, but also on the impact of additional phenomena, such as fall off of the protective layer (e.g. insulation board or char layer), CLT delamination, crack and fissure formation.

Motivated by the aforementioned observations, the main aim of WG1 – TG1 is to develop a systematic approach in determining a range of important physical properties of bio-based construction materials, which are essential for accurate numerical simulations. Towards this end, a variety of research activities is concurrently pursued; these activities fall into two main categories: (a) development of an extensive database of temperature-dependent physical properties relevant to the fire behaviour of bio-based construction materials and (b) establishment of good practices and protocols for testing of bio-based construction materials. WG1-TG1 is led by Davood Zeinali (University of Ghent, Belgium); the co-leader is Dionysios Kolaitis (National Technical University of Athens, Greece).

2. Recent Activities

In the frame of establishing the fire behaviour of bio-based construction materials, an online survey has been developed and sent out to the COST action members, aiming to collect quantitative information on the thermal and structural behaviour of such materials, when exposed to a fire environment. The aim of the survey is to develop a database, where the temperature-dependent physical properties (e.g. thermal, mechanical) of bio-based construction materials will be stored in a systematic and easy to retrieve fashion. Access to the database is currently limited to researchers that have responded to the survey; in the future, the complete database will be available online. So far, a limited amount of data has been collected; increased awareness on the survey is believed to encourage an increased number of submissions.

In addition, aiming to determine best available practices for fire testing of bio-based construction materials, there is a continuous effort to methodically collect relevant information from active testing and research laboratories across Europe. This effort focuses on the systematic
organization of quality test practices, exhibiting well-instrumented measurements and suitable material properties characterization.

A number of papers, relevant to the scope of WG1 – TG1 has already been presented in the Working Group Meeting of COST Action FP1404 (Barcelona, April 2015), as well as in the 1st European Workshop of Fire Safety of Green Buildings (Berlin, October 2015).

3. Future Work

Collection of material properties and fire test results is planned to be continued until the end of the COST action. The contents of the continuously growing database will be organized and systematically categorized; potential trends for bench-scale (e.g. FPA and Cone Calorimeter tests) and large-scale (e.g. SBI and Room Corner tests) fire tests of new and existing bio-based construction materials will be thoroughly explored, by means of extensive comparative and statistical analyses. In addition, efforts will be made to further disseminate the survey in a wider audience. It is envisaged to create a webpage to present, in an easy to access manner, the database of fire properties. The webpage will be actively promoted and a permanent call for more data from interested individuals will be set up. The “final form” of the database will be presented in a journal paper, emphasizing on the characteristics of the tests from different scales and how they relate to each other when considered for bio-based construction materials.

Examples of good fire testing practices are continuously gathered and organized in a systematic way. Results of this effort will be published in the form of a “technical guide”, focusing on the important aspects of material characterization and quality measurements in tests relevant to fire conditions. The technical guide will also include characteristic showcases of good testing practices. The guide will be actively disseminated in a wide audience, broader than the current COST action members. A meeting with WG1-TG1 members is planned, aiming to discuss current testing practices and ways to enhance the characterization of sample materials in the tests; further submissions to the fire properties database will be also discussed and encouraged.

Naturally, there is a continuous effort to identify and propose further research topics relevant to the main scope of WG1 – TG1.

Acknowledgments

The assistance of Davood Zeinali, leader of WG1-TG1, is gratefully acknowledged.

References

Can we predict the charring rate? Opportunities and Challenges in Computational Pyrolysis of Timber

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Keywords: Timber, Charring, Complexity, Uncertainty, Eurocode

The fire behaviour of timber is controlled by charring. The heat of a fire causes the timber to break down (charring) into insulating char and flammable volatiles, absorbing heat in the process [1]. The volatiles diffuse to the surface, where they ignite and release heat. This heat causes the char layer to propagate into the timber until an equilibrium, between heat release and absorption, is reached. Thin beams burn quickly through, but in thick beams a layer of intact timber below the char is retained. If the intact timber still holds the structure after a fire, the structure is deemed safe.

Charring is a complex process as it involves: pyrolysis, oxidation, cracking, and multiphase heat transfer. To model all process involved would create a model so complex, it would be impossible to solve. Current models in the Eurocode are, therefore, simple empirical expression like the constant charring rate [2]. These correlation were derived in furnace under a standard fire exposure [3], making the results unusable for other heating conditions [4, 5]. Lately, there has been an increasing trend towards a more performance-based approach in structural engineering by using more realistic fire curves. An example of such curves are parametric and travelling fires [6]. We require new models to predict the charring behaviour under realistic fires.

In this presentation, we will argue that the appropriate model for predicting the charring behaviour of wood under realistic fires is of higher complexity than current models for the standard fire [5]. Through examples we will explain why current models are too simplistic, while showing that, at the same time, increasing complexity has to carefully evaluate. As complexity without or weak experimental foundation—such as in-depth temperatures and mass loss rates [7, 8]—can lead to worse rather than better predictions [9]. We will illustrate the last effect through examples of model uncertainty against parameter uncertainty, and the compensation effect.

Consequently, we outline why we believe that the appropriate level of complex can only be achieved when experimentalist and modellers work together. This COST action provides the perfect platform to start the collaboration between experimentalist and modellers. Throughout the talk we will highlight the importance of work from this working group.

So, can we predict the charring rate? For a few cases the answer is yes [5], but for realistic fire exposures this question remains open.
References


Fundamental properties of bio-based materials for state-of-the-art modeling of reaction to fire performance

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Keywords: bio-based, material properties, fire modeling, testing

An essential aspect of fire experiments is characterization of sample materials. Experimental data can only be useful for future modeling of reaction to fire performance if the sample material is well characterized with its fundamental properties. Nevertheless, despite the large number of fire experiments conducted and cited in the literature, little data is available regarding the fundamental properties of the used materials. This is whilst today these material properties constitute key inputs to the contemporary fire modeling codes performing complex CFD and pyrolysis computations [1, 2]. In the case of a corner fire [3], for instance, often no data is available regarding the reaction kinetic parameters, surface radiative properties or the heat of pyrolysis of the used sample materials [4-6]. As a result, simulation studies of corner fires face the alternative of adopting these parameters from other studies or approximating them independently [7-9]. In light of this fact, considering the great cost of most large-scale fire experiments, there is a great need for a global call to more scientifically elaborate fire testing. In addition, there is a need to bring together the scattered information that is available surrounding the fire performance of bio-based products, in a way that is useful for all experts in the field of fire safety.

In order to make reliable predictions of reaction to fire performance or fire development, a fire modeling code requires comprehensive validation [10]. This necessitates a balanced assessment of condensed-phase pyrolysis, gas phase kinetics, flame heat transfer and turbulent buoyant fluid flow via comparisons with experimental measurements. Several main quantities can be highlighted, namely, Heat Release Rate (HRR), gas temperatures (e.g. in the smoke layer), surface temperatures (mainly in the flames area), heat fluxes, spread of flames (front, height and length), time to flashover in the large scale, and the velocity or pressure of gases, each at a variety of locations with respect to the fire source. Other measurements may have to be made of char depth or its pattern on the surfaces [7], instantaneous flow stream lines [11], and the density and composition of smoke [12].

Bearing in mind the practical value of experimental data for validation of fire models, another crucial aspect of the experiments to consider is establishing the boundary conditions. Measurements, among others, may have to be made of the development of pyrolysis within and over the combustible material [11], the yield of soot and the production of smoke [12, 13], the
distributions of heat fluxes [14], the visual spread of flames [15], and the flowrate patterns of gases [16].

References


The Influence of Different Fundamental Material Properties on the Pyrolysis of Medium Density Fiberboard – A Sensitivity Analysis by FDS

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Keywords: Timber, Charring, Complexity, Uncertainty, Eurocode

In this paper we present numerical simulations of Medium Density Fiberboard (MDF) pyrolysis using a one-dimensional heat transfer solver that includes in-depth radiation transport [1]. The results are compared with the results of several small scale tests conducted in the Fire Propagation Apparatus (FPA) [2], where nitrogen atmosphere has been used in order to eliminate uncertainties related to gas phase combustion. During the FPA tests, the mass loss rate, surface and back side temperatures have been measured under three constant external heat fluxes (25, 50, 100 kW/m\textsuperscript{2}) in the set-up show in Fig. 1. More details can be found in reference [2].

![Figure 1. Schematic of the MDF sample in the FPA Test.](image)

The influence of the material properties and model parameters on the pyrolysis behaviour of MDF has been investigated in detail through a sensitivity analysis using Fire Dynamics Simulator (FDS, version 6.2.0). A one-step finite rate reaction is assumed; the virgin material is converted to char and the rest is released as pyrolysate. The values of the kinetic parameters and char yield are estimated based on Thermogravimetric Analysis (TGA) test results reported in [3]. It is assumed no shrinkage and swelling occur during the whole process.

The base simulation case considered does not show satisfactory results for the time to reach the first peak and the value of that peak in the mass loss rate curve when compared to experimental data. The predicted time to peak and the value of that peak are significantly lower than the measured value, namely by about 62 to 50\% for heat flux 50 kW/m\textsuperscript{2}.

In order to improve the predictions of the onset of pyrolysis and the value of the peak MLR, the influence of thermal conductivity, specific heat, heat of pyrolysis, and the moisture content was
studied. However, changes in none of these parameters showed satisfactory results for the time to reach the peak value of the burning rate when compared to experimental data. Subsequently, we investigated the effect of the emissivity, through-thickness density profile, and in-depth radiation through the sensitivity analysis.

In the considered parameter ranges, the most significant influence on the time to the first peak comes from the emissivity, followed by the thermal conductivity, specific heat, and moisture content. For the peak mass loss rate, the most significant influence comes from the absorption coefficient, followed by the through-thickness density, then the moisture content, and the specific heat.

