academicJournals

Vol. 8(19), pp. 1029-1035, 23 May, 2013
DOI: 10.5897/IJPS2013.3864
ISSN 1992-1950 © 2013 Academic Journals
http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Full Length Research Paper

The effects of heat treatment on some mechanical properties of laminated black pine (*Pinus nigra*)

Mustafa ORDU[1], Mustafa ALTINOK[2] Abdi ATILGAN[3], Murat OZALP[1] and Huseyin PEKER[3]*

[1]Dumlupinar University, Simav Technical Education Faculty, Simav-Kutahya, Turkey.
[2]Gazi University, Technical Education Faculty,Anakara, Turkey
[3]Artvin Coruh University, Faculty of Forestry, Artvin, Turkey.

Accepted 18 March, 2013

Black pine (*Pinus nigra*) has high industrial usage potential and large plantation in Turkey. Larch wood was treated with heat to determine its mechanical properties, such as bending strength and pressure and order to determine its adhesion strength. Laminating adhesives are used for the construction of polyvinyl acetate and polyurethane. Heat treatment was applied to the samples at 100-150°C for 4 h in drying oven. In the result of the experiments, heat treated samples give better results due to temperature increase.

Key words: Heat treatment, bending strength, compression strength, bonding strength, black pine.

INTRODUCTION

Laminated wood products are becoming popular in various applications such as construction, furniture units and indoor decorations due to the utilization of raw materials with alternative approach. Compared with sawn lumber, laminated lumber can be used to create wood products that are free from defects and are much larger in size than pieces of wood sawn. There are also advantageous in that they are dimensionally more stable, have a variable cross-section and are more attractive than wood products manufactured from solid wood (Dilik, 1997; Kurtoglu, 1978).

Today, wood age is still in common use. It is used by human and insects and the external effects can last longer than the using of the wood. Drying process is done according to the properties of the earth.

Most economical way of drying within the shortest possible time can be done with a minimum defects and loss. Researchers desire to develop alternative methods. One of these is pure superheated steam drying method. The industrial world mostly applied shorter drying time compared to conventional drying method. The technology of wood protection using heat leads to: natural durability of wood, stabilization of wood-dimension as well as improvement and increase without any preservatives (Kantay and Kartal, 2008a). In addition to better durability, other advantages of heat treated wood are: reduced hygroscopic and improved dimensional stability (Jamsa and Viitaniemi, 2001). Heat treated pine and spruce are mainly used for outdoor constructions, for example garden furniture, windows, doors and wall or fence board. When better weather and decay resistance is desired, the temperatures used for heat treatment must be over 200 (Syrjanen and Oy, 2001). Wood was subjected to heat treatment in the first scientific study in 1930 by German scientists Stamm and Hansen and an American scientist in 1940. Bavendam (1950) and Runkel and Buro (1950) continued to work on this issue. Kollman and Schneider (1960) and BurmesterRusch (1970) worked on this issue again.

In the 1990s, the Netherlands, Finland and French

*Corresponding author. E-mail: peker100@hotmail.com.

scientists have done a lot of work on it (Viitaniemi, 2000). Heat-treated wood has led to decrease in the amount of moisture balance. High temperature (220°C) in heat treatment is applied as a result of the normal amount of moisture balance, in almost half of the wood treated with heat. Heat treatment radially and tangentially significantly reduces the amount of shrinkage (Anon, 2003). Environmental pollution caused by reducing the cost of modification of wood and alternative wood protection method considered as heat treatment are applied for several purposes: first, to reduce the moisture of wood, that is, give stabilization to the wood size and enhance biological resistance to wood-destroying organisms.

