Overview of North American CLT Fire Testing and Code Adoption

Samuel L. Zelinka(✉), Laura E. Hasburgh, and Keith J. Bourne

USDA Forest Service Forest Products Laboratory, Madison, WI 53715, USA
samuel.l.zelinka@USDA.gov

Abstract. Cross laminated timber (CLT) is becoming more widely available in North America. However, it has not yet achieved widespread use in construction in the United States because provisions for CLT have only recently been added to model building codes. For example, CLT was recognized for the first time in the 2015 *International Building Code* (IBC), and the 2021 IBC will allow wood buildings made of CLT and other types of mass timber to be constructed up to 18 stories high. The changes to the 2021 IBC were implemented after several years of work from an ICC Ad-Hoc committee on tall wood buildings including fire testing supervised by the US Forest Service, Forest Products Laboratory. The fire tests involved five compartment fire test scenarios on a two-story building and specifically examined occupant egress and firefighter safety in corridors near the compartments. In addition to the fire tests performed by the Forest Products Laboratory, more large-scale fire tests were performed for the revision of the PRG-320 standard; the product standard for CLT in North America. These tests examined the heat resistance of adhesives used in CLT. This paper highlights the important changes to the IBC and the PRG-320 standard as well as summarizes the tests used to validate these changes.

Keywords: Cross laminated timber (CLT) · Fire resistance · Compartment fire testing · Standardization

1 Introduction

Cross laminated timber (CLT) is a massive engineered wood composite panel made from alternating layers of dimension lumber. CLT panels can be made up to 18 m long and are delivered to the jobsite with all fenestrations precut [1]. CLT's versatility as a potential material for wall and floor systems has sparked an interest in mass timber buildings in North America [2–4]. In addition to the erection of CLT buildings, the number of North American CLT manufacturers is rapidly growing [5].

The International Building Code (IBC) dictates the maximum height and area based on construction type. To build beyond these limits with wood, including mass timber, an alternative means-and-methods approach is needed to demonstrate equivalent safety to a building allowed by the code. Typically testing is needed to demonstrate this equivalency. Recently, there have been several large, full-scale testing programs of CLT compartments conducted in North America. These tests provided data in support of mass timber projects throughout North America that justified IBC recognition of

L. Makovicka Osvaldova et al. (Eds.): WFS 2020, *Wood & Fire Safety*, pp. 232–237, 2020.
https://doi.org/10.1007/978-3-030-41235-7_35

three new mass timber construction types which allow significantly greater heights and areas than are permitted for traditional Type IV (heavy timber) construction. This paper provides an overview of these recent test series and changes to the IBC.

2 Fire Protection Research Foundation (FPRF) Tests

A large-scale test series was conducted from February to April, 2017 at the fire laboratory of the National Institute of Standards and Technology (NIST) in Gaithersburg, MD, USA. It was funded by the Fire Protection Research Foundation (FPRF) and the tests were carried out by the National Research Council of Canada (NRC). The test series was the second phase of an FPRF research program looking at CLT buildings. The goal of the test series was to better understand the contribution of CLT to compartment fire dynamics. The first phase resulted in a literature review and gap analysis of the research needs for CLT buildings [6]. Below is a summary of the test series; full details can be found in the final report [7].

2.1 Test Matrix

In total, six compartment fire tests were completed in this series. Each test compartment was 9.1 m × 4.6 m × 2.7 m and constructed from 5-ply CLT (175 mm thick) manufactured with a polyurethane adhesive that does not pass the 2018 PRG 320 fire test protocol (Sect. 4). The fuel load was 550 MJ m^{-2}. A unique aspect of the test program was that two ventilation configurations were used across the 6 tests. The two opening factors were 0.03 $m^{0.5}$ and 0.06 $m^{0.5}$. In addition to studying the effect of ventilation, the amount of protection of the CLT with gypsum wallboard was also examined. Three tests are summarized in this paper; a baseline case where all surfaces were covered with 3 layers of gypsum wallboard with an opening factor of 0.03 $m^{0.5}$ (Test 1–1), a test with one exposed wall (9.1 × 2.7 m) and an opening factor of 0.03 $m^{0.5}$ (Test 1–5), and a test with one exposed wall (9.1 × 2.7 m) and an opening factor of 0.06 $m^{0.5}$ (Test 1–3). Test 1–4 had an opening factor of 0.03 $m^{0.5}$ with a fully exposed ceiling and was used in the development of the PRG 320 standard (Sect. 4).