Through a simple trial and error procedure, a set of ‘optimized’ parameter values has been obtained. For the absorption coefficient, we assumed that the material is opaque until it starts charring, then values of 50000 m-1 and 2000 m-1 have been determined for the absorption coefficient of virgin and char, respectively. During this optimization procedure, the parameters showing significant influence have been considered, which results in better agreement with experimental data (Fig. 2).

![Figure 2. Comparisons between experiment and simulation using optimized parameter values (a) mass loss rate, (b) surface temperature.](image)

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**References**


Working Group 2
Structural Elements made of bio-based building materials and detailing
Review and Determination of Fire Resistance Ratings for Glulam Connectors

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Keywords: fire safety, connections, mass timber buildings, fire testing

Introduction

Engineered timbers such as glulam and cross-laminated timber (CLT) are being utilised for multi-storey buildings. A challenge faced by both medium and high-rise buildings is the fire safe and efficient design of connections in both CLT and glulam. Connections within CLT panels have been mostly proven through manufacturer fire testing. Where glulam members are used as part of the structural frame, the column to beam and beam to beam connections need to be constructed with a fire resistance rating (FRR) equal to that of the connecting members, typically exceeding 60 minutes. Building construction is limited by the few applicable methodologies to assess connection capacity under fire when the timber is exposed and not clad behind fire protective plasterboard.

Background

To achieve an FRR within a glulam beam to column connection there are three approaches:

1. Encapsulate the connection within fire rated gypsum that provides the required FRR.
2. The connector is partly concealed by the timber, with bolts or dowels exposed only.
3. The connector is fully concealed by the timber, so that no part of the connector is exposed.

Encapsulated connectors are addressed by proprietary tested and approved wall and ceiling plasterboard systems. Where a connector will be concealed within exposed timber, the preferred glulam connector is either a steel knife-plate with bolts / dowels; or a proprietary screw-in sleeve type connector. Concealed connectors use the timber to provide the appropriate insulation to protect them from fire. These types of connectors are difficult and expensive to design and construct as strong elements.

From a review of existing literature on fire testing of glulam connectors, the following key points are summarised:

- There are numerous fire or elevated temperature tests are on simple tension connectors, which have limited application to real building situations, as buildings rarely utilise members in tension.
• Analytical methods available are based on tension tests and hence are not as accurate for a real building connection that is undergoing bending and shear. There needs to be more tests on full size, loaded shear type connectors.
• Many fire tests are undertaken on smaller members and tested to a standard time-temperature curve, but very few tests are taken to 60 minutes or beyond.
• Achieving an FRR of 60 minutes to 120 minutes requires significant depth of timber cover and there does not appear to be proven correlations to calculate the FRR for typical beam to column connectors.
• The FRR of a concealed steel knife-plate is influenced by the exposed dowels or bolts. Having no steel exposed increases the FRR and improves the temperature distribution within the residual cross-section.
• Intumescent paint does not increase the fire resistance significantly, as the weak point of the connection is the timber and protecting the steel does not improve this weakness.
• There is a lack of fire testing on real timber connections with real (natural) fires.
• Fully concealed sleeve or seated connections can have the best fire performance.

Why Connectors Fail

Tests on timber connections at elevated temperatures have shown a common failure mode with deformation in the timber through embedment failure. As the timber is exposed to elevated temperatures, it starts to lose its inherent strength (stiffness) around the connector. As the stiffness reduces with increasing temperatures, the ability to resist the applied shear forces drops-off. Embedment failure is first seen through increased ovalisation, with the bolts / dowels typically remaining straight as the timber weakens around them. The ovalisation occurs both parallel and perpendicular to the grain at the bolt or dowel, or screws securing the sleeve connector. The mechanical properties of timber under heating are well researched, though embedment strength is not fully determined [Erchinger, 2010; Maraveas, 2013; Palma, 2014; Audebert, 2011].

Determining a Solution

To effectively support the applied loads and transfer the forces through the connection, therefore preventing the embedment failure, the connection components must be located within timber that will provide adequate stiffness at the knife plate and bolts / dowels, or at the screws to the sleeve connector, for full fire duration. Accounting for the loss of strength in the timber directly behind the char layer and the specific depth of that weakened timber becomes critical for a concealed steel connectors. There are significant difficulties modelling heat-transfer and mechanical properties simultaneously as the timber properties are changing under heating. There are a number of empirical models and FEA models that have limited application.

It is evident from the literature reviewed there is no simple method for determining an FRR past 60 minutes. Factors influencing the connection performance are:
• When there are any parts of the steel connector exposed to a fire, these will weaken the connection through transfer of heat into the connection. Avoiding any steel components being exposed to the fire will improve the FRR.
• The connection may have an increased char rate, due to the connection components. Where there are bolts or dowels exposed, there will be a measurable increase in charring. Where the steel connection is fully concealed, the increased charring will be reduced. The impact of the thermal mass of the connection can increase the char rate by 5 to 10%.

• Accounting for the loss of strength in the timber directly behind the char layer and the specific depth of that weakened timber becomes critical for a concealed steel connector. The timber loses strength quickly, with the strength parallel to the grain about 60% (compression) to 80% (tension) of its ambient value, once the timber reaches 75°C.

• By designing a connection that is within timber that retains strength and stiffness, the significant loss of strength of the timber at elevated temperatures can be minimized or avoided.

The basis of the connection design undertaken has been that timber cover will provide adequate insulation to the fire exposure such that the connector components are within timber that retains 50% of its embedment strength. Also, by designing to a pre-determined embedment value, the influence of load-ratio and the reducing strength of the timber under heat is accounted for.

To determine where the embedment strength will reduce below a critical value, requires an understanding of the temperature profile within the timber, behind the char layer. The “thermal penetration depth” is estimated as ranging from 25mm to 50mm behind the char layer, increasing as the fire duration increases [Frangi, 2003; Friquin, 2010; Konig, 1999; Schmid, 2014].

The value of 50% embedment strength can be attributed to a timber temperature of 100°C. Based on the empirical results, a depth of 15mm to 20mm behind the char layer will maintain a timber temperature of 100°C. The other factor to account for is the increased char rate at the connection, which is increased by 5%.

**Methodology Fire Testing**

Fire testing has been carried out on full-size glulam beam-column connections that are loaded to replicate actual building conditions, to determine an FRR. The connection design is based on a fully concealed steel angle plate that supports the beam in bearing (see Figure 1). The steel angle-plate was designed specifically for the project and can be installed efficiently during construction. The weak point of the connection is the beam base, where a solid timber block is required to fill a pre-cut cavity in the beam, to allow the connection to be installed.

The glulam beam side and base cover to the steel connection was designed to the methodology described above, taking into account timber stiffness related to thermal penetration depth behind the char layer and increased char rate.

The beam-column connection was fire tested using a mid-size furnace of 1.8m x 1.5m square with a furnace depth of approximately 2m. Each beam-column connection was exposed to the ASTM E119 standard time-temperature curve, up to 120 minutes. The member sizes tested ranged in beam width and type of glulam, with five full size specimens tested. The applied loading, representative of an office floor, was provided through a test specific loading frame. Temperatures were recorded at the connection, as were deflections of the beam. Of the five
tests, two achieved an FRR of 120 minutes. Deflections of up to 20mm were measured at the connection.

Figure 1 – Rendering of beam column connection tested to achieve 120 mins FRR

References


Fire part of Eurocode 5 EN 1995-1-2 - revision status and perspective

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Keywords: Eurocode 5, Fire part, EN 1995-1-2

Introduction

The European standards Eurocodes provide common design rules for the design of structures with all main building materials creating the built environment. The European Committee for Standardization (CEN, Comité Européen de Normalisation) is responsible for developing and defining standards at European level and it is officially recognised by the European Union and the European Free Trade Association (EFTA). The technical committee (TC) working on the development and definition of the design rules of common building and civil engineering structures has been numbered as CEN/TC 250 and has currently 11 subcommittees (SC). CEN/TC 250/SC5 is responsible for the European standard Eurocode 5, which deals with the design of timber structures and it consists of 3 parts: Part 1-1: General - Common rules and rules for buildings; Part 1-2: General - Structural fire design; Part 2: Bridges. All parts were published in 2004 after a long historical development starting in 1983 with a CIB report “Structural Timber Design Code” [6].

The European Commission has a strong interest on the further development of the Eurocodes to achieve a further harmonisation of design rules in Europe and the revision process of all Eurocodes has recently started. The second generation of the Eurocodes is expected to be published starting from 2020. The main objectives of the revision are the improvement of the Ease-of-Use of the Eurocodes for practical users, the reduction of National Determined Parameters and the further harmonisation and inclusion of state-of-the-art. After an intensive discussion within CEN/TC 250 it was defined that the Eurocodes are addressed to competent civil, structural and geotechnical engineers, typically qualified professionals able to work independently in relevant fields [6].

Current EN 1995-1-2

The current Eurocode 5, fire part (EN 1995-1-2 [1]) was published 2004 and gives rules for the fire design of timber structures, that are based on the state-of-the-art at the beginning of 2000. Compared to the European pre-standard ENV 1995-1-2:1994, the EN 1995-1-2:2004 undergone considerable changes. Within EN 1995-1-2, charring is dealt with in a more systematic way and different stages of protection and charring rates are applied. For the determination of cross-sectional strength and stiffness properties, two alternative rules are given, either by implicitly taking into account their reduction due to elevated temperature by reducing the residual cross-
section by a zero-strength layer, or by calculating modification factors for strength and stiffness parameters. Design rules for charring and modification factors are also given for timber frame members of wall and floor assemblies with cavities filled with insulation. A modified components additive method has been included for the verification of the separating function. The design rules for connections have been systemised by introducing simple relationships between the load-bearing capacity (mechanical resistance) and time. The current EN 1995-1-2 provides thermal and thermo-mechanical properties for advanced thermal and structural analysis. It also gives some limited design rules for natural fire exposure using parametric fire curves [10].

