EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

Proceedings of the Joint Conference of COST Actions FP1402 & FP1404 KTH Building Materials, 10.3.2016

Cross Laminated Timber – A competitive wood product for visionary and fire safe buildings

Editors:

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Detailing of CLT with Respect to Fire Resistance

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Summary

This publication summarizes the state of the art of detailing for cross laminated timber elements (CLT) and compiles available test data and findings on in-plane joints of CLT elements, joints in CLT component connections as well as the influence of penetrations and mounting parts in CLT, all with respect to the separation and load bearing function in the case of fire.

1. Introduction

Besides the structural stability, the separating function for wall and floor elements represents one of the most essential capacities in the case of fire. The evaluation of the fire resistance for such building elements normally occurs on the basis of standardised fire tests, such as listed in EN 13501-2 [1], as well as approved calculation methods, such as those presented in EN 1995-1-2 [2]. These methods normally do not, or just to a low extent, take into account any joints and junctions to neighbouring elements, mounting parts or typical penetrations of service installations. However, one of the main principles within the European fire safety regulations of buildings is the limitation of the spread of fire and smoke to other compartments and neighbouring buildings.

Element joints, junctions and penetrations of building services through separating elements are unavoidable and also have to fulfil the general requirements with respect to overall fire safety. There is a necessity to plan and approve these for each material and construction method from the beginning of a project to avoid complex and expensive solutions in the latter stages of construction.

However, inspections and surveys of new and existing buildings repeatedly report for all building materials and construction methods that the risk for an early fire spread from one fire cell to the next is mainly caused by inappropriately designed joints and service installations in walls and floors. At the same time, Stürmer (2006) e.g. found 50% of the service installations not installed properly and not

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able to perform correctly in the case of fire, resulting in significant limitations of usability for egress ways and the structural elements [3].

With respect to timber structures, this aspect becomes even more important. On the one hand, only a small amount of approved technical solutions are currently available on the marked. On the other hand, the combustibility of bio-based materials may contribute to a fire spread if hot gases infiltrate the structural elements. Within this context studies showed, that a flow of hot gasses through timber elements increase the charring behaviour due to additional thermal exposure and preheating of typically unexposed regions [4] [5]. In addition, an early failure of integrity may occur as soon as hot gases are passing through separating elements.

For massive timber structures including CLT three flame spread paths can be identified. These must be taken into account within the design process to ensure an overall fire safety for buildings using CLT:

- in-plane joints to neighbouring prefabricated elements
- joints in junctions of components and to other building parts
- joints resulting from service installations and penetrations

A schematic of these paths is given in Figure 1.

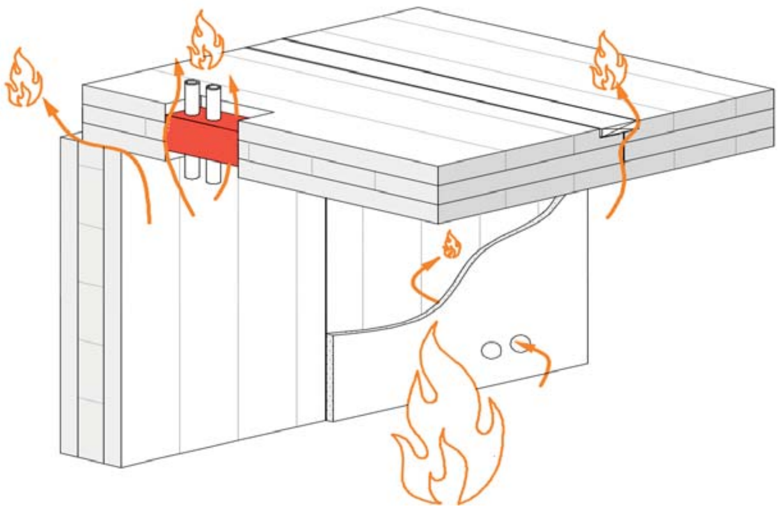


Fig. 1 Flame spread paths for buildings using CLT.

