WETTABILITY AND SURFACE ROUGHNESS OF NATURAL AND PLANTATION-GROWN NARROW-LEAVED ASH (*Fraxinus angustifolia* Vahl.) WOOD

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Plantation-grown wood species are becoming more important. Their anatomical, physical, and mechanical properties are different and generally more variable than wood grown in natural stands. The objective of this study was to investigate the wettability and surface roughness (SR) of natural and plantation-grown narrow-leaved ash (*Fraxinus angustifolia* Vahl.) wood. The logs were cut from a natural stand versus three different spacings of plantation-grown narrow-leaved ash wood stands. Plantation spacings were 3 x 2 m, 3 x 2.5 m, and 4 x 4 m. The wetting behavior of the wood samples was characterized by the contact angle (CA) method (goniometer technique). A stylus type profilometer was used for the SR measurement according to the DIN 4768 (1990) standard. The SR and CA measurements were done on both the radial and tangential surfaces of the samples. Individual values of both SR and CA of ash wood showed statistically significant differences. Based on the findings, it appears that the natural-grown ash wood have higher (less favorable) SR and lower (more favorable) CA values compared to all the plantation-grown ash wood on both radial and tangential surfaces. Tangential surfaces had lower SR values and higher CA values than the radial surfaces for all groups. In conclusion, plantation-grown narrow-leaved ash wood can be utilized for bonded wood products such as plywood, laminated veneer lumber, and glulam.

Keywords: Narrow-leaved ash wood; Plantation; Surface roughness; Wettability

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INTRODUCTION

In 1995, plantation forests covered about 123.7 million hectares across the world and provided about 414 million m^3 yr^{-1} of roundwood. By 2010, it was estimated that the production from industrial plantations in the world has increased to 600 million m^3 yr^{-1} (FAO 2001). Ash species (*Fraxinus excelsior and F. angustifolia*) are becoming more important in Europe because of their fast growth and valuable woods (Cicek et al. 2006). Narrow leaved ash (*Fraxinus angustifolia* Vahl.) is the most common and useful native ash species in Turkey. It is a fast-growing tree in moist bottom land of the north-western swampy woodlands of Turkey (Cicek and Yilmaz 2002). Plantation-grown narrow-leaved ash wood has a higher growth rate than natural grown ash wood, and the volume growth of plantation-grown narrow-leaved ash wood can reach a yield of 23 m^3 ha^{-1} per year (Kapucu et al. 1999). Ash is a ring-porous tree, and its wood has high industrial value because of its high strength and hardness. Ash wood is commonly used in a variety of application areas, such as furniture, wood bending, veneer, tool handles, sports equipment (e.g. hockey sticks and racquets cues), and yachts (Bozkurt and Erdin 1997).

The surface quality of solid wood is one of the most important factors influencing further manufacturing processes such as finishing or strength of adhesive joints. Surface roughness (SR) and wetting properties are usually determined in order to assess the quality of machining processes (Hernandez and Cool 2008). The SR of wood prior to finishing is very important in determining the quality of the finished product. Any irregularity on the surface may show through the thin layer of any finishing materials. The SR is also very important in other applications such as utilization of adhesive in wood (Sulaiman et al. 2009). Smoother surfaces have higher bonding strength properties compared to rougher surfaces (Vick 1987; Ozcifci 2006). The SR values can be affected by various factors such as cross grain, annual ring width, ratio of earlywood to latewood, rays, knots, juvenile and mature wood, reaction wood, and specific cell structures (Dundar et al. 2008). The SR values of several natural grown wood species have been reported in previous studies. Malkocoglu (2007) investigated surface roughness of various natural grown wood species (beech, chestnut, alder, pine, and spruce) planed in different conditions. He found that the chestnut had higher R_z value compared to other wood species. Sieminski and Skarzynskva (1987) studied surface roughness of different wood species after sanding. Kilic et al. (2006) reported surface roughness values of beech and aspen wood.

