SIMULATION OF TIMBER-CONCRETE COMPOSITE FLOORS EXPOSED TO FIRE SCENARIOS

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MOTIVATION

Performance-based fire engineering is the explicit design of structural systems to adequately endure thermal load effects from structural design fires based on specific performance objectives. In contrast, the prescriptive fire design approach is the selection of qualified fire resistive assemblies to meet code requirements for structural fire resistance.

PERFORMANCE-BASED FIRE ENGINEERING

QUANTIFY FIRE HAZARD

• Materials and fuel load
• Ventilation conditions
• Size of compartment
• Occupancy of building

HEAT TRANSFER ANALYSIS

• Temperature-dependent thermal material properties (specific heat, density, thermal conductivity)
• Convection coefficient and emissivity
• Thermal input

STRUCTURAL ANALYSIS

• Temperature-dependent mechanical material properties
• Boundary conditions
• Mechanical load

GOALS OF RESEARCH

Conduct an analysis of temperature-dependent thermal properties of timber to conclude: (1) limitations of application, and (2) ability of thermal properties to simulate heat transfer through timber sections (sawn lumber, CLT, and TCC floors).

BACKGROUND

System-level structural response to fire scenarios must be simulated for engineers to implement performance-based fire engineering approaches during the design of mass timber structures. This requires heat transfer analysis followed by structural (stress-based) finite element (FE) analysis. The heat transfer analysis utilizes temperature-dependent thermal properties of timber to calculate the temperature distribution through the cross-section of the timber member. Currently, numerous models exist that quantify the temperature-dependent thermal properties of timber. However, it is unclear which models are best applicable to accurately simulate heat transfer analyses of mass timber members and timber-concrete composite floors.

METHODS

Four sets of temperature-dependent thermal properties developed for sawn lumber [1-4] were evaluated by using them to simulate heat transfer through sawn lumber, CLT, and timber-concrete composite (TCC) floors. An accompanying structural analysis of a CLT panel in bending at ambient temperature was performed to demonstrate structural modeling capabilities for coupled thermal-structural analysis. The results of the thermal and structural analyses were compared to experimental data from the literature [2,3,5-7].

Heat transfer analysis: FE heat transfer analysis was performed using the commercially available software ABAQUS. The four sets of temperature-dependent thermal properties of timber are shown in Figure 1. Figure 2 shows the dimensions and boundary conditions of the specimens. The properties of the specimens were also implemented:

• Timber and mass timber specimens were assumed to contain 12% moisture content.
• Emissivity of timber was 0.8.
• Emissivity of concrete in the TCC floor was 0.7.
• Temperature-dependent thermal properties of concrete were calculated according to Eurocode 2 [8].
• Convection coefficient was 25 Wm⁻²K⁻¹ on fire-exposed surfaces [9].
• Mesh size was approximately 3 mm x 3 mm [4].

Structural analysis: Figure 3 shows the dimensions and load configuration of the CLT panel modeled in the structural analysis. Only half of the span was modeled to take advantage of symmetry. The mechanical material properties of the CLT panel implemented in the FE model are listed in Table 1.

RESULTS OF SIMULATION

• The thermal properties from EN 1995-1-2 (2004) and Werther et al. (2012) showed the best comparison with experimental data regardless of the type timber tested (sawn lumber, CLT, and NLT-concrete composite floors). The calculated and experimental temperatures of the TCC floor are compared in Figure 4a.
• The two sets of thermal properties that used lower values of specific heat [2,3] overestimated the temperatures in sawn lumber specimens.
• Calculated midspan displacement from the 2D structural analysis of the CLT panel accurately reflected experimental load-deflection behavior (Figure 4b).

REFERENCES


FINITE ELEMENT MODELS

Table 1. Mechanical material properties of CLT panel at ambient temperature [6].

<table>
<thead>
<tr>
<th>Property</th>
<th>Parallel</th>
<th>Perpendicular</th>
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<tbody>
<tr>
<td>E (MPa)</td>
<td>12564</td>
<td>120</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>f_y (MPa)</td>
<td>41.8</td>
<td>4.2</td>
</tr>
<tr>
<td>f_t (MPa)</td>
<td>52.7</td>
<td>5.3</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>450</td>
<td>450</td>
</tr>
</tbody>
</table>

Figure 1. Temperature-dependent (a) thermal conductivity, (b) specific heat, and (c) density ratio of timber [1-4].

Figure 2. Section through sawn lumber, CLT, and TCC floor specimens [2,3,5-7] modeled in heat transfer analyses.

Figure 3. Elevation of CLT panel model and load [6].