**Structure of the second generation of the Eurocodes fire part**

In order to harmonise all material fire parts of the new Eurocodes a Project Team of the Horizontal Group Fire (HGF) has been established. The HGF PT has proposed a common harmonised structure for all material fire parts of the new Eurocodes as shown in figure 1.

![Common harmonised table of content](image)

**Figure 1. Common harmonised table of content for all material fire parts of the new Eurocodes as proposed by the Project Team of the Horizontal Group Fire (HGF) of TC250**

The verification of the mechanical resistance for the required duration of fire exposure can be performed using *tabulated design data* for specific types of members, *simplified design methods* for specific types of members or *advanced design methods* for the analysis of members, parts of the structure or the entire structure. Tabulated design data provide recognised design solutions generally in relation to section typology without recourse to any form of equilibrium equation. Tabulated data may be derived from tests, calculation models or some combination of the two and may be presented either in the form of a table or an equation. Tabulated design data give conservative results compared to relevant tests or simplified or advanced design methods and an extrapolation outside the range of application is not permitted. Simplified design methods are based on global equilibrium equations and do not necessarily require the use of complex analytical or numerical models. Advanced calculation methods are based on fundamental physical behaviour, employing local equilibrium equations which are satisfied at every point in the structure. Calculations are undertaken using complex numerical models based on finite element analyses or other appropriate advanced procedures.

The current EN 1995-1-2 does not have tabulated design data. Thus, it is important that this new opportunity is analysed in detail and the need and preparation of tabulated design data is defined in strong collaboration with the practice and industry.
Current state of work revision of EN 1995-1-2

The revision work of EN 1995-1-2 [1] is performed and coordinated by the Working Group WG4 of CEN/TC250/SC5 chaired by the author of this paper with participants from several countries active in the field. Further, the revision is supported by the Cost Action FP1404 and the global network Fire Safe Use of Wood (FSUW). One fundamental objective of the current work activities of CEN/TC250/SC5/WG4 is the preparation of an extensive background document with the update state-of-the-art with regard to the structural fire behaviour and fire design of timber structures. The background document will be the basis for the drafting work of the new EN 1995-1-2 by the Project Team (PT), which will be established at the beginning of 2018.

Based on the principles set up for the revision and the results of the systematic review of the current EN 1995-1-2, it was possible to identify the need for the improvement and extension of the fire design rules for the second generation of EN 1995-1-2. The following list gives the most important items considered in the revision process:

- The current charring model will be generalised and will consider different phase of protection [8,9]. The failure times (defined as fall-off times) of different protective claddings, including gypsum plasterboard Type A and F (according to EN 520) and gypsum fibre boards (according to EN 15283-2) will be given with simplified equations based on a large data base of fire tests [4]. Further, for the fire design there will be the possibility to use failure times based on full-scale fire tests performed according to EN 13381-7 (Test methods for determining the contribution to the fire resistance of structural members - Part 7: Applied protection to timber members), which has completely been revised, is currently under formal vote and if accepted should be published this year.

- As simplified design method only the current Reduced Cross-section Method (in the future renamed as Effective Cross-section Method) will be given [13]. The current Reduced Properties Method will be deleted. The Effective Cross-section Method will be revised and its use will extended to all common structural timber members [7,14]. The application of the design method should be extended to 90 minutes fire resistance, if possible even more.

- The current annexes C (timber frame assemblies with filled cavities) and D (timber frame assemblies with void cavities) will be improved and moved to the main part of EN 1995-1-2. The revised content will become normative. The design model for timber frame assemblies with filled cavities is based on the Effective Cross-section Method and will allow considering the performance of different kind of insulation (mineral wool, cellulose, wood fibre, etc.). The performance of the insulation can be evaluated with small-scale fire tests and classified in 3 different protection level [5,15].

- The current annexe E (Component additive method for the verification of the separating function) will be improved and moved to the main part of the EN 1995-1-2 [2]. The revised content will become normative.

- New rules for the fire design of cross-laminated timber panel (CLT) and timber-concrete-composite elements (TCC) will be introduced [3,8,9]. For CLT, tabulated design data can be given as discussed in [8].

- Improved rules for the fire design of connections will be given based on extensive experimental and numerical analysis [11,12].

- Effective thermal and mechanical properties for timber, gypsum and insulation will be given for advanced calculation models based on FE-analysis.
It is expected that the second generation of EN 1995-1-2 will fill most gaps of the current EN 1995-1-2 and will allow a safe and economic design of timber structures in fire.

Acknowledgments

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References


Short review of the research conducted on the fire behaviour of timber-concrete composite systems

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Keywords: TCC structures, fire, SOA, experiments, simplified models

Composite structures present very optimized and popular structural bearing systems. Usually, composite structures are composed of two different materials in such a way that each of the material can be fully exploited, for instance timber-concrete composite systems combine the high compressive load capacity of concrete and additionally the tension capacity, low weight and also lower environmental impact of timber. In fire, the changes in stiffness and strength that occur in the different components (timber, concrete, and connector) of the timber-concrete composite structure are of special interest. Experimental work of structures exposed to fire is usually not as extensive as in case of experimental work at room temperature. The present abstract presents a short review of the research work of the timber-concrete composite (TCC) systems in fire conditions carried out in recent years.

TCC beams with screwed connections and dowels were extensively investigated at ETH Zurich. During this research, 23 full-scale tests fire tests using the standard ISO fire curve [1] and 46 small-scale tests at elevated temperature were performed. The work is summarised in the PhD thesis of Frangi [2]. Inclined screws were tested in small-scale fire tests with tensile and shear loading of the connectors. The main outcome of the fire tests showed that (i) the load-carrying behaviour of the connection with axially loaded screws depends on the temperature-dependent reduction of withdrawal strength and stiffness of timber, and (ii) that the temperature measured around the connection mainly depends on the timber side cover of the connection. Based on the experimental investigations Frangi et al. [3] developed a simplified design method for the calculation of the fire resistance of timber-concrete composite slabs using screwed connections. The calculation method is based on the reduced cross section method given in EN 1995-1-2 [4] and on the basis of the γ- method for mechanically jointed beams with flexible elastic connection given in EN 1995-1-1 [5].

O'Neill [6] investigated the failure behaviour of timber-concrete composite floors exposed to standard ISO 834 design fire [1]. Beams were made from Laminated Veneer Lumber (LVL). Two different types of connections between concrete slab and LVL beam were used in each test specimen. The first type of connection was a notched connection with steel screws and the second type was a plate solution connection (i.e. toothed steel plate). Overall, two tests with
different beam heights were carried out, as well as series of small-scale tests, to investigate the failure strength and behaviour of the LVL at different temperatures (46 tests altogether). Main conclusions from the tests were: (i) beams with steel plate connection behave stiffer than the ones with a notched connection, (ii) the charring rate on the sides of the LVL beams was found to be 0.58 mm/min on average, (iii) separation of the double LVL members during the latter stages of burning was noticed, (iv) the charring rate on the underside was on average four times larger than the charring rate from either side of the beam, (v) concrete spalling in the slab was noticed for the lower quality concrete mix. A simplified design model was developed based on the experimental results.

TCC floor systems were also investigated at Czech technical University. Caldova [7] reported the results of two full-scale experimental tests and presented a validation of a 3D numerical model. The floor specimens of size 3.5 m by 4 m were exposed to standard ISO fire [Source]. Additionally, the test was also performed at room temperature. The composite timber-concrete floor was composed of a timber frame, two secondary beams, and a concrete slab connected to floor joists. Screwed connections were used between timber and concrete.

Tests on a CLT floor system, laminated and plywood assemblies connected to a concrete layer are reported in [8]. All specimens were exposed to standard ISO fire. For the CLT floor system self-tapping screws were used as connectors inclined at 45°, and in case of the laminated assembly steel truss plates were used. In both cases, large fire resistances was observed (over 120 min). The advantage of the laminated wood assembly is that the layers (plies) are continuous across their depth and thus charring was slower than in the CLT floor assembly. The use of shear connectors between the timber and the concrete had little or no observable impact on transferring heat into the concrete while a minimal temperature increase at the timber-concrete interface was observed.

The new Eurocode 5 will contain new rules for the fire design of timber-concrete-composite elements. This task group will support the revision of Eurocode and thus CEN/TC 250/SC5/WG4.

References

Fire safety of timber buildings under construction – Overview of guidelines and recommendations

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Keywords: fire safety, timber building, construction phase, fire incidents, guidelines

In the last few years, the construction of timber multi-storey buildings has been gaining more importance in most European countries. Timber construction presents numerous strong points for sustainability and there are also other pragmatic reasons why timber constructions are increasing their market share to the detriment of heavy constructions: prefabrication, speed of assembly, new architectural tendencies, possibility of enlarging the thermal insulation layers in the façade without increasing the traditional thickness of the facades. New knowledge concerning the performances of wooden constructions and materials has been developed, e.g. regarding to acoustic quality [1] [2] and fire safety [3]. As a result, many countries have revised their fire regulations, permitting greater use of timber. Many countries do not limit the number of storeys in timber buildings and the traditional use of timber for low-rise (two-storeys or less) and mid-rise (three- to five-storeys) buildings is now being extended with design for new high-rise buildings (six-storeys or greater) [4] [5].

Numerous fire safety concepts during the usage phase of buildings were developed reaching a very good level and allowing e.g.

