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ORIGINAL ARTICLE

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Outdoor exposure tests of structural laminated veneer lumber (II): evaluation of the strength properties after nine 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 article is the second interim report on the results after 9 years of exposure. Seven kinds of structural LVL with no preservative treatment were subjected to the tests. Almost all the exposed specimens were decayed by a kind of brown rot fungi (*Pseudomerulius aureus* (Fr.) Julich). The degree of decay varied with wood species; grand fir and western hemlock LVL in particular showed weak resistance against the decay. All the specimens were stored for more than 1 year in a testing room conditioned at 20°C and 65% relative humidity. We then measured the ultrasonic velocity of the specimens by the Pundit method, penetration depth by the Pilodyn method, and bending strength by a conventional bending test. Correlation between nondestructive measurement factors and the density was strong even on LVL with many adhesive layers. The nondestructive testing method was found to be applicable to LVL as well as solid lumber. After the nondestructive measurements, each LVL was cut into three types of specimen (top: T, middle: M, and bottom: B) for the bending tests. The bending strength varied with the type of specimens. Correlation between modulus of elasticity and modulus of rupture was strong even in the decayed specimens.

Key words Laminated veneer lumber · Outdoor exposure test · Durability

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Introduction

To increase the demand of structural laminated veneer lumber (LVL) for exterior use in Japan, it is necessary to accumulate as much durability testing data as possible under outdoor exposure conditions.[1] For this reason, we have been conducting an outdoor exposure test on structural LVL since 1990 at a field-testing site at the Forestry and Forest Products Research Institute in Ibaraki Prefecture, Japan.

In the first interim report,[2] we reported the evaluations after 6 years on color difference (ΔE^*) by the CIE $L^*a^*b^*$ system,[3] weight loss, swelling, modulus of elasticity (MOE) by longitudinal vibration frequency, penetration depth of a pin by the Pilodyn method,[4] compression strength, and bending-shear strength.

In this report (the second interim report), the strength properties of the LVL decayed by brown rot fungi during 9 years of exposure were evaluated with nondestructive testing methods (Pundit and Pilodyn) and by a conventional four-point bending strength test.

Materials and methods

Specimens

Seven kinds of structural LVL with no preservative treatment and no surface finishing were subjected to the tests. These kinds of LVL were chosen from the same product lot used in previous studies.[2,5,6]

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.).

Table 1 summarizes the basic specifications of the LVL. Regarding the adhesive to laminate the veneers, phenol–formaldehyde resin was used for all products.

Table 1. Specification of laminated veneer lumber

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

[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.

