INVESTIGATION OF THE EFFECTS OF LAMINATION AND DENSIFICATION TO THE MECHANICAL AND PHYSICAL PROPERTIES ON BEECH WOOD

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Key words

Beech, Densification, lamination, Polyvinyl acetate glue, Density, Static bending strength, Modulus of elasticity in Bending.

Abstract

In this study, beech density, static bending strength and change in the modulus of elasticity are determined by the application of densification and lamination technique. For this purpose, beech (Fagus orientalis L.) is laminated as four-layer with PVAc wood glue. On sample; densification, bending strength and modulus of elasticity in bending are determined according to TS 2472 (1976), TS 2474 (1976) and TS 2478 (1976) basis respectively. As a result, density, static bending strength and bending modulus of elasticity of beech wood have been found to be increased depending on the temperature and pressure by the application of densification (as the temperature and pressure increase in densification) and lamination technique. The highest density, static bending strength and modulus of elasticity increase in bending; occurred in the laminate samples concentrated in 160 °C temperature and under 8 N/mm² pressure. In the samples with low temperature and pressure, a reduction in the increase in density, static bending strength and modulus of elasticity in bending values is determined.

1. INTRODUCTION

The wood species of low density and less commercial value can be converted into high-performance and valuable products by being modified with densification process. Even more, high density woods are improved in terms of hardness and resistance properties by densification. Wood material can be densificated together with the impregnation of some chemicals through the cell walls under pressure or application of mechanical press with the impregnation. In mechanical densification in press, on the other hand, gap volume is reduced by collapsing the cell wall of the wood. A major disadvantage of mechanical densification is that densificated wood returns to its original dimensions before the compression if it is exposed to moisture (Pelit and Sonmez 2015; Cooper and Wang 2005; Boonstra 2008).

Laminated wood, which is commonly used in construction industry, is also preferred in the furniture industry, since the material has some good advantages such as; it can be obtained in more precise and larger sizes than the solid material, and it demonstrates high performances to gluing and high resistance. As TS EN 386 (2006) defines, the laminated wood is a construction element which is obtained by means of attaching wood veneer fibers in parallel (Keskin 2001; Yıldız 2002) (Dubey 2010). In the studies made by Keskin (2009); Keskin and Togay (2003), laminated wood materials which have been obtained from Oriental spruce

Küreli et al. (2015), "Investigation of the effects of lamination and densification to the mechanical and physical properties on beech wood "

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(Picea orientalis L.) wood and prepared in 5-layered form with PVAc-D4 glue, are used. In laminated East spruce, the air dried density, bending strength, and modulus of elasticity have been found as 0.466 g/cm³, 75.29 N/mm², and 10359.77 N/mm² respectively. At the end of the experiments; it has been found that, the physical and mechanical properties of the material, which has been obtained by laminating Eastern spruce, are superior to representative solid wood material. In the study done by Keskin (2001), it is understood that the technological properties of the wood materials, which were made from Taurus Cedar (Cedrus libani A. Rich), Scots pine (Pinus sylvestris L.), Beech (Fagus orientalis L.) and Oak (Quercus petraea L.) that have 5 mm thick veneers, are superior to representative solid materials, those of which are laminated in four layers with PVAc-D4 adhesive.

In the study wherein adhesion performances of incurved laminated and vacuum membrane pressed elements are examined, vertical adhesion performance is the highest in the beech (Altnok et al. (2009)).

In this study, the beech has been laminated and condensed by thermo-mechanical methods, compared with untreated versions, and the changes in density, static bending resistance and modulus of elasticity in static bending have been observed.

2. MATERIALS AND METHODS

In this study beech wood (Fagus orientalis L.) (Density=0.63 g/cm³) as wood material and polyvinyl acetate (PVAc) as adhesive were used. The principles in TS 3891 (1983) have been considered in application of the lamination.

