Available online at www.sciencedirect.com

SCIENCE DIRECT®

Applied Surface Science 233 (2004) 268–274

applied surface science

www.elsevier.com/locate/apsusc

Activation of wood surfaces for glue bonds by mechanical pre-treatment and its effects on some properties of veneer surfaces and plywood panels

İsmail Aydin*

Forest Industry Engineering Department, Faculty of Forestry, Karadeniz Technical University, 61080 Trabzon, Turkey

Received in revised form 18 March 2004; accepted 18 March 2004

Available online 27 April 2004

Abstract

Some chemical pre-treatments with chemical reagents are widely applied to wood surfaces in order to improve bonding ability, wettability and reactivate wood surfaces for glue–wood bonds. Besides these chemical treatments, some mechanical pre-treatments such as sanding and planing can be applied to get a fresh surface which eliminates bonding problems and improves glue bonding of wood. In this study, 2 mm thick rotary cut veneers obtained from steamed beech (*Fagus orientalis*) logs were used as material. Both air-drying and oven-drying methods were used for drying veneer. After drying, the surfaces of some veneers were sanded with 100 and 180 grit sandpapers. Three-layer-plywood panels were produced from sanded and non-sanded veneers by using urea formaldehyde and phenol formaldehyde glue resins to evaluate the effects of sanding some mechanical properties of plywood. Changes in pH, surface roughness and adhesive wettability of veneers were evaluated. Wettability of veneers was assessed with contact angle measurements according to the sessile drop method. Both veneer and plywood properties investigated in this study improved clearly after the sanding process. Shear and bending strength values of plywood panels manufactured from sanded and non-sanded veneers were vary depending on glue types and veneer drying methods.

Keywords: Wettability; Wood; Surface roughness; Plywood; Mechanical properties

1. Introduction

The wood properties of veneers are essentially no different from those of lumber; however, manufacturing processes, including cutting, drying and laminating into plywood can drastically change physical and chemical surface properties of veneer.

Some chemical pre-treatments with chemical reagents are widely applied to wood surfaces in order to improve bonding ability, wettability and reactivate wood surfaces for glue–wood bonds [1,2]. In this process, the functional groups present on the wood surface are modified so that they can react and bond more effectively with the functional groups in the adhesive [3]. Besides these chemical treatments, some mechanical pre-treatments such as sanding and planing can be applied to get a fresh surface which eliminates bonding problems and improves glue bonding of wood. However, mechanical pre-treatments of wood surfaces prior to glue bonding have received less attention compared to chemical pre-treatments [2].

* Tel.: +90-462-3773258; fax: +90-462-3257499.
E-mail address: iaydin@ktu.edu.tr (I. Aydin).

0169-4332/$ – see front matter
doi:10.1016/j.apsusc.2004.03.230

Wood surfaces are best prepared for maximum adhesive wetting, flow and penetration by removing all materials that might interfere with bond formation to sound wood. Ideally, wood should be knife-planed or sanded within 24 h of adhesive spreading. Properly planed flat surfaces help ensure that a layer of adhesive of uniform thickness can be uniformly spread over the adherent [4].

A clean solid surface is one of the basic requirements for optimum adhesion between a substrate and an adhesive. Wood is no exception, but in addition to regular airborne contamination, such as dust particles, a wood surface is subjected to what can be described as self-contamination. This is a result of a natural surface inactivation process where low-molecular wood extractives—fatty and resin acids and their esters, terpenes, phenols, etc.—migrate to the surface [5,6].

Within a short period of time, freshly cut wood surfaces undergo a transform that has been termed surface inactivation. The rate and amount of inactivation tends to depend on the individual wood species and the temperature it is exposed to whether as a stage of manufacturing or during storage [7]. Wood surface inactivation is a surface phenomenon resulting in a loss of bonding ability [8–10]. A wood surface, which is exposed to high temperature condition, can experience surface inactivation [11]. Its removal by sanding or planing opens a fresh surface, which eliminates the bonding problem. A freshly produced surface contains all of the molecular attractive forces that previously held the material together [12].

