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Experimental study of fire-induced-delamination of cross laminated timber

Introduction

Cross Laminated Timber (CLT) is increasingly used as a structural material for tall buildings, due to its structural properties and low carbon footprint. CLT is a mass timber product, which is made by crosswise gluing layers of timber lamellae. Recent architectural trends include having visible CLT surfaces, which, in the event of a fire, can become involved in the fire and act as fuel to the fire. A study by the *Fire Protection Research Foundation* (FPRF; USA), *National Fire Protection Association* (NFPA; USA), *National Research Council Canada* (NRC-CNRC; Canada), *Research Institutes of Sweden* (RISE; Sweden) and *National Institute of Standards and Technology* (NIST; USA) has focused on the contribution of exposed CLT to compartment fires. The study included a review of previous compartment fire tests [1], full-scale fire tests of compartments with and without exposed CLT structures [2], the development of design methods for engineers [3] and intermediate scale fire tests to identify high-temperature resistant adhesives for CLT [4]. The full-scale compartment tests showed the undesirable consequences of CLT delamination during a fire (i.e. fall-off of exposed lamellas), which occurred due to weakening of the CLT adhesive. These consequences included fire regrowth after a period of decay or a continuation of a fully developed fire. This can make self-extinction of a compartment fire not possible, implicating that the fire will lead to collapse if the fire is not manually extinguished or extinguished by sprinklers.

In order to achieve self-extinction of flaming combustion in compartments with exposed CLT it is important to avoid fire-induced delamination [3]. It was shown that fire-induced-delamination can be avoided using high-temperature-resistant adhesives. A test method was developed to identify adhesives that are not prone to fire-induced-delamination under relevant fire conditions [4]. A summary of the test methodology, evaluation and results is discussed in this article.

Test methodology

To identify adhesives that do not exhibit fire-induced-delamination in conditions of a compartment fire, a cost-effective intermediate scale furnace test was developed that aimed to replicate relevant conditions of a compartment fire (i.e. fire conditions that lead to similar damage). A compartment fire test involving an exposed CLT ceiling (and all other surfaces sufficiently protected) by Su et al. [2] was considered as a relevant basis for the replication of fire conditions, because ceilings are more prone to delamination than walls and because the exposed surface area is greater than the recently-proposed regulatory limit in the USA [5].

The intermediate scale tests were performed in a furnace with internal dimensions of 1.0 m × 1.0 m × 1.0 m and the CLT specimen was placed above the furnace, as shown in Figure 1. Plate thermometers were facing away from the specimen positioned at 100 mm (which corresponded to the full-scale compartment test) and at 150 mm from the CLT surface. The oxygen concentration was measured in the exhaust of the furnace. The implemented plate thermometer temperatures and oxygen content were replicated from the full scale compartment fire tests during the first 120 minutes of the test. To achieve this, the oxygen content was adjusted by adding nitrogen or regular air into the furnace through an inlet, when needed. In the full scale compartment fire tests, delamination has led to fire regrowth after approximately 150 minutes. In order to identify delamination in the furnace test, the sudden temperature rise resulting from delamination observed at 150 minutes of the full-scale compartment fire test, was disregarded and the target temperature of the intermediate scale test was extrapolated for the last part of the test. The target oxygen concentration was also extrapolated after 120 minutes, using oxygen measurements of a similar fire test without delamination (see Figure 2).

