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# Strength Properties of Laminated Veneer Lumber After Extended Exposure to High Temperatures

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## Abstract
When wood is exposed to elevated temperatures (greater than 37 °C or 100 °F), its strength and stiffness can be degraded. The National Design Specifications for wood construction contain reduction factors for mechanical properties of wood and engineered wood used in these situations. These reduction factors were based on experiments where wood and engineered wood were conditioned at high temperatures. Since these experiments were conducted, adhesive formulations used in structural composite lumber have changed. This work compared strength properties of laminated veneer lumber made with non-phenolic adhesives and exposed to high temperatures against previous literature values. The results suggest that the safety factors in the National Design Specifications for Wood Construction are appropriate even for new adhesive formulations.

## Keywords
structural composite lumber, elevated temperatures, modulus of elasticity, modulus of rupture

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**Cover photo:** An edgewise bending test of a laminated veneer lumber member after long term exposure at 66 °C (151 °F) (Forest Service photo by Dwight McDonald).

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# Introduction

As wood is heated, it undergoes pyrolysis reactions, ending in the formation of char at around 300 °C (570 °F) (White 1988, White and Dietenberger 2010, White and Nordheim 1992). Most of the thermal degradation occurs at temperatures above 150 °C (300 °F) and is not a concern for typical structural applications of wood, in which the end-use environments rarely exceed 150 °C for an extended period. However, research has shown that prolonged exposures to temperatures as low as 66 °C (150 °F) can cause a permanent reduction in the structural capacity of wood (Gerhards 1982). When wood is used in situations where the temperature may exceed 37 °C (100 °F), its design value is lowered.

Table 2.3.3 in the National Design Specifications (NDS) for wood construction lists temperature reduction factors (American Wood Council 2017). For wood that is exposed to dry service conditions between 37 °C and 51 °C (125 °F), the design bending strength is multiplied by a factor of 0.8 and the design modulus of elasticity (MOE) is multiplied by a factor of 0.9. For wood that will be in dry service conditions between 51° C and 66° C, the design bending strength is multiplied by a factor of 0.7 and the design modulus of elasticity is multiplied by a factor of 0.9. The values in NDS Table 2.3.3 apply to solid sawn lumber, glued laminated timber, wood I-joists, structural composite lumber, wood structural panels, and cross laminated timber.

The reduction factors in NDS Table 2.3.3 were heavily influenced by the work of Gerhards (1982), who examined how temperature and moisture affected strength properties. Green et al. (2003) examined solid-sawn lumber and wood composites exposed to an environment of 66 °C and 75 percent relative humidity (RH) for times that ranged from 6 to 68 months. Since the publication of this important document over 20 years ago, the adhesives used in structural composite lumber have changed. While phenolic-based adhesives were primarily used in the late 1990s and early 2000s, newer structural composite lumber may use non-phenolic adhesives, such as emulsion polymer isocyanate (Tobisch et al. 2023).

This study sought to confirm that the NDS temperature reduction factors are valid for structural composite lumber containing structural joints made with non-phenolic adhesives.

# Materials and Methods

Sixty boards of 2.0E (13.79 GPa on average) laminated veneer lumber (LVL) with dimensions of 38 mm by 89 mm by 1.8 m (1.5 by 3.5 by 70 inches) were obtained from an LVL manufacturer. Douglas-fir LVL was produced with phenolic and non-phenolic adhesives. Specifically, the primary face bonds were made with phenol formaldehyde, the secondary face lamination was made with emulsion polymer isocyanate, and the end joints were bonded with polyurethane emulsion polymer.

The modulus of elasticity of each specimen was measured non-destructively with transverse vibration (ASTM International 2021). The boards were then sorted into the following three groups with matched elastic moduli:

- Control (30 specimens) conditioned at 20 °C (68 °F) and 65 percent RH until moisture equilibrium was achieved.
- 6 months exposure (15 specimens) conditioned at 66 °C and 75 percent RH for 232 days (approximately 6 months). They were then conditioned at 20 °C and 65 percent RH until moisture equilibrium was achieved prior to mechanical testing.
- 12 months exposure (15 specimens) conditioned at 66 °C and 75 percent RH for 428 days (approximately 12 months). They were then conditioned at 20 °C and 65 percent RH until moisture equilibrium was achieved prior to mechanical testing.

After final conditioning, all specimens were tested in edgewise bending in the third-point loading method according to ASTM D198 (ASTM International 2005) with points located at 0.52 m (21 inches) and 1.07 m (42 inches) of the 1.6 m (63 inches) on-center span. The width of the bearing plates was 76 mm (3 inches).

