Fire Performance of Laminated Veneer Lumber (LVL)

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Warren Lane is undertaking post-graduate research in engineering (Fire) after 25 years experience in civil & structural consulting, and government project work. He returned to Canterbury University to learn from those at the forefront of developments in the field, to apply current research in practice.

Summary
This paper describes the results of an investigation into the fire performance of laminated veneer lumber (LVL), considering both the early fire hazard and the structural fire performance.

To determine ignition properties and charring rates, cone calorimeter tests were carried out on blocks of LVL with a number of grain orientations, each for a range of heat flux exposures. Some samples included embedded thermocouples. Charring experiments were also carried out on three LVL beams, approximately 100 x 300 mm in cross section and 2 m long, tested in a pilot scale furnace following the ISO 834 standard fire curve. Embedded thermocouples were used to record layer temperatures, which were then used to calculate the residual cross section for prediction of structural behaviour in fire conditions.

A load-bearing fire resistance test was carried out on a larger LVL beam spanning 4 m in a full size furnace, following the ISO 834 standard fire curve.

Keywords: Charring, fire performance, ignition, laminated veneer lumber, LVL

1. Introduction
Fire is one of the most unpredictable and dangerous accidents that may occur in our environment, especially in residential buildings. Fire development and behaviour and the effects of fire on structural members are very complex because of the large number of variables involved.

Ignition is one of the essential fire properties of a material and must always be considered in any assessment of fire hazard. The ignition of wood is more complex than for many other materials, especially because a layer of char is formed. The time to ignition depends on the species, moisture content, inherent variability of wood as a natural material, and the grain orientation of the specimen when exposed to the incident heat flux. In the case of laminated veneer lumber (LVL), the inherent variability of the timber may be a lesser factor because the raw material is carefully selected.

Once ignition has occurred, a layer of char is formed as the wood burns. A structural wood member will lose load capacity as the wood is converted to charcoal which has no strength. The thickening char layer protects the remaining wood, resulting in a predictable rate of charring below the surface. The rate of development of this charred layer determines how long the member can continue to carry load before the strength of the remaining unburned wood material is exceeded. A thin layer of heat-affected wood below the char layer will have reduced strength and stiffness.

LVL is made from thin veneers of timber glued together into large planks, which can be sawn into structural members. LVL is similar to thick plywood except that all the veneers have the same grain orientation and the continuous process can produce very large lengths. This paper describes an investigation into the fire performance of laminated veneer lumber (LVL) made from New Zealand grown radiata pine.
2. Test Material

The LVL used in these tests was manufactured in New Zealand by Carter Holt Harvey Ltd using veneers 3 mm thick, glued into panels of up to 105 mm thickness. The average measured density and moisture content for the material used in each series of tests is shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Density kg/m³</th>
<th>Moisture content %</th>
<th>Dry density kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ignition &amp; instrumented</td>
<td>607</td>
<td>13.7</td>
<td>556</td>
</tr>
<tr>
<td>Pilot tests</td>
<td>604</td>
<td>12.0</td>
<td>540</td>
</tr>
<tr>
<td>Loaded test</td>
<td>608</td>
<td>12.4</td>
<td>541</td>
</tr>
</tbody>
</table>

3. Ignition Tests

Ignition tests were carried out at five different levels of heat flux and two main grain orientations, with three replications of each test. The grain orientations were on the exterior veneer face (face grain) and on the edges of the cut veneers parallel to the grain of the veneers (edge grain). The results of these tests are shown in Figures 2 for the face grain and 3 for the edge grain where the inverse of the square root of the temperature has been plotted against the incident heat flux, together with the line of best fit. Two methods were used to estimate the ignition properties of the LVL. The first method is that of Mikkola & Wichman [1] and the second one is by Delichatsios, Panagiotou & Kiley [2]. These methods were recommended by Ngu [3] as having the best correlations based on his testing of the ignition properties of New Zealand timbers.

The resulting values for the surface ignition temperature ($T_{ig}$) and the thermal inertia ($k_{pc}$) of the LVL samples, along with the estimate of the critical heat flux ($q_{cr}$) are shown in Table 2.

Table 1: Density and moisture contents of samples tested.

Table 2: Estimated ignition properties, MW – Mikkola & Wichman [1], DPK – Delichatsios, Panagiotou & Kiley [2]

<table>
<thead>
<tr>
<th></th>
<th>Face grain</th>
<th>Edge grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical heat flux ($q_{cr}$ kW/m²)</td>
<td>7.66</td>
<td>9.90</td>
</tr>
<tr>
<td>Surface ignition temperature ($T_{ig}$ °C)</td>
<td>251</td>
<td>294</td>
</tr>
<tr>
<td>Thermal inertia ($k_{pc}$ kW/m²/s)</td>
<td>1.080</td>
<td>0.678</td>
</tr>
</tbody>
</table>
4. Charring Tests

Charring tests were carried out using small blocks of LVL in the cone calorimeter and tests of larger unloaded LVL beams in a pilot scale furnace.

4.1 Cone calorimeter tests

Instrumented tests were carried out using the cone calorimeter to determine the char depths with time. Eighteen samples of LVL measuring 100 mm square and 85 mm deep were instrumented using thermocouples placed in the central region of the blocks and at depths of 13, 25, 38, 50 and 63 mm from the face as shown in Figure 4. These samples were exposed to a constant heat flux of 35, 50 or 65 kW/m². The char depths were determined by using the thermocouples to locate the 300°C isotherm which characterises the char front within the samples. From the results of these tests, the time for each thermocouple to reach 300°C was interpolated for each thermocouple depth and the results averaged. Figure 5 shows the plot of char depth against time for each grain orientation and each heat flux.