Preparation of the test specimens

Preparation of the wood material

The test samples have been prepared in accordance with TS 53 (1981), TS 2470 (1976), TS 2471 (1976) and TS 2472 (1976) regulations, so that annual rings will meet the surface perpendicularly. In the preparation of test samples, variation of “massive control+densificated massive+laminated control+densificated lamination; at 140 °C and 160 °C press temperature and under pressure of 6 N/mm² and 8 N/mm²” has been taken into consideration. For static bending strength and elasticity modulus of bending tests, a total of 160 tolerated test samples and density samples have been left to wait in air conditioning devices until they reach invariable weight under 20±2 °C temperature and 65±5% relative humidity conditions after being cut in 500 mm x 40 mm x 40 mm and 20 mm x 20 mm x 30 mm dimensions.

Destination of the wood material

120 static strength and elasticity in bending test samples have been concentrated under 140 °C and 160 °C temperature and 6 N/mm² and 8 N/mm² pressure in a hydraulic test press, which is adjustable for heat and press and located in wood mechanics laboratory of Gazi University, Faculty of Technology, Department of Industrial Engineering of Wood Products. Laminated control samples to be used for static bending strength and elasticity experiments and condensed laminated samples from each group have been prepared in the dimensions of 20 mm x 20 mm x 360 mm (Figure 1).
**Determination of the static bending strength and modulus of elasticity**

The bending strength in accordance with the principles stated in TS 2474 (1976), modulus of elasticity in accordance with the principles stated in TS EN 310 (1999) and TS 2478 (1976) are determined by applying 5 mm/min pressure in Universal Testing Device.

**Data analysis**

The measurement differences (after the densification) have been used as data in the statistical evaluation. Multiple analysis of variance (MANOVA) in the statically evaluation program MSTAT-C has been applied to the data and in case of major differences between groups, the difference between mean values have been compared via the Duncan test. Thereby, success ranking among each factor taken into trial has been determined by means of dividing homogeneous groups according to the critical value of least significant difference (LSD).

### 3. FINDINGS

**Density**

Statistical average values of densificated untreated laminated and solid control samples are given in Table 1:

<table>
<thead>
<tr>
<th>Test samples</th>
<th>Pressing temperature (°C)</th>
<th>Pressing pressure (N/mm²)</th>
<th>Density value (g/cm³)</th>
<th>Densification ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid control</td>
<td>-</td>
<td>-</td>
<td>0.534</td>
<td>-</td>
</tr>
<tr>
<td>Condensed solid</td>
<td>140</td>
<td>6</td>
<td>0.600</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>6</td>
<td>0.678</td>
<td>22</td>
</tr>
<tr>
<td>Laminated control</td>
<td>-</td>
<td>-</td>
<td>0.565</td>
<td>-</td>
</tr>
<tr>
<td>Condensed Lamination</td>
<td>140</td>
<td>6</td>
<td>0.648</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>6</td>
<td>0.720</td>
<td>22</td>
</tr>
</tbody>
</table>

According to Table 1, the density values of solid control and laminated control samples have been found as 0.534 g/cm³ and 0.565 g/cm³. It has been seen that, as the heat and pressure increase, the density value also increases. The highest increase in density has occurred in intensified laminated samples (27%) under 160 °C temperature and 8 N/mm² pressure.
whereas the lowest occurred in intensified solid (12%) under 140 °C temperature and 6 N/mm² pressure. The ratio of densification has been realized in the same measurements for solid and intensified laminated samples under the same temperature and pressure change.

**The mean values of statistical bending strength and Modulus of Elasticity**

The mean values of statistical bending strength and modulus of elasticity of untreated control and solid control samples that have been densificated are shown in Table 2.

