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Outdoor exposure tests of structural laminated veneer lumber I: evaluation of the physical properties after six years

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Abstract To investigate the durability of structural laminated veneer lumber (LVL), outdoor exposure tests have been conducted since 1990 at a field-testing site at the Forestry and Forest Products Research Institute. This paper is an interim report on the results after 6 years' exposure. Seven kinds of structural LVL with no preservative treatment were subjected to the tests. These specimens were sampled at the testing site each year and then stored for more than 1 year in a testing room conditioned at 20°C and 65% relative humidity. We then measured the modulus of elasticity (MOE) by longitudinal vibration frequency, the penetration depth by the Pilodyn method, weight loss, color difference (ΔE^*) by the CIE $L^*a^*b^*$ system, swelling, compression strength, and bending-shear strength. Deterioration caused by outdoor exposure was obvious in the color, weight, MOE, and compressive strength of LVLs, but not in the penetration depth by the Pilodyn method or the bending-shear strength. The retention values of MOE and compressive strength after 6 years of exposure were 78% and 77%, respectively. The difference in durability among material species was not significant in general, except that heavy decay by brown rot fungi took place on some of the grand fir specimens. It should be noted that no significant delamination occurred in any of the adhesive layers, although slight checks developed on the surface of the specimens.

Key words Laminated veneer lumber · Outdoor exposure test · Durability

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Introduction

In recent years the demand for structural laminated veneer lumber (LVL) in the Japanese market has been increasing steadily, although its growth rate is not as high as that of structural glued laminated timber. There are several reasons for this lower growth rate. One is that the application of LVL for outdoor use is limited because of the shortage of durability testing data.

There are several experimental studies on specific products made of Douglas fir in North America,[1–3] but their test data are not applicable to Japan because of differences in testing conditions such as climate and material species. Thus, to increase the demand for structural LVL for exterior use in Japan, it is necessary to accumulate as many durability testing data as possible under outdoor exposure conditions.

For this reason, we have been conducting outdoor exposure tests on structural LVL since 1990 at a field-testing site[4] at the Forestry and Forest Products Research Institute. This research paper, which is an interim report after 6 years' exposure, reports evaluations for color difference (ΔE^*) by the CIE $L^*a^*b^*$ system,[5] weight loss, swelling, modulus of elasticity (MOE) by longitudinal vibration frequency, penetration depth of a pin by the Pilodyn method,[6] compression strength, and bending-shear strength.

Specimen

Seven kinds of structural LVL with no preservative treatment and no surface finishing were subjected to the tests. Wood species used for the LVL were Douglas fir (*Psudotsuga menziesii* Franco), Siberian larch (*Larix sibirica* Ledeb), Japanese larch (*Larix leptolepis* Gord), western hemlock (*Tsuga heterophylla* Sarg), grand fir (*Abies grandis* Lindl), radiata pine (*Pinus radiata* D. Don), and meranti (*Shorea* spp.).

These LVLs had been prepared for a series of strength tests conducted to obtain fundamental data for establishing

Table 1. Specification of laminated veneer lumber

Species	No. of plies	Thickness (mm)	Joints	Comments
Douglas fir[a]	16	38	Lap	Brand name: Micro-lam 2.0E
Siberian larch[b]	21	38	Butt	High-density veneer
Japanese larch[c]	13	38	Scarf	Veneer from small diameter log
Western hemlock[d]	14	41	Butt	
Grand fir[e]	15	40	Scarf	
Radiata pine[f]	15	38	Scarf	High-density veneer
Meranti[g]	17	38	Scarf	

[a] *Pseudotsuga menziesii* (Mird.) Franco
[b] *Larix sibirica* Ledeb
[c] *Larix leptolepis* (S. and Z.) Gord
[d] *Tsuga heterophylla* (Raf.) Sarg
[e] *Abies grandis* (Dougl.) Lindl
[f] *Pinus radiata* D. Don
[g] *Shorea* spp.