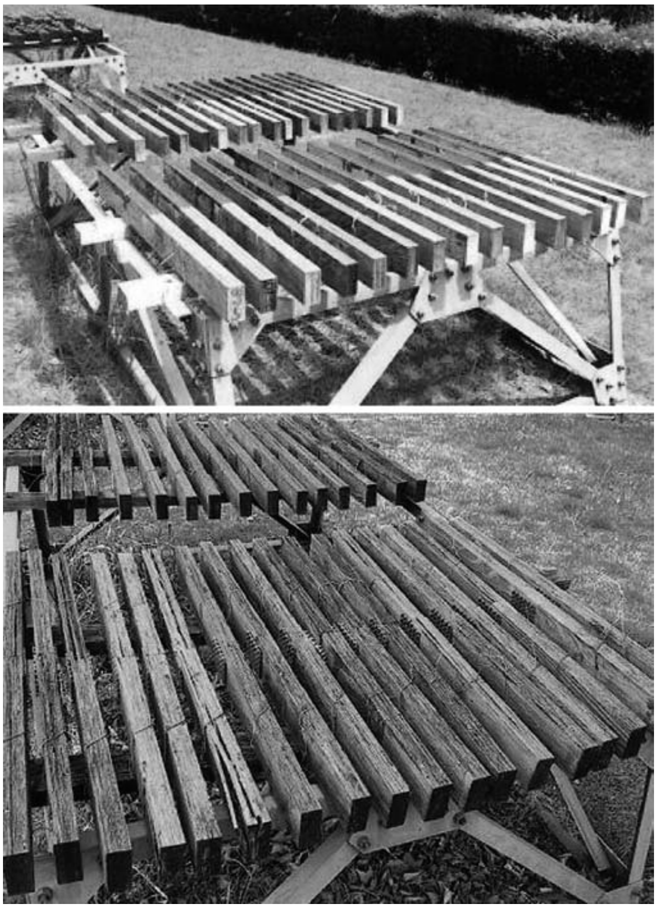

Fig. 1. Laminated veneer lumber (LVL) specimens and steel rack for outdoor exposure test at the beginning of the test (*upper*) and after 8 years (*lower*)

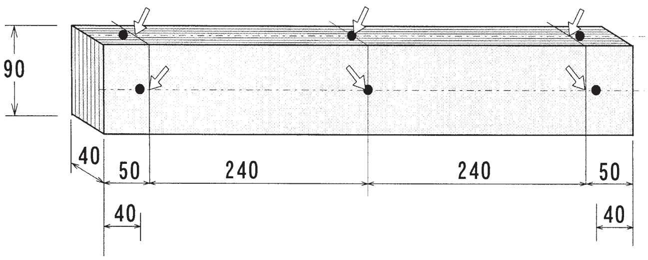

Fig. 2. Measuring points for nondestructive tests. *Circles*, Pundit test; *arrows*, Pilodyn test. Dimensions in millimeters

LVL specimens with a nominal 2 × 4 inch cross section and 70 cm in length were end-jointed with metal plate connectors (MPCs).[7] These jointed specimens were set up on two wood supports (sugi lumber) mounted on special steel racks 75 cm high above ground level, and the distance between each specimen was about 5 cm (Fig. 1). The purpose of end-jointing was to lengthen the specimens and to fit them to the steel rack. Furthermore, the purpose of using MPCs was to check the plate backout phenomena[7] by outdoor exposure. This was irrelevant to the purpose of this study.

The lumber was set in an east–west direction, and the glue layers were vertical to the ground. This exposure condition contrasted to the condition used in the previous study;[2] the direction was north–south, and glue layers were horizontal to the ground.

After 9 years of exposure, all the LVL specimens were removed from the rack and then stored for more than 1 year in a testing room conditioned at 20°C and 65% relative humidity. Specimens with fatal damage that were inappropriate for measurements were eliminated from the samples. Control specimens (no exposure) were also stored for more than 10 years in the same conditioning room.

Test method

After conditioning, jointed portions were cut off from the specimens. Consequently, all MPCs were removed. Then the measurement of ultrasonic velocity by the Pundit method was conducted in each LVL (Fig. 2). As shown in this figure, three measuring points at 240-mm intervals were located in each surface of the specimen. Measurements with the Pundit were conducted between two measuring points (face and back) in the same cross section. For the following