In addition, heat treatment reduces the amount of moisture balance in the wood, increases its permeability, such as CCA and CCB impregnated materials (varnish and paint-surface) to improve its performance (Yildiz, 2002). Many fungi and insects are checked by the use of biological degradation, open-air effects, burning and more importantly, reduction of dimensional instability (Rowell, 2005). Heat treated wood is the most important feature of the balance due to the decrease in the amount of moisture in the wood (Kantay, 1993). In this study, the effects of wooden materials treated with heat on hardness, brilliance and resistance to stickiness of varnishes were investigated. For this purpose, firstly Scotch pine (*Pinussylvestris* L.) and chestnut (*Castanea sativa* M.) wooden samples were kept in temperatures of 100, 150 and 200°C for 2, 4 and 6 h and after that they were varnished by the water-based varnish.

According to the test results, it was determined that while the hardness, brightness and resistance to stickiness were improved in both wooden types which were kept for 2 h in 100, 150 and 200°C, but they deteriorated when kept for 4 and 6 h in same temperatures (Ozalp and Gezer, 2009). In a study of wood of Scotch pine (*Pinus sylvestris* L.), it underwent thermal processing for 4, 6 and 8 h at 150, 170 and 190ºC. When scotch pine was treated with heat in the experiments, its bending elasticity module (EM), bending resistance (ED), pressure resistance (BD), weight loss (AK), total color change (ΔE^*) and volumetric swelling (HS) values were determined. In the test results according to the EM and ED values of the heat treatment, reduction in Scotch pine led to increase in BD values. ED has been mostly affected by mechanical resistance.

Heat treatment resulted in the dark color of Scotch and made the swelling volume to decrease by approximately 50%. When the temperature of heat treatment and application time increases, the amount of change in all of these features increases (Ozçiftçi et al., 2009). Modified thermal (heat) properties of the materials used in treated wood are directly connected to low and high temperatures, resulting in the use of different materials. Thermal processing with low temperature can be applied in wood building elements such as furniture, garden furniture, sauna elements and in door-window frames, shutters etc. Thermal processing with high temperature can be applied to equipment outside the door and fence, exterior cladding, sauna and bathroom elements, flooring materials, garden furniture and as sound barriers (Kantay and Kartal, 2008b).

Application of inadequate glue to the surface of wooden material will lead to weak joint; and when high pressure is applied on the specimen mechanic adhesion decreases leading to a weak joint (McNamara and Waters, 1970). Woods of diffuse porous show different sticky characteristics than ring-porous wood. The resistance of glue line of ring-porous wood increases relative to the density. Marra (1992) conducted a study on beech wood samples kept in 100 and 150˚C for 4 h, and after that they were laminated with polyurethane and polyvinyl acetate adhesives. The test results of heat-treated laminated beech wood and control samples showed that mechanical properties including compression strength, bending strength and bonding strength were affected positively by heat treatment; and increase in temperature and duration further increased strength values of the laminated wood specimens (Altinok et al., 2010).

The aim of the present study is to investigate the effects of heat treatment on same mechanical properties of laminated black pine. This study also aspired to determine the ideal heat and adhesive.

MATERIALS AND METHODS

Black pine wood was used in all sample experimental studies. The Black pine wood was taken from the area of Simav Mountain in Simav-Kutahya Province of Turkey. Samples are prepared from whole sap wood trunk. Density of dry wood is 0.53 g/cm^3.

All tests in this study were carried out in Department of Furniture and Decoration Education Laboratory on universal testing device.

Bending strength tests were carried out according to TS 2474 standards (TS 2474, 1976). The samples having 2×2×30 cm dimensions with 3 layers were used for bending strength. The thickness of the layers is 6.5 mm. 10 samples have been used for each experiment. The samples prepared are acclimatized up to 12% moisture at 20°C and 65% relative humidity conditions. Test specimens are determined through measurement from the middle parts by ± 1% mm sensitivity micrometer. Span to thickness ratio for bending is 24 cm. Bending strength test mechanism is given in Figure 1.