2. In-plane Joints of CLT Elements

In recent years many studies dealt with the evaluation of CLT elements for walls and floors with respect to load bearing or separating function in the case of fire. The main part of these research projects or industrial reports used standardised fire tests according to EN 1363 [6] and EN 1365 series [7]. Using these standards CLT wall and floor elements showed a fire resistance of up to 90 minutes. Beside the element itself these fire tests investigate the in-plane joints of the CLT elements. Moreover, full-scale natural fire tests were performed.

To evaluate the performance of in-plane connections current testing standards use the “EI” criterion according to EN 13501-2[1]. This approach ensures that the temperature does not increase more than 180°C in relation to ambient conditions and that hot gases do not ignite objects on the unexposed side. Some reports also investigate the smoke-tightness as a third criterion, which is not a standardized criterion so far. This leads to the situation that the results are hard to compare between different reports. The criterion of smoke tightness contributes to evaluate the overall fire performance as well as the efficiency of different measures for in-plane joints with CLT. Table 1 summarises fire tests with respect to in-plane joints from the last years.

Table 1: Overview of selected CLT fire tests including element joints.

Reference	**Description**
Frangi & Fontana 1999[8]	Small scale and full scale fire tests with hollow core CLT elements for 60 and 90 minutes; standard fire exposure including three different configurations of joints.
Polleres & Schober 2004 [9]	Fire tests to asses different element joints using an external single spline on the surface or an interior spline; 140 mm massive timber floor; standard fire exposure
Hosser & Kampmeier 2008 [10]; Kampmeier [11]	1) Small scale fire test to assess smoke tightness of massive timber elements including connecting joints, 160 mm thick unprotected elements, standard fire exposure to an area of 450 x 450mm², three different joint configuration
	2) Mid-sized scale test to assess smoke tightness and thermal integrity of massive timber elements for element joints and joints in wall-floor junctions,110 mm thick elements, standard fire exposure to an area 1200 x 1600 x 500mm^3
	3) Full scale test to assess fire resistance and smoke tightness of three different connections, 120 mm thick massive timber elements including CLT; standard fire exposure
Winter & Stein 2007 [12]	Full scale tests with loaded massive timber element
Association for glued timber products 2013 [13,14]	Full scale tests of protected wall elements 0,08 x 2,98 x 3,28 m; 3-layered CLT elements; standard fire exposure over 90 minutes
Mc Gregor 2013 [15]	Full scale tests assembly 3,5 x 4,5 x 2,5 m^3, 3 layered CLT elements; natural fire exposure

The outcome of all tests can be summarised as follows: Joints may lower the fire resistance and influence the smoke tightness in a negative way. Gaps resulting from fabrication inaccuracy or needed construction tolerances allow hot gases and smoke to pass through in the presence of over-pressure under fire conditions. Especially butt connections should be prevented or at least need additional actions.

In this context, McGregor (2013, [15]) found gases escaping from individual CLT elements as well as from the joints between neighbouring elements in many places in his first tests. Therefore, he used a fire rated silicon in all following tests to improve the performance of the element joints. This was effective, but still gases were observed escaping from the spatial elements to some degree. He reported an increase in temperature and a glowing combustion at the unexposed surface of an element joint. This burning-through occurred earlier than in the undisturbed panels (Fig. 2).