The concentration of some extractives on wood surfaces is known to delay the curing and setting of for example, phenolic and urea resins adhesives [13].

Rotary cutting produces continuous sheets of flat-grained veneer by rotating a log by its ends against a knife. As the knife peels veneer from the log, the knife forces the veneer away from the log at a sharp angle, thereby breaking or checking the veneer on the knife side. This checked surface will cause imperfections in a finished surface.

Because adhesives work by surface attachment, the adherend's surface qualities are extremely important to satisfactory joint performance. The wood surface to be bonded should be smooth, true and free of machine marks or other surface irregularities such as torn, chipped grain or planer skip. Contaminants not only interfere with wetting and adhesion but can also interfere with development of cohesive strength (cure) within the adhesive film [14].

All wood surfaces obtained for manufacturing purposes are artificial surfaces such as those produced by sawing or flaking. Several known changes occur to the wood surface over time: oxidation of the surface especially during exposure to high temperature, migration of extractives to the surface, modification of cellulose/lignin ratio and acidification of the surface [7]. So, wood should be surfaced or resurfaced just before bonding to remove all materials that interfere with bonding and also to reduce the chance for a change in moisture content that could distort the surface from a flat condition.

The aim of this study was to determine the influence of sanding as a mechanical treatment on some veneer surface properties such as wettability, bondability and surface roughness depending on drying methods. The relationship between the sanding process of veneer surfaces and some mechanical properties of plywood panels was also investigated.

2. Material and methods

Beech (*Fagus orientalis*) logs with 45 cm diameter obtained from the region near the border of Turkey–Georgia were used for veneer production in this study. Beech wood is the most widely used wood species for plywood manufacturing in Turkey. Before veneer production, beech logs were steamed for 20 h. Two-millimeter thick rotary cut veneers with dimensions of 55 cm $\times$ 55 cm were obtained from the steamed logs. The horizontal opening was 85% of the veneer thickness and the vertical opening was 0.5 mm in the peeling process.

Veneer sheets obtained were divided into two groups. First group of veneers were air-dried (at 20 °C) while other group of veneers were oven-dried (at 110 °C) in a veneer dryer.

The surfaces of some veneers of both groups were sanded with 100 and 180 grit sandpapers after the air and oven-drying process and formed test groups as shown in Table 1.

After sanding, veneer surfaces were wiped pneumatically to remove wood dust from the surface and obtain clean surfaces for surface analysis tests and adhesive application.

Table 1
Test groups based on drying method

Air-dried	Oven-dried
A: non-sanded (control group)	B: non-sanded (control group)
A1: sanded with 100 grit sandpaper	B1: sanded with 100 grit sandpaper
A2: sanded with 180 grit sandpaper	B2: sanded with 180 grit sandpaper

Plywood panels with three plies and 6 mm thick were manufactured from both control and sanded veneers by using urea formaldehyde (UF) and phenol formaldehyde (PF) glue resins. All veneers used in plywood manufacturing were conditioned in a climatization chamber until they reached about 7% moisture content before the gluing process. The formulations of adhesive mixtures used for plywood manufacturing is given in Table 2. Two replicate panels were manufactured for all test groups. Approximately 160 g/m^2 adhesive mixture was spread on single surfaces of veneers by using a four roller gluing machine. Hot press time and pressure were 5 min and 12 kg/m^2, respectively, press temperature was 110 °C for UF and 140 °C for PF glues in the manufacturing of plywood panels.

Wettability of veneer surfaces by UF and PF resins, surface roughness, changes in pH values of veneer were determined.