2.2 Results

The test matrix allows a straightforward examination of the effect of exposed CLT and ventilation factors. Figure 1 shows heat release data from tests 1–1, 1–3, and 1–5. Test 1–1 was the baseline case for the small opening factor. All CLT surfaces were protected on the walls and ceiling in this test. The fire reached flashover at 14.9 min and started to decay around 50 min until it self-extinguished between 2–3 h.

Test 1–5 had a similar opening factor to that of Test 1–1 but an exposed wall. In this test, the fire exhibited largely the same behavior during the first 50 min, except that the heat release rate was slightly higher due to the exposed wall. However, the decay period of Test 1–5 was noticeably different from that of Test 1–1. Between 50 and 75 min, the first layer of CLT delaminated; this exposed unburnt surfaces of the second layer of CLT, which burned and increased the heat release rate. Starting at 140 min, the second layer of CLT delaminated, which resulted in an increased fuel load and thus an increase in heat release rate. This caused a second flashover in the compartment, which caused the gypsum wallboard on the ceiling to fail and continued fire growth until the test was terminated.

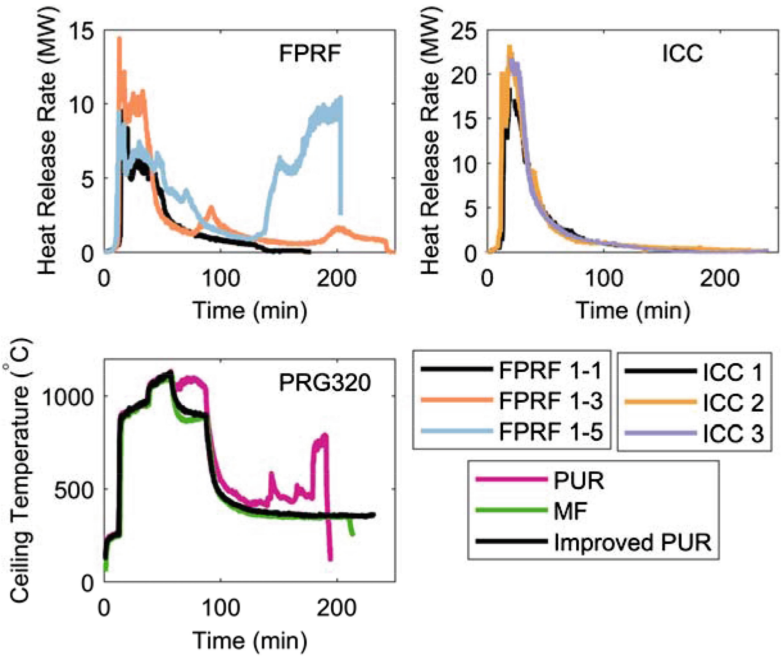

Fig. 1. Relevant test data from the three large scale test series discussed in the paper. (Data replotted from [7–9]).

Like Test 1–5, Test 1–3 had an exposed wall, but a much larger opening factor. Flashover occurred at nearly the same time. However, in Test 1–3, the fully developed fire was more intense but of a shorter duration with decay beginning to occur at 35 min. Although flaming combustion on the exposed wall had ceased by around 50 min due to the formation of a protective char layer, flaming combustion of the exposed wall was observed again at 80 min, which corresponds with the increase in heat release. This was due to the failure of the first bond line of CLT. At 180 min into the test, the second layer of CLT fell off and the third layer began to char. This second bond line failure also resulted in an increase in heat release rate, although to a lesser extent. Subsequent to both of these bond line failures, the fire self-decayed. The test was terminated at 4 h.