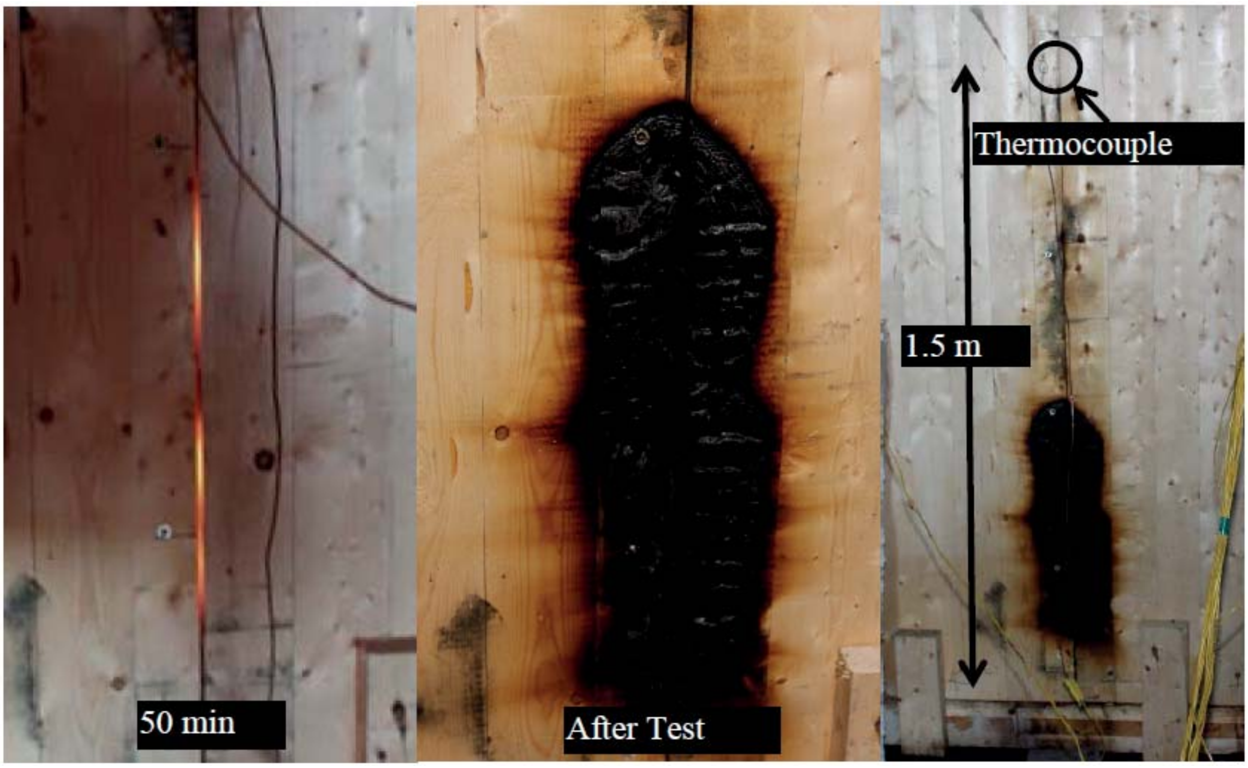


Fig. 2 Results from McGregor's work [15].

To avoid flow paths Hosser and Kampmeier (2008, [10]) examined the performance of compressed mineral wool implemented in simplified element joint configurations (Fig. 3). From the small-scale tests it was concluded that a 10 mm compressed mineral wool stripe is reasonable to achieve smoke-tightness in the in-plane element joints.

Further full-scale tests investigated the performance of realistic element joints using exterior splines and single or double tongue and groove joints. With respect to the smoke tightness, all in-plane element joints failed within 60 minutes in the tests although the double tongue and groove joint performed better as the single one. However, the separation function was fulfilled during the entire tests (Fig. 4). Therefore, the authors recommend using an elastic joint sealant on both sides of the connection if the element size does not allow an even compression of a mineral wool in the element gap due to structural purposes or fabrication inaccuracies.

Fig. 3. Variations of in-plane CLT element connections with 10 mm compressed mineral wool stripes (in green), Kampmeier (2008) [4], *Fig. 24.*
A) *butt joint with mineral wool*
B) *step joint with mineral wool*
C) *interior double spline with mineral wool.*