After the testing, small clear sections were cut from near the failure section of about 50 mm long, 38 mm thick and 89 mm deep from each specimen. The exact mass and dimensions (thickness, depth, and length) of each specimen were measured. The specimens were then placed in the oven for 36 hours in accordance with ASTM D4442 (ASTM International 2020). Oven dry weight was measured immediately after the specimens were removed from the oven, to determine the moisture content and the specific gravity of each specimen at the time of testing.

The MOE and MOR were calculated following the test. MOE is a measure of a material's stiffness and is calculated from test geometry and the slope of the linear portion of the load/deflection curve (in this paper, the linear region was taken as the region between 20 and 40 percent of the maximum load). MOR (modulus of rupture) is a measure of a material's bending strength and is calculated from test geometry, cross-sectional dimensions, and the maximum load achieved during the test.

## Results and Discussion

A summary of the data collected in the current test is presented in Table 1. The data show a decrease, as expected, in the MOE and MOR of the LVL after 6 and 12 months of exposure at 66 °C.

Figure 1 compares the reduction in MOE and MOR to the NDS reduction factors and illustrates that the reductions in MOE and MOR were less than the design reduction factors in the NDS (solid black line). These data suggest that the current NDS design reduction factors can still be applied to LVL made with current non-phenolic adhesives.

Figure 2 compares the MOE and MOR of LVL tested in the current study (blue bars) against that measured in the study conducted by Green et al. (2003) (orange bars) along with 95 percent confidence interval error bars. Notably the MOE of the current LVL is significantly less than the MOE measured by Green et al (2003). However, the MOE of the control samples that were not exposed to high temperatures were also lower. It is also important to note that the measured MOE for the control samples was greater than the published design value of LVL grade, and that Green et al. (2003) measured moduli of elasticity that were approximately 15 percent higher than the grade stamp. Nevertheless, no appreciable change in MOE was observed after 12 months of exposure in either study. It is also worth noting that the coefficients of variation increased after high temperature conditioning. The MORs of the control samples in both studies were nearly identical. No statistically significant differences could be found between the MOR measured in the two studies at 0-, 6-, or 12-months exposure.

## Conclusions

After extended exposures for up to 1 year at high temperature and dry conditions, the LVL exhibited a decrease in modulus of elasticity and bending strength. The decreases in MOE and MOR were not as severe as predicted using the temperature factors for the high-temperature use specified in the National Design Specifications for Wood Construction. Compared with previous work that tested LVL with older adhesives, there was no statistically significant difference in the bending strength of the LVL with newer adhesives at 0, 6, and 12 months of exposure. The modulus of elasticity measured in the current study was lower than that measured in previous studies. However, the control specimens also had a lower modulus than the previous study.

These results suggest that the safety factors in the National Design Specifications for Wood Construction are appropriate for LVL with the current new adhesives.

Table 1.—Mean results of the tests after exposure for 6 or 12 months at 66 °C (150 °F) and 75 percent relative humidity. Moisture content and specific gravity (oven-dry mass, volume at testing) were measured under the conditions of the mechanical test and not the elevated temperature. Coefficients of variation (COVs) are presented in parentheses.

| Exposure time (months) | Number of specimens | Moisture content | Specific gravity | Modulus of elasticity (GPa) | Modulus of rupture (MPa) |
|---|---|---|---|---|---|
| 0 | 30 | 9.6% (3.4%) | 0.53 (3.2%) | 14.29 (3.2%) | 61.4 (8.4%) |
| 6 | 15 | 11.0% (3.7%) | 0.52 (3.4%) | 13.85 (5.0%) | 54.0 (15%) |
| 12 | 15 | 10.4% (2.1%) | 0.52 (3.6%) | 13.93 (4.9%) | 53.1 (12%) |