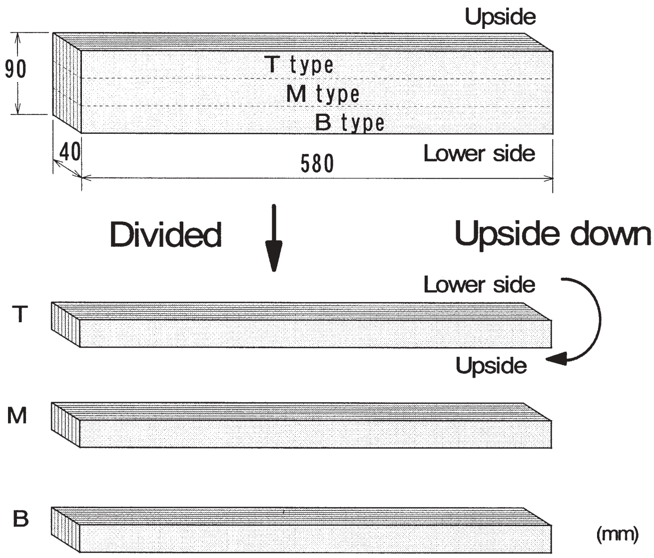

Fig. 3. Specimen preparation for bending tests

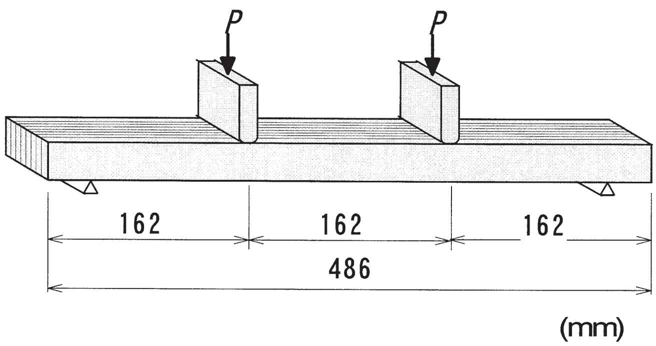

Fig. 4. Four-point bending test

analysis and discussion, the average value of six measurements is used.

After the measurement of ultrasonic velocity, penetration depth of a pin by the Pilodyn method was conducted. An iron pin was driven into each specimen at the measuring points shown in Fig. 2, and the penetration depth of the pin was measured.

Afterward, three specimens (top: T, middle: M, and bottom: B) for the bending test were cut from every piece of lumber (Fig. 3). Of course, some specimens were too deteriorated to be tested in bending. We selected the survived test specimens that were not heavily deteriorated for the bending test. Thus the data from the bending test does not represent the whole or average strength properties of LVL after 9 years of exposure.

Three specimens were prepared for one testing condition. In total, 84 specimens (7 species × 4 types × 3 replications) were used for the bending test.

A four-point bending test was made on each specimen with a universal testing machine with a capacity of 2000 kN (Fig. 4). For T-type specimens, the specimen was turned upside-down to set the exposed surface to the bottom. Bending deflection at the center of the specimen was measured with displacement transducers. Load was applied monotonously until failure of the specimen. During loading, digital output signal for load and deflection were automatically recorded on a personal computer through a general purpose interface bus (GPIB) device. The interval from the beginning of loading to the failure of the specimen was about 3–5 min for each specimen.

After the bending test, a small wood block was cut from the specimen, and its moisture content was measured by an oven-dry method. The average of all the specimens was 10.5%.

Results and discussion

Changes of specimen appearance

The following phenomena were observed for all specimens. After 2–3 months of outdoor exposure, the color of the specimens faded obviously. After 2 years, a kind of algae grew on the surface of some of the specimens and their color turned green.

After 4 years, decay by brown rot fungi (*Pseudomerulius aureus* (Fr.) Julich) took place on a grand fir specimen, and the extent of its infection spread gradually year by year. Similarly, the decay began to transmit to adjacent specimens one after another through wood supports.

In the previous report,[2] it was not clear whether the grand fir was the weakest among the seven species or the decay occurred by chance. Judging from the results in the present study, grand fir was probably the weakest against the fungi.

The condition and appearance of the specimens after 9 years varied with material species. Grand fir and hemlock specimens were observed to be heavily decayed throughout the specimen length. Such difference occurred by the difference in decay resistance which each species originally posseses. Metal plate connectors were almost pulled out on several specimens. On the other hand, meranti and siberian larch specimens were observed to be sound and slightly decayed. The reason was probably due to the fact that the fungi (*Pseudomerulius aureus* (Fr.) Julich) dislikes attacking hardwood species, and softwood LVL with many glue layers. Radiata pine, Japanese larch, and Douglas fir specimens were observed to be partially decayed.

Density loss

Figure 5 shows the density loss of the exposed specimens in comparison with the control specimens. It is apparent that heavy decay reduced the density of grand fir and western hemlock specimens. The density of exposed specimens decreased to 80.4% of control specimens on average. The minimum was 63.3% for grand fir, and the maximum was 94.7% for Douglas fir.