The following equations were used in the calculation of bending strength (σ_e):

$$\sigma_e = \frac{3.P.L_s}{2.b.h^2} \qquad (1)$$

Where σ_e is bending strength (N/mm^2); P is maximum force at the moment of breaking (N); Ls is distance between points of support

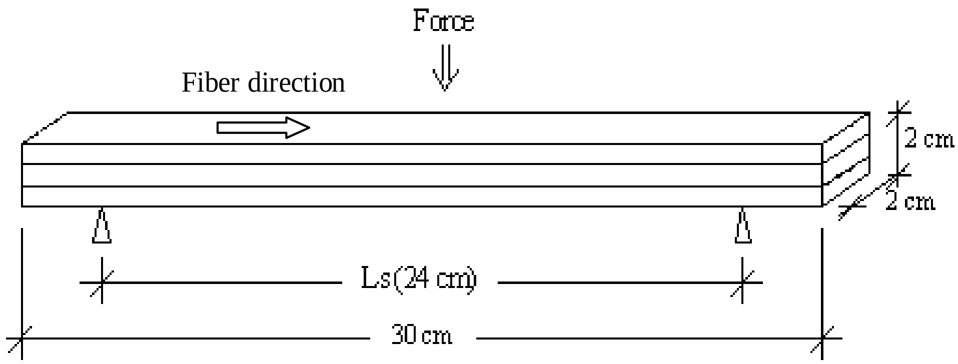

Figure 1. The dimensions of bending strength test specimens.

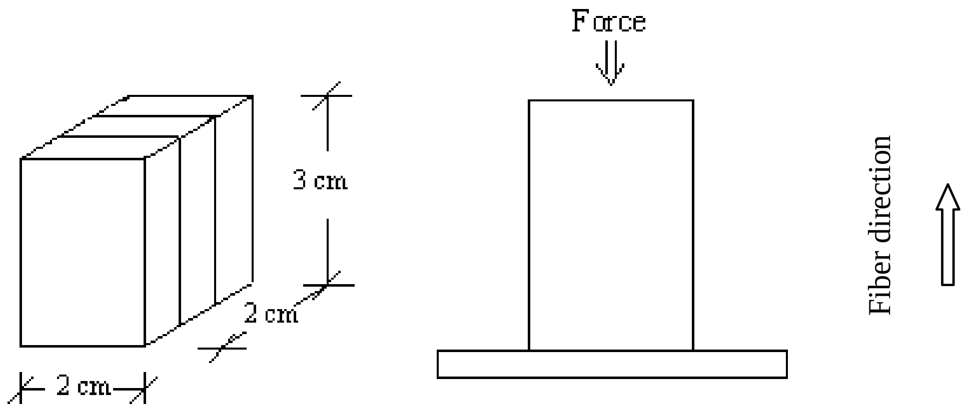

Figure 2. The dimensions of compression strength test specimens.

(mm); b is width of sample piece (mm); h is thickness of sample piece (mm).

Compression strength tests were carried out according to TS 2595 standards (TS 2595, 1976). The thickness of the layers is 6.5 mm. 10 samples have been used for each experiment. The samples prepared are acclimatized up to 12% moisture at 20°C and 65% relative humidity conditions. Test specimens are determined through measurement from the middle parts by ± 1% mm sensitivity micrometer. Span to thickness ratio for bending is 24 cm. Compression strength test mechanism is given in Figure 2. The following equations are used for the calculation of compression strength (σ_b);

$$\sigma_b = \frac{F_{max}}{a.b} \qquad (2)$$

Where σ_b is compression strength (N mm^2); F_{max} is maximum force at the moment of breaking (N); *a* is width of sample breadth cross-section (mm); *b* is lengthof sample breadth cross-section (mm).