Table 2. Statistical values of bending strength and modulus of elasticity of control and condensed samples

<table>
<thead>
<tr>
<th>Test samples</th>
<th>Pressing temperature (°C)</th>
<th>Pressing pressure (N/mm²)</th>
<th>Bending strength Mean (N/mm²)</th>
<th>Change ratio (%)</th>
<th>Modulus of Elasticity Mean (N/mm²)</th>
<th>Change ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid control</td>
<td>Room temp.</td>
<td>-</td>
<td>95.83</td>
<td>-</td>
<td>9576.10</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>140</td>
<td>6</td>
<td>102.12</td>
<td>06.5</td>
<td>10798.43</td>
<td>11.32</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>8</td>
<td>114.97</td>
<td>20.0</td>
<td>14470.68</td>
<td>33.83</td>
</tr>
<tr>
<td>Condensed control</td>
<td>140</td>
<td>6</td>
<td>118.87</td>
<td>24.1</td>
<td>12710.44</td>
<td>24.66</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>8</td>
<td>135.03</td>
<td>40.1</td>
<td>16151.81</td>
<td>40.72</td>
</tr>
<tr>
<td>Laminated control</td>
<td>Room temp.</td>
<td>-</td>
<td>101.05</td>
<td>-</td>
<td>15428.86</td>
<td>-</td>
</tr>
<tr>
<td>Condensed laminated</td>
<td>140</td>
<td>6</td>
<td>122.91</td>
<td>21.6</td>
<td>19124.36</td>
<td>19.33</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>8</td>
<td>140.75</td>
<td>39.2</td>
<td>20425.95</td>
<td>24.47</td>
</tr>
</tbody>
</table>

According to Table 2, means of static bending strength of solid and laminated control samples have been found as 95.83 N/mm² and 101.05 N/mm². It has been found that, as the temperature and pressure increase, as a result of that the static bending strength also increases. The highest increase of bending strength has seen in intensified laminated samples (57.3%) under 160 °C temperature and 8 N/mm² pressure. The lowest increase, on the other hand, has been found for intensified solid sample (6.5%) under 140 °C temperature and 6 N/mm² pressure. Increase in the static bending strength of intensified laminated sample has been 1.5 to 3 times more than it has been realized for intensified solid sample.

According to statistical results in Table 2, means of modulus of elasticity of solid and laminated control samples have been found as 9576.10 N/mm² and 15428.86 N/mm². As the temperature and pressure increases the modulus of elasticity also increases. The highest increase in the modulus of elasticity has occurred in intensified laminated samples (40.72%) under 160 °C temperature and 8 N/mm² pressure, whereas the lowest occurred in intensified solid (11.32%) under 140 °C temperature and 6 N/mm² pressure. The increase has occurred 1.15 times more in intensified solid than intensified laminated samples. This increase does not constitute a major difference. Multiple variance analysis in relation to bending strength and modulus of elasticity of condensed solid and laminated samples affected by variable factors is shown in Table 3.
Table 3. Duncan test and homogenous results of the effect of triple interaction of temperature, pressure and wood to bending strength and modulus of elasticity.

<table>
<thead>
<tr>
<th>Wood specie</th>
<th>Temperature (°C)</th>
<th>Pressure (N/mm²)</th>
<th>Bending strength (N/mm²)</th>
<th>HG</th>
<th>Modulus of elasticity (N/mm²)</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid control</td>
<td>-</td>
<td>-</td>
<td>095.83</td>
<td>-</td>
<td>9576.0</td>
<td>-</td>
</tr>
<tr>
<td>Condensed solid</td>
<td>140</td>
<td>6</td>
<td>099.52</td>
<td>B</td>
<td>10190.0</td>
<td>BC</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>103.00</td>
<td>B</td>
<td>11140.0</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>6</td>
<td>112.10</td>
<td>AB</td>
<td>12020.0</td>
<td>AB</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>117.30</td>
<td>A</td>
<td>12860.0</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>LSD : ±13.070</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laminated control</td>
<td>-</td>
<td>-</td>
<td>101.05</td>
<td>-</td>
<td>15430.0</td>
<td>-</td>
</tr>
<tr>
<td>Condensed laminated</td>
<td>140</td>
<td>6</td>
<td>103.30</td>
<td>B</td>
<td>17900.0</td>
<td>BC</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>108.80</td>
<td>B</td>
<td>19120.0</td>
<td>BC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>6</td>
<td>138.80</td>
<td>AB</td>
<td>21000.0</td>
<td>AB</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>155.80</td>
<td>A</td>
<td>23920.0</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>LSD : ±26.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

According to Table 3, The highest static bending strength and modulus of elasticity in terms of temperature of 160 °C and pressure levels of 8 N/mm² have been obtained 12860.0 N/mm² for condensed solid, and 23920.0 N/mm² condensed laminated. The lowest bending strength in terms of temperature of 140 °C and pressure of 6 N/mm² has been resulted in 10190.0 N/mm² for condensed solid and 17900.0 N/mm² for laminated.