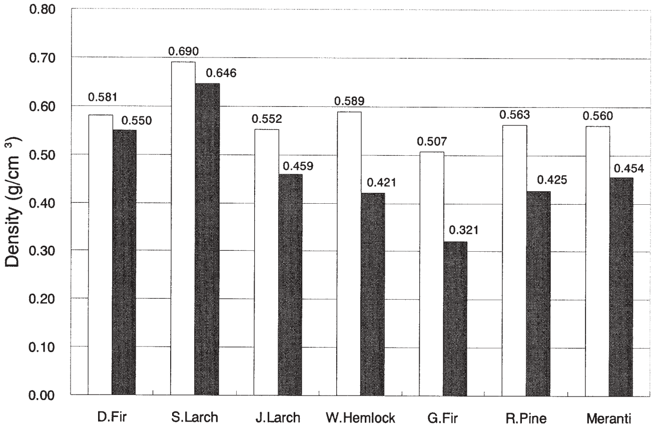

Fig. 5. Comparison of the density of specimens. *Open bars*, controls; *filled bars*, 9-year exposure

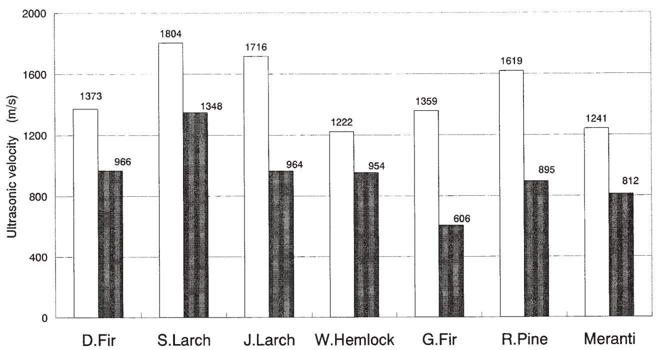

Fig. 6. Comparison of the ultrasonic velocity of specimens

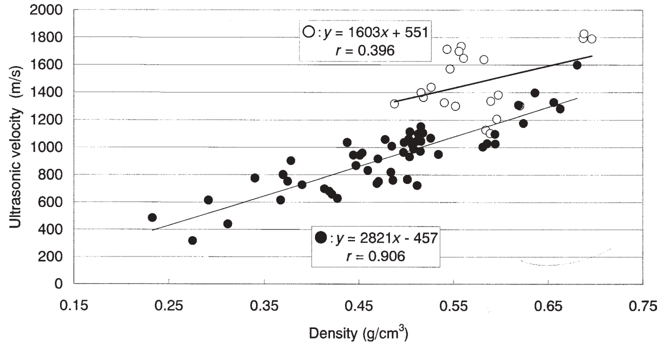

Fig. 7. Relation between the density and ultrasonic velocity of specimens. *Open circles*, controls; *filled circles*, 9-year exposure

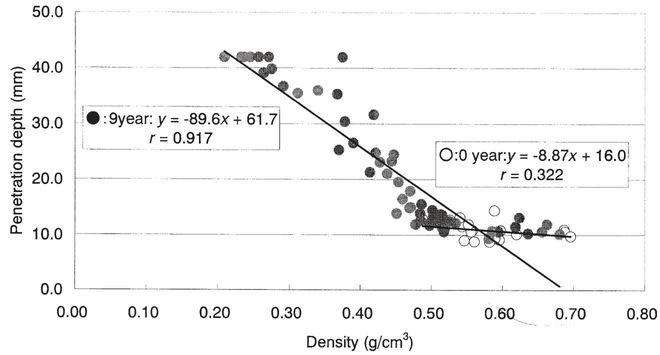

Fig. 8. Relation between the *density* and *penetration depth* of a pin

Ultrasonic velocity measured by the Pundit method

The decrease of ultrasonic velocity caused by the decay in the exposed specimens is shown in Fig. 6. The ultrasonic velocity decreased to 62.8% of control specimens on average. The minimum was 41.6% for grand fir, and the maximum was 74.7% for Siberian larch. Comparing these data with the results of density loss, it is obvious that the ultrasonic velocity is more sensitive to the decay than the density. A principal reason for the difference of sensitivity is that partial or slight decay influences the ultrasonic velocity.