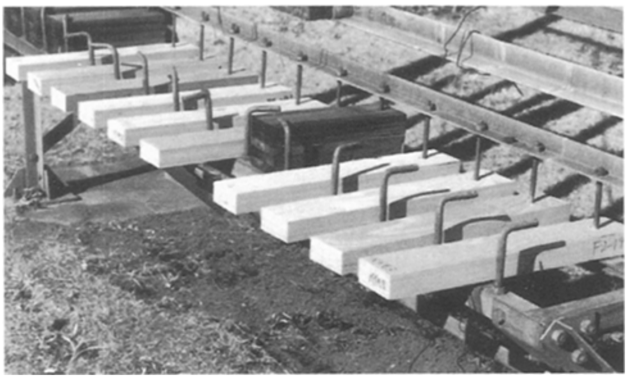

Fig. 1. Steel rack for outdoor exposure test

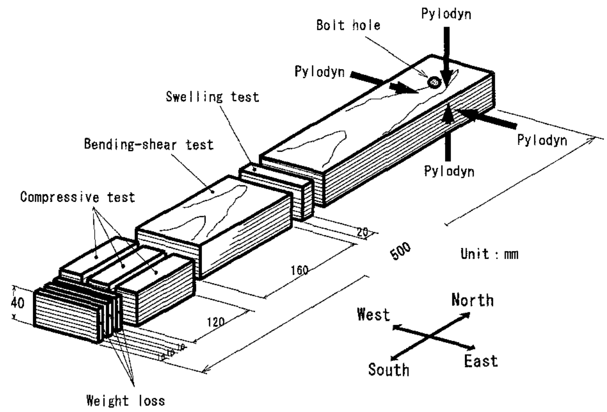

Fig. 2. Specimens

"Japanese Agricultural Standard for Structural LVL"[7] before this outdoor exposure test started. Their product specifications and testing data have already been reported in three research papers.[8–10] Table 1 summarizes the basic specifications of the LVL. As the adhesive for laminating the veneers, phenol-formaldehyde resin was used for all products.

The LVL boards with a nominal 2 × 4 cross section and 50 cm length were set up on special steel racks 75 cm high above ground level and were exposed to outdoor conditions (Fig. 1). The direction of the boards and the schematics of small test specimens are shown in Fig. 2. As shown in Fig. 2, glue layers in the boards are horizontal.

Seven kinds of LVL board were randomly sampled at the testing site every year: one board for each kind of LVL. These boards were then stored for more than 1 year in a testing room conditioned at 20°C and 65% relative humidity. Control specimens (0 year) were stored for more than 7 years in the same conditioning room.

After conditioning the color and the MOE were measured. Afterward, small specimens were cut from the boards. Then weight loss was measured, and swelling test and strength tests were conducted. A total of 49 boards (7 species × 7 durations of exposure) were used for this interim test.

Test method

First, the MOE of the boards was measured by longitudinal vibration frequency. Then, using the Pilodyn method, an iron pin was driven into each board from its four sides (Fig. 2), and the penetration depth of the pin was measured.

After these measurements, LVL boards were cut into small specimens as shown in Fig. 2. Three 10 mm long specimens for the measurement of weight loss, three 120 mm long specimens for the compressive test, one 160 mm long specimen for the bending-shear test, and one 20 mm long specimen for swelling test were cut from each board.

Color measurements on the surface of the LVLs were taken five times on both the face and back sides of the bending-shear specimens by a color difference meter (Minolta CR200). The recommended CIE (Commission International del'Eelarirange) L^* (lightness), a^* (along the x-axis red to green), and b^* (along the y-axis yellow to blue) color parameters were obtained directly from the meter.

The color difference (ΔE^*) was calculated by the following formula: $\Delta L^* = L_t^* - L_0^*$; $\Delta a^* = a_t^* - a_0^*$; $\Delta b^* = b_t^* - b_0^*$; $\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$, where the subscript 0 is a value obtained before exposure, and t is the value obtained after t years' exposure.