• modern apartment buildings with timber frame to have a lower rate of fire incidents compared to the entire apartment building stock [6]
• timber frame to show similar area of heat and flame damage in fires when compared to other construction types [7]

However, during the construction phase, timber buildings could be particularly vulnerable to fire. The main fire safety measures were developed to operate only at the final state of the building, e.g. detection and suppression systems, compartmentation and fire-resistant protection layers. Before the implementation of these measures, timber constructions could be unprotected and directly exposed to e.g. hot works, a term that covers a number of work techniques producing
sparks, using flames or generating strong heat. According to an analysis of fires in buildings in England (period 2009 to 2012) [7], the area of heat and flame damage over 20 m² in fires in timber buildings under construction is overrepresented when compared to other construction types [7] – see Fig. 1. Out of total fires in timber framed dwellings under construction, 24% of these resulted in damage of an area of more than 100 m² compared to 4% for dwellings of other types. Among buildings under construction, the ratio of fires in timber frame buildings to fires in other type buildings is much higher at (1:9) compared to the same ratio for buildings not under construction (1:57).

\[ \text{Area of heat and flame damage (m}^2) \]

![Figure 1. Distribution of heat and flame damage over 20 m² in fires under construction. Timber framing is overrepresented in large areas when compared to other construction types [7]](image)

Finally, fires in timber buildings have a psychological impact on the society, taking further the perception of an increased fire hazard.

For these reasons, it seems necessary to recommend measures to extend the fire safety of timber buildings to the construction phase. In the technical working group WG2-TG7 of the COST Action FP 1404, a study has been recently started to collect guidelines and to propose recommendations for fire safety of timber buildings during the construction phase. The study is divided in two main tasks:

- 1/ Collect information and create a database of fire incidents in timber buildings during the construction phase.
- 2/ Compilation and comparison of guidelines, norms and laws from different countries.

Finally, the objective is to establish a state-of-the-art in matter of fire safety of timber buildings under construction in order to propose a selection of measures and recommendations regarding this issue.

For the development of the database about fire incidents in timber buildings under construction, the following information has been collected: general information (country, city, month and year), building characteristics (type of planned occupation, number of (timber) storeys, light or heavy
timber framing), consequences (injuries, fatalities, direct consequences to neighbourhood, surface of damage, ...), possible cause (hot work, arson, ...), sources and subjective quality evaluation of the available information.

The information was collected through

- 1/ a literature review (general news articles and technical reports)
- 2/ an invitation to the members of Cost Action FP1404 to add fire accidents and/or to ask the contribution of experts of their countries who could contribute to the research.

72 fire incidents of timber buildings under construction (66 from the literature review and at the moment 6 from the COST-members) were gathered and investigated. Fire incidents were found in Canada (33%), USA (32%), UK (27%), Italy (5%) and Belgium (3%).

The number of gathered incidents is not impressive (especially when compared to 118 fires of timber buildings under construction in UK for a period a 2 years analysed by [7]). It is difficult to collect information because only sensational fires get detailed attention and the majority of fires are small and remains unknown or confidential. Unfortunately, the collected information are not always exhaustive, e.g. the type of timber construction (heavy framing or light framing) is unknown for 82% of the entries, the damage to neighbouring buildings is unknown for 71% of the entries (12% without damage and 17 % with damage). The analysis shows that the main (suspected) cause of ignition for fires under construction actually is arson (36%) followed by hot work (19%). Unfortunately, the cause of 35% of collected fire incidents remains unknown.

It is important to repeat that the sample is too small to draw conclusions. These results are just a trigger for further investigations. Contribution form experts (e.g. fire brigades) of the different countries should be needed to increase the number of entries.

The second task of the study concerns the overview of guidelines, norms and laws regarding to fire safety of (timber) buildings under construction. First, a broad literature review is undertaken. Similar works were already conducted in UK [8], Canada [9] and Sweden [10]. Based on the analysed guidelines, an overview is created and structured as illustrated in Fig. 3.

The general information provides a short description about the origin of the document. Important aspects are on the one hand the type of the document (regulation, guideline, technical report or paper / presentation), on the other hand if the document is timber specific or not. Fire safety objectives are divided in 2 generic types of measures

- Preventive measures to prevent fire events on construction sites: e.g. general fire safety plan, hot works, fuel sources and storage in general and of flammable products and protection against arson.
- Fire management measures to fight fire events on construction sites: e.g. alarm and detection, active protection, compartmentation, protecting, escape routes and access for the fire brigades.

Significant inputs were received from the experts during the month December 2016 and January 2017. A qualitative overview of all evaluated guidelines is provided in Fig. 5.
Concerning the type of document, it is interesting to notice that 15 countries (on a total of 24 who provided information) have regulations concerning the fire safety of buildings during the construction phase but only 2 with timber specific rules (Croatia on national level and Scotland for the city of Edinburgh). 6 countries (Australia, Canada, Finland, Italy, Sweden and UK) have guidelines with timber specific recommendations, with the nuance in the Australian guideline preferring the term “combustible materials” instead of “timber”.

The main input from the collection of guidelines is the subdivision of recommendations in 20 topics plus 2 categories concerning the frame conditions (main responsibility and range of application) – Fig. 4. The 20 topics are grouped into 2 main chapters as previously mentioned: “preventive measures” to prevent the fire and “fire management measures”, which come into operation only once a fire occurs.

For the 20 topics and 2 categories (responsibility and application), first recommendations based on the collected information have been proposed. The combination of information gathered from a large span of guidelines from various sectors and countries allows to have specific information for each topic in a single document. Many of the proposed measures lead to substantial benefits in terms of fire safety during the construction. However, most of them could be also expensive. A qualitatively cost-benefit analysis (only subjective evaluation) has been proposed in order to identify measures that should be particularly efficient.
This study has realised a state-of-the-art and established a proposition for a European guideline on fire safety of timber buildings under construction. Further updates and reviews should be performed to propose and publish a European guideline on this topic.
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Fig. 5. Qualitative overview of guidelines regarding fire safety on construction sites
Acknowledgments

We would like to thank Jan Gmür and Eliott Odermatt, students at the ETH Zurich. Without their commitment during their Project Work “Fire Safety of Timber Buildings under Construction” from September to December 2016, this study could definitively not have been successfully realised. Thanks to their structured and pragmatic approach, a big step has been made towards a European guideline regarding this topic. We would also like to thank all the members of the COST Action FP1404 and other experts who gave input for the database of fire incidents and for the overview of the guidelines in their countries.

References


Simulation of charring depth of wooden-based products when exposed to natural fire curves

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Keywords: timber, natural fire, performance-based design, pyrolysis, simulation

Justification by calculation of the fire resistance of structures made of wooden-based products is mainly based on the determination of the thickness of char that is formed at the surface exposed to fire. For example, the Eurocode 5 part 1-2 proposes a method entitled "reduced cross-section" which is based on analytical models of charring versus time. Charring models are given for unprotected and protected structures (by wooden-based panels or plasterboard). This method is today the most used in engineering to verify or to design timber structures when exposed to fire. The Eurocode charring models have been validated on the basis of tests carried out with the standard fire curve [1]. This method is therefore limited to a prescriptive calculation, which can be very conservative for the structure. Moreover, the Eurocode 5 part 1-2 also offers an analytical charring model for wooden elements exposed to "parametric" fires but it is limited in time. For a performance-based design, more advanced fire models are needed. For example, compartment fire models or CFD software can be used. When using advanced fire models, there is no analytical model for corresponding charring. In that case, the use of a numerical charring model, coupled to the fire calculation, is therefore necessary. Some approaches of this kind have been experienced for steel and concrete constructions and very close studies also exist on wooden-based products [2], [3], [4]. The aim of this study is to contribute to the use of a performance-based design when assessing the fire resistance of a wooden structural element. The coupling between different types of fire models (standard, parametric and 2 zones model) and a numerical model for charring of wooden-based products is presented.

Firstly, the physical background of the charring model is presented. The model is based on the thermal diffusion equation in a solid, in which supplementary terms are added in order to take into account the energy linked to thermal reactions into wood. Water vaporization and pyrolysis of the different components of wood are simulated by using independent Arrhenius laws. The thermal properties are calculated at each time step by mixture laws that are controlled by the reactions rates. The model parameters are then calibrated based on an existing experimental study where wood samples were exposed to standard and non-standard fire curves [1]. The calibrated model is then compared to a second experimental study where 9 non-standard fire curves were tested [5]. The comparison between measured and calculated valued allows discussing about the importance of thermally-induced thermal reactions into wood, as flaming and smouldering, especially during the decay phase of low heating rate fire curves.
Finally, the model is directly used as a tool for assessing the fire resistance of a common glue-laminated beam. The structure is exposed to the standard fire curve and to two non-standard fire curves (parametric fire and a two-zones fire). The results underline the importance for a designer to correctly choose the fire scenario when assessing the fire resistance of a structure.

References


Fire behaviour and design of beam-to-column steel-to-timber dowelled connections

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Keywords: timber, connections, fire resistance, design

Background

The fire performance of a timber structure is largely influenced by the behaviour of its connections. Current structural fire design methods for timber connections according to EN 1995-1-2:2004 [1] are based on empirical rules derived from a limited number of fire resistance tests on timber connections loaded in tension parallel to the grain. At normal temperature, connections loaded in the direction parallel and perpendicular to the grain exhibit very different behaviours, the latter being prone to brittle splitting failures. Given these different failure modes and with metal fasteners being responsible for increasing charring in the connection area, a question arose about how different the fire behaviour of connections loaded in the direction perpendicular to grain would be.

Experimental research

Beam-to-column steel-to-timber dowelled connections were tested at normal temperature and in fire [2] and reached more than 30 and even 60 min of fire resistance, cross sections with 160×260 cm² and 240×340 cm², respectively, for degrees of utilisation $E_{il} / R_{20°C,mean}$ between 0.23 and 0.39. Most connections failed after extensive embedment deformations in the beam side of the connection. Aspects such as a wider gap between the beam and the column and the presence of reinforcement with self-tapping screws decreased the fire resistance, as observed in a previous study [3]. The failure mode at normal temperature and the dowel diameter did not seem to influence the fire resistance, suggesting that the thickness of the side members and the degree of utilisation are more relevant.

