Evaluation of Physical and Mechanical Properties of Non-certificated Laminated Veneer Lumber (LVL) Circulated in Domestic Lumber Market*1

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ABSTRACT

The selected physical and mechanical properties of non-certificated LVL circulated in domestic lumber market were investigated and compared to relevant standards. The tested LVL passed the moisture content and the soaking delamination rate limit as per domestic (KS) and Japanese standard (JAS). The evaluated mechanical properties were flatwise/edgewise bending strength, modulus of elasticity (MOE), horizontal shear and compressive strength. The 30 mm-thick LVL showed significantly higher bending strength than that of the 25 mm-thick LVL. The modulus of elasticity (MOE) showed same tendency in the results of bending strength. The edgewise bending strength and MOE were higher than that of flatwise bending strength and MOE. The horizontal shear strength values were also showed similar results to bending strength values. The tested results were compared each other and each products were graded according to JAS 701 grade specification. The failure mode of LVL in bending test showed the similar failure mode of solidwood that failed in a simple tension manner (splinterly tension). The glue line failure was severe in 25 mm-thick specimens due to concentration of shear stress in layer discontinuity containing small voids and starved glue lines. In horizontal shear strength test, failure mode of LVL showed the typical horizontal shear failure. Compressive specimens failed with fiber crushing in company with apparent delamination that splitted along the length of the specimens. From the results, the complete bonding between lamination and consistency in thin veneer layer were considered as a critical factor in the mechanical properties of LVL. Moreover, the standard test procedure and specification for non-certificated LVL should be required to check the performance of uncertificated materials.

Keywords: laminated veneer lumber (LVL), bending strength, MOE, horizontal shear, JAS, KS

1. INTRODUCTION

Laminated veneer lumber (LVL) is a composite of wood veneer sheet elements manufactured from one or more species, either separately or mixed, with wood fibres primarily oriented along the length of the member (ISO, 2010). It has been developed as an alternative material to solid wood products used in wood frame construction. Typically, veneers with high
Table 1. Configuration of LVL tested in this study

<table>
<thead>
<tr>
<th>Nominal thickness (mm)</th>
<th>Number of ply</th>
<th>Species</th>
<th>Product type</th>
<th>Dimension (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>21</td>
<td>Birch</td>
<td>lumber</td>
<td>25 × 25 × 2,400</td>
</tr>
<tr>
<td>30</td>
<td>25</td>
<td>Japanese Larch</td>
<td>panel</td>
<td>30 × 1,220 × 2,440</td>
</tr>
</tbody>
</table>

grades are placed on the face and back, inexpensive or low-grade veneers are in the inner plies. So, it can reduce the processing costs and effectively utilize the low grade materials like thinnings, second and third growth timber with small diameters. Generally, LVL is used as headers and beams, chords for trusses, flanges in prefabricated I-joist, and scaffold planks. It is also used as columns, shear wall framing studs and even structural members in upholstered furniture frames (Williamson, 2002). Moreover, it is used as nonstructural elements like window frames, interior materials, and stair treads, etc.

Currently, LVL is imported from North America for structural materials used in wood frame construction and this product is certificated from corresponding agency. Meanwhile, any information on the properties of imported laminated veneer lumber from other countries and circulated in domestic market are still very limited. This products are non-certificated materials and has some potential problems applying to the intended uses, lead to cause possible the consumer's distrust to the products. So some critical information is needed to evaluate the physical and mechanical properties of this product and compare each other. Also, it is needed to align the testing standard and quality certification.

In Korea, some species reaches the moderate diameter for making veneers for plywood and LVL, rather than lumber products. This leads to the development of value added products like structural composite materials including LVL, and the basic information is also needed for comparing competitive products.

In this study, the physical and mechanical properties of non-certificated imported laminated veneer lumber were investigated and the results were compared with its corresponding standards.

2. MATERIALS and METHODS

Laminated veneer lumber (LVL) was obtained from commercial suppliers in Incheon, Korea. Nominal thickness of LVL were 25 mm, 30 mm respectively and LVL with the thickness of 30 mm were the panel type product with the dimension of 1,220 mm × 2,440 mm. LVL with the thickness of 25 mm was sized product with the length of 2,400 mm. These species were Japanese Larch in 30 mm product and Birch in 25 mm products as shown in Table 1.