The specimens were prepared according to TS 53 and TS 2470 TS 2474-53 (1976). Bonding strength test was done according to DIN 53255 standards. The samples having 15x20x150 mm dimensions with 2 layers were used for bonding strength. The thickness of layers is 7.5 mm. 10 samples have been used for each experiment. The samples prepared are acclimatized up to 12% moisture at 20°C and 65% relative humidity conditions. Test specimens are determined through measurement from the middle parts by ± 1% mm sensitivity micrometer. Bonding strength test mechanism is given in Figure 3. The following equations are used for the calculation of bonding strength (σ),

$$\sigma = \frac{F_{max}}{b.l} \qquad (3)$$

Where σ is bonding strength (N mm^{-2}); F_{max} is maximum force at the moment of breaking (N); *b* is width of bonding surface (mm); l is length of bonding surface (mm).

Adhesives used

In this study, polyurethane and polyvinyl acetate (PVAc) adhesives are used for preparing all samples. The amount of the adhesives applied to the surface of the samples is 235.4 (g/m^2) on average. General properties of polyurethane and polyvinyl acetate adhesives used are given in Tables 1 and 2.

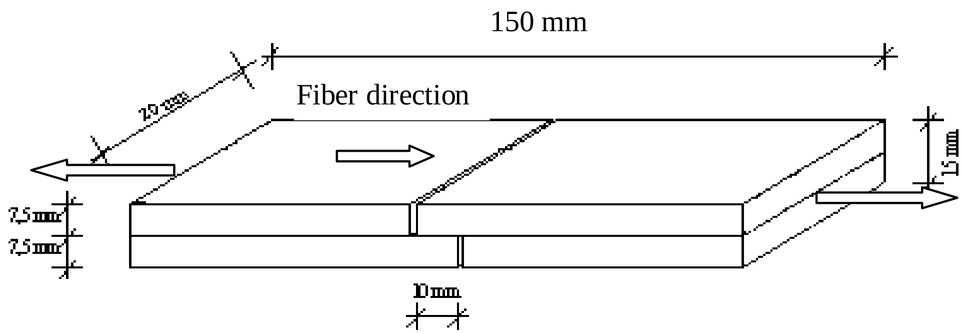

Figure 3. The dimensions of bonding strength test specimens.

Table 1. General properties of polyurethane adhesive.

General properties	Polyurethane adhesive (PU)
Commercial type	Liquid-solid
Storing period (month)	6–9
Colour	Bold brown
Effect on health	Harmfull above 60°C
Wood humudity (%)	Max. 15
Dry material (%)	20–90
Amount of using (gr/m^2)	200–250
Fitting time (hour)	0.5–1
Pressure (N/mm^2)	0.3-0.8
Temperature (°C)	10–60
Resist to water	Resist to boiled water
Resist to microorganism	Extra

Table 2. General properties of polyvinyl acetate.

General properties (°C)	Polyvinyl acetate (PVAc)
Amount of using	150–200(g/m^2)
Density (20)	1.1 (g/m^3)
Viscosity (20)	160-200 cps
pH (20)	5
Pressing time (20)	20 min

Heating process practices

Heat treatment was applied to the samples at two controlled (±1°C) temperatures (100-150°C) for 4 h under atmospheric pressure at drying oven. After heat treatment, treated and untreated samples were conditioned to 12% moisture contents (MC) in a conditioning room at 20 ± 2°C and with 65% (±5) relative humidity (RH) according to TS 642 ISO 554. Then they were laminated with polyurethane and polyvinyl acetate adhesives.

Press pressure and pressure period

All laminated samples were pressed and prepared at 20°C temperature, with 65% relative humidity and under 0.4 N/mm^2 pressure with 3 h time period in hydraulic press.

RESULTS AND DISCUSSION

Bending strength results

The values of average bending strength for laminated Black pine (3 layers) are given in Table 3. The increase of temperature in the heat treatment affected the bending strength properties of laminated black pine positively. The interaction between these obtained values has been examined with the variance analysis and the results obtained are given in Table 4. According to the results of the variance analysis conducted, the effects of heat treatment and type of adhesive on the bending strength of laminated Black pine are found significant with 5% error.