Numerical simulations

A framework to model timber connections at normal temperature and in fire, based on combined finite-element (FE) heat-transfer analyses and temperature-dependent Johansen-type load-carrying models, was developed [4] and applied in a parametric study of the previously tested connection typologies. The results showed a clear influence of the thickness of the side members on the fire resistance of the analysed connections and that a side member thickness $t_1 = 116$ mm would suffice for reaching 60 min of fire resistance.
Design of timber connections in fire

Current design rules of EN 1995-1-2:2004 for timber connections in fire were reviewed, taking into account the experimental research conducted before and after its publication in 2004. Some design rules are shown to give unsafe estimates of the fire resistance, while others give very conservative results. New design rules that take into account the experimental research conducted since the publication of EN 1995-1-2:2004 were formulated [5]:

\[ R_{fi} = R_{20^\circC} \cdot e^{-k(t_f - t)} \]

where \( R_{fi} \) is the load-carrying capacity after a given period \( t_f \) of fire exposure, \( R_{20^\circC} \) is the load-carrying capacity at normal temperature (or the load-carrying capacity at \( t_f = 0 \)), \( k \) is the rate of decay of the load-carrying capacity, \( t_f \) is the thickness of the timber side members, and \( c_1 \) and \( c_2 \) are specific parameters for each connection typology.

Figure 1. Proposed and current EN 1995-1-2:2004 models, and experimental results on beam-to-column connections [2]: a) connections with a side member thickness \( t_1 = 77 \) mm (R 30); b) connections with a side member thickness \( t_1 = 117 \) mm (R 60).

References


Current state of working group 2:
Fire behaviour of CLT

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Keywords: Cross-laminated timber; fire behavior; fire tests; charring rate; fire design

Introduction

Cross-Laminated Timber (CLT) is currently used in modern timber for load-bearing wall, floor or roof elements as a high quality, innovative and cost-effective structural element. Careful planning and implementation ensures the safe use of CLT in buildings with increased fire protection requirements and in accordance with the requirements of building-design standards (e.g. EN 1995-1-1 and EN 1995-1-2) [1,2]. Task group 1 of working group 2 of this COST Action aims to deliver important information for the fire design of CLT to be used for the revision of the fire part of Eurocode 5. This abstract summarises the current state of the work and the planned next steps.

Current state of work

The fire part of Eurocode 5 is currently under revision and should include information on the fire design of CLT, which is not included in the present version of Eurocode 5. However, fire design models for CLT are already available in the European technical guideline for fire safety in timber buildings [1], in the scientific literature and probably also in different national guidelines and all this information will of course be used as input for the revision of Eurocode 5 and improved as much as possible.

This revision work is coordinated within the Working Group 4 of CEN/TC 250/SC5 chaired by Andrea Frangi (ETH Zurich, Switzerland) with participants from several countries active in the field. Further, the revision is supported by this task group and the global “Fire Safe Use of Wood (FSUW)” network.

A reliable model for the fire design of CLT needs to be verified and compared with fire test data in order to be useful and not too conservative for an economical design. There are some fire test data published in the scientific literature that can be used. These tests are summarized in a database and provide important information to be used during the revision of Eurocode 5.

There are also data from fire tests that different producers have performed within the certification process of their products. Those data are the property of the producers and some of these tests have been incorporated in the database already.
Based on the comprehensive overview on fire tests with CLT elements taken from this database, the European charring model and other models (such as a Canadian charring model, a Japanese charring model, an US charring model, etc.) have been compared to test results. The char depth of initially unprotected CLT wall and floor elements is taken from the database (based on the fire test reports) and compared to the char depth calculated according to the different charring models. Fig. 1 shows a comparison of the char depth obtained from fire tests with the European charring model for initially unprotected CLT elements as an example.

The following conclusions can be drawn for initially unprotected CLT elements on the basis of Fig. 1, and according to [3]:

- The European charring model gives mainly conservative results, meaning that the char depth predicted by the model is usually greater than the char depth obtained in the fire tests.
- The difference of char depth between the model and the fire tests increases with increasing time of fire exposure, demonstrated by the dashed trendline. That means that the model becomes more conservative with increasing time of fire exposure.
- The difference between the model and the fire tests for a fire resistance of 60 minutes is only about 2 minutes.
- The European model overestimates the char depth on average by 5 mm. Assuming a one-dimensional charring rate of 0.65 mm/min this results in a difference with respect to the fire resistance of about 8 minutes.

Additional to the charring rate, the zero-strength layer $d_0$ for CLT has been investigated. The work will be published soon.

**Planned next steps**

The next steps of this task group are directly related to the work of CEN/TC 250/SC5. It is planned to provide the following possibilities to perform the fire design of CLT in the future Eurocode 5:
1. Tabulated data
2. Simplified design method
3. Advanced design method

This task group will support the work performed within the revision of Eurocode 5. Interested people are welcome to join.

**Acknowledgments**

The authors gratefully acknowledge the European COST Action FP1404 on the Fire safe use of bio-based building products.

**References**


Working Group 3

Regulations for fire safety of bio-based building materials
Report on building regulation concerning the bio based building products in Hungary

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Keywords: Priorities, Fire protection and resistance, Wood, Tradition, Deviation

In Hungary there is a new fire safety regulation¹ valid since 2014, which is intended to secure a harmonization with the EU laws. The EU defined the Fire Protection Categories and their specifications. All buildings must be classified into risk classes according to their capacity, to their vertical dimension by height and depth and to their capacity to escape of persons. The building constructions, components and materials must be classified into Fire Protection Classes and specified according to the Fire Resistance Regulations. The definition of the detailed requirements of these classes is a national competence and has to be formulated by the members. The Fire Protection Technical Directives in Hungary provide only requirements which can help planning but they don't give any actual solution proposals. So these are the legislative framework which doesn't contains any dedicated regulations for named materials and products. Not even the words like “steel, wood, concrete, RC” etc. are really mentioned in this laws. Obviously, there are no references in them neither for the bio based building products. For helping with the fire safety classification of the building products there are some Fire Protection Audits by the EU and some by the National Institute for Quality Control (ÉMI) but these concern mainly to constructions and materials belonging to proven building systems and not to innovative products and solutions. The use of the bio based building products in small-scale buildings are very traditional either as constructions or as cover materials and it is not very difficult to correlate them to the Fire Regulations. But their use in Hungary in large-scale buildings as construction elements reckon, or rather, would reckon among innovative solutions. Bio based building product in Hungary means first of all the wood. The planning and design using wood for construction elements, for example, in a multi-story building demand lots of innovative powers because of the fire regulations, but it is not an impossible challenge in principle. At the same time there are a lot of difficulties in practice which counteract the wider use of bio based products (wood) by construction of a large scale building:

1. The principle of the Fire Protection of the building products traditionally has intense dominance. In countries such as in England or in Germany where the requirements are better concerning the use of bio based products (wood) in a multi-story large-scale building the regulation focus more on the Fire Resistance.

2. In this context the Safeguarding of valuables and the Protection of lives are on the same importance level in Hungary, while the priority of the Safeguarding lives would help using of innovative products.
3. The *passive* fire protection traditionally is still dominant opposite the *active* solutions which has of course financial reasons, too.

4. Nowadays the planners and designers have the *application for the deviations from the norm* as the only device for building something different from the ordinary. These applications usually can work but the solutions and the approval are always unique and often accidental rather than comprehensive and focused on the complexity of the project. A complex Fire Protection Conception for the whole project elaborated in cooperation by the authority and the planners could create a positive condition for using bio based products.

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**Figure 1. Family house in Zsida, Gábor U. Nagy**

**Figure 2. Pajta in Őriszentpéter, Gábor U.Nagy**

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**Acknowledgments**

Special thanks to Prof. Tibor Alpár, Gábor U. Nagy, Péter György Horváth, Károly Wágner

**References**

Fire-fighting concepts for buildings made from bio-based products

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Keywords: fire, fire-fighting, timber buildings, equipment, extinguishing, conception, bio-based materials, fire safety

Fire-fighting conception as a system of fire-fighting procedures is developing with new challenging building constructions, new materials and new fire-fighting equipment. Primary mission of fire and rescue services is to protect life, health and property of citizens against fire and to provide effective help in emergencies. In the event of fire many aspects are important especially if a building is constructed from flammable bio-based building products.

Fire-fighting conception is an important system of effective ensuring of fire safety related to current situation, including organisation, operational procedures, area coverage etc. With regards to current increasing number of timber buildings and lack of knowledge and experience with real fires in Europe, research to specify main risks, safety limits, extreme fire behaviour as well as best practice are highly needed.

Strategy of fire-fighting

Fire-fighting conception is affected by various factors, which response to current situation in a country. Some of them are stated below:

- Economic factors (fire-fighting equipment, number of fire stations, number of stuff)
- Local dangers (fabrics, mines, forests, ...)
- Traditions and culture of fire safety protection (voluntary fire-fighters, population ability of danger awareness, ...)
- Geographical situation (population density, area, weather, ...)
- Traditions of building conception (depending on local access to building materials and their prices)
- Regulations, etc.

All these aspects affect establishing of fire-fighting conception and its planning which includes building of new fire stations, local fire brigade equipment, area coverage setting by fire and rescue service (including category of fire units – response time of units in case of emergency), designing of extinguishing systems in buildings, fire-fighting plans, etc.
Many of bio-based buildings are used as dormitories, offices, schools, hospitals, etc. which specify unusual conditions for effective rescuing and extinguishing. Special fire-fighting documentation is used as supported documentation for fire-fighting in these buildings. The documentation includes recommendation for commanders, special risks, type of construction, recommended extinguishing equipment and agents, recommended fire-fighting routes, etc.