Wettability is often evaluated by measuring the contact angle (CA) of a droplet as well as by evaluating its progress with respect to time (Shi and Gardner 2001). It has an important role in the ability of an adhesive to wet, flow, penetrate, and cure on wood surfaces (Wang et al. 2007). The wettability can be affected by various factors such as surface roughness, polarity, heterogeneity and porosity, wood grain direction, the chemical components of the wood surface, extractives, and acidity (Shupe et al. 1998, Nussbaum and Sterley 2002). Shupe et al. (2001) investigated the wettability of 22 southern hardwood species. They found that CA values of white and green ash in the tangential surface were 57.5º and 60.4º for sanded surfaces, while the values were 44.3º and 47.2º for unsanded surfaces.

The anatomical, physical, and mechanical properties of wood from plantations are different and generally more variable than wood grown in natural stands (Bendtsen 1978). Plantation spacing is the most important criterion determining stand quality and ratio of juvenile wood. Wider plantation spacing generally induces knottier wood and a higher ratio of juvenile wood (Cicek 2002). Cicek (2002) indicated that narrow-leaved ash should be planted at a square spacing of 2x2 and 2.5x2.5 m to get high quality wood. To our knowledge, there is no information about surface roughness and wettability of natural and different plantation spacing grown narrow-leaved ash wood. Therefore, the knowledge on the properties of ash wood grown in plantations could be of value in its utilization. The objective of this study was to investigate the variation of surface roughness and wettability of natural and plantation grown narrow-leaved ash planted at different spacings.

EXPERIMENTAL

Materials

The sample trees were harvested from natural and plantation-grown narrow leaved ash stands in Adapazari Suleymaniye Forest, in north western part of Turkey (40º 8' N, 30º 32' E) (Cicek et al. 2006). Until 1980, the spacings in ash plantations was 3x2 m and 3x2.5 m. Afterwards, the spacing changed to 4x4 m. Plantation areas were planted with Hendek (in north western part of Turkey) origin seeds. The properties of sample areas and trees are shown in Table 1. The experimental areas are located at an average altitude of 25 m above the sea level. Average annual precipitation and temperature are approximately 800 mm and 14.2 ºC, respectively. All climatic data were obtained from the Adapazarı meteorology station located very near the research areas. The area has heavy clay soil with a soil pH of 7.5 to 7.9 (Cicek et al. 2006).

Table 1. Properties of Sample Areas and Trees

Groups	Growth Type	Planting spacing (m)	Number of trees in hectare	Tree age (year)	Tree height (m)	Diameter (at 1.30) (cm)	Annual ring width (mm)
A	Natural	-	350	43	33	36	3.74 (0.22)
B	Plantation	3 x 2	1666	38	34	37	5.26 (0.30)
C	Plantation	3 x 2.5	1428	26	27	30	8.63 (0.67)
D	Plantation	4 x 4	625	25	21	24.5	6.80 (0.58)

Numbers in parantheses are standard deviations.

Four trees from each stand (total 16 sample trees) were cut. Then, 1.5-m logs from each tree were obtained between 2 and 4-m height. The cutting schedule of lumber and samples from the logs are shown in Fig. 1. The specimens having 5 x 5 x 5 cm dimensions were cut with a circular saw. Saw diameter, number of teeth, and speed of revolution were 30 cm, 28, and 4500 rpm, respectively. The specimens of all the groups were successively cut with the same saw from pith to bark. The specimens were conditioned at 20±2 ^{o}C temperature and 65±5% relative humidity until they attained at 12% equilibrium moisture content. Then, SR and CA measurements described below were carried out on both radial and tangential surfaces of the specimens.

Methods

Determination of annual ring width

Annual ring width was measured on all samples. The number of annual rings across each specimen was determined and the total distance measured with a ruler in mm to get an average ring width.

Determination of wettability

The wetting behavior of the wood samples was characterized by the contact angle method (goniometer technique). The CA value was obtained using a KSV Cam-101 Scientific Instrument (Helsinki, Finland). The CA is determined from the tangent with the sessile drop profile at the point of contact with the solid surface. The drop image was stored by a video camera, and an image analysis system calculated the CA from the shape of the distilled water drop at room temperature. After a 5 μL droplet of distilled water was placed on the sample surface, CA values from the images were measured at 1-s time intervals up to 10 s total. CA values were obtained from the average of the measurements over the 10 s period. Sixteen samples were used from each group for the CA measurements.

