EFFECT OF PINE CONE RATIO ON THE WETTABILITY AND SURFACE ROUGHNESS OF PARTICLEBOARD

Umit Buyuksari,[a*] Erkan Avci,[b] Nadir Ayrilmis,[b] and Huseyin Akkilic [b]

In this study, the effect of pine cone ratio on wettability and surface roughness of particleboards was examined. Contact angles of water on the produced samples were measured with a goniometer. The surface roughness of the samples was determined with a fine stylus tracing technique**.** Particleboards made from 100% wood particle had the lowest average contact angle (95.6°), but the highest was for the particleboards containing 50% pine cone (116.3°). Average surface roughness was higher for samples containing a higher amount of pine cone in the mixture. The smoothest surface (9.77 µm R_a) was observed when panels were produced using 100% wood particles. On the other hand, the roughest surface (15.50 µm R_a) was found for the samples containing 50% cone particles in the mixture. R_{max} and R_z parameters had similar trends to the R_a values. Increasing the pine cone ratio in the mixture negatively affected the contact angle and surface roughness parameters of the particleboard.

Keywords: Particleboard; Pine cone; Surface roughness; Wettability

*Contact information: a: Department of Wood Mechanics and Technology, Duzce University, Duzce, TURKEY; b: Department of Wood Mechanics and Technology, Istanbul University, Istanbul, TURKEY; *Corresponding author:* buyuku@istanbul.edu.*tr*

INTRODUCTION

The demand for wood in the forest products industry has been growing, but the production of industrial wood from the natural forests continues to decline. There is still an ongoing research interest to find out alternative sources of raw materials for composite manufacturing (Guntekin et al. 2008). Therefore, alternative non-wood based materials may play an important role in the forest products industry (Nemli et al. 2009; Bektas et al. 2005). The total area covered by stone pine woodlands is 380.000 ha, 75% of which were in Spain, 9% in Portugal, 9% in Turkey, 5% in Italy, and lower percentages in Greece, Lebanon and France (Moussouris and Regato 1999). Turkey has 54,000 ha stone pine forests, and its total stone pine cone production is annually 3500 tons (Ayrilmis et al. 2009). Pine cone, a renewable resource, has not been used effectively. It is collected, dried to facilitate seed release, and generally discarded or burned in stoves in the winter. Also, cone collection does not require extra costs.

Much research has been done on the use of non-wood based resources for particleboard manufacturing. Most of these studies found non-wood based materials to be practically suitable in particleboard manufacturing (Guler et al. 2009; Guntekin and Karakus 2008; Sampathrajan et al. 1992; Alma et al. 2005; Nemli et al. 2003, 2009; Guntekin et al. 2008; Ntalos and Grigoriou 2002). Non-wood based materials in the mixture generally decreased the mechanical properties of the particleboard. Buyuksari et al. (2010) stated that stone pine cone could be considered as an alternative to wood material in the manufacturing of particleboard panels used in an indoor environment due to lower thickness swelling, water absorption, and formaldehyde emission. On the other hand, mechanical properties of particleboard decreased with increasing pine cone ratio.

Coating wood-based panels with different materials has resulted in better mechanical properties and dimensional stability and also has eliminated the formaldehyde emission (Rybaczyk and Wojciechowski 1978; Grigoriou 1987; Nemli and Colakoglu 2005; Nemli et al. 2005a 2007). Particleboard manufacturers currently use decorative surface materials to coat the particleboard and MDF. The coated panels are mostly used for furniture, educational establishment laboratories kitchen cabinets, and worktops, etc.

Wettability and surface roughness of the substrate are very important when the panels are to be coated with thin overlays such as melamine impregnated papers, foils, and thin films (Ayrilmis and Winandy 2009). Any surface irregularities on the substrate may show through the overlay and influence the quality of final products (Hiziroglu et al. 2004; Nemli et al. 2005b). Good wettability will lead to good bonding strength and smaller contact angles, indicating greater wettability (Aydin 2004). This analysis is important to determine the adhesive and coating properties of wood and wood-based composite surfaces. Various factors influence the wettability of wood, e.g., porosity, density, and chemical composition of the wood surface, as well as temperature, viscosity, and surface tension of the liquid (Rolleri and Roffael 2008).