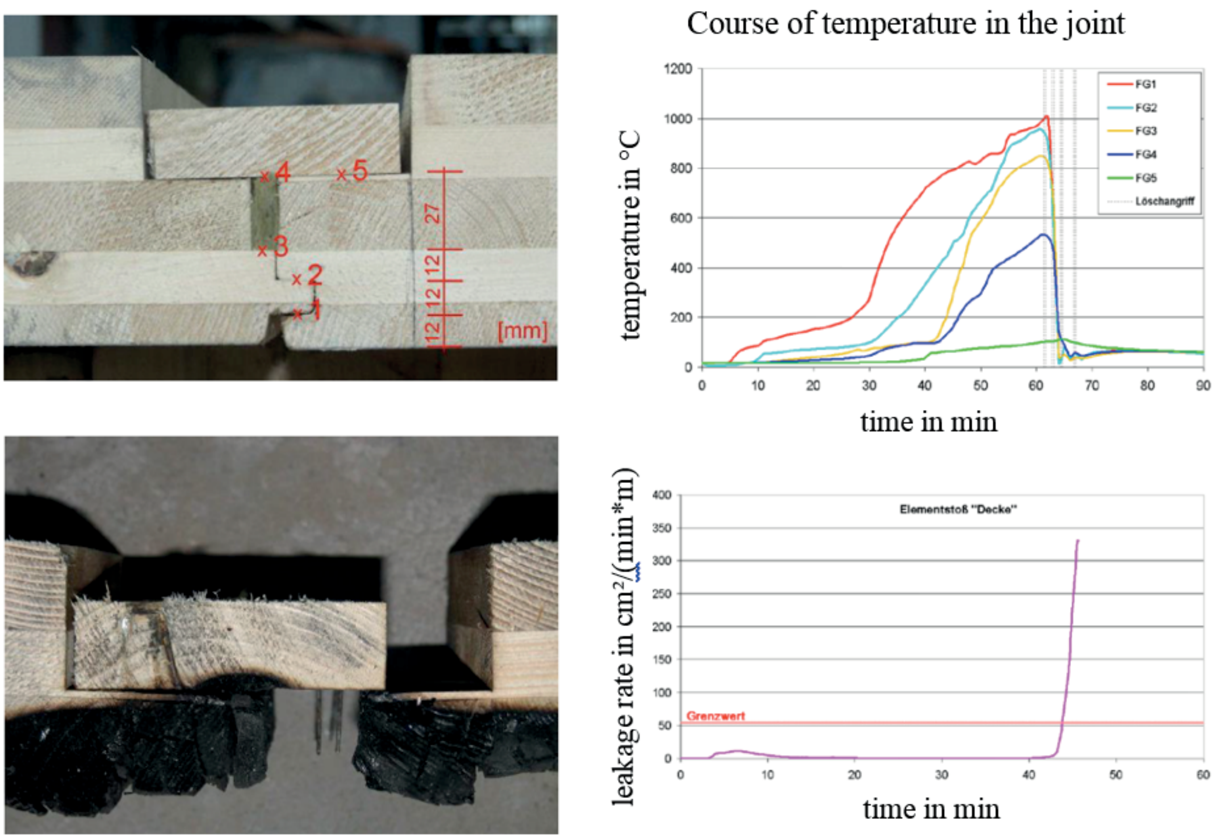


Fig. 4 Assessed element joint with location of thermocouples before and after the fire test and course of the temperatures and leakage rate during fire exposure, Hosser and Kampmeier (2008, [10]*).*

Nowadays, CLT element joints are normally based on exterior splines or step joints. These joints have been tested in Polleres and Schober (2004, [9]) or in tests of the Association for glued timber products (2013 [13], [14]). These covered and uncovered fire test show a fire resistance of the element joints of more than 90 minutes.

Teibinger (2012, [21]) derived from the Austrian tests that the fire safety will be reached if the remaining cross section covering an interior double spline, a step joint or an exterior spline is at least 2 cm. To avoid hot gases passing through additional sealing generally used for the purpose of air tightness were implementedin the tests of the Association for glued timber products ([13, 14]).

Frangi and Fontana (1999, [8]) confirm these statements with their investigation on hollow core CLT elements. The highest fire resistance was achieved using element joints where all cavities are filled with mineral wool in combination with a tongue and groove joint on the exposed as well as on the unexposed side. A big amount of smoke gases passed through joints using intumescent material as it takes a while to achieve the activating temperature of this material. A similar behavior was found in Winter and Stein (2007, [12]).