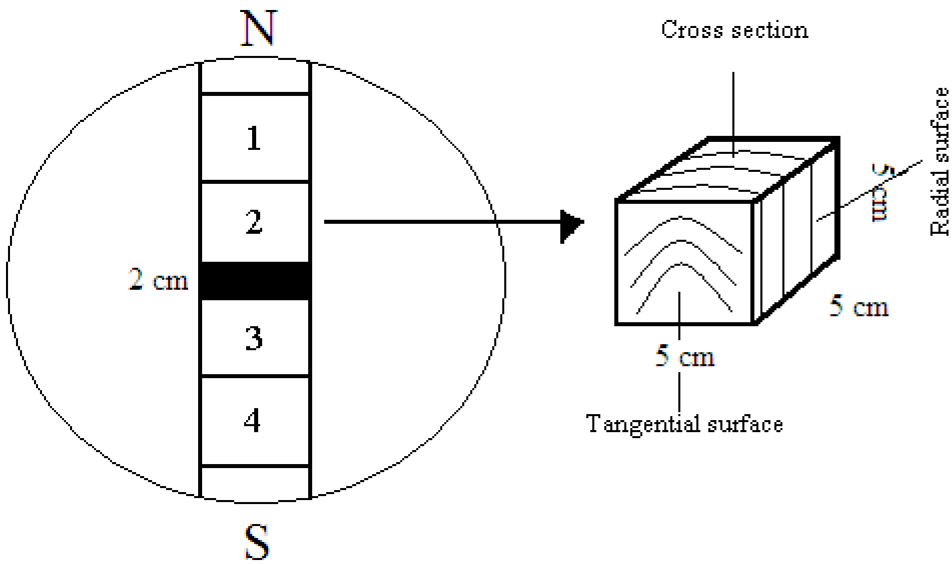

Figure 1. Cutting schedule of lumber and samples from the logs

Determination of surface roughness

Measurements were conducted according to DIN 4768 (1990) standard by using a stylus type profilometer (Mitutoyo SJ-301, Japan) on the radial and tangential surfaces of wood samples. Roughness values were measured with a sensitivity of 0.5 μm. Measuring speed, pin diameter, and pin top angle of the tool were 10 mm/min, 4 μm, and 90°, respectively. The length of the tracing line (L_t) was 12.5 mm, and the cut-off was $\lambda = 2.5$ mm. The measuring force of the scanning arm on the samples was 4 mN (0.4 g). The points of roughness measurement were randomly marked on the surface of the samples. Measurements were carried out perpendicular to the fiber direction. Sixteen samples were used from each group for the SR measurements.

Measurements were done at room temperature, and the pin was calibrated before the tests. The calibration of the instruments was checked by using a standard reference plate with an R_a value of 3.02 μm. Three roughness parameters, average roughness (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_{max}) commonly used to evaluate surface characteristics of wood samples were determined.

Data analyses and statistical methods

For the surface roughness and wettability data, a variance analysis (ANOVA) at $p<0.05$ was carried out, and significant differences between mean values of the groups were determined using Duncan's multiple range test.

RESULTS AND DISCUSSION

Natural-grown ash wood had lower annual ring width value (3.74 mm) than all plantation-grown ash wood samples. This result is in good agreement with the work by Kapucu et al. (1999). They stated that plantation-grown narrow-leaved ash wood has a higher growth rate than natural grown ash wood. In the plantation-grown ash wood, group C having 3x2.5m plantation spacing had the highest annual ring width value (8.63 mm) while group B having 3x2 m plantation spacing had the lowest annual ring width value (5.26 mm). Annual ring width of group D was 6.80 mm.

The results of ANOVA and Duncan's mean separation tests for R_a, R_{max}, and R_z values of natural and plantation grown ash wood are shown in Table 2. The results of Duncan's multiple range tests are shown by letters.