Eighteen additional un-instrumented LVL blocks of the same dimensions were exposed to the same heat fluxes for specific periods of time; 20, 40 & 60 minutes. At the end of the test time, the blocks were immediately removed from the heat source, the char removed, and remaining solid LVL measured and recorded. The un-instrumented results for each of the heat fluxes and the different grain orientations have been included in Figure 5. It can be seen that very good correlations were obtained between the instrumented and the un-instrumented test results.

For each of the 18 un-instrumented tests, the cumulative charring rate was calculated, and the average for each heat flux, including both grain orientations, was plotted against time as shown in Figure 6.

4.2 Pilot Furnace Tests

Three tests on instrumented LVL beams exposed to the standard ISO 834 design fire were carried out using the pilot furnace at the BRANZ Fire Research facility. In the first two tests, the beams were 105 mm x 300mm deep and 2200 mm long. In the third test, two 66 mm thick by 360 mm beams were glued together using resorcinol adhesive prior to being instrumented, to give a beam size 132 mm x 360 mm deep. The beams were instrumented at two sections along the beam with 12 thermocouples installed at depths of 18 mm and 36 mm as shown in Figure 7. The instrumented sections were at the 1/3rd points in tests 1 and 2, and at one 1/3rd point and the centre for test 3. The thermocouples at the corners were affected by fire exposure on two faces whereas all other thermocouples essentially had single face exposure.
The results from the tests in the pilot furnace are shown in Figure 8 where they are compared with the results from the cone calorimeter tests. The current design charring rate of $\beta = 0.65$ mm/min from NZS 3603 [4] is also shown in the Figure. A typical beam cross-section after the fire test is compared with the original section in Figure 9.

The average char rate obtained from the 3 pilot tests varied from $\beta = 0.72$ mm/min at 18mm depth to $\beta = 0.70$ mm/min at 36 mm depth. The char rate of 0.72 mm/min was used to predict the behaviour of the load test in the full scale furnace.

From the pilot test results the time lag at each thermocouple between recording 100°C and 300°C was evaluated. This was used with the cumulative charring rate for that particular thermocouple to calculate the thickness of LVL at a temperature over 100°C. This layer of material is likely to have reduced mechanical properties because of the elevated temperatures. The estimated thickness of the temperature-affected material varied from 6 to 13 mm, with an average thickness of 9 mm. This information is useful because some design methods require an estimate of the thickness of zero-strength heated wood below the char layer [5]. The Australian timber code [6] states that a zero-strength layer thickness of 7.5 mm should be used, which is consistent with the findings of this study, recognising that not all of the wood between 100°C and 300°C will have zero strength.
5. Load-bearing tests

The 105 x 300 mm LVL beam that was used for this test is shown in Figure 10 prior to being loaded and exposed to the standard ISO 834 design fire, in the full-scale furnace at the BRANZ Fire Research facility.

The beam was subjected to an ambient temperature bending test to obtain a value for the Modulus of Elasticity (E). From the E value and by interpolation from the manufacturer’s data [7] a value for the mean bending strength ($f_b$) was estimated.

The following properties were used for design of the 105 x 300 mm LVL beam:

- Modulus of elasticity $E = 11.15$ GPa
- Mean bending strength $f_b = 55.58$ MPa
- Ultimate section capacity $\phi M_n = 87.5$ kN.m
- Bending moment in test $M = 34.1$ kN.m

The beam was simply supported over a span of 4.4 metres and subjected to a central point load of 30kN applied by means of a hand-operated hydraulic jack. The load was kept constant during the test and the mid-span deflection of the beam was recorded. Figure 11 shows the beam after the fire test, while Figure 12 shows the plot of applied load and central deflection.

It was observed through the observation ports of the furnace that charring of the surface did not begin until 3 or 4 minutes into the test. This delay in the onset of charring is not considered in most design methods which assume a constant rate of charring from the time of flashover [5].

Figure 10  LVL beam before the fire test  Figure 11  LVL beam after the fire test

Figure 12  Load and deflection plots
6. Discussion

Based on a charring rate of 0.72 mm/min. from the cone calorimeter and pilot furnace tests, the loaded beam was expected to fail after approximately 38 minutes. It can be seen from Figure 12, that the beam actually failed at about 37 minutes after the start of the fire. Measurements of the remaining cross-section approximately 7 minutes after the test finished confirmed that the rate of charring for the section was similar to the pilot tests.

Considering the above findings and observations the following two options for fire design of LVL can be considered:

1. Design using the char rate $\beta = 0.72$ mm/min (found experimentally in this study) to calculate a reduced cross section which can be used with normal temperature properties (characteristic bending stress and modulus of elasticity) with no zero-strength layer of LVL below the char line.

2. Design using the char rate $\beta = 0.65$ mm/min (complying with NZS 3603 [4]) to calculate a reduced cross section which can be used with normal temperature properties, with an allowance for a 7 mm to 9 mm zero-strength layer of LVL below the char line.

7. Conclusions

A series of ignition and charring tests was carried out on laminated veneer lumber (LVL) manufactured from radiata pine. The results were similar to those previously found for solid timber of the same species.

More investigations should be carried out to determine the effects of the delay in the onset of charring under exposure to post-flashover fire conditions, and also on the thickness and properties of the “zero-strength layer” below the char line.

A simple method for predicting the fire performance of radiata pine LVL exposed to post-flashover fires is to use the experimentally found char rate $\beta = 0.72$ mm/min to determine a reduced cross-section, and design using normal temperature properties without considering a heat-affected layer of wood below the char line.

8. References