The wettability of materials can be determined by various methods. Contact angle analysis is a widely used method to study the wetting characteristics of solid materials [15–17]. Therefore, contact angle analysis was used to determine the wettability of veneer surfaces in this study. A goniometer equipped with a video camera was used to obtain contact angles for urea formaldehyde and phenol formaldehyde glue resins on the sanded and non-sanded veneer surfaces. Thirty drops of UF and PF glue resin with 5 μl volume were deposited on veneer surfaces from an adjustable pipette. Contact angle measurements were made in 5 s after the resin drops were deposited. Mean contact angle values for all resin drops were determined by analyzing drop shapes by means of a computer with image analysis software.

Table 2
The formulations of UF and PF glue mixtures used for the manufacturing of plywood panels

Glue types	Adhesive ingredient	Parts by weight
UF glue	UF resin (with 55% solid content)	100
	Wheat flour	30
	NH_4Cl (with 15% concentration)	10
PF glue	PF resin (with 47% solid content)	100
	Hardener (POLIFEN 10)[a]	30

[a] POLIFEN 10 is the commercial name of the hardener for phenol formaldehyde resin.

The Mitutoyo Surftest SJ-301 instrument was employed for surface roughness measurements. The R_z roughness parameter was measured to evaluate surface roughness of veneer surfaces according to DIN 4768 (1990). R_z is the arithmetic mean of the 10-point height of irregularities (DIN 4768). Before the surface roughness measurements, all veneer samples were conditioned to an equilibrium moisture content so that the moisture content could not alter the results of measurements. Cut-off length was 2.5 mm, sampling length was 12.5 mm and detector tip radius was 5 μm in the surface roughness measurements. Thirty veneer samples with 50 mm × 50 mm size were used for each test group to evaluate surface roughness.

Many wood properties are affected by pH value. The pH value of wood is required to be within certain limits for the occurrence of curing reactions of urea and phenol formaldehyde resins which are used in wood-based panel products [18]. Therefore, the pH values of the veneers were determined in this study. Approximately 5 g wood samples obtained from non-sanded and sanded veneers according to TAPPI T m-45 were shaken with 150 ml distilled water for 24 h. After filtering, pH values of test groups were determined.

Besides the tests applied to veneer samples; shear strength and bending strength tests were conducted for plywood panels manufactured from the non-sanded and sanded veneer groups. EN 314-1 and EN 310 norms were used to evaluate shear strength and bending strength of plywood panels, respectively. Thirty samples for shear strength and 20 samples for bending strength evaluation were used. Before the shear strength tests, samples obtained from the panels manufactured with UF glue were immersed for 24 h in water at 20 ± 3 °C and samples obtained from the panels manufactured with PF glue were immersed for 6 h in boiling water, followed by cooling in water at 20 ± 3 °C for 1 h to decrease the temperature of test pieces to 20 °C.

Table 3
pH, surface roughness and adhesive wettability measurement results based on veneer drying method

Tests applied to veneers	Air-dried groups[a]			Oven-dried groups[a]		
	A	A1	A2	B	B1	B2
pH	5.90 (0.04)	4.88 (0.01)	4.71 (0.04)	5.91 (0.03)	4.78 (0.03)	4.67 (0.05)
Surface roughness (R_z)	107.15 (17.12)	59.25 (9.56)	61.33 (8.89)	120.63 (11.53)	62.82 (9.97)	59.98 (12.62)
Contact angle of UF (°)	82.3 (8.3)	55.4 (9.3)	54.7 (4.9)	67.8 (8.5)	56.9 (7.1)	49.4 (6.0)
Contact angle of PF (°)	112.0 (7.4)	95.1 (4.5)	91.2 (3.9)	110.7 (6.7)	91.9 (4.4)	89.9 (5.4)

[a] Values in parenthesis are standard deviations ($n = 30$ for surface roughness and contact angle measurements).

3. Results

3.1. Wettability, surface roughness and pH of veneers

Results of surface roughness and adhesive wettability measurement tests applied to veneer surfaces and pH values of veneers are given in Table 3.