Table 2. Surface Properties of Natural and Plantation Grown Ash Wood and the Test Results of ANOVA and Duncan's Mean Separation Tests

Roughness parameters (µm)	Groups	Radial surface	Tangential surface
R_a	A	8.38 (0.89) ^{s}	5.34 (0.70) ^{s}
	B	7.72 (0.70) ^{t}	4.58 (0.31) ^{t}
	C	6.53 (0.66) ^{u}	4.18 (0.82) ^{t}
	D	7.51 (0.52) ^{t}	4.44 (0.66) ^{t}
R_{max}	A	63.35 (3.06) ^{s}	41.11 (1.74) ^{s}
	B	52.86 (2.56) ^{t}	31.73 (1.43) ^{t}
	C	48.51 (4.01) ^{u}	28.59 (1.89) ^{u}
	D	51.70 (3.60) ^{t}	34.63 (1.50) ^{v}
R_z	A	39.73 (3.61) ^{s}	26.34 (3.17) ^{s}
	B	34.20 (2.48) ^{t}	20.70 (1.65) ^{t}
	C	29.31 (3.23) ^{u}	17.87 (2.32) ^{u}
	D	32.93 (3.22) ^{t}	21.34 (1.84) ^{t}

Numbers in parantheses are standard deviations.
^{s,t,u,v} Values having the same letter were not significantly different (Duncan Test).

Natural-grown ash wood had higher SR value than all plantation-grown ash wood for both tangential and radial surfaces. The highest SR value (8.38 µm and 5.34 µm for radial and tangential surfaces) was measured for natural grown ash wood with the narrowest annual ring width (3.74 mm), while the lowest SR value (8.38 µm for radial and 5.34 µm for tangential surfaces) was obtained on both radial and tangential surfaces in group C, which had the widest annual ring width (8.63 mm). The SR values of all groups on both radial and tangential surfaces decreased with increasing annual ring width. Hecker and Becker (1995) found that surface roughness of Douglas fir veneer increased as annual ring width increased. Dundar et al. (2008) mentioned that SR value of wood is influenced by its annual ring width and earlywood and latewood ratio. Kilic et al. (2006) found that surface roughness of sawn tangential and radial surface were 10.7 µm and 13.26 µm for aspen and 11.05 µm and 12.77 µm for beech. Natural and plantation-grown narrow-leaved ash wood had smoother surfaces in both radial and tangential surfaces compared to beech and aspen wood. This can be related to anatomical structure, annual ring width, rays, and specific cell structure of the wood species (Dundar et al. 2008; Kilic et al. 2006). In terms of plantation grown ash wood, group B had the highest surface roughness value, while group C had the lowest surface roughness value on both surfaces. R_{max} and R_z values showed similar trends to results of the R_a values.

Tangential sections had lower (generally regarded as favorable) SR values than the radial sections for all groups. Similar results were observed for different wood species in previous studies (Sulaiman et al. 2009; Kilic et al. 2006; Ors and Gurleyen 2002). SR values of ash wood can be lowered with sanding. Several researchers found that sanding improved SR value of wood (Kilic et al. 2006; Sulaiman et al. 2009; de Moura and Hernandez 2006).

The CA values of natural and plantation-grown ash wood are shown in Fig. 2. Natural-grown ash wood had lower CA value than the entire plantation-grown ash wood on both radial and tangential surfaces. It also meant that natural-grown ash wood was more wettable compared to plantation-grown ash wood. For the plantation-grown ash wood, when the planting spacing was increased from 3x2 m to 3x2.5 m, CA was increased. But, additional increase in plantation spacing tended to decrease CA values. Shupe et al. (2001) found that CA values of white and green ash in the tangential surface were 44.3º and 47.2º for unsanded surfaces, respectively. They used 5 second measurement time and phenol formaldehyde resin for liquids. Narrow-leaved ash wood had lower CA values compared to white and green ash. Various factors such as porosity, density, and chemical composition of the wood surface, temperature, viscosity, and surface tension of the liquid affect the wettability of wood (Rolleri and Roffael 2008). The differences in wettability may be attributed to anatomical and chemical properties of natural and plantation grown wood. Holocellulose has large number of polar hydroxyl groups, and these polar hydroxyl groups are mainly responsible for hydrogen bonds with polar adhesive polymers. The hydrogen-bonding interactions may play a significant role in surface wettability (Aydin 2004). Shupe et al. (2001) found highly significant differences between wettability of various wood species. Scheikl and Dunky (1998) found that the penetration behavior of liquids into wood surfaces depends on the different diameters of wood cells. Chen (1970) reported that wood extractives can influence wettability of wood.