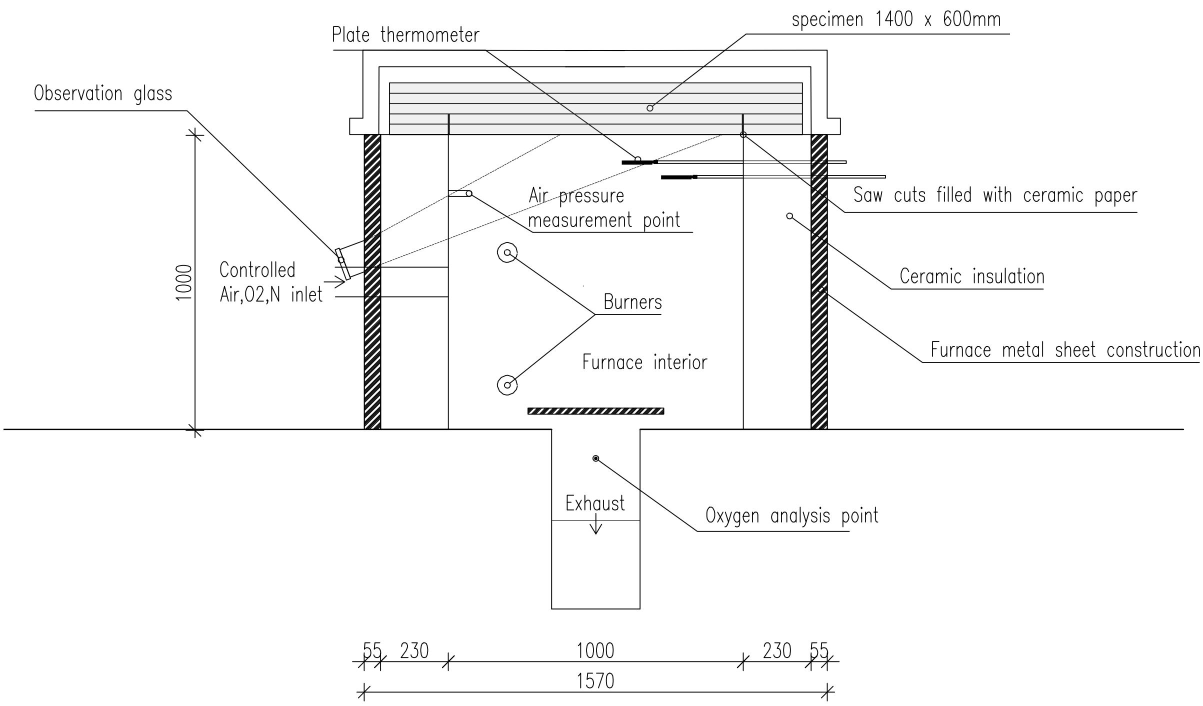

Figure 1: Cross section of the furnace test setup.

All specimens tested were 5-ply CLT panels with dimensions of 1400 mm × 600 mm × 175 mm and a lamella-thickness of 35 mm. A *Melamine Formaldehyde* (MF), a *Phenol Resorcinol Formaldehyde* (PRF), an *Emulsion Polymer Isocyanate* (EPI) and two *Polyurethane* (PU) adhesives were tested. One of the polyurethane adhesives tested (PU1) was the same as the adhesive used in the full scale compartment fire test. The other polyurethane adhesive (PU2) was developed for an improved fire performance. Each furnace test was repeated twice, resulting in a total of 10 furnace tests.

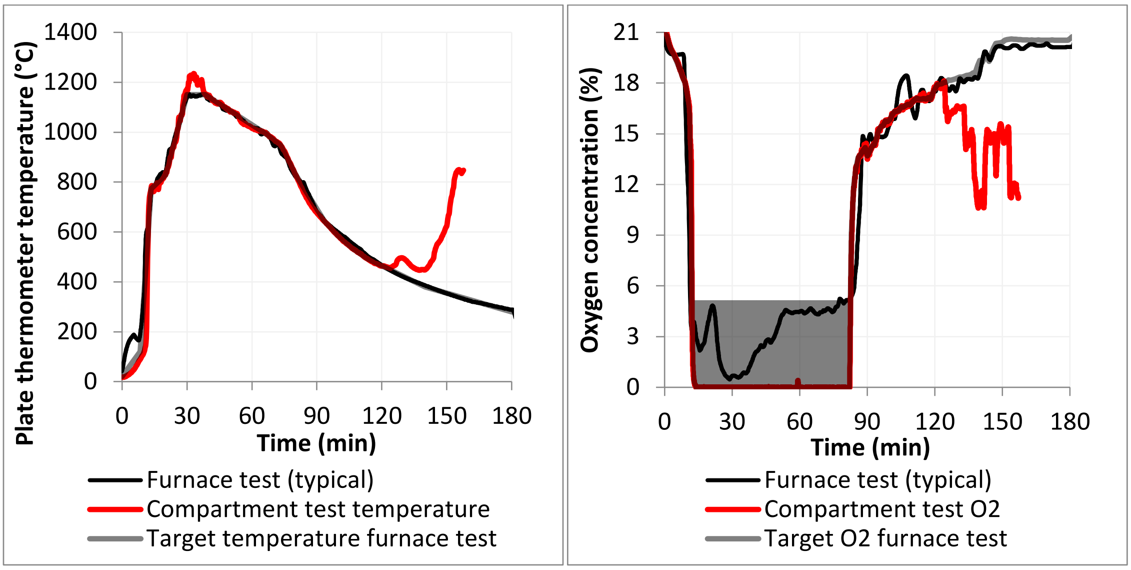

Figure 2: Temperatures and oxygen concentrations of the furnace and compartment tests.