Specimens were cut from each billet and panels according to ISO/FDIS 22390, ASTM D 5456 and JAS 701 standards for conducting the tests for the evaluation of physical and mechanical properties of LVL. The testing programs are shown in Table 2. Before the tests, the specimens were stored in a humidity chamber at 20°C and 65% relative humidity until equilibrium moisture content of 12% was reached. The static bending to edgewise/flatwise strength and stiffness, compression strength parallel to the grain, and horizontal shear strength related to flatwise bending tests (short span bending) were conducted according to the standard described earlier. In static bending test, ten bending samples were selected in each billet and loaded at third point loading along 420 mm span by 100 kN universal testing machine. After each sample was broken, the moisture
Table 2. Strength test programs in this study

<table>
<thead>
<tr>
<th>Materials</th>
<th>Static bending</th>
<th>Compression parallel to the grain</th>
<th>Horizontal shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 mm LVL</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>30 mm LVL</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

where $b =$ sample width (mm)  
$h =$ sample depth (mm)  
$p_{\text{max}} =$ maximum strength (N)  
$p_{\text{prop}} =$ load to proportional limit (N)  
$y =$ deflection to proportional limit (mm)  
$A =$ cross section area (mm$^2$)

3. RESULTS and DISCUSSION

3.1. Physical Properties

Table 3 summarizes the mean values and the standard deviation of the MC and density of the tested specimens. As shown in Table 3, the density values of birch LVL were lower than those of Japanese larch LVL. As the density of LVL made from the Japanese larch, 0.79, is higher than that of solid Japanese larch wood, 0.60 (Rijsdijk and Laming, 1994). This results came from the adding the adhesive and compaction within and between the lamination during the hot pressing. Sulaiman, etc. (2009) also reported that there was an increase in density of LVL made from oil palm compared to solid oil palm. But the density of LVL made from birch, 0.50, were lower than that of solid birch, not less than 0.55 (Woodhandbook, 1999). This is due to the non-compact layer structure containing a lot of voids between lamination, and lead to higher standard deviation and unconsistency in each lamination as shown in Fig. 3. From the results, not only the density of raw materials but also the layer structure is considered as important factors affecting to the density of LVL.

All the tested LVL samples passed the mois-
Table 3. Mean and standard deviation of MC and density of tested specimens

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density (g/cm³)</th>
<th>Moisture Content (%)</th>
<th>Average</th>
<th>Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 mm LVL</td>
<td>0.50 (0.19)</td>
<td>11.53 (0.87)</td>
<td>passed</td>
<td></td>
</tr>
<tr>
<td>30 mm LVL</td>
<td>0.79 (0.02)</td>
<td>9.10 (0.18)</td>
<td>passed</td>
<td></td>
</tr>
</tbody>
</table>

*1) Values in parenthesis are standard deviation.  
*2) JAS 701; 14% or less.

Table 4. Test results of soaking delamination rate of LVL

<table>
<thead>
<tr>
<th>Materials</th>
<th>Delamination rate (%)</th>
<th>Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 mm LVL</td>
<td>3</td>
<td>passed</td>
</tr>
<tr>
<td>30 mm LVL</td>
<td>0</td>
<td>passed</td>
</tr>
</tbody>
</table>

* KSF 3119; 10% or less (sum of delamination length in both side of cross section devided by sum of glue line length in both side of cross section).

Table 5. Test results of strength test of LVL

<table>
<thead>
<tr>
<th>Materials</th>
<th>Bending strength (N/mm²)</th>
<th>Compressive strength (N/mm²)</th>
<th>Horizontal shear strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flatwise</td>
<td>Edgewise</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MOR</td>
<td>MOE</td>
<td>MOR</td>
</tr>
<tr>
<td>25 mm</td>
<td>49.5</td>
<td>9248.3</td>
<td>55.9</td>
</tr>
<tr>
<td></td>
<td>(19.4)</td>
<td>(175.5)</td>
<td>(8.3)</td>
</tr>
<tr>
<td>30 mm</td>
<td>104.1</td>
<td>12863.9</td>
<td>114.5</td>
</tr>
<tr>
<td></td>
<td>(7.4)</td>
<td>(364.6)</td>
<td>(5.8)</td>
</tr>
</tbody>
</table>

* Values in parenthesis are standard deviation.

ture content limit as per Japanese standard (JAS 701) to 14%. In the soaking delamination rate test, the test results showed good results in soaking 24 hrs followed by drying under the 60 ± 3°C condition in drying oven (Table 4). There was no visible delamination in 30 mm-thick LVL samples and all the tested LVL passed the soaking delamination rate limit as per domestic standard (KS F 3119) to 10%. In spite of the results, 25 mm-thick LVL made from birch demands more attention to use under wet service condition due to the potential swelling by the moisture inclusion to voids and poor layer structure.

3.2. Mechanical Properties

The average and the standard deviation of bending strength (MOR) and modulus of elasticity (MOE) of LVL are given in Table 5. From the test results, the 30 mm-thick LVL showed significantly higher bending strength than that of 25 mm-thick LVL, and this is considered due to higher density of 30 mm-thick LVL. Quite number of thin veneer was laminated in 30 mm-thick LVL lead to higher density and such to higher bending strength. Especially the higher standard deviation of MOR and MOE in 25 mm-thick LVL was considered to be originated from poor quality control in making LVL. In domestic market, the 25 mm-thick LVL is considered to be used as non-structural materials rather than structural application.