Tangential surfaces had lower CA values than the radial surfaces in all groups. For instance, average CA values of group D in the tangential and radial surfaces were 33.11º and 26.05º, respectively. The tangential surfaces are more wettable compared to radial surfaces. Good wettability is considered as an indicator of better bond strength. Aydin and Colakoglu (2007) showed that bond strength increased as CA value decreased.

The CA values of ash wood increased with decreasing surface roughness in both radial and tangential surfaces. In general, if CA on surface is higher than 80º, it increases as surface roughness increases. If CA is below 60º, it decreases as surface roughness increases (Aydin 2004). Buscher et al. (1983) stated that a rough wood surface had a smaller CA value compared to a smoother surface due to higher surface area. Aydin et al. (2006) found similar results. They stated that CA values of spruce veneer increased as surface roughness of the veneer decreased.

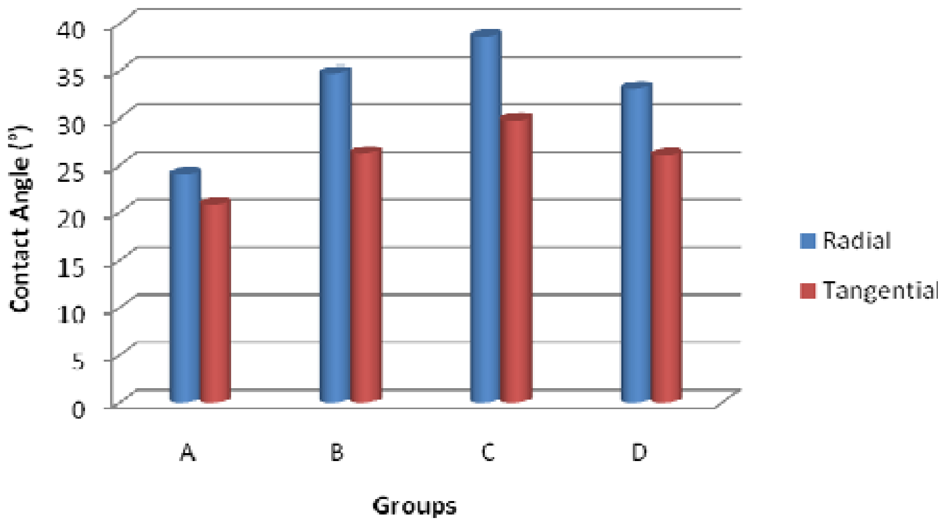

Figure 2. Contact angle values of natural and plantation-grown ash wood

Time-dependent variations of the CA values in both radial and tangential surfaces of the all the ash wood are presented in Fig. 3 a and b. For the natural-grown ash wood, the average CA values decreased from 32.8º to 17.5º on radial surfaces and from 31.6º to 14.2º on tangential surfaces as the time increased from 1 to 10 s. For the plantation-grown ash wood, CA values were higher than those of natural-grown ash wood in both radial and tangential surfaces.