3.2. Shear and bending strength of plywood

Figs. 1 and 2 show the results of shear and bending strength values of plywood panels manufactured with

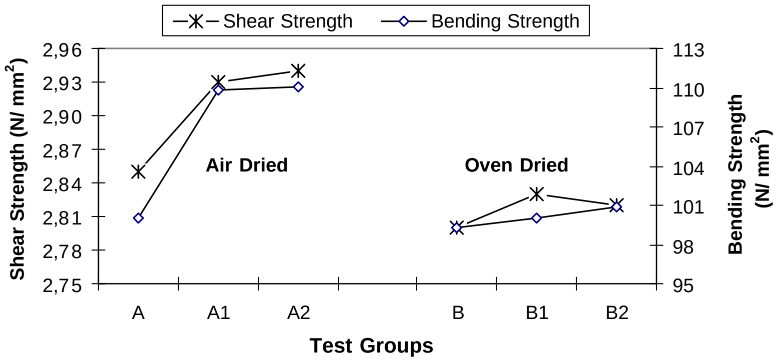

Fig. 1. Shear and bending strength values of plywood panels manufactured from the non-sanded and sanded veneers with UF glue resin based on drying methods.

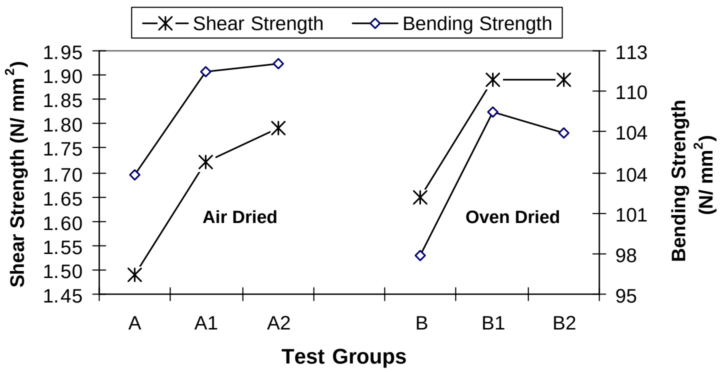

Fig. 2. Shear and bending strength values of plywood panels manufactured from the non-sanded and sanded veneers with PF glue resin based on drying methods.

UF and PF glue resins, respectively. Test results are presented based on the veneer drying methods.

4. Discussion

4.1. pH and surface roughness

pH values of sanded samples with 100 and 180 grit sandpapers were found to be lower than those of non-sanded samples. As can be seen from Table 3, the differences between the pH values of sanded and non-sanded groups were very clear, however, the differences in pH values for sanded groups (sanded with 100 and 180 grit sandpapers) were less. Drying methods had no effect on pH values of samples.

The surfaces of the oven-dried samples were found to be rougher than those of the air-dried samples. Because some surface checks may develop in the oven-drying process [19], this was normal. It was also found in a study conducted by Aydın and Çolakoğlu [20] that the surface roughness values of beech and spruce veneers dried at 110 °C were higher than those dried at 20 °C (air-dried). The surface roughness values (R_z) of air-dried and oven-dried samples decreased by about 45 and 50% with sanding process compared to the control material. However, the differences between the surface smoothness of sanded groups with 100 and 180 grit sandpapers were not clear.

4.2. Adhesive wettability

As can be seen from Table 3, contact angle values of PF resin drops were higher than those of UF resin drops for both sanded and non-sanded test groups. The reason for this was the higher viscosity value of PF resin. The viscosity values of UF and PF resins used in this study were 700–900 and 3900–4500 MPa s (cup Ø = 6 mm), respectively. Scheikl also reported in his study that static contact angle increased with increasing viscosity value [21]. The sanding process improved the wettability of the veneer surfaces. Lots of studies reported that the smaller contact angles (indicate good adhesion and improved wettability) were obtained after sanding of wood surfaces [2,4,22–24]. However, no important differences in contact angle values, just like the pH and surface roughness, were found between the sanded groups with 100 and 180 grit sandpapers.