Wettability and surface roughness properties of the wood-based panels produced with 100% wood particles and fibers were investigated by several researchers (Rolleri and Roffael 2007, 2008; Hiziroglu et al. 2004; Hiziroglu and Suzuki 2007; Hiziroglu and Baba 1999). However, there is a lack of information on surface roughness and wettability properties of panels containing non-wood based resources. The objective of this study was to investigate effect of non-wood based material ratio on wettability and surface roughness of particleboard.

EXPERIMENTAL

Materials

Pine (*Pinus nigra*) and beech (*Fagus orientalis*) wood particles used in this study were obtained from a commercial particleboard plant in Gebze, Turkey. Stone pine (*Pinus pinea* L.) cones were collected from Fatih Forest District in Belgrade Forest in Istanbul, Turkey. The samples were soaked in hot water for 4 hours at 80ºC to remove gum on the cones in order to improve the grinding process and the bonding properties of the cone particles. The wet pine cones were dried in an oven up to 20 to 25% moisture content (based on the oven-dry cone weight) at 60°C. Pine cones were coarsely chipped and then classified using a horizontal screen shaker. The particles that remained between 3-1.5 mm and between 1.5-0.8 mm sieves were utilized in the core and middle sections of the panels, respectively. The wood particles used in production were dried at 100-110°C in a laboratory type dryer to reach a target moisture content of 3%. The experimental design is shown in Table 1.

Table 1. Experimental Design

Board type	Raw material	
	Pine Cone (%)	Wood (%)
A	0	100
B	10	90
C	20	80
D	30	70
E	40	60
F	50	50

Urea formaldehyde (UF) resin (solid content 55%, formaldehyde/urea mole ratio 1.25) at a 10% adhesive level was used for the core and outer layers based on the oven-dry weight of the wood particles. One-percent ammonium chloride (concentration 20%) solution was added to the resin as a hardener based on the solid adhesive amount. The chips were placed in a drum blender and sprayed with urea formaldehyde and ammonium chloride for 5 min to obtain a homogenized mixture. External wax or water-repellent chemicals were not utilized in this study. In the panel production, resin type (UF), and ratio, press parameters, etc. were kept constant, and the only variable altered in this study was the cone ratio in the mixture. The production parameters are shown in Table 2. The produced particleboards were conditioned at 20 ± 2°C and 65 ± 5% of relative humidity to the moisture content of about 12%. Edges of the panels were trimmed to the final dimension of 50 x 50 x 1 cm.

Table 2. Production Parameters of Particleboards

Parameter	Value
Press temperature (^{0}C)	150
Pressing time (min)	7
Peak pressure (N/mm^2)	2.6
Thickness (mm)	10
Dimensions (mm)	550x550
Outer layer (Whole of board %)	35
Target density of panel (g/cm^3)	0.650
Middle layer (Whole of board %)	65
Number of board for each type	2

Methods

Determination of wettability

The wetting behavior of the samples conditioned at 65% relative humidity at 20°C was characterized by the contact angle method (goniometer technique). Contact angles (CA) were measured with water using a KSV Cam-101 Scientific Instrument (Helsinki, Finland). The sessile drop method is the most widely used procedure. The CA was determined simply by aligning a tangent with the sessile drop profile at the point of contact with the solid surface. The drop image was stored by a video camera. An imaging system was used to measure the CA, shape, and size of water droplets for the tested surfaces of the particleboard samples at room temperatures. After the 5 μL droplet of distilled water was placed on the sample surface, contact angles from the images were measured at 5-s time intervals up to 100 s total, and the average CA was calculated.

Twenty samples with a size of 50 mm x 50 mm were used from each type of panel for CA measurements.

Determination of surface roughness

Test specimens (50 mm × 50 mm × 10 mm) to determine surface roughness were conditioned in a climate chamber until they attained 12 percent equilibrium moisture content. The surface roughness measurement points were randomly marked on the sample surfaces, and twenty measurements for each type of panel were accomplished.