3 International Code Council (ICC) Tests

The International Code Council (ICC) formed an ad-hoc committee to study the safety of tall wood buildings and explore the potential adoption of tall wood buildings through the ICC code proposal process. The ad-hoc committee determined that more fire test data were needed to support potential code changes. The American Wood Council (AWC) worked with the US Forest Service, Forest Products Laboratory (FPL) to carry out the test program. The tests were conducted at the US Department of Justice Alcohol Tobacco Firearms and Explosives Fire Research Laboratory (ATF). Below is a summary of the tests; full details can be found in the final report [8].

3.1 Test Matrix

The ICC tests consisted of five fire tests conducted in a one-bedroom apartment. The test structure was two stories tall and had identical one-bedroom apartments (9 m $\times$ 9 m $\times$ 2.7 m) on each level. In addition to the apartments, there was a corridor on each floor and a stairway between the two floors, which were monitored to evaluate firefighter safety and occupant egress. The CLT was 5 layers, 175 mm thick and utilized the same polyurethane adhesive as the CLT used in the FPRF tests. The fuel load was 570 MJ m^{-2}. Compared to the FPRF tests, the ventilation factor was much bigger; 60% of one of the 9 $\times$ 2.7 m walls which is equivalent to an opening factor of 0.09 $m^{0.5}$. Tests 4 and 5 examined the effect of automatic sprinkler systems on fire suppression in CLT buildings and are not discussed further in this paper. Test 1 was a baseline where all surfaces were protected with gypsum wallboard. In Test 2, 30% of the area of the ceiling was exposed in the living room and bedroom. In Test 3, there was one, fully exposed wall in both the living room and the bedroom.

3.2 Results

Figure 1 presents the heat release rate curves collected in the ICC tests. In contrast to the FPRF tests, full burnout was achieved in all three ICC tests performed without an automatic fire sprinkler system. Furthermore, after the decay phase started, the heat release did not increase for any of the three tests. Some localized flaming and char falloff were observed late in Tests 2 and 3. However, at this time, the compartment had cooled considerably from the peak temperatures and no fire regrowth occurred.

4 Product Standard PRG 320

PRG 320 is the product standard for cross-laminated timber in North America. In the 2018 revision of the standard, a new method was developed to qualify adhesives to ensure that delamination of CLT did not occur due to adhesive failures during fire scenarios. Adhesives for use in PRG 320 compliant CLT must pass a large scale test as described in Annex B of the standard [10].

The PRG 320 large scale test method was designed to mimic the exposure to which the exposed CLT ceiling was subjected in FPRF Test 1–4, where delamination and subsequent fire regrowth occurred. In the tests, a compartment 5.8 m × 2.7 m × 2.4 m is constructed with an exposed CLT ceiling and an opening factor of 0.03 $m^{0.5}$ to match the FPRF test.

Instead of a prescribed fuel load, the compartment temperature profile is controlled by a gas burner. In a "calibration test" where the CLT is not exposed, the fuel to the burner is measured while a specific temperature profile is maintained at the ceiling for a 240 min test. This fuel flow rate is then duplicated in tests with CLT panels. The ceiling and compartment temperatures are monitored in tests with CLT. The CLT adhesive qualifies under PRG 320 Annex B if the temperature measured within the compartment stays below 510 °C during the last 90 min of the test. As stated in PRG 320, this is intended to identify and exclude use of adhesives that permit CLT delamination resulting in fire regrowth during the decay phase of a fully developed fire.

4.1 Results

As each company is responsible for testing their own products, there is little published data on the test method. However, the American Wood Council sponsored testing on CLT made with three different adhesives and the final test report is available [9].

Three different CLT panels were tested: a CLT made from spruce-pine-fir with a polyurethane adhesive, a CLT made from Douglas fir-larch with a melamine-formaldehyde adhesive and one made from Douglas fir-larch with an "improved polyurethane adhesive". The polyurethane adhesive used on the spruce-pine-fir specimen was the same adhesive used in the FPRF and ICC tests. This specimen was tested in order to validate the test method by ensuring that the fire growth (and regrowth) behavior was similar to that observed in FPRF Test 1–4.