Bending-shear tests (only horizontally laminated type) and compressive tests were carried out following the testing procedure stipulated in JAS for structural LVL and JIS Z2101-1994, respectively. A universal testing machine with a loading capacity of 5 tons was used for these tests.

Specimens for swelling tests were immersed in water at 20°C for 10 days. Their dimensions and weight were measured before and after the immersion.

Results and discussion

Appearance and color difference

The following phenomena were observed for all the specimens. After 2–3 months' exposure the color of the specimens faded obviously, and several slight cracks developed along lathe checks in the surface veneer on top. After 2 years algae grew on the surface of some of the specimens, and they turned green. After 3 years heavy decay by brown rot fungi took place on some of the grand fir specimens. The appearance was not different from other specimens, but the weight was clearly decreased. After examining a cross section, it was found that the inner portion was heavily decayed throughout the specimen, and it had turned brown. Concerning the durability of the glue line, no delamination was observed in any of the specimens even after 6 years' exposure.

Table 2 shows the L^*, a^*, b^*, and ΔE^* values. Each value is an average of five measurements. The table shows that changes in surface color due to outdoor exposure have the following tendencies. The ΔE^* (color difference) values on the top of the specimens are higher than those on the bottom. The L^* (lightness) values on both sides of the specimens decrease abruptly after 1 year of exposure but not markedly after that.

The a^* (along the x-axis red to green) and b^* (along the y-axis yellow to blue) values on the top of the specimens show the same tendency as L^*, whereas these values on the bottom tend to decrease gradually as the exposure duration increases.

Table 2. Summary of color measurements

	Top				Bottom			
Years	L^*	a^*	b^*	ΔE^*	L^*	a^*	b^*	ΔE^*
Japanese larch								
0	66.2	8.91	24.50	0	66.2	8.91	24.50	0
1	48.4	1.06	4.30	28.0	40.5	5.81	16.26	27.2
3	37.1	0.48	6.02	35.5	40.3	3.92	10.08	30.1
6	37.2	0.90	6.89	34.8	49.7	1.78	6.32	25.5
Siberian larch								
0	66.3	9.26	26.22	0	66.3	9.26	26.22	0
1	36.6	1.32	3.71	37.0	42.6	7.18	17.22	24.8
3	37.6	1.57	7.66	34.0	39.9	3.95	10.20	30.4
6	31.5	1.00	6.15	40.0	45.6	1.81	9.75	26.3
Western hemlock								
0	67.9	7.91	37.53	0	67.9	7.91	37.53	0
1	46.1	0.27	7.14	27.9	61.3	7.35	24.15	5.1
3	41.8	−0.34	7.98	30.8	48.9	1.96	17.24	20.0
6	39.3	0.80	7.52	32.8	46.7	1.54	10.94	24.9
Douglas fir								
0	62.1	13.27	27.02	0	62.1	13.27	27.02	0
1	43.3	2.01	6.59	29.8	46.7	8.88	17.88	20.5
3	44.6	0.58	5.79	29.7	45.5	5.62	13.12	23.8
6	39.6	1.22	6.13	33.2	53.4	0.45	12.15	19.6
Grand fir								
0	72.0	7.35	23.71	0	72.0	7.35	23.71	0
1	42.0	0.88	4.91	32.1	50.0	7.11	20.72	16.7
3	37.4	−0.54	9.52	33.8	48.0	3.40	12.25	22.6
6	42.7	0.68	6.39	30.8	38.1	0.23	12.04	31.9
Radiata pine								
0	78.2	4.59	23.75	0	78.2	4.59	23.75	0
1	41.5	1.72	7.21	30.9	58.7	8.29	25.66	7.6
3	39.7	0.63	13.05	30.0	52.3	3.78	19.57	15.6
6	39.4	1.07	7.27	32.8	55.0	2.25	10.49	19.1
Meranti								
0	58.8	5.85	17.14	0	58.8	5.85	17.14	0
1	49.9	1.46	6.59	25.3	50.4	6.76	20.33	16.5
3	44.0	0.54	7.93	28.9	48.2	4.24	16.12	20.3
6	40.5	0.61	6.45	32.4	52.0	5.04	19.46	15.5