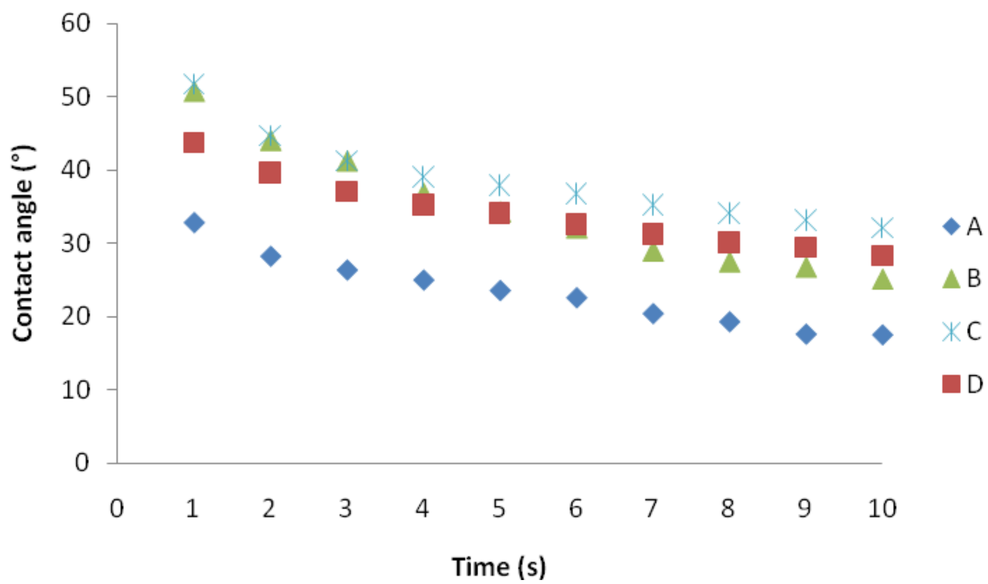

Figure 3(a). Time dependent variations of the contact angle values of the ash wood in radial and tangential surfaces: Radial surface

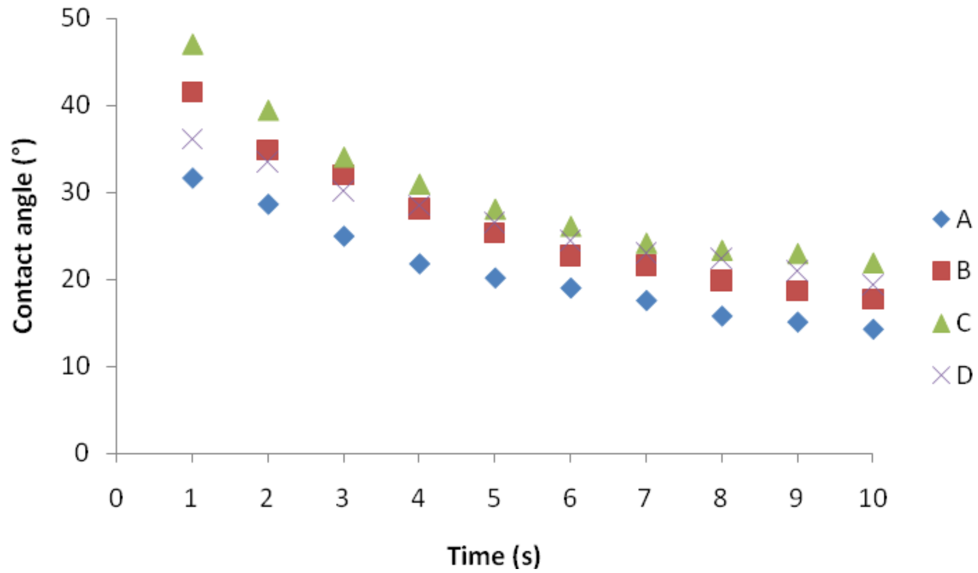

Figure 3(b). Time dependent variations of the contact angle values of the ash wood in radial and tangential surfaces: Tangential surface

CONCLUSIONS

1. Plantation-grown ash wood had a smoother surface than that of natural grown narrow-leaved ash wood on both tangential and radial surfaces. It follows that plantation grown ash wood can be utilized for bonded wood products such as plywood, laminated veneer lumber, glulam, fiberboard, and particleboard.
2. Surface roughness values of all the narrow-leaved ash wood increased with decreasing annual ring width.
3. In the plantation-grown ash wood, 3x2.5 m plantation spacing yielded the smoothest surface. However, 4x4 m plantation spacing had the lowest wettability.
4. Tangential surfaces of all the narrow-leaved ash wood had lower surface roughness and contact angle (CA) values than those of radial surfaces.
5. Natural-grown ash wood had lower CA value than the entire plantation-grown ash wood in both radial and tangential surfaces.
6. CA values of all the narrow-leaved ash wood decreased with increasing surface roughness.

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