A Mitutoyo SJ-301 surface roughness tester, stylus type profilometer, was employed for the surface roughness tests. Three roughness parameters, average roughness (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_{max}) characterized by ISO 4287 (1997) standard, were determined to evaluate the surface characteristics of the panels. The surface roughness parameters can be calculated from the digital information. The vertical displacement of the stylus is converted into electrical signals by a linear displacement detector before the signal is amplified and converted into digital information. Typical roughness profiles of panel types A, C, and E are shown in Fig. 1. R_a is the arithmetic mean of the absolute values of the profile deviations from the mean line and is by far the most commonly used parameter in surface finish measurement. The 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 tracing line (L_t) was 4 mm, and the cut-off was λ = 0.8 mm. The measuring force of the scanning arm on the samples was 4 mN (0.4 gf). Measurements were done at room temperature, and the pin was calibrated before the tests.

Fig. 1. Typical surface roughness profiles of some panel types. A(bottom), C(middle), and E(upper)

Data analyses and statistical methods

For the surface roughness and wettability, all multiple comparisons were first subjected to an analysis of variance (ANOVA) at p<0.01, and significant differences between mean values of the particleboard groups were determined using Duncan's multiple range test.

RESULTS AND DISCUSSION

Table 3 shows the results of ANOVA and Duncan's mean separation tests for surface roughness and contact angle values of particleboards made using mixtures of pine

Table 3. Surface Roughness Parameters and Wettability of Particleboards and the Test Results of ANOVA and Duncan's Mean Separation Tests

Properties	Board Type	Mean [a]	Std. Deviation	Std. Error	X_{Min} [b]	X_{Max} [c]	p [d]
R_a (µm)	A	9.77^{p}	2.00	0.576	7.04	12.97	*
	B	11.13^{s}	1.11	0.321	9.39	12.86	*
	C	11.80^{su}	1.45	0.418	9.83	14.29	*
	D	12.69^{uv}	1.69	0.488	10.12	15.53	*
	E	13.47^{v}	1.48	0.428	11.26	15.92	*
	F	15.50^{y}	1.62	0.467	12.53	17.29	*
R_{max} (µm)	A	52.77^{p}	7.64	2.207	40.82	63.94	*
	B	60.98^{s}	5.86	1.692	53.31	70.31	*
	C	62.31^{su}	4.92	1.420	56.56	71.58	*
	D	67.14^{uv}	7.65	2.207	56.17	77.41	*
	E	69.80^{v}	6.09	1.758	61.65	81.72	*
	F	77.89^{y}	6.22	1.795	66.84	85.20	*
R_z (µm)	A	36.22^{p}	3.95	1.139	29.41	41.59	*
	B	42.62^{s}	4.70	1.356	36.19	50.25	*
	C	44.77^{s}	6.89	1.989	35.76	55.38	*
	D	50.28^{u}	5.05	1.457	42.02	59.12	*
	E	52.49^{u}	4.63	1.337	44.32	60.82	*
	F	60.96^{v}	4.96	1.433	53.37	70.04	*
CA (º)	A	95.6^{p}	7.05	2.66	85.5	102.2	*
	B	109.9^{s}	3.20	1.07	104.2	113.6	*
	C	111.4^{su}	5.91	2.23	101.7	116.4	*
	D	112.8^{su}	3.52	1.17	108.2	117.0	*
	E	113.2^{su}	2.60	1.16	111.0	117.6	*
	F	116.3^{u}	5.83	2.37	111.1	124.7	*

[a] Mean values are the average of 20 specimens. [b] Minimum value; [c] Maximum value; [d] Significance level; * significant at 0.01 for ANOVA; ^{p,s,u,v,y,z} Values having the same letter were not significantly different (Duncan test).

cone and wood chips. Statistical analysis showed some significant differences ($p<0.01$) between wettability and surface roughness values of produced particleboards.

The particleboards made from 100% wood particles had the lowest CA value of 95.6°, while the highest CA (116.3°) was observed for the particleboards consisting of 50% pine cone in the mixture. The average CA values of the produced panels increased as the pine cone ratio in the mixture increased. The CA values of particleboards containing cone particles increased from 15.0% to 21.7% as compared to those of the panels made from 100% wood particles (Fig. 2). Various factors, 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). A reason for the wettability reductions in the particleboard containing pine cone is the presence of a higher amount of extractives in pine cone. The reductions also may be attributed to lower holocellulose content of stone pine cone. 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 of the cone and adsorption of the resin on the molecular structure of wood (Aydin 2004). Therefore, loss of hygroscopicity is attributed to a gradual loss of wood hydroxyl groups. Adhesion between wood particle and cone particle surfaces can be improved by several chemical treatments such as sodium hydroxide, calcium hydroxide, nitric acid, hydrogen peroxide, and borax (Christiansen 1990; Chow 1975) or using coupling agents and different adhesives (diphenylmethane diisocyanate (MDI) resin). Also, adhesives with low molecular weight, low viscosity, and low surface tension can better penetrate and wet inactive particleboard surfaces.