**Various approaches in Europe - example**

Each country has its own conception with respect to current situation. Sweden with almost six times larger area than the Czech Republic has similar number of population.

In Sweden, it is more traditional and usual to build timber structures than in the Czech Republic. For example, Sweden has much lower density population and more extreme weather phenomena. Additionally, population in countries have different approach to fire prevention. The conception is quite different in comparison with the Czech Republic.

In comparison, each country has different response time in case of fire, different number of voluntary and professional fire-fighters, equipment, and fire stations cover different area.

**Risks for fire-fighters**

Fire-fighters should be informed about special risks related to structure and material behaviour, for example if steel construction achieved temperature higher than 400°C, entering of fire-fighters into the building is not recommended. Similar recommendation should be developed for new bio-based buildings (if steel joint achieve 400°C, inform about light-weight/heavy-weight type of construction, etc.).

Bio-based materials and new types of construction use represent risk in event of the fire, for instance:

- Extensive use of engineered wood-frame construction
- Synthetic fire loading in the interior and in the exterior
- Void spaces
- Open floor plan/atrium-like design living spaces (lack of compartmentation allows faster fire development and spreading)
- Fire involvement throughout, etc.

As new materials are developed, fire-fighting conditions and aspects should be further researched and implemented in fire-fighting tactic, training and equipment.

Main goal of WG3TG1 is to summarise and compare possible risks and dangerous behaviour of bio-based materials in fire, as well as experience from fire-fighters and the best practice of various fire-fighting equipment and agents. This work should help fire-fighters to react to changes of wider use of bio-based materials.
Construction site fire safety – UK experience

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Keywords: fire safety, construction, risk assessment

The purpose of this presentation is to explain the background to the current UK provisions in relation to fire safety on construction sites where the principal method of construction is timber frame (including light timber framing, Cross Laminated Timber panels and Structural Insulated Panel systems).

The presentation will explain the background to the current situation and describe the response provided by the UK Structural Timber Association (STA).

The presentation will focus on a number of incidents where large fires have occurred during the construction phase to identify the important issues to be addressed (speed of fire spread, radiated heat to adjacent buildings, partial occupation of completed buildings within the site boundary).

The issue will be addressed in relation to regulatory issues and the provision of guidance to the construction industry on risk mitigation factors and the preparation of a Fire Safety Plan for the construction phase for large timber frame construction sites.

In addition to guidance on risk mitigation STA members have to comply with Site Safe Guidance which includes registering all large construction sites on a confidential web site run by the UK Fire Service.

The UK STA have issued guidance for dealing with the off-site risk of a fire on a timber frame construction site impacting on adjacent buildings outside the site boundary. Easy to use tables are provided to specify the minimum separation distances based on the area of the potential emitting surface. The allowable separation distance is a function of the form of construction. Test and assessment procedures are in place to classify construction products based on ignitability and reaction to fire properties during the construction phase (Figure 2).
Figure 1 Fire during the construction phase of a large timber frame project.

Figure 2 STA Small room fire test for assessment and classification of construction products

References


Background to building regulations – Change of fire safety regulations in Finland

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Keywords: fire exposure, HC fire curve, charring rate, visible timber, requirement

Background

Changes of fire safety regulations in Finland have occurred quite regularly: 1997 performance based fire safety design was made possible and timber framed buildings up to 4 storeys (residential and office) came possible according to prescribed rules; 2002 European reaction to fire classes were implemented; 2011 timber framed buildings up to 8 storeys (residential and office) were made possible according to prescribed rules. The next change is planned to be at the beginning of 2018.

Several background studies during 2015 and 2016 have been carried out to further develop the Finnish fire safety regulations. The topics have included e.g.:
- clarification of the regulations and guidance to reduce different interpretations,
- extension of prescribed rules of maximum 8 storey building to covers also other than residential and office buildings,
- conditions for use of timber structures without coverings in building with more than two storeys, and
- protection of insulation materials which are not at least A2 or B class.

One of the studies is shortly summarised in the following. Background for this study arises from the basic principles for timber framed buildings (more than 2 storeys) in the Finnish regulations: Both sprinklers and coverings (K<sub>2</sub>10 or K<sub>2</sub>30 with A2 material) are required. And the probability of structural failure shall be at the same level as for buildings with at least A2 class structures.

Fire exposure

As a starting point a design fire exposure curve was generated for the situation where load bearing structures are made of visible massive timber and sprinklers fail (or are not installed). The structures may be protected partly by gypsum board, or may be totally unprotected.

First a probabilistic approach using parametric fire curves was applied to find out possible fire exposure levels and effects of openings. Parametric temperature-time curves according to Eurocode EN 1991-1-2 do have a linear decay slope which reached low (original) temperatures faster than in reality. The walls, ceiling and floor stay warm for a long period (in a non-collapsed room) and there may be also some residue of the movable fire load glowing on the floor. Parametric fire curves are quite close to the HC (Hydro Carbon) fire curve for the first half an hour. After that the parametric curves are higher until short after the decay phase has started.

In Figures 1 and 2 experimental results are given for temperature developments in room fire tests with massive timber structures which have been totally or partly protected or there has been no
gypsum board protection at all. When having a lot of wood visible the temperature-time curves are quite close to the HC fire curve which reaches 1100°C in 30 minutes and stays there.

![Figure 1. Room with 660 MJ/m² movable fire load. About half of CLT walls and ceilings visible [2].](image1)

![Figure 2. Room with less than 350 MJ/m² movable fire load when wooden floor excluded [3].](image2)

The difference between total energy (fire exposure to the structures) of the HC fire curve and the standard temperature-time curve which is used in fire classification of structural members is illustrated in Figure 3.

![Figure 3. Fire exposure comparison in energy between HC and standard temperature-time curves.](image3)

Based on results of the probabilistic parametric fire curves and comparisons with real scale experimental results it was decided to use the HC curve as a fire exposure design curve for measuring charring rates of structural members.

**Charring rates**

Measured one-dimensional charring rates [4] for standard fire exposure are given in Table 1 and for HC fire exposure in Table 2. The following specimen were included in the test series: LVL (fire exposure perpendicular to laminations and in direction of laminations), CLT (fire exposure perpendicular to lamellas and in direction of lamellas), solid timber and glued laminated timber.
Table 1. One-dimensional charring rates (standard fire exposure).

<table>
<thead>
<tr>
<th>Time from start</th>
<th>Charring rate (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LVL up LVL down CLT up CLT down Sawn timber Glulam</td>
</tr>
<tr>
<td>30 min</td>
<td>0.62 0.60 0.70 0.73 0.65 0.68</td>
</tr>
<tr>
<td>60 min</td>
<td>0.66 0.62 0.66 0.71 0.62 0.61</td>
</tr>
<tr>
<td>90 min</td>
<td>0.64 0.63 0.73 0.70 0.61 0.59</td>
</tr>
<tr>
<td>120 min</td>
<td>0.62* 0.63*</td>
</tr>
</tbody>
</table>

*Estimate

Table 2. One-dimensional charring rates (HC fire curve).

<table>
<thead>
<tr>
<th>Time from start</th>
<th>Charring rate (mm/min) HC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LVL up LVL down CLT up CLT down Sawn timber Glulam</td>
</tr>
<tr>
<td>30 min</td>
<td>1.24 1.27 1.16 1.24 1.12 1.15</td>
</tr>
<tr>
<td>60 min</td>
<td>1.07 1.08 1.15 1.01 0.92 0.95</td>
</tr>
<tr>
<td>90 min</td>
<td>1.03 0.97 1.09 0.85 0.82 0.84</td>
</tr>
<tr>
<td>120 min</td>
<td>1.08* 0.95* 0.75 0.79* 0.76*</td>
</tr>
</tbody>
</table>

*Estimate

**Load bearing requirements**

For the design of load bearing timber elements it is essential to define requirements using the R classification values also for performance based fire exposures such as the HC fire curve in this case.

The R60 requirement corresponds the 600 MJ/m² fire load density limit in the Finnish regulations. When this requirement is given in terms of total energy of fire exposure, it can be assumed that certain safety factors must be included in the required R levels. Thus it has been proposed that the 600 MJ/m² fire load density limit includes the contribution of 20 % of visible structural wood surfaces on walls and ceiling (see Figure 4).

Concerning safety of rescue personnel, it is assumed that there will be no collapse of load bearing structures during one hour (real time) of natural fire development. Total energy exposure the structures in a test with HC fire curve during one hour is about 700 MJ/m². This corresponds fire exposure during 107 minutes under standard fire curve conditions (Figure 4).

For HC fire exposure the one-dimensional char depth was not more than 65 mm in 60 minutes for LVL, sawn timber and glulam [4]. This corresponds char depth at 100 minutes under standard fire curve conditions (Figure 4).

In Figure 4 it has been assumed that the total energy of fire exposure increases linearly with increasing area of visible timber structures. Thus also a linear model for R equivalency based on energy and char depth is applied. The percentage value of visible structures is calculated for the walls and ceiling, not taking floor into account.
Figure 4. Total energy during 60 min fire exposure and R equivalency as a function of percentage of visible timber structures.

Conclusions

Scientific studies are needed to form solid background for changes of national fire regulations. In the described study key finding were the following:
- HC fire can be used to describe situations were large areas of timber structures are exposed to fire and there are no sprinklers or they fail.
- Increase in charring rate caused by a higher fire exposure can be taken into account with increased fire resistance requirements (which are based on standard fire exposure).
- Char depths in timber structures can be calculated based on standard Eurocode 5 rules and product specific calculation guides.

Acknowledgments

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References

Serbia: Fire safety in regulations, research and future challenges

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Keywords: Timber structures, Fire regulations, Education, Research

Timber constructions sector in Serbia – overview

Serbia is a country with about 27% of total area covered by forests, what is estimated as 65% of optimal forest cover (considering ecological, social and economic parameters in harmonic correlation). Broad-leaved stands represent 86.4%, coniferous stands 6.8% and mixed stands about 6.8%. [1]. As a consequence of poor natural coniferous wood resources and sawn softwood production, the import of technical construction timber is present (Bosnia & Herzegovina, Ukraine and recently from Austria and Russia).