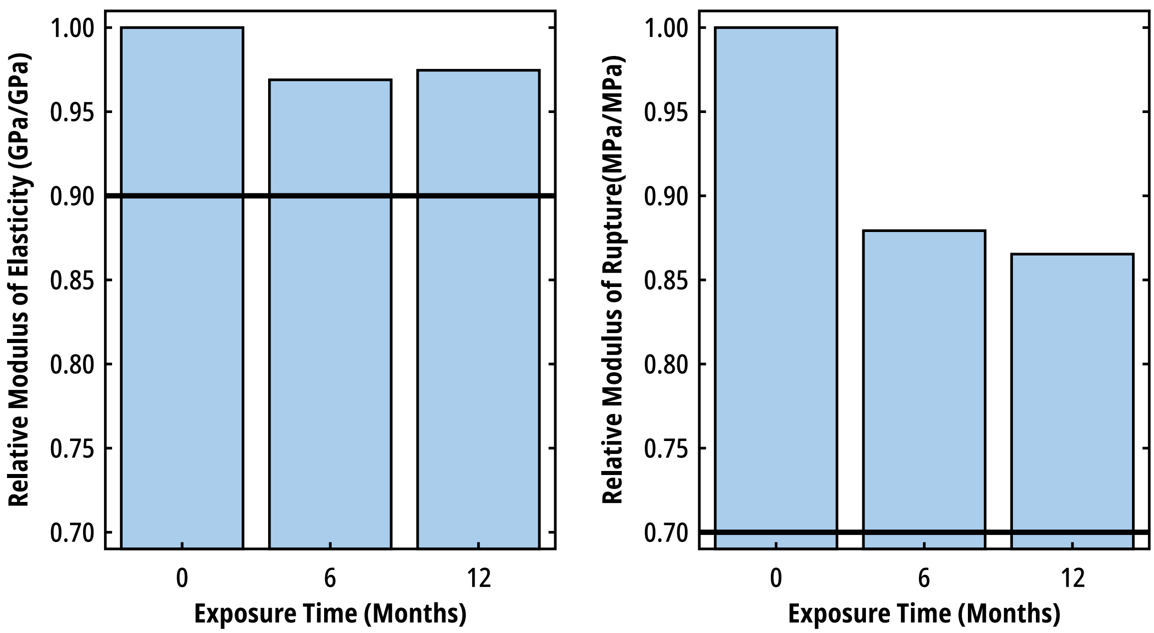


Figure 1.— Relative MOE and MOR (blue bars), normalized to the control values at 0 months exposure compared against the NDS correction factors (solid black line).

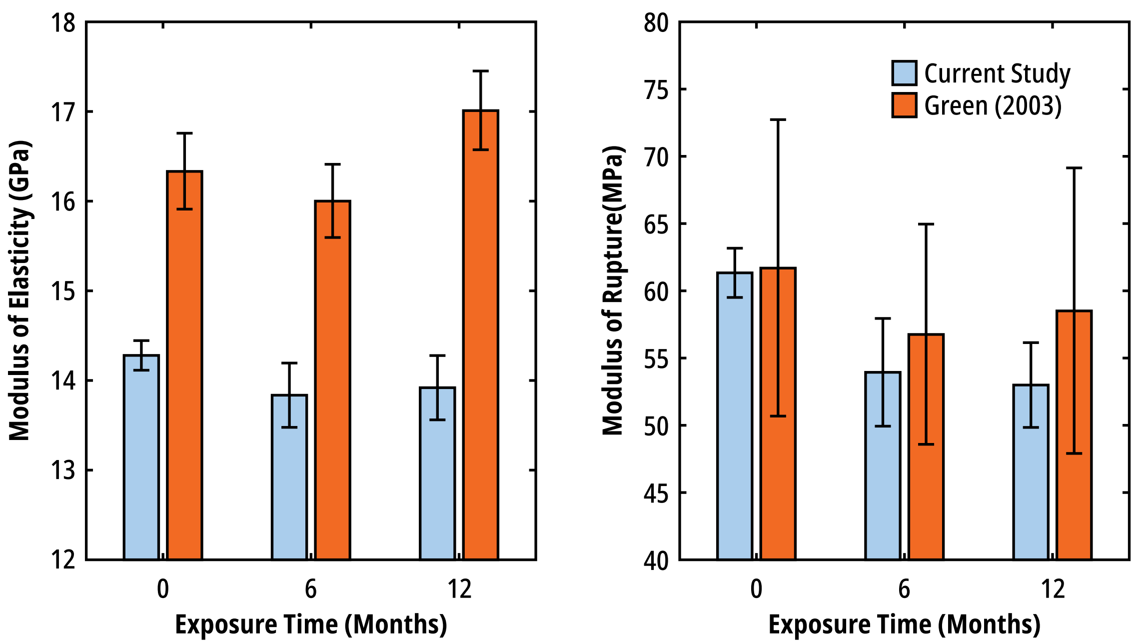


Figure 2.— Comparison of the MOE and MOR between the current study (blue) and historical data (orange) as a function of exposure time at 66 °C (150 °F) and 75 percent RH for times up to 12 months. Note that the control group in the current study had twice the number of replicates as the 6- and 12-month groups whereas in the work of Green et al. (2003), all groups had the same number of replicates.

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