ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 12 N° 2 2016
pp. 3-8

PROPERTIES OF LAMINATED VENEER LUMBER MANUFACTURED FROM HEAT TREATED VENEER

Hamiyet Sahin KOL
Assoc. Prof. Dr - Karabuk University
Faculty of Forestry, Forest Industry Engineering
Address: Karabuk University 78050, Karabuk-Turkey
Email: hsahinkol@karabuk.edu.tr

Belgin SEKER
Research Ast.- Karabuk University
Faculty of Forestry, Forest Industry Engineering
Address: Karabuk University 78050, Karabuk-Turkey
Email: belginseker@karabuk.edu.tr

Abstract:
The objective of this study was to determine and compare properties of laminated veneer lumber (LVL) panels manufactured from heat treated (212^{o}C, 2h) and untreated pine veneer with melamine urea formaldehyde (MUF) adhesive. The results showed that, heat treatment considerably decreased all investigated physical properties of LVL. The reductions in density (D), moisture content (MC), and thickness swelling (TS) were 8.33%, 33.78% and 14.03%, respectively. The findings of this study demonstrated that heat treatment resulted in adverse effect on bending strength and hardness of LVL panels. Heat treatment caused a decrease in bending strength (MOR) by 31.85% and in hardness (HT) by 25.44%. However, modulus of elasticity (MOE) and compressive strength (CS) values of LVL panels were higher than those of untreated groups. Compressive strength and modulus of elasticity (MOE) of LVL panels made of heat treated veneer respectively were 11.17% and 7.46% higher than untreated LVLs.

***Key words**: heat treatment; laminated veneer lumber; physical and mechanical properties.*

INTRODUCTION

In view of the increasing awareness of society concerning the natural environment, structural composite lumber (SCL) have become important recently. Laminated veneer lumber is one of the most known and commercially produced SCL that can be defined as a composite of wood veneer sheets have been manufactured by using appropriate adhesive, processing conditions, veneers from different wood species with wood fibers primarily oriented along the longitudinal axis of the member, where the veneer element thickness are 6.4mm or less (ASTM D-5456-14b). Physical and mechanical properties of LVLs are governed by the properties of the wood species utilized, the manufacturing process, the quality control process and finally the application of these products (Lam 2001). Laminated veneer lumber has the potential to be used in structural and non-structural applications such as construction and furniture industry, material for flooring and numerous other areas (Barbu *et al*. 2014, Hayashi and Oshiumi 1993, Eckelman 1993, Ozarska 1999, Lam 2001, Shukla and Kandem 2008).

One of the objectives of composite technology is to produce a product with acceptable performance characteristics using low quality raw materials combining beneficial aspects of each constituent. New composites are produced with the aim to reduce the costs and to improve performance (Schuler and Adair 2003). By proper choice of the suitable wood component, its orientation, adhesives and processing conditions, different types of wood panel products are manufactured (Shukla *et al*. 1999). Thermal modification has increased significantly in the last few years and still growing as an industrial process to improve some properties of wood and wood based composites. This interest is due to the declining production of durable timber, to the increasing demand for sustainable building materials, to the deforestation of especially sub-tropical forest, and to the increased introduction of governmental restrictive regulations reducing the use of toxic chemical (Esteves and Pereira 2009). Heat treated wood is a material with changed chemical composition. The chemical modifications that occur in the material at high temperatures are accompanied by several favorable changes in its physical properties, including reduced shrinkage and swelling, improved biological durability, low equilibrium moisture content, enhanced weather resistance, a decorative dark color, improved thermal insulation properties, low pH, several extractives flowed from the wood, and better decay resistance (Rapp 2001). However, heat treatment causes decreases in certain mechanical properties of wood and wood based materials such as shear strength (Sahin Kol *et al*.

2009, Chen *et al*. 2015) and bending strength (Nazerian *et al*. 2011, Sahin Kol 2010) and requests special tools or increased the wear during processing.

