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Test Methods to Evaluate the Adhesive Performance in CLT when Exposed to Fire

Steven Craft[1], David Barber[2], Michael Klippel[3], Joachim Schmid[3], Andrea Frangi[3]

ABSTRACT: In recent years, many tall timber buildings have been designed utilizing cross-laminated timber (CLT) as structural elements. Given the interest in taller and larger buildings with CLT where non-combustible construction is currently required, current research projects in North America and Europe have been investigating both the charring behaviour and the contribution to the fuel load of exposed CLT. For buildings to be designed to withstand a fully developed fire and have a structure that utilises exposed CLT, the CLT panels need to perform in a manner that is predictable. Based on a number of fire tests, the new PRG 320-2018 North American CLT product standard was recently developed using a compartment fire test to assess the adhesive performance in CLT when exposed to fire. In Europe, a different test method is under development using a mass loss rate to draw conclusions about the possibility of a burn-out and thus avoiding a regrowth of the fire sometimes referred to as a second flashover. This paper summarises recent developments and discussions in both North America and Europe regarding the consequences of exposed CLT when exposed to fire. It presents a medium-scale test methodology to determine if char fall off occurs when the CLT panel is exposed to fire, a critical design consideration for fire safety engineering of mass timber buildings.

KEYWORDS: timber, cross-laminated timber, adhesive, fire exposure, temperature measurement, mass loss

1 INTRODUCTION

Cross-laminated timber (CLT) panels have been produced and used in fire-rated wall and floor assemblies for the past two decades. During this time, it has been recognized that the adhesive commonly used to manufacture CLT panels tends to lose strength and allow the charring layer to fall-off when exposed to fire. As interest grows in building high-rise buildings using CLT, as one of several mass timber products, the contribution to the fuel load of exposed mass timber has become a focal point of research. Many compartment fire experiments have been carried out in recent years in North America and Europe to study this contribution, which have demonstrated that the fall-off of charring layers of CLT can lead to a regrowth in the fire during the decay phase. This regrowth may prevent the structure from surviving a full burnout of the fire. It is critical to understand that the high-rise buildings being proposed are typically sprinklered buildings. Therefore, the fire scenario in which the fall-off of charring layers of CLT may play a role in the fire severity is in the unlikely event that both, the sprinklers, and the fire service fail to control the fire. However, it is still of interest to constitute a standard test method to evaluate the adhesive performance in CLT when exposed to fire.

2 INTERNATIONAL CODE DEVELOPMENT

With the increase in interest in sustainable construction practices, developers, architects and engineers have been working to seek approval on a project by project basis for high-rise mass timber buildings. More recently, building code committees in North America have begun working on proposals to allow high-rise timber buildings. In Europe and North America, already several high-rise timber buildings are under construction or in use.

3 LITERATURE REVIEW

3.1 FIRE RESISTANCE EXPOSURE TESTS

CLT manufacturers carry out standardized fire testing to allow their product to be used as a compliant construction material. Full size standardized fire tests, such as to ISO 834, ASTM E119 and CAN/ULC S101 have shown the impact of the fall-off of charring layers of CLT panel leading to increased charring rates. This impact in standardized fire testing has been documented within the CLT Handbooks in North America, where the methodology for calculating the char depth assumes the fall-off of charring layers. In Europe, it is differentiated

[1] CHM FIRE CONSULTANTS, Canada, steve.craft@chmfire.ca
[2] ARUP, USA, david.barber@arup.com
[3] Institute of Structural Engineering, ETH Zurich, Switzerland, klippel@ibk.baug.ethz.ch

between CLT wall and floor elements when calculating the charring depth. For CLT floor elements, a so-called stepped charring model is used if the CLT panel is expected to show a fall-off of charring layers. In case of no fall-off, the single one-dimensional charring rate β_n = 0.65 mm/min can be used. For CLT wall elements, a slightly increased charring rate of β_n = 0.8 mm/min is recommended to be used if a fall-off is expected. Fire tests showed that for CLT wall elements, fall-off is less pronounced than for floor elements.