4. CONCLUSIONS AND DISCUSSION

In this densification study that has been performed in order to inhabitiliate physical and mechanical attributions of East Beech by modifying it, important physical and mechanical alterations such as specific weight, bending strength and modulus of elasticity are examined.

Density variation

Before the densification, the density values of solid control and laminated control samples have been detected as 0.534 g/cm³ and 0.565 g/cm³. According to that, the density of laminated beech control samples is higher than solid control samples. This can be explained by means of the contribution of adhesion layers in between the laminated layers to the weight. This result is also supported by the data results of Altınok et al (2009).

Density change of condensed solid and laminated samples has increased due to pressure and temperature of the pressing machine that makes the concentration. The highest increase in density has been observed for condensed laminated samples (27%) under 160 °C temperature and 8 N/mm² pressure, whereas the lowest (12%) has been occurred in condensed solid under 140 °C temperature and 80 kg/cm² pressure. The change in concentration has been seen in the same ratio for condensed solid and laminated under the same temperature and pressure. In both wood samples (condensed solid and laminated), the highest concentration has been found 2.25 times bigger than the lowest. This result has been supported with reference to Pelit and Sonmez (2015).
**Static bending strength variation**

Before the densification, the average of static bending strength values of solid control and laminated control samples have been detected as 95.83 N/mm² and 101.05 N/mm². It has been observed that as the pressing temperature and the pressing pressure increases, the static bending strength significantly increases due to their compacting. The highest increase in bending strength has been occurred in laminated sample (57.3%) under 160 °C temperature and 8 N/mm² pressure. The lowest increase, on the other hand, has been seen in condensed solid sample (6.5%) under 140 °C temperature and 8 N/mm² pressure. The increase in static bending strength of condensed laminated sample has been realized 1.5-3 times bigger than condensed solid sample. This result has been supported with reference to Pelit and Sonmez (2015). It has been found that during the concentration, the most important effect on the static bending strength is primarily the wood specie, secondly the interaction between the pressure and the specie. Additionally, the temperature has been determined to be less effective than the other two. The reason for that can be explained by the insufficiency of low temperature increase (60-80 °C) in softening the lignin, which is a natural resin that provides lignification in cell structure.

**Bending modulus of elasticity variation**

Before the densification, the average values of bending modulus of elasticity of solid control and laminated control samples have been detected as 9576.10 N/mm² and 15428.86 N/mm². It has been observed that as the pressing temperature and the pressing pressure increases, the modulus of elasticity significantly increases due to their compacting. The highest increase in specific weight has been observed for condensed solid samples (40.72%) under 160°C temperature and 8 N/mm² pressure, whereas the lowest (11.32%) has been occurred in condensed laminated under 140°C temperature and 8 N/mm² pressure. The increase in bending modulus of elasticity of condensed solid sample has been realized 1.15 times bigger than condensed laminated sample. The reason why the highest increase in modulus of elasticity has been observed for condensed solid sample can be explained by the defects such as fiber cut and gluing occurred during the lamination. Keskin (2001) supports these related results. Consequently, physical and mechanical properties of the wood can be improved by means of modification. During the densification that is being performed for this purpose, important physical and mechanical properties such as specific weight, bending strength and bending modulus of elasticity increase depending on pressure and temperature of the pressing. The greatest impact of this increase is observed in wood specie and pressure of the pressing. The effect of the pressing machine is also low in the lower temperatures.

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