There have been some studies of the use of heat treatment to improve performance of wood based materials. Effects of different heat treatment conditions on the physical and mechanical properties LVL were investigated by Nazerian *et al*. (2011) and Nazerian and Ghalehno (2011) for LVL made from beech, maple and poplar bonded with urea folmaldehyde (UF), by Perçin *et al*. (2015) for LVL made from black pine glued with MF and D-Vtka polyurethane, by Altınok *et al*. (2010) for beech LVL bonded with polyurethane and polyvinyl acetate (PVAc). Chen *et al*. (2015) were reported the feasibility of heat treatment for Masson pine veneers and its application in plywood. Reports from various studies indicate that, the extent of change in wood based composites properties by heat treatment varies depending on the chemical and anatomical nature of wood utilized, adhesives used, the methods of treatment, treatment temperature and time (Nazerian *et al*. 2011, Nazerian and Ghalehno 2011, Perçin *et al*. 2015, Altınok *et al*. 2010, Chen *et al*. 2015). Heat treatment of wood affect the shear strength in several ways depending on the adhesive type used (Boonstra *et al*. 1998, Sernek *et al*. 2008, Sahin Kol *et al*. 2009, Chen *et al*. 2015).

A better understanding of the effect of heat treatment process on the properties of LVL made of different wood species and adhesives can help us develop productive uses for heat treated wood, thereby efficient usage of LVLs made from heat treated veneer in the construction and building industry. This work is designed to determine and compare physical and mechanical properties of LVLs made from untreated and heat treated pine veneers bonded with MUF adhesive. Such scientific and technical information is required by the forest products industry to meet and develop future market demands especially for improving the bio-degradability.

MATERIAL AND METHODS

Wood Material

Pine (*Pinus Nigra*) planks were obtained from Nova Forest Products Inc., Bolu, Turkey. The planks (32×125mm cross section and 3000mm long) have approximately an initial moisture content of 50% - 60%. Each plank was divided into 2 treatments groups. One of them was kept as an untreated control group and the other was thermally treated at 212^{o}C.

Preparation of Laminated veneer lumber samples

Untreated control groups were dried in industrially kiln-drying at approximately at a temperature of 70ºC until moisture content of 11%-15%. The commercial Thermowood method patented by International Thermowood Association was applied to other planks in NOVA Forest Products Inc. The process was carried out in three main phases. Firstly, wood temperature was raised rapidly using heat and steam to a level around 100^{o}C. Thereafter the temperature was increased steadily to 130^{o}C, and the moisture content was reduced to nearly zero. Whenever high heat drying was occurring, the temperature was increased to a level of 212^{o}C and held constant through 2 hours. In the final stage, the temperature was reduced to 50 to 60^{o}C by using a water spraying system. This process was continued until the moisture content of planks reached 4 to 6%. The total time of the heat treatment was 113h. The heat treatment operation was carried out quite slowly because the initial moisture of the planks was high. For, the cracks formed during the drying are to be a big risk. After heat treatment only the planks that were free of defects were selected for further testing.

Subsequently, untreated control planks (MC = approximately 11-13%) and heat-treated pine planks (MC = approximately 4-6%) were cut into veneers (4mm thick) and the veneer were conditioned in a standard climate with 65% relative humidity (RH) and at a temperature of 20^{o}C until they reached equilibrium MC. The MC of the veneers was determined by the gravimetric method. The MC of the untreated and heat treated veneers prior to bonding were 12.9% and 8.7%, respectively.

Five-layer LVL panels (size 650mm length x 125mm weight) with 20mm thickness were manufactured from the veneer sheets. A commercial MUF adhesive was used. The MUF adhesive has a pH of 8.8 with a viscosity of 160cP, a solid content of 55%, and density of 1.24gcm^{-3} at 20^{o}C. The adhesive spreading rate was 200gm^{-2}. To manufacture experimental five-layer LVLs, adhesives were spread on veneers' surfaces and they were immediately assembled with their tight sides facing out on each veneer and with their grain directions parallel to each other. The panels were hot-pressed at a temperature of 120ºC for 25min and pressure of 2kgcm^{-2}. The panels were conditioned for 24h, after which they were cut into their final dimensions. All samples were further cut according to the specified standards and conditioned at 20±2°C and 65±3% relative humidity before further testing. Thirty replicates were used for each test.