Compression strength results

The values of average compression strength for laminated Black pine (3 layers) are given in Table 5. The increase of temperature in the heat treatment affected the compression strength properties of laminated Black pine positively. The interaction between these obtained values has been examined with the variance analysis and the results obtained are given in Table 6. According to the results of the variance analysis conducted, the effects of heat treatment and type of adhesive on the compression strength of laminated black pine have been found significant with 5% error.

Bonding strength results

The values of average bonding strength for Black pine are given in Table 7. The increase of temperature in the

Table 3. The values of average bending strength results (N/mm^2).

Used Adhesives	The values of average bending strength results (N/mm^2)			
		Non-treatment	100°C	150°C
Polyvinyl acetate (PVAc)	Min	57.013	59.555	61.282
	Max	62.412	66.604	66.855
	Average	59.132	63.214	63.232
	δ_x	1.74	2.19	2.12
	n	10	10	10
Polyurethane (PU)	Min	54.523	56.829	59.384
	Max	60.231	62.89	65.361
	Average	57.807	59.084	62.382
	δ_x	1.65	1.71	1.92
	N	10	10	10

Table 4. Bending strength variance analysis results.

Variance source	Df	Sum of squares	Mean squares	F test	P
Type of adhesive	1	66.341	66.341	16.33	0.000
Heat treatment	2	191.471	95.735	23.57	0.000
Error	56	227.436	4.061		
Total	59	485.248			

Table 5. The values of average compression strength results (N/mm^2).

Used Adhesives	The values of average compression strength results (N/mm^2)			
		Non-treatment	100°C	150°C
Polyvinyl acetate (PVAc)	Min	22.16	23.83	29.76
	Max	27.48	27.85	33.53
	Average	24.59	25.80	30.89
	δ_x	1.47	1.22	1.19
	n	10	10	10
Polyurethane (PU)	Min	26.95	28.52	31.63
	Max	32.21	32.68	36.36
	Average	29.74	30.37	33.96
	δ_x	1.54	1.27	1.59
	n	10	10	10

Table 6. Compression strength variance analysis results.

Variance source	Df	Sum of squares	Mean squares	F test	P
Type of adhesive	1	272.65	272.65	131.43	0.000
Heat treatment	2	315.23	157.61	75,98	0.000
Error	56	116,17	2.07		
Total	59	704.04			

Table 7. The values of average bonding strength results (N/mm^2).

Used adhesives	The values of average bonding strength results (N/mm^2)			
		Non-treatment	100°C	150°C
Polyvinyl acetate (PVAc)	Min	11.21	12.21	13.94
	Max	12.04	14.66	16.07
	Average	11.52	13.63	15.15
	δ_x	0.26	0.81	0.72
	n	10	10	10
Polyurethane (PU)	Min	11.39	13.20	14.12
	Max	12.13	16.01	16.80
	Average	11.81	14.70	15.12
	δ_x	0.20	0.80	0.81
	n	10	10	10

Table 8. Bonding strength variance analysis results.

Variance source	Df	Sum of squares	Mean squares	F test	P
Type of adhesive	1	3.435	3.435	7.05	0.010
Heat treatment	2	127.228	63.614	130.58	0.000
Error	56	27.282	0,487		
Total	59	157.945			

heat treatment affected the bonding strength properties of laminated Black pine positively. The interaction between these obtained values has been examined with the variance analysis and the results obtained are given in Table 8. According to the results of the variance analysis conducted, the effects of heat treatment and type of adhesive on the bonding strength of laminated Black pine have been found significant with 5% error. As a result of the researches conducted, it is observed that as the heat treatment increased from 100 to 150°C, bending strength increased by 6. 93% in samples laminated with polyvinyl acetate adhesive and by 7.65% in samples laminated with polyurethane adhesive. Compression strength increased by 25.62% in samples laminated with polyvinyl acetate adhesive and by 14.18% in samples laminated with polyurethane adhesive. Bonding strength increased by 31.51% in samples laminated with polyvinyl acetate adhesive and by 28.02% in samples laminated with polyurethane adhesive.