According to the results of contact angle measurements achieved on non-sanded (control) samples, mean contact angle values of air-dried samples (82.3° for UF resin and 112.0° for PF resin) were found to be higher than those of oven-dried samples (67.8° for UF resin and 110.7° for PF resin). This difference was very clear especially for UF resin drops. Shupe et al. [25] also found from their study that air-dried samples had higher contact angle values than oven-dried and freeze-dried samples.

4.3. Mechanical properties of plywood

According to Fig. 1, mean shear strength values of panels obtained from air-dried samples were a bit higher than those obtained from the oven-dried for UF glue type. However, there was not a clear difference in bending strength resulting from the drying methods. In contrast, mean shear strength values of plywood panels manufactured from oven-dried veneers were higher than those manufactured from air-dried veneers for PF glue as shown in Fig. 2.

While there was almost no difference in bending strength of panels manufactured from air-dried and oven-dried veneers with UF glue, the strength value of panels obtained from air-dried veneers was higher than that of obtained from oven-dried veneers.

Shear and bending strength values of panels manufactured from sanded veneers were found to be higher than those manufactured from non-sanded veneers both for air-dried and oven-dried groups and for UF and PF glues (Figs. 1 and 2).

Shear strength values of plywood panels manufactured with PF glue were lower that those of manufactured with UF glue. This was not surprising because panels glued with PF resin were tested after being held in boiling water, while panels glued with UF resin were tested after being held in water with 20 °C.

4.4. Relationship between pH, surface roughness, adhesive wettability of veneers and mechanical properties of plywood panels

Freeman [26] studied the physical and chemical relationships between wood and adhesives. He found that the shear strength of a bond decreased with increasing pH using urea formaldehyde, but found no apparent effect when resorcinol–phenol formaldehyde was used. Our results agreed with this statement. Shear strength values of plywood panels manufactured both with UF and PF glues increased with decreasing pH values as shown in Table 3.

The roughness of a veneer surface affects the wettability of the surface hence the gluability [27]. Good wettability will lead to good bonding strength. It was also stated that smaller contact angles indicate greater wettability [28]. In this study, as a result of the decrease in surface roughness after sanding process, contact angle values were decreased and consequently, the shear strength values of plywood panels were increased.

Bending strength values of panels also increased after sanding process because of increased bonding strength.

Acknowledgements

The author acknowledges the financial support of this study by Research Fund of Karadeniz Technical University (Project No. 2000.113.2.1).