Physical and mechanical properties determination

Density (D), moisture content (MC), and thickness swelling after 24 h (TS) were determined to study the physical properties. ASTM D-2395-14$^{\varepsilon 1}$ was used for the density determination, ASTM D-4442-15 for MC measurement, and ASTM D-1037-12 for thickness swelling.

Four types of mechanical test were conducted in this study: center-point flexure test (MOE⊥ and MOR⊥) perpendicular to the surface (F||), compression strength parallel to the surface (C||), hardness test (HT). ASTM D-3501-05a was used for C||, ASTM D-3043-00 for F|| and ASTM D-1037-12 for HT determinations.

RESULTS AND DISCUSSION

The mean values and standard deviations of the obtained properties of LVLs manufactured from untreated and heat-treated veneers and the decreases of properties are presented in Table 1.

Table 1

The physical and mechanical properties of LVLs

Properties	Un-treated	Heat-treated	Decrease of property (%)
D (g cm^{-3})	0.60 (0.13)	0.55 (0.06)	-8.33
MC (%)	10.42 (0.23)	6.90 (0.45)	-33.78
TS (%)	7.48 (2.59)	6.43 (1.03)	-14.03
MOR⊥ (N mm^{-2})	102.67 (14.87)	69.96 (19.00)	-31.85
MOE⊥ (N mm^{-2})	11547.27 (1840.59)	12408.86 (1265.80)	7.46
CS|| (N mm^{-2})	59.61 (3.38)	66.27 (5.20)	11.17
HT (N mm^{-2})	22.4 (7.0)	16.7 (4.5)	-25.44

Results are expressed as the mean (n=30 for each properties); values in parentheses represent the standard deviation.

Based on the findings in the work, the physical properties of LVLs decreased after the planks were exposed to heat. LVLs made from veneers produced heat treated planks exhibit about 8.33% lower density than the untreated samples (Table 1). LVLs made from heat treated planks exhibit about 14.03% lower thickness swelling than the untreated samples (Table 1). Also heat treatment caused a decrease in MC by 33.78%. Similar results have been observed in previous studies (Nazerian and Ghalehno (2011), Nazerian *et al*. (2011), Percin *et al*. 2015). Decreases in physical properties of LVLs made from veneers produced heat treated wood were mainly the results of changes in chemical reactivity of wood utilized by heat treatment. The reduction on EMC and swelling are due to several factors. The degradation of hemicelluloses, which are the most hygroscopic structural compounds, plays an important role but the degradation amorphous regions of cellulose and cross-linking reactions also contribute on decrease on EMC and swelling as reported by several researchers (Bhuiyan and Hirai 2005, Tjeerdsma and Militz 2005, Esteves *et al*. 2008, Boonstra *et al*. 2007). Heat treatment results in a reduction of the accessible, free hydroxyl groups. As a consequence of reduces hydroxyl groups, swelling are lower (Ates *et al*. 2009). The main reasons for the decrease of the density of LVLs after heat treatment are: degradation of wood components (mainly hemicelluloses) into volatile products which evaporate during treatment; evaporation of extractives; and a lower equilibrium moisture content of the panels since heat treated wood is less hydrophobic (Boonstra *et al*. 2007).