The results of this study (bending strength, compression strength, bonding strength) are compatible with studies done by Altinok et al. (2010).

Conclusion

Polyvinyl acetate and polyurethane wood glue is used to laminate Black pine at 100 and 150°C for 4 h in heat treatment. Through thermal processing, the popular Black pine wood gave better results, as reflected in its mechanical properties. Degree of increase of heat treatment has a positive impact on its mechanical properties. Through heat treatment wood species with no commercial value can be used in areas where they had no use previously. As a result, application of heat treatment is suggested to improve its strength properties before laminating Black pine.

REFERENCES

Altinok M, Ozalp M, Korkut S (2010). The Effects Of Heat Treatment On Some Mechanical Properties Of Laminated Beech Wood (*FagusOrientalisL.*). Wood Res. 55(3):131-141.

Anon (2003). Thermoodwood Handbook. Finnish Thermowood Association, Helsinki, Finland.

Dilik T (1997). Production Of Window Profiles From Laminated Lumber and Determination Of Manufacturing Factors. Istanbul University; Ph.D. Thesis, Istanbul, Turkey.

Jamsa S, Viitaniemi P (2001). Heat Treatmet of Wood -Better Durabılıty Wıthout Chemıcals. Proceedings of Special Seminar held in Antibes, France on 9 February, 2001: 21. http://www.holzfragen.de/bilder2/dgfh_hitze_eng.pdf.

Kantay R (1993). "Lumber Drying and Steaming", Forestry Educational and Cultural Foundation Publishing number 6, Istanbul.

Kantay R, Kartal N (2008a). Istanbul University, Faculty of Forestry Department of Forest Industrial Engineering. http://www.ahsaponline.net.arsiv/dergi/35/termalmod.htm.

Kantay R, Kartal SN (2008b). Properties of Heat Treated Wood Materials. Istanbul University, Faculty of Forestry Department of ForestryForestIndustryEngineering, Department of BiologyandWoodProtectionTechnologywood magazine 33. http://www.ahsaponline.net.arsiv/dergi/33/termawoo.htm

Kurtoglu A (1978). Moisture Distribution in Laminated Layered Loud Bearing Thick Wood Materials. Rev. Fac. For. Series-A. 28(1).

Marra AA (1992). Technology of wood bonding, New York.

McNamara VS, Waters D (1970). Comparison of the rate glue-line strength development for oak and maple. F.P.J. 20(3).

Ozalp M, Gezer I (2009). The investigation of heat treatment with water-based varnish single component in varnish applications of wood material. Afr. J. Biotechnol. 8(8):1689-1694.

Ozçiftçi A, Altun S, Yapıcı F (2009). International Symposium on Advanced Technologies (IATS'09), 13-15 May 2009, Karabük, Türkiye.

Rowell RM (2005). Chemical modification of wood. In: Handbook of Wood Chemistry and Wood Composites. Ed: Roger M. Rowell. CRC Press, Boca Raton, London, Newyork, Washintgon DC. ISBN 0-8493-1588-3.

Syrjanen T, Oy K (2001). Productıon And Classıfıcatıon Of heat Treated Wood In Fınland Proceedings of Special Seminar held in Antibes, France on 9 February 2001.

TS 2470 (1976). Wood-sampling methods and general requirements for physical and mechanical tests, Ankara, (in Turkish).

TS 2474-53 (1976). Wood-determination of ultimate strength in static bending, Ankara, (in Turkish).

TS 2595 (1976). Wood-determination of ultimate stress in compression parallel to grain, Ankara, (in Turkish).

TSE 53 (1976). Wood-sampling and test methods-determination of physical properties, Ankara, (in Turkish).

Viitaniemi P (2000). New Properties for Thermally-Treated Wood.Industrial Horizons, P. 9.

Yildiz S (2002). Physical, mechanical, technological and chemical properties of beech and spruce wood treated by heating. Ph.D. dissertation, Karadeniz Technical University, Trabzon.