L^*, lightness; a^*, parameter along the x-axis red to green; b^*, parameter along the y-axis yellow to blue; ΔE^*, color difference

Weight loss

Weight loss due to outdoor exposure was observed only on the first row (south side) specimens, not in those on the second or third row. Significant weight loss was observed in several grand fir specimens, where heavy decay took place as noted before. Because the data for these decayed specimens are unnecessary for discussing the weight loss, we do not consider it in this section. One-way analysis of variance revealed that the differences among seven species were not significant at a 95% confidence level.

Figure 3 shows the relation between retention of weight in the first row specimens and the exposure period. The average retention of weight after 6 years is 89.4% based on the linear regression equation shown in Fig. 3.

Swelling

Figure 4 represents a specimen for the swelling test. As can be seen, h and b (b_b and b_t) are the thickness and width of the LVL, respectively. Figure 5 shows the relation between the coefficient of swelling from the air-dried condition to a green condition, as well as the exposure period. Because no significant differences among material species were observed, each plot in Fig. 5 represents the average of seven specimens. As shown in Fig. 5, the coefficient of swelling of h decreases at a rapid rate during the first year but remains constant after that. This may be because the stress generated by the hot pressing of the board is released within 1 year.

Because veneers used for the LVL were rotary-peeled, the direction of their thickness and width correspond to the radial and tangential directions in solid wood, respectively. Consequently, the directions of lamination (h) and width (b) of LVL also correspond to the radial and tangential direction in solid wood, respectively. As is generally known, swelling of solid wood is anisotropic; the coefficient of swelling in the radial direction is about one-half that in the tangential direction. If these LVL specimens have the same anisotropic swelling properties as solid wood, the ratio of the swelling (h/b) should be about 50%. However, as shown in Fig. 5, the h/b ranges from 60% to 70%. This difference may be attributed to the existence of adhesive layers in LVL that restrict the swelling of veneers in the width direction.

The coefficient of swelling of b_t is lower than that of b_b. This phenomenon may be also explained by the existence of adhesive layers. When the specimens are subjected to wet and dry cycles, the adhesive layers restrict their swelling and shrinkage in the width direction. In the upper part of the specimens, the extent of swelling and shrinkage is larger than that in the lower part, so shallow cracks that restrict swelling take place more easily. This may have caused the difference in the coefficients of swelling between b_t and b_b.

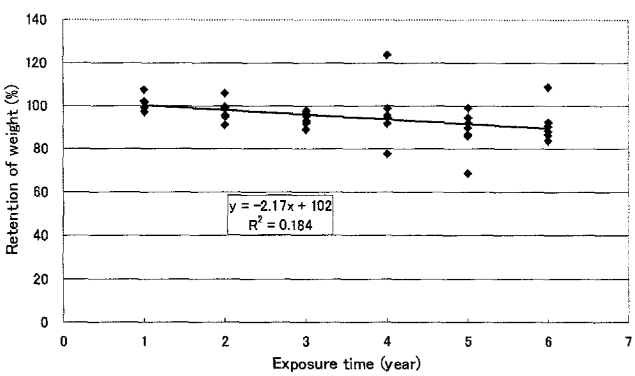

Fig. 3. Relation between exposure time and retention of the weight of first-row specimens

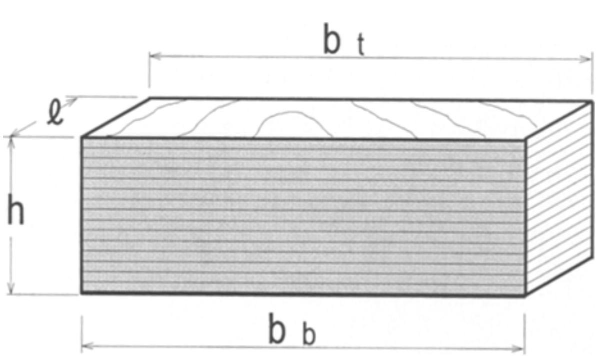

Fig. 4. Specimen for the swelling test. h, thickness; b_b, b_t, width

Modulus of elasticity

Figure 6 shows the relation between the retention of MOE and the exposure period, as well as a linear regression line. Each plot represents the ratio of MOE of an individual specimen to that of a control specimen (0 year). Because there were no significant differences among material species, all data are assembled together as a set here.