The bending strength (MOR$_{\perp}$) showed a rather large decrease by heat treatment. Untreated LVLs had an average bending strength value of 102.67Nmm^{-2} which is 31.85% higher than those samples exposed to a temperature of 212ºC. Similar findings were reported in the literature for wood and wood based materials. Researchers reported that MOR increases slightly in the beginning of heat treatment at moderate temperature and then decreases significantly at higher temperature and/or after a longer heating period (Kubojima *et al*. 2000, Bekhta and Niemz 2003, Boonstra *et al*. 2007, Kocaefe *et al*. 2008), Nazerian and Ghalehno (2011) and Nazerian *et al*. (2011) found that the MOR of LVL heat treated at 120-180^{o}C decreased 43-83% compared to those untreated LVLs. Perçin *et al*. (2015) reported that MOR of LVLs heat treated at 200^{o}C and laminated with MF and DVTKA decreased 14.8, 18.2% respectively. Chen *et al*. (2015) reported that bending strength of plywood increased by increasing heat treatment temperature and then decreased at 190^{o}C. Altınok *et al*. (2010) found that the increase of heat treatment temperature from 100C to 150^{o}C affected bending strength of LVL positively. The mechanical property loss was explained as the results of hemicellulose degradation, increasing crystalline cellulose content, and replacement of flexible hemicellulose–cellulose–

hemicellulose bonds with more rigid cellulose–cellulose bonds (Kocaefe *et al*. 2010, Kocaefe *et al*. 2008, Boonstra *et al*. 2007).

MOE of LVLs showed a slightly increase by heat treatment. LVL made from veneers produced heat treated planks had MOE value of 12408.9Nmm-^{2} which is 7.46% higher than those untreated samples. Kocaefe *et al*. (2010), Sahin Kol (2010) and Boonstra *et al*. (2007) showed that MOE of heat treated wood was higher compared to those of the untreated wood. Somewhat different results were reported by Nazerian and Ghalehno (2011). These authors found that MOE values in LVL produced from heat treated veneer at 180°C were 31% lower than control samples. This difference in the MOE, this is not explicitly stated, appear to correspond to the method and temperature and time of heat treatment, accordingly, a modified chemical structure. Degradation of the hemicelluloses, disrupting the load-sharing capacity of the lignin-hemicelluloses matrix, and increase of the relative amount of crystalline cellulose could contribute to the increase of the MOE. The increased cross linking of the lignin network probably also affects the MOE, since it is expected that an increased cross linking improves the rigid structure around the cellulose microfibrils/fibrils and the strength characteristics of the middle lamella. Furthermore, heat treated wood is less hygroscopic than untreated wood (Table 1), which affects the MOE making wood less pliable (Boonstra *et al*. 2007).

The compressive strength ($CS_{||}$) of heat treated LVL was higher than those of untreated samples. Untreated samples had an average compressive strength value of 59.61Nmm^{-2} that is 11.17% less than those samples exposed to a temperature of 212ºC. The findings of compression strength of the LVL samples in this work are agree with those determined in various past studies (Percin *et al*. 2015, Sahin Kol 2010, Boonstra *et al*. 2007, Altınok *et al*. 2010). The increase of the compressive strength in longitudinal direction might be due to a lower EMC in heat treated wood (Table 1). An increased cross linking of the lignin polymer network could be another reason for this improvement. Lignin acts as a stiffener of the cellulose microfibrils/fibrils (Sweet and Winandy 1999) and an increased cross linking of this polymer appears to prevent or limit movement perpendicular to the grain (which occurs during compressive loading parallel to the grain). Furthermore, lignin is the main component of the middle lamella and an increased cross linking of the lignin polymer network improves the strength of the middle lamella which subsequently affects the strength properties of the cell wall (Boonstra et al 2007).

Hardness values of the LVLs also decreased with heat treatment. Heat treatment caused a decrease in hardness by 25.44% which can be related to deterioration of the cell wall structure after the heat treatment. These findings are in accordance with that found in literature for wood under heat treatment (Karamanoğlu and Akyildiz 2013, Kocaefe *et al*. 2010, Won *et al*. 2012, Salca and Hiziroglu 2014, Sahin Kol 2010).