Figure 7 shows the relation between the density and ultrasonic velocity of the specimens. Each plot represents the average of six measurements of a specimen. The coefficient of correlation for control specimens was 0.396 showing weak correlation. On the other hand, the coefficient of correlation for exposed specimens was 0.906 showing very strong correlation. These results demonstrate that the measurement of ultrasonic velocity by the Pundit is effective for detecting decay even in LVL with many adhesive layers, as well as in wood itself. However, it is impossible to predict the extent of density loss after exposure using only control data (no exposure), because the linear regression line of the control specimens is significantly different from that of the exposed specimens.

Penetration depth of a pin by the Pilodyn method

The relation between penetration depth of a pin by the Pilodyn method and the density of the specimen is shown in Fig. 8. Each plot represents the average of six measurements of a specimen. As shown in Fig. 8, decayed specimens with lower density showed deeper penetration than sound control specimens. The coefficient of correlation (r) was 0.322 and 0.917, for the control and exposed specimens, respectively. This tendency that r is high in control specimens and low in exposed specimens is similar to the tendency observed for the ultrasonic velocity. This leads to the conclusion that the Pilodyn method is effective to predict the density loss as far as exposed data is available.

Bending strength

The failure mode of bending specimens was typical bending failure that initiated at the center of the specimen, except for some radiata pine specimens that snapped at the portion near support.

Figure 9 shows the retention of density, MOE, and modulus of rupture (MOR) for each material species. Each bar is an average of three specimens. As stated above, these testing results do not represent the average properties of each decayed LVL product. Therefore, it is practically of no

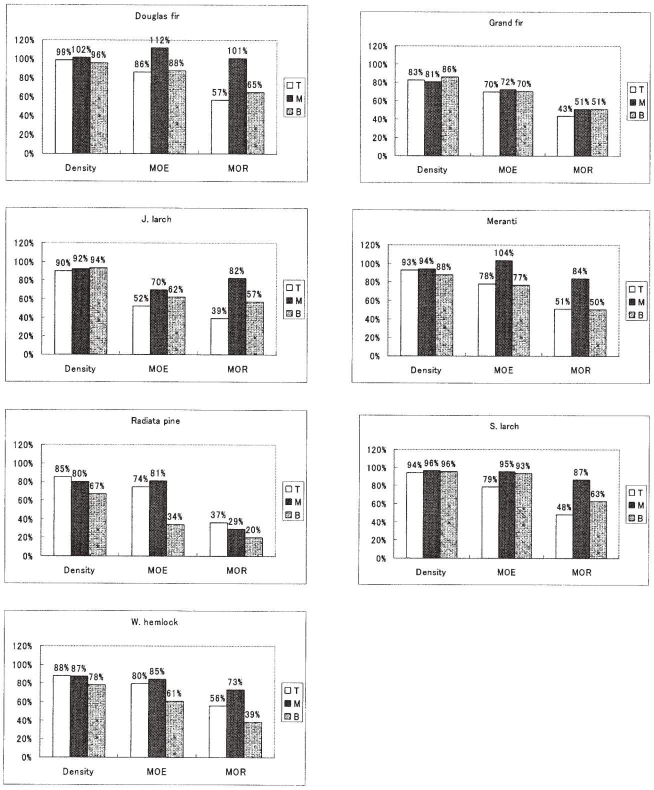

Fig. 9. Retention of the *density*, modulus of elasticity (*MOE*), and modulus of rupture (*MOR*) of the top (*T*), middle (*M*), and bottom (*B*) specimens for the seven species studied