Also, highly relevant are small-scale fire tests that have been used by many researchers to determine the mechanics of such a fall-off. The first work to verify the impact of differing adhesive types was by ETH Zurich in 2009, which showed a clear difference between polyurethane (PUR) and (melamine-urea-formaldehyde) MUF adhesives. Following from the ETH work, further small-scale testing has been carried out, among others, by FPInnovations (Canada), showing consistent results. In the US, small-scale CLT fire testing by the Forest Products Laboratory (FPL) has recently confirmed fall-off of charring layers in the CLT panels using the PUR adhesive and the lack of fall-off of charring layers in CLT panels utilizing a MUF adhesive. More recently, small-scale tests conducted at ETH, successfully differentiated between a PUR adhesive that led to fall-off of charring layers and one which does not. Thus, it is important to underline that it is not possible to classify the adhesive just on their "family background". Different PUR adhesives can lead to a substantial different behaviour in case of fire when used in CLT, as it is also the case for MUF type of adhesives.

3.2 COMPARTMENT FIRE EXPERIMENTS

Fire experiments on CLT compartments have been carried out by various research and testing organizations, including Carleton University, ETH, VTT, Delft University, University of Edinburgh, University of Queensland, FPRF and ICC. The experimental tests have had a variety of goals. The majority of tests have been aimed at testing characteristics such as the contribution of the exposed CLT to fire growth and peak heat release rate as well as the compartment burn-out characteristics and behaviour of glued timber products such as CLT in more realistic fires, since a standard fire test cannot estimate the behaviour of construction in the cooling phase.

The exposed CLT has been shown to impact the fire dynamics of the compartment. The compartment experiments have been based on fully developed fires, and these have shown that the fire growth rate, heat release rate (HRR) and fire duration will all be influenced by the exposed CLT timber to varying degrees. The tests have shown that exposed CLT increases the peak HRR and lengthens the fire duration, due to the added combustible fuel, when compared to a compartment without any exposed timber. The degree to which this occurs will depend on the amount of exposed CLT.

4 DISCUSSION OF CRITICAL PARAMETERS

Avoiding fall-off of charring layers of CLT is required where large areas of CLT are exposed as this allows for predictable fire behaviour. The key aspect for CLT performance in fire is the CLT should char at a consistent rate through the adhesive line. A panel that is susceptible to char fall-off will not have a consistent char rate, with increased charring as the adhesive line is reached. While this phenomenon is currently accounted for in the design for fire resistance, the impact on the decay phase of a compartment fire is more difficult to assess. For those CLT manufacturers who can produce CLT that does not show this phenomenon, through the use of improved adhesives, then the issues of fire regrowth and "second flashover" are addressed.

To determine if a panel will experience the fall-off of charring layers, and consequently an increased charring rate under fire exposure, requires tracking the char front by recording the 300^{o}C isotherm, using many thermocouples embedded in the panel. However, it is important that the thermocouples are installed correctly as shown in and. The CLT panel is required to be in the horizontal plane (floor/ceiling configuration) since the effect of fall-off is more pronounced compared to e.g. wall elements. A standard test method should guarantee reliable and reproducible test outcome. Any measurement and instrumentation used for evaluating the test should therefore carefully be elaborated.

5 CONCLUSIONS

Based on the critical parameters discussed above, a standard test method is proposed in this paper to evaluate the tendency of an adhesive to lead to an early fall-off of charring layers of CLT when exposed to fire.

The desire to build high-rise buildings using mass timber products, and in particular, CLT, has led to the extensive research investigating the contribution of CLT to fire severity. This research has identified the fall-off of charring layers of CLT as increasing the fire severity, and in some cases leading to regrowth of the fire after the room contents have been consumed (so-called "second flashover"). Based on the literature review, a proposed methodology to screen adhesives which lead to the fall-off of charring layers of CLT during fire exposure is proposed. This test method is more economical than the current test required in North American product standard PRG-320 as well as providing a solution for both North America and Europe.

For those CLT manufacturers, which can produce CLT which does not exhibit this charring layer fall-off behaviour, using improved adhesives, then the issues of fire regrowth and "second flashover" will not be an issue for compartments with exposed CLT. This will allow designers to expose more CLT, as well as other products such as glulam, and predictably determine conditions for fire self-extinguishment.