CONCLUSIONS

This work investigated the effect of heat treatment on physical and mechanical properties of laminated veneer lumber. According to the results obtained this work, heat treatment of planks alters the physical and mechanical properties of LVLs. Heat treatment of planks had an enhancement effect on thickness swelling, modulus of elasticity and compressive strength and adverse effect on hardness and bending strength of LVL panel. It appears that strength losses can be limited through alternative modified heat treatment techniques. On the basis of the results, it appears that the production of LVL from heat treated pine planks may be contribute to use raw material more efficiently.

Acknowledgements

The authors wish to thank Nova ThermoWood, Gerede, Turkey for providing timber material for this study.

REFERENCES

Altınok, M, Ozalp M, Korkut S (2010) The Effects of Heat Treatment on Some Mechanical Properties of Laminated Beech (Fagus Orientalis L.) Wood. Wood Research 55(3):131-141.

ASTM D-1037-12 (2012) Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials. ASTM International, West Conshohocken.

ASTM D-5456-14b (2014) Standard Specification for Evaluation of Structural Composite Lumber Products. ASTM International, West Conshohocken.

ASTM D-2395–14$^{\varepsilon 1}$ (2014) Standard Test Methods for Density and Specific Gravity (Relative Density) of Wood and Wood-Based Materials. ASTM International, West Conshohocken.

ASTM D-4442-15 (2015) Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood- Based Materials. ASTM International, West Conshohocken.

ASTM D-3501-05a (2011) Standard Test Methods for Wood-Based Structural Panels in Compression. ASTM International, West Conshohocken.

ASTM D-3043-00 (2011) Standard Test Methods for Structural Panels in Flexure. ASTM International, West Conshohocken.

Ates S, Akyildiz MH, Ozdemir H (2009) Effects of Heat Treatment on Calabrian Pine (Pinus brutia Ten.) Wood. BioResources 4(3):1032-1043.

Barbu MC, Reh R, Irle M (2014) Wood composites, Chapter 1 in “Research Developments in Wood Engineering and Technology”. IGI-Global.

Bekhta P, Niemz P (2003) Effect of High Temperature on the Change in Colour, Dimensional Stability and Mechanical Properties of Spruce Wood. Holzforschung 57:539–546.

Bhuiyan MTR, Hirai N (2005) Study of Crystalline Behaviour of Heat-Treated Wood Cellulose during Treatments in Water. Journal of Wood Science 51(1):42-47.

Boonstra MJ, Tjeerdsma BF, Groeneveld HAC (1998) Thermal Modification of Nondurable Wood Species Part 1. The Plato Technology: Thermal Modification of Wood. International Research Group on Wood Pre, Section 4 - Processes, 29 Annual Meeting, Maastricht Document no. IRG/WP 98-40123.

Boonstra MJ, Van Acker J, Tjeerdsma B, Kegel E (2007) Strength Properties of Thermally Modified Softwoods and Its Relation To Polymeric Structural Wood Constituents. Ann Forest Sci 64:679-690.

Chen N, Rao J, He M, Mei G, Huang Q, Lin Q, Zeng Q (2015) Preparation and Properties of Heat-Treated Masson Pine (*Pinus Massoniana*) Veneer. BioResources 10(2):3451-3461.

Eckelman CA (1993) Potential uses of laminated veneer lumber in furniture. Forest Prod J 43(4):19–24.

Esteves BM, Pereira HM (2009) Wood modification by heat treatment: A review. Bioresource 4(1): 370-404.

Esteves BM, Domingos IJ, Pereira HM (2008) Pine Wood Modification by Heat Treatment in Air. Bioresources 3:142–154.

Hayashi T, Oshiumi S (1993) Bending Strength Distribution of Laminated Veneer Lumber for Structural Use. Mokuzai Gakkaishi J Japan Wood Res Soc 39(9):985–992.

Karamanoğlu M, Akyildiz MH (2013) Colour, Gloss and Hardness Properties of Heat Treated Wood Exposed to Accelerated Weathering. PRO LIGNO 9(4):729-738.