3. Corner Connections of CLT

Similar to element joints, joints in corner connections and joints to other building parts need an equivalent fire resistance. The aim is to prevent the spread of fire and smoke to other fire compartments. However, no standardised test method exists at the moment to assess the performance of fire exposed corner junctions. Therefore, existing test data and recommendations are based on tests following in general the EN 1365 series [7] procedures but also on small-scale tests or full-scale natural fire tests.

Teibinger (2011, [16]) tested two different corner connections with respect to fire performance. The CLT wall was lined with a 12.5 mm gypsum plasterboard and connected to a glulam floor element using a PUR elastomer vibration absorber to prevent sound transmission (Fig. 6a). In one test, the elastomer support was additionally sealed with an intumescent sealing compound at the exposed side, in another test, a simple non-fire rated acryl-sealing was used. The test with the intumescent sealing showed excellent results with no additional charring within the connection but also the second test with an acryl sealing reached 90 minutes without failure of integrity or escaping of smoke (Fig. 6a). Both setups met the same fire resistance as for the spatial elements.

Equivalent test results were reported by Merk et al. (2014, [17]) for mid-size scale fire tests with unprotected CLT floor elements and K_260 encapsulated walls. An elastomer vibration absorber was installed in the junction as typically used in practice (Fig. 6b). The vibration absorber was partly covered by the encapsulation cladding but no further sealing was applied at the fire exposed side. Within the tests only little penetratation of smoke occurred and no glowing combustion became evident. After testing, neither the connection nor the elastomere showed any fire impact (Fig. 6c).

Hosser and Kampmeier (2008, [10]) tested corner connections without any lining. They found that the connections easily resist a 60 minutes fire if the entire depth of the element is filled by a 10 mm mineral wool stripe, which is compressed to 5 mm when connecting the elements. All corner connections were secured with outside surface splines as well. The authors also pointed out, that the measured charring depths within the corner were less compared to the spatial elements and explained this fact with the lower heat flux density at inside corners.

(a) (b) (c)

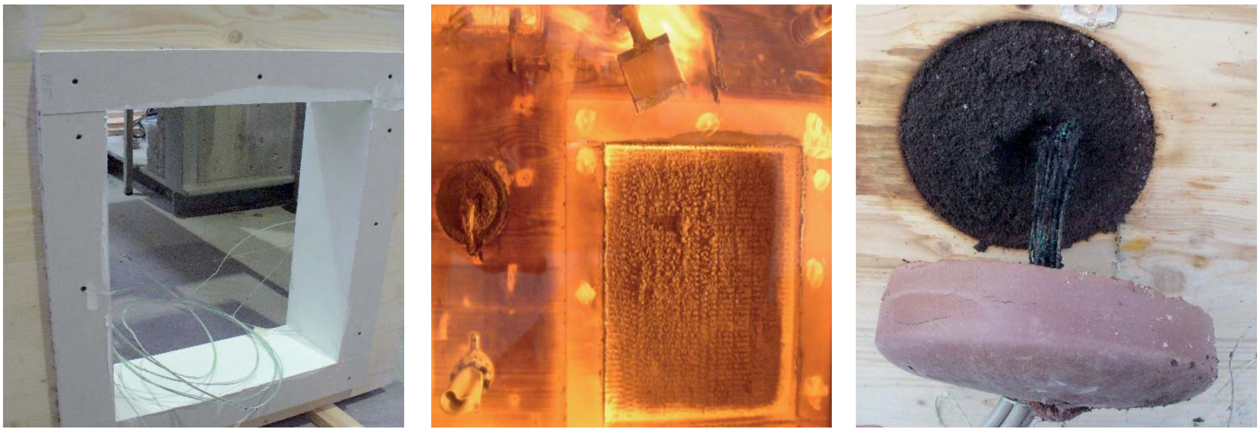
Fig. 6 Fire test with elastomer vibration absorber in wall to floor junction.
a) source [16], *b) source* [17], *c) source*[17].