References

[1] D.J. Gardner, T.J. Elder, Surface activation treatment of wood and its effect on gel time of phenol–formaldehyde resin, Wood Fiber Sci. 20 (3) (1988) 378–385.
[2] J. Belfas, K.W. Groves, P.D. Evans, Bonding surface-modified Karri and Jarrah with resorcinol formaldehyde. I. The effect of sanding on wettability and shear strength, Holz als Roh Werkstoff 51 (1993) 253–259.
[3] S.S. Kelley, R.A. Young, R.M. Rammon, R.H. Gillespie, Bond formation by wood surface reactions. Part III. Parameters affecting the bond strength of solid wood panels, For. Prod. J. 33 (2) (1983) 21–28.
[4] C.B. Vick, Adhesive Bonding of Wood Materials, Wood Handbook—Wood as an Engineering Material, General Technical Report FPL-GTR-113, Forest Products Laboratory, US Department of Agriculture, Forest Service, Madison, WI, 1999, 463 pp.
[5] E.L. Back, Oxidative activation of wood surfaces for glue bonding, For. Prod. J. 41 (2) (1998) 30–36.
[6] F.P. Liu, T.G. Rials, Relationship of wood surface energy to surface composition, Langmuir 14 (1998) 536–541.
[7] M.W. Carpenter, Characterizing the chemistry of yellow-poplar surfaces exposed to different surface energy environments using DCA, DSC and XPS, Master Thesis, Department of Wood Science, College of Agriculture, Forestry and Consumer Sciences, West Virginia University, Morgantown, West Virginia, 1999.
[8] E.O. Walters, The effects of green veneer water content, dryer schedules, and wettability on gluing results for southern pine veneer, For. Prod. J. 23 (6) (1973) 46–53.
[9] A.W. Christiansen, How overdrying wood reduces its bonding to phenol–formaldehyde adhesives—a critical review of the literature. Part II. Chemical reactions, Wood Fiber Sci. 23 (1) (1991) 69–84.
[10] C. Forbes, Wood surface inactivation and adhesive bonding, Wood Products Notes, Department of Wood and Paper Science, College of Forest Resources, North Carolina State University, 1998.
[11] M. Sernek, Inactivation of Wood Surfaces: A Literature Review, Technical Report No. 103, Wood-based Composites Center, Virginia Technical University, 2001, 14 pp.
[12] M. Sernek, F.A. Kamke, W. Glasser, Comparative Analysis of Inactivated Wood Surfaces, Technical Report No. 112, Virginia Technical University, Wood-based Composites Center, 2002, 20 pp.
[13] R.M. Nussbaum, Natural surface inactivation of Scots pine and Norway spruce evaluated by contact angle measurements, Holz als Roh- und Werkstoff 57 (1999) 419–424.
[14] Bonding Wood and Wood Products, Wood Handbook: Wood as an Engineering Material, Agric. Handb. 72. Rev., Forest Products Laboratory, US Department of Agriculture, Washington, DC, 1987.
[15] E. Liptáková, J. Kúdela, Analysis of wood-wetting process, Holzforschung 48 (2) (1994) 139–144.
[16] M. Wålinder, G. Ström, Measurement of wood wettability by Wilhelmy method. Part 2. Determination of apparent contact angles, Holzforschung 55 (1) (2001) 33–41.
[17] İ. Aydın, G. Çolakoğlu, The effects of veneer drying temperature on wettability, surface roughness and some properties of plywood, in: Proceedings of the Sixth European Panel Products Symposium, North Wales Conference Centre, Llandudno, North Wales, UK, October 9–11, 2002.
[18] E. Plath, Die härtung von duroplasten bei der herstellung von holzwerkstoffen, Holz als Roh- und Werkstoff 16 (1958) 467–471.
[19] J.E. Reeb, Drying Wood, Cooperative Extension Service, College of Agriculture, University of Kentucky, 1997, 8 pp.
[20] İ. Aydın, G. Çolakoğlu, The effects of steaming and veneer drying temperature on the weathering reactions, in: Proceedings of the Wood Based Materials—Wood Composites and Chemistry International Symposium, Vienna, Austria, September 19–20, 2002.
[21] M. Scheikl, Wettability of wood determined with urea-formaldehyde adhesives, Ph.D. Thesis, Institut für Holzforschung, Universitaet fuer Bodenkultur, Wien, Austria, 1995.

[22] T.F. Shupe, C.Y. Hse, W.H. Wang, An investigation of selected factors that influence hardwood wettability, Holzforschung 55 (2001) 541–548.

[23] V.R. Gray, The wettability of wood, For. Prod. J. 12 (9) (1962) 452–461.

[24] URL1, Wood Structure, http://www.tech.purdue.edu/at/courses/at308/Technical_Links/Ac43-13-1B/CH1_1.pdf (last visited on 11 August 2003).

[25] T.F. Shupe, C.Y. Hse, W.H. Wang, An investigation of factors affecting wettability of some southern hardwoods, in: Proceedings of the International Contribution to Wood Adhesion Research, Proceeding No. 7267, Forest Products Society, Madison, WI, 1999, pp. 132–136.

[26] H.G. Freeman, Relationship between physical and chemical properties of wood and adhesion, For. Prod. J. 9 (12) (1959) 451–458.

[27] C.Y. Hse, Method for computing a roughness factor for veneer surfaces, Wood Sci. 4 (4) (1972) 230–233.

[28] A. Adamson, Physical Chemistry of Surfaces, 4th ed., Wiley, NY, 1982, 664 pp.