Kubojima Y, Okano T, Ohta M (2000) Bending Strength and Toughness of Heat Treated Wood. J Wood Sci 46:8–15.

Kocaefe D, Poncsak S, Boluk Y (2008) Effect of Thermal Treatment on the Chemical Composition and Mechanical Properties of Birch and Aspen. BioResources 3(2):517-537.

Kocaefe D, Poncsak S, Tang J, Bouazara M (2010) Effect of Heat Treatment on The Mechanical Properties of North American Jack Pine: thermogravimetric study. Journal of Materials Science 45(3): 681-687.

Lam F (2001) Modern Structural Wood Products. Prog Struct Eng Mater 3:238–245.

Nazerian M, Ghalehno MD (2011) Physical and Mechanical Properties of Laminated Veneer Lumber Manufactured by Poplar Veneer. Journal of Agricultural Science and Technology A 1:1040-1045.

Nazerian M, Ghalehno MD, Kashkooli AB (2011) Effect of Wood Species, Amount of Juvenile Wood and Heat Treatment on Mechanical and Physical Properties of Laminated Veneer Lumber. Journal of Applied Sciences 11(6):980-987.

Ozarska B (1999) A Review of the Utilization of Hardwoods for LVL. Wood Sci Technol 33:341–351.

Perçin O, Sofuoglu AD, Altunok M (2015) Effect of Heat Treatment on Some Physical and Mechanical Properties of Laminated Wood. Proceedings of the 27th International Conference, Research for Furniture Industry, Ankara, pp. 149–155.

Rapp AO (2001) Review on Heat Treatments of Wood. Cost Action E22 - Environmental Optimisation of Wood Protection, Proceedings of Special Seminar in Antibes, Franca, pp. 68.

Salca EA, Hiziroglu S (2014) Evaluation of Hardness and Surface Quality of Different Wood Species as Function of Heat Treatment. Materials and Design 62:416–423.

Sahin Kol H (2010) Characteristics of Heat-Treated Turkish Pine and Fir Wood after Thermowood Processing. Journal of Environmental Biology 31(6):1007-1011.

Sahin Kol H, Özbay G, Altun S (2009) Shear Strength of Heat-Treated Tali (Erythrophleum Ivorense) and Iroko (Chlorophora Excelsa) Woods Bonded with Various Adhesives. BioResources 4(4):1545–1554.

Sernek M, Boonstra M, Pizzi A, Despres A, Ge´rardin P (2008) Bonding Performance of Heat Treated Wood with Structural Adhesives. Holz Roh Werks 66:173–180.

Schuler A, Adair C (2003) Engineered and Other Wood Products – An Opportunity to “Grow the Pie”. 37th International Wood Composite Materials Symposium, Washington State University, Pullman, WA, pp. 43–53.

Shukla SR, Kamdem DP (2008) Properties of Laminated Veneer Lumber (LVL) made with Low density Hardwood Species: Effect of the Pressure Duration. Holz Roh Werkst 66:119–127.

Shukla SR, Rao RV, Sharma SN (1999) Evaluation of Strength Properties of Parallel Splint Lumber (PSL) and Its Comparison with Laminated Veneer Lumber (LVL), Rubber Wood and Teak. Holz als Roh- und Werkstoff 57:267-270.

Sweet MS, Winandy JE (1999) The Influence of Degree of Polymerization (DP) of Cellulose and Hemicellulose on The Strength Loss of Fire-Retardant-Treated Wood. Holzforschung 53:311–317.

Tjeerdsma BF, Militz H (2005) Chemical Changes in Hydrothermal Treated Wood: FTIR Analysis of Combined Hydrothermal and Dry Heat-Treated Wood. Holz Roh- Werkst 63:102–111.

Won KR, Kim TH, Hwang KK, Chong SH, Hong NE, Byeon HS (2012) Effect of Heat Treatment on the Bending Strength and Hardness of Wood. J Korean Wood Sci Tech 40(5):303-310.