When integrity requirements cannot be fulfilled by the CLT panel alone additional linings can be used to increase the failure time. These linings will not only contribute to an improved fire resistance of the CLT element but also to a reduction of the smoke permeability and a better thermal integrity of the element junction. These findings were derived by Winter and Stein (2007, [12]) from smoke tightness and fire resistance tests under ISO fire exposure with timber frame and CLT elements. Similar to in-plane element joints all examinations underline the need of an air tight sealing which is also required with regard to building physics such as for sound- and thermal insulation purposes.

4. Service Penetrations and Mounting Parts

In principle, penetration through fire rated assemblies should be limited. If they are essential for the use of a building or a unit by certified systems to maintain the assembly’s fire rating. Until now approved sealing systems for service installations are typically only available for drywall or concrete constructions. Tested and approved solutions for timber structures are rare and slowly reaching the marked, even though they can be tested in accordance with EN 1366 series [18]. In general, fire tests and technical approvals show that every type of service installation passing through fire separating elements has its own specific characteristic, level of performance and, therefore, range of application. Hence, there is no single solution or product that will be used for all services and protects all elements in the same manner to avoid early fire spread. However, some research projects tried to provide general solutions in order to adapt existing and approved sealing systems for a fire safe use in timber structures like CLT (Fig. 7, Werther et al. 2012, [19]).

Investigations of Werther et al. (2012, [20]) comprised tests with penetrations of single wires, cable bundles, combustible service pipes, non-combustible service pipes and mixed penetrations. It was found, that systems with intumescent materials efficiently seal the gaps between the supply line and solid timber elements. For passive systems without capacity to expand under fire exposure a further sealant should be applied on both sides of the penetrated element. As a main concept to install multi penetration sealing systems, such as mineral wool boards, a non-combustible lining of the area over the entire thickness of the separating element is recommended.



(a) (b) (c)

Fig. 7 Fire test for various penetration sealings (Werther et al. 2012, [19]*).*

In addition, Teibinger and Matzinger (2012, [21]) tested sealing systems in CLT walls and floor elements for more than 90 min fire resistance. They also investigated potential joining details of service shafts and CLT floor elements. The tests showed that all sealing systems in the solid timber element fulfilled the requirements. However, the authors pointed out, that intumescent systems should be used preferably and the fastening means must be designed according to the aimed fire resistance.

With respect to mounting parts in CLT elements, like sockets and recessed electrical boxes that penetrate a fire rated lining or encapsulation cladding Merk et al. (2014, [17]) recommend an intumescent coating, to protect the timber behind the penetrated lining (Fig. 8). The intumescent coating was applied not only in the recession of the CLT elements but also at its surface circular around the penetration. This procedure prevented an early ignition and burning of the timber, because the protective lining always arched upwards during the fire exposure.

(a) (b) (c)

Fig. 8 Fire tests with recessed sockets in CLT treated with intumescent coating (the activation of the intumescent coating resulted in a black coloring at surface) (Merk et al. 2014, [17]*).*

5. Conclusion

To restrict the spread of fire and smoke and maintaining the integrity of fire seperating CLT elements several studies have been conducted. The focus lied on joining details, resulting from in-plane element joints, component connections and service installations.

All studies show that the prevention of flow paths is one of the essential measures to fulfil the fire safety requirements for the entire structure. For element joints and junctions, like wall to wall and wall to floor connections, the fire safety can easily be reached if the requirements for statics and building physics are fulfilled. The solid nature of CLT supports these characteristics. Several fire tests show that existing penetration sealing can be used in combination with CLT elements to assure fire safety.

Approved details for designing fire safe CLT structures can be taken from construction catalogues, such as published by the Holzforschung Austria (Teibinger and Matzinger 2013, [22]) or Technical University of Munich (Merk et al. 2014 [17]).

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