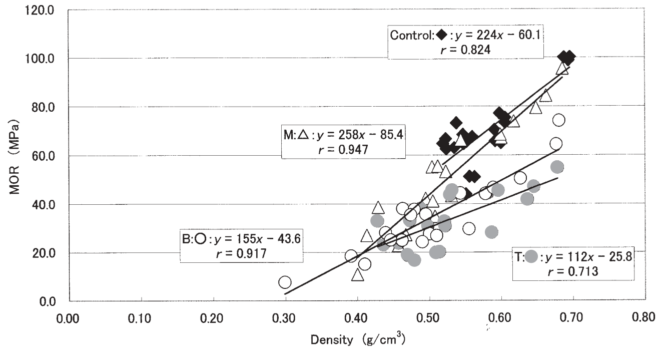

Fig. 10. Relation between the *density* of specimens and *MOR*

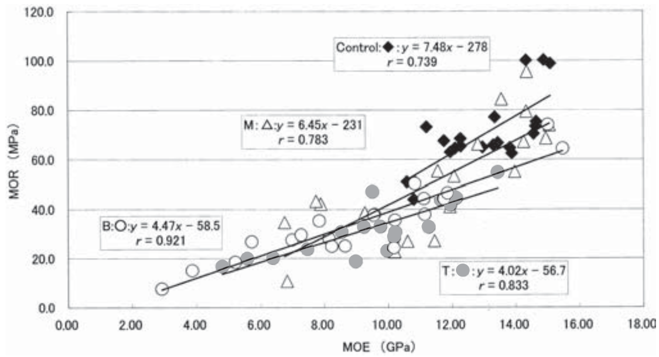

Fig. 11. Relation between *MOE* and *MOR* of specimens

use to compare and consider the difference of each data among material species.

As shown in Fig. 9, the decrease of the retention appears strong for MOR, followed by MOE and density. The decrease of density was rather small and the retention ranges from 80% to 100%.

In comparing the retention data according to the type of test specimen (T, M, and B types), the difference is apparent for MOE and MOR but not for density. It is natural that M type having less decay on both tension and compression sides has higher retention value than T and B types. One-way analysis of variance revealed that the difference between T and B types were not significant at a 95% confidence level.

Because all the control specimens were classified into Grade-1 by MOE (120E–140E) regulated in JAS,[8] the difference of material species is disregarded in the following discussion; the bending strength properties are discussed hereafter on the survived Grade-1 LVL with 120E–140E after 9 years of outdoor exposure.

The relations between density of specimens and MOR with a linear regression line are shown in Fig. 10. As is shown in this figure, each coefficient of correlation (r) is high, and strong correlation exists between density of specimens and MOR. The regression line of M type is similar to that of control specimens while T type and B type are similar to each other.

Calculated from the regression equation for control and M-type specimens described in Fig. 10, the MOR decreases by 22.4–25.8 MPa with 0.1 g/cm^3 decreases in density. It should be noted that the decrease of density leads to the considerable decrease in MOR even if the appearance is normal and slightly decayed. In comparison of M with T and B-type specimens, it is clear that MOR decreases considerably when the appearance is deteriorated.

Similar relations between the MOE and MOR of specimens are observed in Fig. 11 showing that the decrease of MOE leads to the considerable decrease of MOR even if the appearance is normal and slightly decayed.

Conclusions

Because the exposure conditions in this study were rather severe for the specimens with no preservative or surface treatment, decay by brown rot fungi easily took place in only 4 years of exposure and spread to the adjacent specimens through wood supports year by year.

Measurement of ultrasonic velocity by the Pundit method was effective to predict the density of specimens exposed for 9 years; correlation between the density and the ultrasonic velocity of the specimens was strong.

Measurement of penetration depth of a pin by the Pilodyn method was also effective for predicting the density of specimens exposed for 9 years.

It should be noted that correlation between the density and MOR of specimens and that between MOE and MOR are strong even in decayed specimens.

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