An assessment of delamination in the intermediate scale fire test was performed using (1) measurements of the lamella and bond line temperatures, (2) measurements of the char depths and charring rates (3) a video made of approximately 50 % of the exposed surface and (4) estimations of the total mass loss after the tests.

Evaluation of the method

The oxygen concentration and the plate thermometer temperature at 10o mm from the CLT surface were controlled to be similar to that of the full scale compartment fire test with an exposed CLT ceiling. In Figure 2 indicates the accuracy of this replication in a typical furnace test in which no CLT delamination took place.

The aim of the replication was to impose structural damage to the CLT in a relatively cheap intermediate scale furnace test that is comparable to the damage observed in the full scale compartment fire test. A comparative study of damages imposed on the CLT in both (compartment and furnace) was performed to evaluate whether this aim was achieved. In the full report [4] it was shown that the measured char depth in the CLT after the furnace test was within the range of the char depths measured in the CLT ceiling of the compartment. It was also shown that the temperatures measured in the CLT at different depths generally corresponded well between both tests if the same CLT was tested. Figure 3 shows temperatures inside CLT at a depth of 20 mm (measured from the exposed surface) for three different tests. The temperatures of the compartment test and the furnace test with PU1 adhesive followed a similar trend and values. Both tests involved a significant temperature jump of temperatures measured in the exposed lamella at around 60 minutes, indicating that delamination took place in both tests. It should be noted that the temperatures were measured in 12 locations in the exposed layer of lamellae and that there was a variation of times at which this significant temperature jump took place. Figure 4 shows box plots indicating this variability. The times at which temperature jumps occurred in the CLT of the furnace tests were approximately similar to those in the CLT of the compartment test, indicating that the fire exposure is comparable.

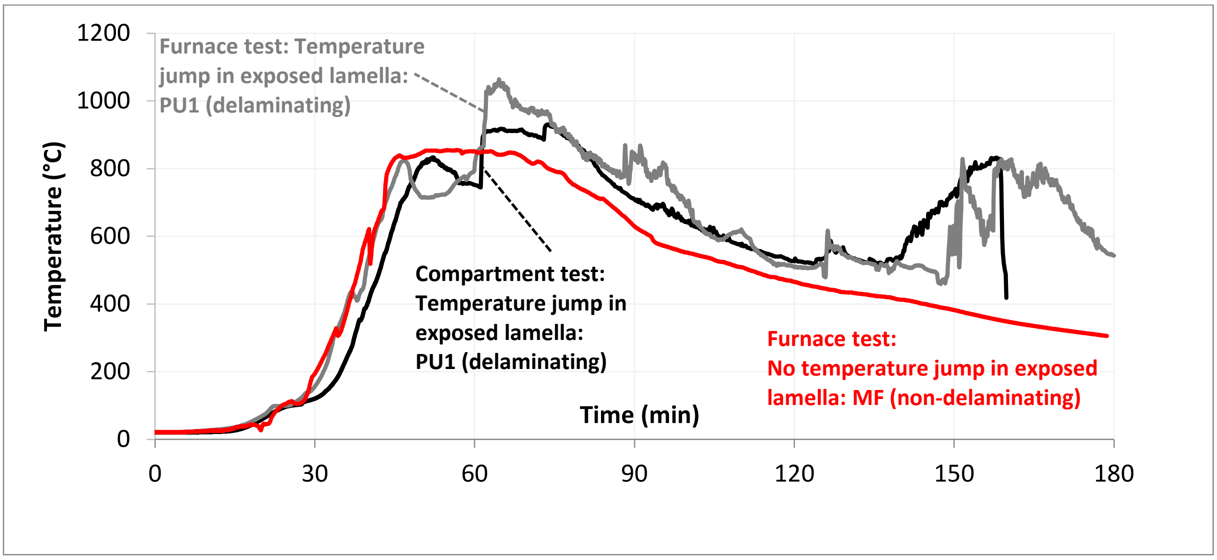

Figure 3: Typical temperatures of thermocouples inside CLT at 20 mm from the exposed surface (in the exposed lamella) of furnace tests and the compartment fire test.