When the outdoor exposure test started, we had no proper device to measure the MOE of a specimen with a nominal 2 × 4ft cross section and short length (50cm). Hence we did not measure the MOE of each specimen. For this reason, the dispersion of plots is rather high, and several plots show values higher than 100%. The average retention of the MOE after 6 years calculated from the linear regression equation was 77.1%.

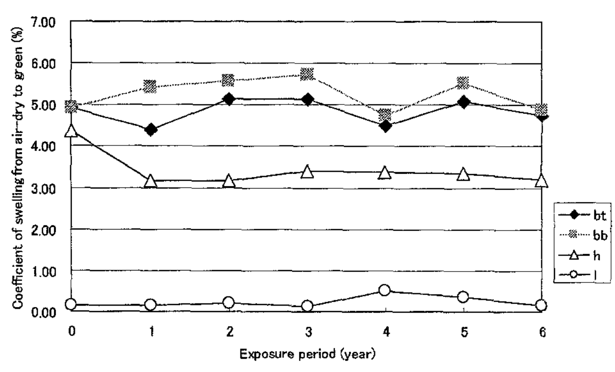

Fig. 5. Relation between coefficient of swelling from air-dried to a green condition and exposure period

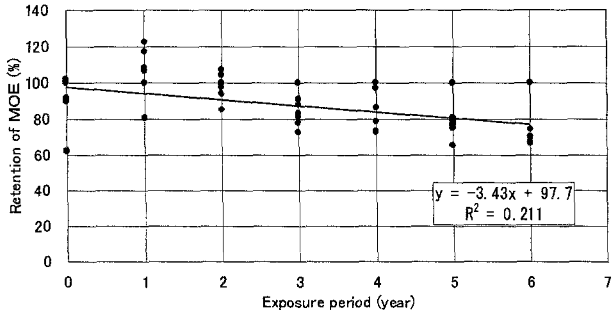

Fig. 6. Relation between retention of modulus of elasticity (*MOE*) and exposure period. Data for decayed specimens were eliminated

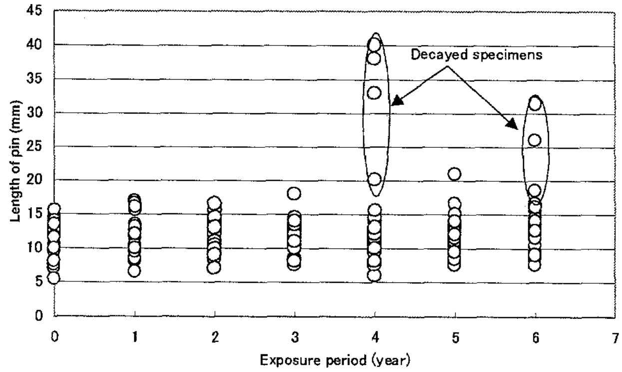

Fig. 7. Relation between penetration depth of a pin and exposure period

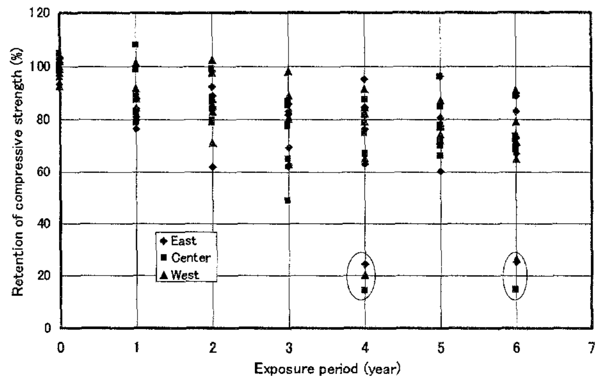

Fig. 8. Relation between retention of compressive strength and exposure period

Table 3. Summary of the average retention of compressive strength

Duration of exposure (years)	Retention (%)
0	100.0
1	88.6
2	86.3
3	77.2
4	79.7
5	77.5
6	75.7