Serbian building heritage includes wooden churches and monasteries as well as numerous historical buildings in rural and central urban areas, completely (walls, etc.) or partially (only roofs and ceilings) made by wood. Traditional buildings by local poplar wood and mud mixed with straw, covered and enforced by reed are present in north region of Serbia, i.e. Vojvodina (Fig. 1).

\textbf{Figure 1. Traditional housing in Vojvodina} \hspace{1cm} \textbf{Figure 1. Timber prefabricated modular house}

Today concrete (RC, AAC), steel and brick (clay products) dominate in residential or public building in Serbia. The official statistics show that the percentage of wooden houses is about 1% of total housing (residential homes) construction in Serbia. Although the wood is not a dominant building material in Serbia, it could be said that it is inevitable: traditional roof structures made by solid timber are still dominantly used in residential buildings, both in single family houses and multi-
levelled apartment blocks. Engineered wood prefabricates, such as light-frame trusses connected by punched metal plates, are frequently used for rehabilitation of flat roofs in urban areas. Other prefabricates (such as LVL, “I” joists and beams etc.), are not in use because there is no domestic production. Residential prefabricated modular houses (Fig. 2) made by timber frame panel walls finished by timber board (OSB, particle, veneer, plywood, etc.), recently (after a severe earthquake in 2010) achieved significant progress because of rapid installation and good performance in cases of seismic events. Massive wall timber systems in form of log homes are still partially used for rest houses. Glulam products are usually used for sport halls, swimming pools, hotels, small bridges and other public representative buildings or special canopies. Technologically advanced products, such as cross laminated timber (CLT), are not present in modern construction sector in Serbia.

Fire Safety Regulations in Serbia

In Serbia fire regulation codes were traditionally based on prescriptive approach, until 2009 when the new Fire Protection Law introduced performance based design and risk analysis. All facilities have to be categorized by Fire inspectors (Sector for Emergency Management – Directorate for preventive protection, Ministry of Interior RS) according to vulnerability to fire. It depends on technological process, the type and amount of material that is produced, processed or stored, type of material used for construction and the importance and size of a building. There are 3 fire risk categories (FRC): (1) High fire risk, (2) Increased fire risk and (3) certain fire risk.

Both in the conceptual design phase and in the main design project phase, it is obligated to submit separated volumes of technical documentation (Fire protection Elaborate and Fire protection Main Design Plan, respectively) in order to prove that the building meets the basic fire safety requirements: the load-bearing capacity of the structure can be assumed for a specific period of time, the generation and spread of fire and smoke within the building are limited, the spread of fire on neighbouring buildings is limited and to insure safe and timely evacuation or rescue of occupants. Basic requirements are considered as fulfilled if foreseen fire protection measures are in accordance with technical rules, standards and fire risk assessment. The risk assessment is obligatory to be done for all buildings. Fire protection Law demands fire detection systems for hotels, department stores, shopping centres, cinemas, kindergartens, schools, higher education institutions, cultural institutions, medical facilities, sports and concert halls, stadiums with commercial space, airport buildings and tall buildings, regardless of the results of risk assessment. Additionally, the risk assessment is obligatory for proving that there is no need for a suppression system for those facilities. All tall buildings, except residential, have to be equipped with fire suppression systems.

The Serbian Building Codes (SBC) consider the wood based structures in general as “combustible”. In fire risk classification and analysis, SBC do not treat differently timber or timber based structures due to applied type of wood or wood based product, cross-sectional area of elements or applied structural system and type of structural connections. The number of stories is not strictly limited by Fire safety codes, because buildings with main timber structure are generally
constructed as low-rise buildings with max two stories. Bio-based materials are not considered in SBC, although they are traditionally present in old residential houses, and there is strong intention of their use in new energy efficient buildings as insulating materials (particularly straw and types of timber and bio waste). Some fire safety requirements for timber buildings could be found as parts of different structural codes for timber structures, mostly as empirical ones, and they are dealing with construction protection measures, chemical protection of wood and safety protection claddings with non-combustible sheets. As the test furnaces for full scale testing do not exist in the country, the attestation of fire performance is limited and oriented to prefabricated wood-based panel walls covered with gypsum sheets.

Most important for fire safety are the regulated fire safety standards (Building Code) that provide integrated fire suppression systems such a sprinklers, fire rated wall and floor assemblies, and fire separation of habitable spaces from emergency exits. Under this proposal, such fire safety systems would be identical for tall wood buildings and tall steel or concrete buildings, only the construction material would be different.

Education and Research

In higher educational system in Serbia, Fire Safety Engineering studies are accredited at a few Higher Education Institutions (2 academic and 4 applied study programmes). At Department for Civil Engineering and Geodesy (University of Novi Sad, Faculty of Technical Sciences), academic 5-years/300 ECTS study programmes Civil engineering and Disaster Risk Management & Fire Safety Engineering are running simultaneously. As Serbia is in the process of adoption of EU building codes and Directives, the study programmes are innovated in order to be complementary and synchronized. It is expected that Erasmus+ project "K-FORCE", started in 2016, October, will speed up modernization Master and development of PhD studies in this field. The synergy of two study programmes is visible in several high quality master and PhD thesis, that are finished or in progress. In lack of testing laboratories, the main focus of the research is oriented to numerical modelling of fire performance of building elements.

Challenges

The main challenge in domain of timber structure and fire safety in Serbia is to deliberate modern timber products and bio-based materials from numerous preconceptions and administrative obstacles. With continuous data collection about previous and actual fires of timber based structures, with more detailed description about structural systems and used connections and (non)existing fire protection, it could be possible to develop the risk matrices and to influence correlation between risk categories and modern timber products present at the Serbian market. In lack of experimental opportunities, the focus of numerical modeling has to be based on foreign fundamental research about charring rates of different types of wood, data that includes the contribution of other present combustible materials to fire performance of timber structure and data about metal connection behavior. Also, the introduction of existing proved details suitable
for implementing in Serbian practice will also be one of the tasks, in order to enhance the existing codes.

References

Designers’ Opinions on the Use of Bio-based Materials in Buildings

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Abstract

This study aims to evaluate building designers’ views of construction using bio-based materials and timber, across Europe in terms of; sustainability, Eurocode 5 (EN 1995), construction materials, combustibility, sprinkler or deluge protection, and fire retardant treatments or impregnations. It will provide an indication of designers’ opinion on the use of bio-based materials and timber using Lime Survey. In summary, designers are generally aware of the sustainability benefits of these materials, however there is a definite concern in relation to the combustibility of these materials. There is overall a general acceptance that sprinklers, and surface coatings or impregnations may help to alleviate the issue to some degree.

Keywords: Bio-based, timber, designers, buildings, opinions

Introduction:

There is an increased number of researchers investigating the properties of timber and other bio-based materials, many driven by an overarching theme to improve the carbon footprint of our buildings (Lawrence 2014, Lawrence 2015, Fan and Fu, 2017 ). However the use of timber as a key structural material in buildings is still very much the exception, rather than the rule. Each time that a building is envisaged at concept stage, the overall building envelope is chosen, the main structural materials are decided upon, and whether large amounts of exposed bio-based surfaces
will be part of the building features. The building designers, such as architects, interior architects, and structural engineers, have an important role in deciding (Haroglu, 2009) whether timber or other bio-based materials are used.

In order to ascertain designers’ opinions on the use of timber and other bio-based materials in buildings, an online survey, using Lime Survey, was undertaken. This survey covered areas such as; sustainability, EN 1995 (Eurocode 5), materials most commonly used in construction, sprinkler/deluge protection, coatings, impregnations, and the potential for a 3rd party review of designs. 161 responses from designers primarily from across Europe were received, however some did not complete all of the 23 questions asked.

**Importance of Sustainability**: Very few designers disagree that timber and bio-based materials are more sustainable than other building materials, however 1 in 4 designers are neutral in their views. As can be seen in Figure 1, only 50% of those designers who agree that timber and bio-based materials are more sustainable are in favour of increasing its use in their buildings. This could be due to lack of familiarity, concerns over combustibility, concerns over durability, additional costs, and larger member size in some cases.

![Figure 1. Sustainability & Use of Timber & Bio-based Materials in Buildings](image)

**Eurocode 5 (EN 1995)**: Many designers do not appear to have transferred over to the Eurocode from their existing older timber design codes and standards, (See Figure 2 below). This can often be the case if one is only designing in a material very infrequently, then the lead in time to become familiar with a large code may encourage a designer to remain with an earlier code, even though it may have been superseded. It is good to see that there is only minimal disagreement with the statement that “Eurocode 5 is an improvement”, showing the standard in a good light. However there may be some cause for concern, as many designers are in agreement, while a lesser number of designers are willing to strongly agree that EN 1995 is an improvement. There is also over one third of designers neutral or unconvinced that Eurocode 5 is an improvement. This may be due to unfamiliarity with EN 1995, or it may be due to the complexity of the document, while very suitable for larger more complex buildings, may be somewhat unwieldy for smaller simpler projects.
**Construction Materials:** As shown in Figure 4 below, reinforced concrete appears to be the most commonly used structural construction material, followed closely by structural steel. Approximately 50% of building designs are in reinforced concrete, with a further 1/3 of building designs using structural steelwork. Only 5% of designers use either timber post & beam or cross laminated timber (CLT) construction in the majority of their building projects, as such the use of larger structural timber elements seems to be limited to a small number of specialist structural designers.

