Abstract

Fire hazards are one of the major concerns for wooden constructions. U.S. Building Code restricts wooden buildings to four stories, despite data on the fire resistance of cross-laminated timber (CLT), generated in Europe, Japan, Canada, and the US, in a growing body of evidence that CLT is an acceptable material for tall construction. The major reason for code restrictions in the US is the scarcity of full-scale tests conducted on “made in the US” structural CLT. Therefore, the objective of this project was reducing this barrier by testing full-scale unprotected CLT according to the ASTM E119 fire resistance on CLT wall assemblies produced by US manufacturers. The assemblies represented two species groups (SPF and DF), two adhesion systems PUR and MUF. All assemblies were conducted in a loaded condition. Two walls (DF-LPUR and DF-MUF) assemblers met ASTM E119 standard qualifying criteria for 2-hour Time-Temperature Area, but SPF/PUR wall assembly passed 101 min. The statistical significant difference was observed depending on the adhesives type. SPF held char layer more efficient than PUR. The major driving force of char rate was furnace temperature and adhesives types than wood species. The unprotected half-lap joints provided an adequate barrier against transmission of hot gases and flames through the assemblies before char depth reached half of total CLT thickness.

Keywords: Fire resistance; cross-laminated timber; CLT; walls; half-lap joints; PUR; MUF; SPF; Douglas-fir.

Introduction

Historically, fire hazard situations are one of the major concerns for four stories, or more, cap on wooden constructions, despite a predictable rates of a solid wood burning (i.e. about 0.63 mm/min or 3.81 cm/hour for spruce in standard fire tests [4, 5]), it causes tall wooden building code restrictions in the US. Despite data on the fire resistance of cross-laminated timber (CLT), which are already tested in Europe, Japan, and Canada, and proved that CLT is acceptable use materials of tall construction against fire hazard. Another reason for its building code restrictions in the US is the lack of full-scale tests which are conducted using “made in the US” structural CLT [2].

Materials and Methods

The fire performance of three unprotected CLT assemblies was determined in full-scale tests following the ASTM E119 fire test procedure for tests of buildings and construction materials [1], by the Western Fire Center (WFC) in Kelso, Washington. All CLT assemblies were structural grade 5 ply, Layers were made up of visual grade #2 or better (i.e. 35 mm x 140 mm laminations). The assemblies differed by species of the laminations and adhesive systems used to non-edged glue, and represented two species groups (SPF and combination of Pseudotsuga menziesii and Larix spp.), and two adhesive system (polyurethane PUR adhesive and melamine formaldehyde MUF). The origins and material composition of the assemblies are summarized in Table 1. The diagrams showing the external dimensions, the connector spacing in the wall assemblies in figure 1a.

The assemblies were instrumented with 9 type K thermocouples installed 0.51 mm thermocouples placed on the unexposed surface covered with a 152 mm x 152 mm ceramic fiber pads. Each group was placed in a square configuration 102 mm apart. These thermocouples are marked as grey dots in figure 1a. In addition, three groups of two thermocouples were positioned along the lap joint: one pair would be located at the joint surface groove, the other 5 cm (2 in) away from the joint surface groove at the half-lap. These thermocouples are marked as orange dots in figure 1a. Diagrams illustrating through-the-thickness positions of the thermocouples are explained in figure 1b.

Out of plane deformation of the wall panels was monitored with four LVDT sensors distributed along the joint in walls. The in-plane deflection of the wall assemblies was monitored with one LVDT positioned in the bottom left and right corner of the assembly frame.

The progress of the char limit layer in the assemblies was initially assumed from threshold temperature of 300°C [4] recorded with the embedded thermocouples, and later confirmed by the measurement of the final char depth at the conclusion of the tests.

Table 1: Description of the test assembly

<table>
<thead>
<tr>
<th>Assembly ID</th>
<th>Source</th>
<th>Wood species (lumber grade)</th>
<th>PURGL-CLT grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall 1 SPF/PUR</td>
<td>SPF/PUR</td>
<td>Doug fir (SPF, grade B2)</td>
<td>V1</td>
</tr>
<tr>
<td>Wall 2 SPF/PUR</td>
<td>SPF/PUR</td>
<td>Larix (grade B2)</td>
<td>V1</td>
</tr>
<tr>
<td>Wall 3 SPF/PUR</td>
<td>SPF/PUR</td>
<td>Doug fir (DF, grade B2)</td>
<td>V1</td>
</tr>
</tbody>
</table>

Figure 1: Wall assembly diagrams including the position of connectors and in-plane thermocouple position (a), and the placement of the thermocouples through the thickness of the panel and in the lap joint (b).

Results (cont’d)

The char rate of SPF PUR second layer was increasing, and its value was the highest than others because of increasing furnace temperature. Therefore, the major driving force of char rate was furnace temperature and adhesive types than wood species.

Conclusions

Two of the three wall assemblies produced by American manufacturers passed the 2-hour fire resistance test following ASTM E119 standard procedure. One assembly (SPF/PUR) passed 101 min mark before the diaphragm was breached. Statistical significant difference was observed depending on the adhesives type. MUF held char layer more efficient than PUR. Thus, the amplitude of thermocouples plot of MUF CLT was smaller than PUR. It was caused by increasing flame area by falling char caused increasing temperature in the furnace.

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The heat energy exposed time caused softening of the PUR bonds because the temperature of softening of the PUR bonds was decreasing depending on distance from exposed surface.

The unprotected half-lap joints during the 2-hour standard test exposed provided adequate barrier against transmission of hot gases and flames through the assemblies before char depth reached to half of total CLT thickness.

References