The highest modulus of elasticity (MOE) was found in 30 mm-thick LVL and 25 mm-thick has the second highest value. In comparing to JAS 701 standard, MOR of 30 mm-thick LVL was over the limit value to any grade and MOE was to be considered as 120E grade in flatwise and 140E grade in edgewise bending. Also, MOR of 25 mm-thick LVL was passed 120E grade in flatwise and 140E grade of this standard.
MOE of 25 mm-thick LVL was to be considered as 90E grade in flatwise and edgewise bending. So it found to be 120E grade in 30 mm thick LVL and 90E grade in 25 mm thick LVL according to MOE grade specification.

The standard deviations of MOR and MOE in 30 mm-thick LVL were significantly lower than that of 25 mm-thick LVL. It was come from the poor layer structure as shown in Fig. 3, because 25 mm-thick LVL contained severe defects like starved joint and missing layer structure. If the bending design value is needed in 25 mm-thick LVL, more considerations should be required due to material’s nonuniformity with wide variation of the properties between materials.

The edgewise bending strength and MOE were higher than that of flatwise bending strength and MOE in 25 mm and 30 mm-thick LVL specimens. Their relations are shown in Fig. 2. Burdurulu etc. (2007) reported that the bending strength and MOE parallel to the glue line is somewhat higher than that of perpendicular to the grain, but the difference was is not consistent according to ply organization. In this study, the bending strength and MOE parallel to the glue line (edgewise) is higher than that of perpendicular to the grain (flatwise) and showed good relationship between flatwise and edgewise bending strength data.

In compression test, 30 mm-thick LVL showed significantly higher compressive strength than that of 25 mm-thick LVL. This results also come from the difference of raw materials which has different density and the cursory layer structure in 25 mm-thick LVL as shown in Fig. 3. The 25 mm-thick LVL contains several voids and starved joint due to inconsistency in each layer, and these defects lead to the lower compression strength values. The compact layer structure was found in 30 mm-thick LVL and this lead to higher compressive strength.

The horizontal shear strength values were also showed similar results to bending strength values and this is also due to the difference in the density of LVL. The standard deviation of 25 mm-thick LVL specimens was somewhat higher than 30 mm-thick LVL specimens and this is also to the uneven interlayer structure. In comparing to JAS 701 standard, horizontal shear strength of 30 mm-thick LVL was over the maximum limit value in this standard and showed highest grade, 65V-55H. 25 mm-thick LVL was to be considered as 45V-38H, the second lowest grade in this standard.

The failure mode of LVL in bending test showed the similar failure mode in solid wood that test specimens failed in a simple tension
manner. First, the failure occurred in tension side of specimens as a splintering tension mode and then the failure was progressed along the glue line in which was the weakest region among the glue lines as shown in Fig. 4(a). The glue line failure was severe in 25 mm-thick specimens due to concentration of shear stress in layer discontinuity containing small voids and starved glue lines as shown in Fig. 4(b). Bodig and Jayne (1982) reported that species containing internal checks and shakes which can act as planes of weakness for shear failure. The defects like voids and starved joints also can act as planes of weakness and the same results were found in this study.

In horizontal shear strength test, failure mode of LVL showed the typical horizontal shear failure, in other words, shear failure near the neutral plane occurred as shown in Fig. 5(a). Among the specimens, the 25 mm-thick LVL samples showed significant shear failure in weakness region containing defects rather than in neutral plane as shown in Fig. 5(b). This lead to the more inclined to this type of failure and lower strength values.

Compression specimens failed with fiber crushing with apparent delamination as shown in Fig. 6(a). Splitting along the length of the specimens due to the delamination was particularly significant in 25 mm-thick LVL samples and this is a result of weakness like internal void and poor layer structure as shown in Fig. 6(b). Combined compression and splitting occurred in parts of 30 mm-thick LVL samples. From the results, the bonding strength between lamination
and uniform thin veneer layer structure were considered as critical factors in evaluating strength properties of LVL.

4. CONCLUSION

The physical and mechanical properties of LVL available, but non-certificated products in domestic market were investigated and compared each other. All the tested LVL passed the moisture content limit as per domestic standard (KS) and Japanese standard (JAS). Also, all the tested samples passed the soaking delamination rate limit as per domestic standard and Japanese standard.

The bending strength and MOE of 25 mm-thick and 30 mm-thick LVL were compared each other and the differences were come from the difference of raw materials’ density and degree of compaction in layer structure of lamination.

Also, 25 mm-thick and 30 mm-thick LVL were graded per JAS 701 standard, and special consideration is needed to set design value of 25 mm thick LVL due to it’s high standard deviation in strength properties. The horizontal shear strength values were also evaluated and graded per JAS 701 standard.

The failure modes of LVL in bending, horizontal shear and compression test were compared each other and major cause of failure were investigated. From the results, the bonding strength between lamination or thin veneer layer was considered as a critical factor in evaluating strength properties of LVL.

Finally, the domestic standard test procedure and specification for non-certificated LVL should be required to check the performance of un-certificated materials.

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REFERENCES

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