**Combustibility:** The combustibility of timber and bio-based building materials shows up as a definite concern for designers, with 62% of designers stating they are either concerned or very concerned about the combustibility of both structural timber elements, and exposed combustible wall and ceiling linings. (See Figure 5). On a positive note only 1/3 of those showing a concern are stating that they are very concerned. Approximately 20% of building designs either incorporate combustible facades or combustible internal linings to buildings. The survey suggests that designers in Croatia, Finland, Germany, Slovakia, and Spain may be more likely to use timber or bio-based combustible materials in their building facades.
Sprinkler or Deluge Protection: The support for sprinkler protection follows an approximate bell curve, with the greatest number of designers being in favour of its use. (See Figure 7 below). There seems to be particular concern about the use of sprinkler protection to combustible facades, possibly due to potential adverse weather effects, such as freezing of water within the pipework systems, or strong winds blowing the water spray away from the area that requires protection. Sprinklers like any other active system is never as certain as a passive system, as a local explosion may render an entire system inoperable.

Fire Retardant Treatments & Impregnations: Almost 60% of designers are in favour of fire retardant treatments and impregnations, while just over 20% disagree with their use. This concern may be due to the relatively thin coating and the shallow depth of impregnation, thus affecting lining properties more than duration of fire resistance. Furthermore coatings may get damaged or painted over during their lifetime and their effectiveness could then become compromised. (See Figure 8 below).
3rd Party Design Review: 71% of designers are in favour of a 3rd party review of timber designs, with only 14% not being in favour. (See Figure 9 above). This strong opinion on the need for a 3rd party review may suggest a lack of familiarity with the design of building elements composed of timber or bio-based materials.

Conclusions & Recommendations: Designers in general see the sustainable benefits of using timber and bio-based materials in buildings. However there appears to be concerns about the combustibility of these materials, a lack of familiarity with their design, and this combined with a potentially higher construction cost, which may be more weather dependant on site, leads to a cautious approach for building designers as they consider moving away from reinforced concrete, structural steel, and masonry. There is a general acceptance that sprinklers or surface coatings and impregnations may help to alleviate some concerns. As the main driver is sustainability, together with the visual attractiveness of timber and other bio-based materials, there is rarely an economic incentive to produce timber buildings. The low level of Post & Beam or CLT construction leads to an unfamiliarity with design using these materials, and this in turn leads to many building contractors unsure of building using these methods. One possibility which may to encourage the use of timber and bio-based materials, is the creation of easy to use guidelines for simpler elements of construction using well thought out detailing, both from a fire safety aspect and from a durability point of view. If designers used timber more regularly thus seeing its visual benefits, then they may become more familiar with its design, and building contractors would in turn follow their lead. As all members of the construction industry become more familiar with the use of these materials, then its advantages should become more apparent.

References


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Abstract

This investigation evaluates regulators’ opinions of construction using bio-based materials and timber, primarily across Europe in terms of; sustainability, Eurocode 5 (EN 1995), construction materials, combustibility, sprinkler or deluge protection, and fire retardant treatments or impregnations. It aims to provide an indication of regulators’ views on the use of bio-based materials and timber in buildings, using Lime Survey. This survey indicates that regulators are generally aware of the sustainability benefits of these materials, however they are concerned about the combustibility of these materials. There is a certain level of guarded acceptance in relation to the use sprinklers, and surface coatings or impregnations, with a preference for impregnations over surface coatings.

Keywords: Bio-based, timber, designers, buildings, opinions

Introduction:

Regulators, and fire officers, are required to certify larger building designs in many countries and they tend to rely on prescriptive codes and standards when examining these designs (Meacham et al. 2016). In many cases their standards require certain building elements to be non-combustible, and this prescriptive requirement may mean that a fire engineering solution must be prepared by the designer and submitted to the regulatory authority (Brannigan and Smidts 1999, Lo and Yuen 1999, Lataille 2002, Lo et al. 2002). This places additional workload on both the designer and the regulator, and also additional costs onto the developer. This system varies between countries,
and this regulator survey sets out to determine the underlying opinions of regulators and fire officers, regarding the use of timber and bio-based materials in buildings.

A short 16 question online survey using ‘Lime survey’ was created to determine regulators views on the use of timber and other bio-based materials in buildings. This questionnaire encompassed concepts such as; sustainability, EN 1995 (Eurocode 5), construction materials, sprinklers, coatings, impregnations, and a 3rd party review. Responses were received from 121 regulators mainly from Europe. There was an increased response from Ireland of 34 respondents, and this should be noted when analysing the results. Some regulators chose not to answer a number of questions, and the percentages have been adjusted accordingly to take this into account.

**Importance of Sustainability:** The majority of regulators were neutral, or did not give an answer, regarding their view on the sustainability of timber and bio-based materials, the remainder generally agreed that these materials are more sustainable. When asked whether they would be in favour of an increase in the use of timber and bio-based materials in buildings, they gave a more positive response with 1/3 being in favour. (See Figure 1 below).

![Figure 1. Sustainability & Use of Timber & Bio-based Materials in Buildings](image)

**Lack of Familiarity with Eurocode 5 (EN 1995):** Over 90% of the regulators surveyed agreed, or strongly agreed, that they are not familiar with Eurocode 5 (EN 1995, with the remaining 10% being neutral. (See Figure 2 below). This lack of familiarity with this key timber structural design document by fire officers and regulators suggests a possible lack of awareness of timber fire engineering design principles and the current state of the art.
Construction Materials: The majority of regulators rarely if ever examine timber Post and Beam or Cross laminated Timber (CLT) structures, as they only occur in approximately 8% of developments certified or inspected. Reinforced concrete construction would account for over 50% of building projects, while structural steel would be used in approximately 30% of structures. The remaining structural elements would primarily be masonry type developments. (See Figure 3 below).

Board Protection to Timber Structural Elements: There appears to be a large variation in the use of board protection, primarily using gypsum based boards. Over 20% of regulators have plasterboard protection in the majority of the timber buildings that they examine or certify. At the other end of the scale almost 40% of regulators do not see board protection, suggesting that exposed timber may be present in these building projects. The remaining 40% have a range of values, examining buildings with both exposed and protected timber structural elements. (See Figure 4 above).
**Combustibility:** The main concern of regulators is the combustibility of timber and bio-based materials when used in buildings. 85% of responses indicated a concern in relation to this issue. (See Figure 5 below). The highest level of concern being indicated by regulators in Belgium, France, Germany, Ireland, Poland, & Turkey. This current widespread concern by regulators is certainly a deterrent to the use of timber and bio-based materials in the construction industry. Figure 6 shows the breakdown of % of combustible facades and internal linings found in buildings which have been inspected or certified by regulators. This indicates that many regulators, almost 30%, do not allow combustible facades or internal linings in the majority of the buildings that they certify or inspect. Examining the overall responses, approximately 15% of buildings have combustible facades, with approximately 17% of projects having combustible internal linings.

**Sprinkler Protection:** There is a general level of approval for the use of sprinkler protection by regulators (See Figure 7 below), however there are 20% of regulators who disagree with their use. This concern may be due to the fact that any active system may not be as reliable as a passive system, particularly if the passive system has non-combustible elements. There was a higher level of agreement with internal sprinklers, than external ones, possible due to the effects of weather on their operation.
Fire Retardant Treatments & Impregnations: Almost 60% of designers are in favour of fire retardant treatments and impregnations, while just over 20% disagreeing with their use. This concern may be due to the relatively thin coating and the shallow depth of impregnation, thus affecting lining properties more than duration of fire resistance. Furthermore coatings may get damaged or painted over during their lifetime and their effectiveness could then become compromised. (See Figure 8 below).

3rd Party Design Review: Most regulators, 72% are either in favour, or strongly in favour of a 3rd party review of projects with structural timber elements. (See Figure 9 above). The countries that appear to be most in favour of such a review are; Belgium, Greece, Ireland, & Turkey.

Conclusions & Recommendations: Regulators across Europe appear to be significantly concerned about the combustibility of timber and bio-based materials when used in buildings. However this does not seem to translate into the provision of protective plasterboard protection in all cases, with some regulators allowing exposed timber. The combustibility of structural elements, internal linings, and facades are all a cause of concern to regulators. The extreme lack of familiarity with
Eurocode 5 among regulators is alarming and suggests that a campaign aimed at educating regulators in the use and fire safe design of timber may be required.

References


Working Group 4
Dissemination
First COST Action FP1404 Training School – Fire Safe Use of Bio-Based Materials – University of Edinburgh, UK

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The first COST Action FP 1404 training school was held at the BRE Centre for Fire Safety Engineering, School of Engineering, University of Edinburgh, from 3-5 October 2016. The Training school was specifically designed to give participants a detailed and fundamental view of some of the fire safety problems associated with bio-based building materials. Practical laboratory experiments (Figures 1 and 2), combined with lectures from international experts and classroom work, explored concepts of heat transfer, fire dynamics, material response, and structural fire engineering. The course was delivered by Dr Rory Hadden (Edinburgh), Prof Luke Bisby (Edinburgh), Dr Guillermo Rein (Imperial College London), Dr Dionysiο ο Colitis (National Technical University of Athens), and Prof Ulf Wickstrom (Lulea University of Technology).

Figure 1. Training School participants observe a compartment fire dynamics experiment on a cross-laminated timber compartment with exposed internal timber surfaces.

The lecture topics included: Compartment fire dynamics; pyrolysis, ignition and burning of wood; structural fire engineering and modelling; real fire exposures; numerical modelling of timber structures’ response in fire; and heat transfer [1] and pyrolysis modelling. The final day of the workshop consisted of students’ presentations on their own research projects, and reflections on these in light of the experiences obtained during the training school. This first COST Action FP1404 Training School was, in the opinions of the organisers, highly effective and useful; thanks
to all the enthusiastic students and interesting, engaging lecturers. Looking forward to the next one!

Figure 2. Training School participants observe a structural fire experiment on a loaded laminated bamboo beam.

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References

Notes