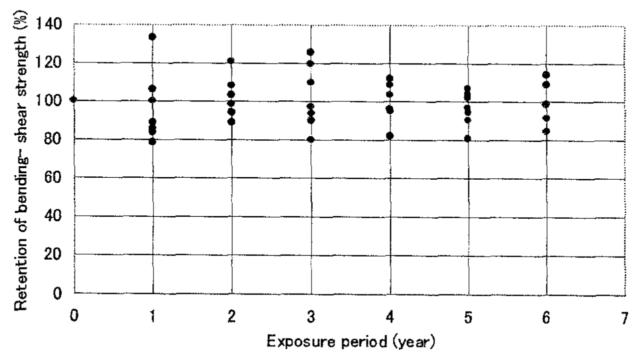

Fig. 9. Relation between retention of bending-shear strength and exposure period. Data for decayed specimens were eliminated

Penetration depth of a pin by the Pilodyn method

The relation between the penetration depth of a pin by the Pilodyn method and the exposure period is shown in Fig. 7. Note that the decayed specimens had deeper penetration than sound specimens. Analysis of variance (eliminating the data of decayed specimens) revealed that the differences among seven species, four inserting directions, and seven exposure periods were not significant at a 95% confidence level. These results demonstrate that the Pilodyn method is effective for finding decayed members or portions in a wooden structure but ineffective for evaluating the extent of degradation of the member.

Compressive strength

The relation between compressive strength and the exposure period is shown in Fig. 8. Each plot represents the ratio of the compressive strength of an exposed specimen to the average of three control specimens (west, center, east). Three-way analysis of variance (eliminating the data for decayed specimens) revealed that the differences among seven species, at three exposed positions, were not significant.

Table 3 shows a summary of the average retention of compressive strength. As can be seen from Fig. 8 and Table 3, the average value decreased to 77% after 3 years but remained constant after that. This decrease in the rate is attributed to the fact that the degradation of the veneer starts at the outer layers and progresses into the inner layers, which are less sensitive to the exposure conditions.

Bending-shear strength

The failure mode of bending-shear specimens was horizontal shear initiated at the end of a specimen. The relation of the bending-shear strength to the exposure period is shown in Fig. 9. Each plot represents the ratio of the bending-shear strength of an exposed specimen to a control specimen.

It is apparent from Fig. 9 that no correlation exists between the exposure period and retention of bending-shear strength. That is, outdoor exposure did not affect the bending-shear strength within the limits of this experiment.

Conclusions

Because the exposure conditions in this study were rather severe for the specimens, with no preservative or surface treatment, deterioration caused by weathering was obvious in terms of the color, weight, MOE, and compressive strength of the specimens. However, no significant deterioration was observed for the penetration depth of a pin by the Pilodyn method or for the bending-shear strength. It should be noted that no significant delamination took place in any of the adhesive layers, although slight checks along the grain of the veneer were observed on the surface of the specimens.

Generally, the difference in durability among material species was not significant, except that heavy decay by brown rot fungi took place in some of the grand fir specimens. It is not clear so far whether the grand fir was the weakest of the seven species, or the decay occurred by chance. By the time this 15-year exposure test ends, further information will have been obtained on the durability of each species.

Because the specimens used in this study had horizontal glue layers and no treatment, we could not obtain data for the specimens with horizontal glue layers or on the effects of preservatives[11] or paints. Further exposure tests should be conducted to quantify these effects.

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