The ceiling temperature as a function of time are shown for three adhesives in Fig. 1. The temperature decays for the melamine-formaldehyde and improved polyurethane adhesive demonstrated that they do not exhibit delamination leading to fire regrowth under the conditions in which delamination was observed in the FPRF test. Further testing on smaller compartments has also demonstrated the effectiveness of the improved polyurethane formulation [11].

5 Conclusions

This paper summarizes several large, North American testing programs that have looked at the fire dynamics of CLT compartments and have shaped building code development in North America. Of primary importance in all testing was the performance of the adhesives during the fire.

In the FPRF tests, delamination and subsequent fire regrowth was observed in several tests, especially with the smaller opening factor. In contrast, the ICC tests used the same adhesive, however, only localized char falloff and no fire regrowth was observed. These tests highlight the importance of the opening factor in the fire safety of CLT buildings. The latest version of the PRG 320 standard contains a large-scale fire test specifically designed to screen adhesives that may delaminate and lead to fire regrowth. The improved polyurethane adhesive showed no fire regrowth, even with the small ventilation factor.

These fire tests have been important in the code development and code adoption of CLT in the United States. The changes to the PRG 320 standard appreciably decrease the likelihood of fire regrowth caused by delamination in a potential fire in a CLT building.

References

1. Mohammad M, Gagnon S, Douglas BK, Podesto L (2012) Introduction to cross laminated timber. Wood Des Focus 22:3–12
2. Green M, Karsh J (2012) TALL WOOD- The case for tall wood buildings. Report prepared for the Canadian Wood Council on behalf of the wood enterprise coalition and forest innovation investment, Vancouver, BC
3. Iqbal A (2018) Recent developments in tall wood buildings. In: Mukhopadhyaya P (ed.) 1st international conference on new horizons in green civil engineering (NHICE-01), Uniersity of Victoria, Victoria, B.C., pp 111–116
4. Jakes JE, Arzola X, Bergman R, Ciesielski P, Hunt CG, Rahbar N, Tshabalala M, Wiedenhoeft AC, Zelinka SL (2016) Not just lumber—using wood in the sustainable future of materials, chemicals, and fuels. JOM 68:2395–2404
5. Franklin S (2019) The U.S. mass timber industry is maturing while it branches out. Archit Newsp 17:17
6. Gerard R, Barber D, Wolski A (2013) Fire safety challenges of tall wood buildings. National fire protection research foundation
7. Su J, Lafrance P-S, Hoehler M, Bundy M (2018) Fire safety challenges of tall wood buildings – phase 2: task 2 & 3 cross laminated timber compartment fire tests. Fire protection research foundation, Quincy, MA
8. Zelinka SL, Hasburgh LE, Bourne KJ, Tucholski DT, Ouellette JP (2018) Compartment fire testing of a two-story mass timber building. General technical report FPL-GTR-247, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI
9. Janssens M (2017) Development of a fire performance assessment methodology for qualifying cross-laminated timber adhesives. SwRI Project No.01.23086.01.001a, Southwest Research Institute, San Antonio, TX
10. Anon: ANSI/APA PRG 320: standard for performance rated cross-laminated timber. APA-The engineered wood association, Tacoma, WA
11. Su J, Leroux P, Lafrance P-S, Berzins R, Gratton K, Gibbs E, Weinfurter M (2018) Fire testing of rooms with exposed wood surfaces in encapsulated mass timber construction. National Research Council of Canada, Ottawa

In: Makovicka Osvalova L Markert F, Zelinka SL (eds) Wood & Fire Safety 2020 Springer, Cham pp:3-8 (refereed) (note, proceedings published ahead of conference, which was postponed due to the coronavirus). Wood & Fire Safety, doi:10.1007/978-3-030-41235-7_35; 2020