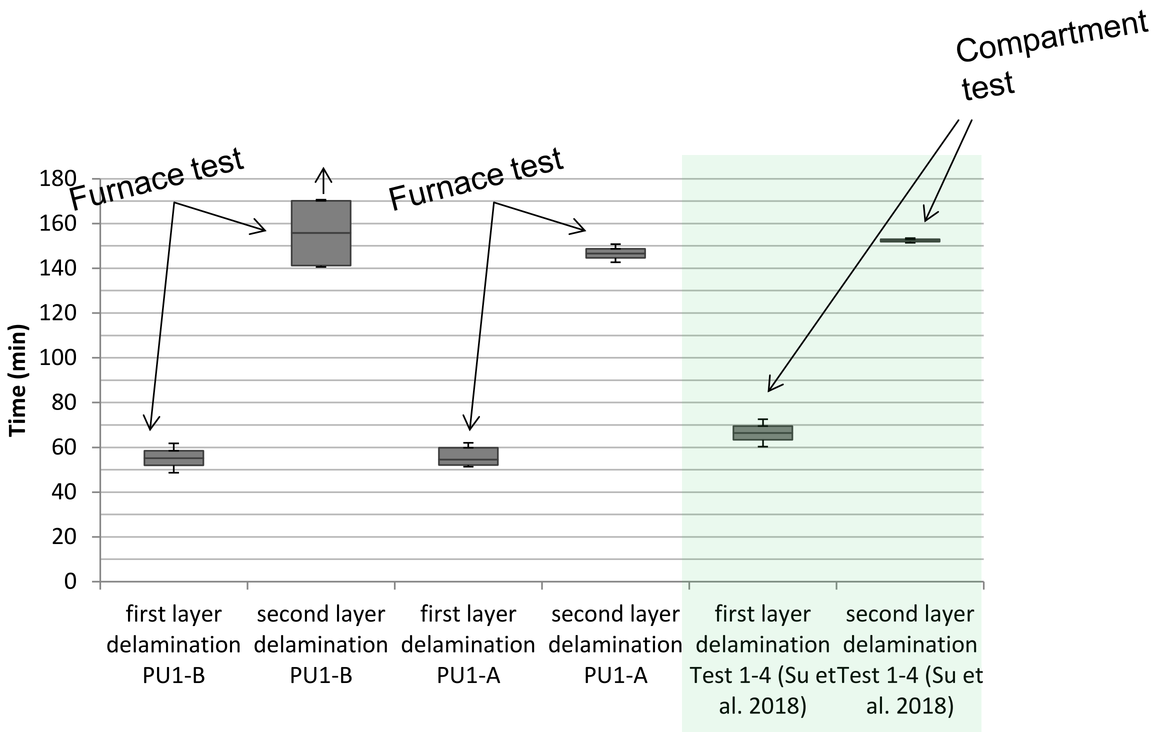

Figure 4: Times of temperature jumps measured in the bond line

Adhesive performance

The polyurethane adhesive that was used for the CLT in the full scale compartment fire test (PU1), exhibited delamination in, both, the compartment test and intermediate scale furnace tests in comparable fashion. The delamination of two layers was observed on video and significant temperature jumps measured in the bond line indicated the fall-off of lamellas. This was not observed in the non-delaminating CLT specimens, glued using the MF, PRF and

PU2 adhesive. Additionally, the char depth and mass loss of specimens were significantly lower in these non-delaminating specimens than in the delaminating PU1 specimen.

The specimen with the EPI adhesive exhibited local char fall-off at a late stage during the decay phase of the fire. The delamination did, however, not lead to a rapid increase of temperatures in the bond line and the specimens did not have a higher mass loss and char depth than the non-delaminating specimens.

The test results discussed here are only applicable to the exact adhesive products tested. The type of adhesive (for example: melamine formaldehyde) does not give a reliable indication of the fire performance.

Conclusions

An intermediate scale furnace test method to identify CLT adhesives, that do not exhibit fire-induced-delamination, was developed and evaluated. In the furnace, certain fire conditions (plate thermometer temperature and oxygen concentration) were replicated from a full scale compartment fire test, aiming to impose comparable damage to a CLT specimen. Results indicated that this aim was achieved, as it was shown (more extensively in the full report [4]) that the temperatures, char damage and delamination behavior of CLT in the furnace test were comparable to those in the compartment test, if the same CLT material was tested.

The test method was used to identify non-delaminating adhesives. A specific melamine formaldehyde adhesive, phenol resorcinol formaldehyde adhesive and polyurethane adhesive were identified as non-delaminating adhesives.

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