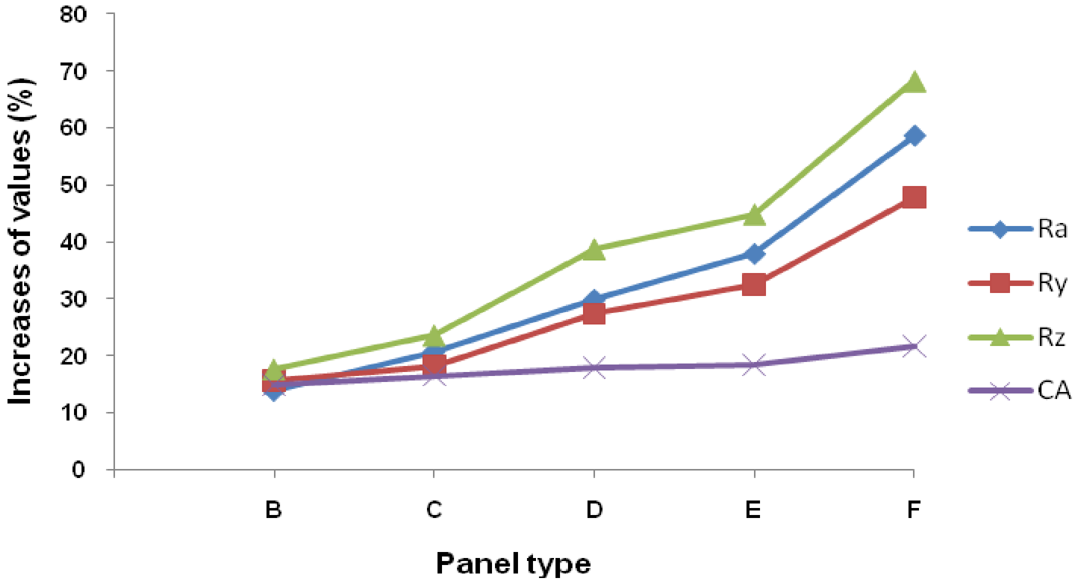

Fig. 2. Percent increases in average values of surface roughness properties and wettability of the panel types

The average R_a values of the produced panels increased with increasing the pine cone ratio in the mixture. Panels made from 100% wood particles had the smoothest surface (9.77 µm R_a), but the roughest surface (15.50 µm R_a) was obtained from the panels containing 50% pine cone. Surface roughness is a function of raw material characteristics, species, particle size and distribution and manufacturing variables, press parameters, resin content, face layer densification, and sanding process of the panels (Hiziroglu et al. 2008a). Differences in the average surface roughness of the produced particleboards were most likely due to the morphologies properties of wood and pine cone particle. Nemli et al. (2005a) found that raw material type affected surface roughness of particleboard. Particleboards produced using oil palm empty-fruit bunches had 138 µm R_a after sanding grit sequence of 120-150 (Ratnasingam et al. 2008).

The R_{max} and R_z parameters of panels had similar trends to the R_a values. These values also increased with increasing the pine cone ratio in the mixture. The increase in pine cone in the mixture resulted in higher the R_a, R_{max}, and R_z values of 13.9% to 58.7%, and 15.7% to 47.8%, and 17.7% to 68.3%, respectively (Fig. 2). Surface roughness of the particleboards containing pine cone particles could be improved by sanding and increasing panel density, shelling ratio, and press pressure. In our experimental study no sanding was applied to the panels. Earlier studies reported that sanding and overlaying of the panels improved surface quality (Hiziroglu et al. 2008b). Nemli et al. (2005a) found that increase in shelling ratio, panel density, and press pressure improved the surface roughness of particleboard.

Time-dependent variations of the CA values of the produced panels are presented in Fig. 3. For the control group, the average CA values decreased from 112.1 to 75.1º when the time increased from 5 to 100 s. For the other groups (including pine cone particles), the decreases in the CA values were less than those of the control group.

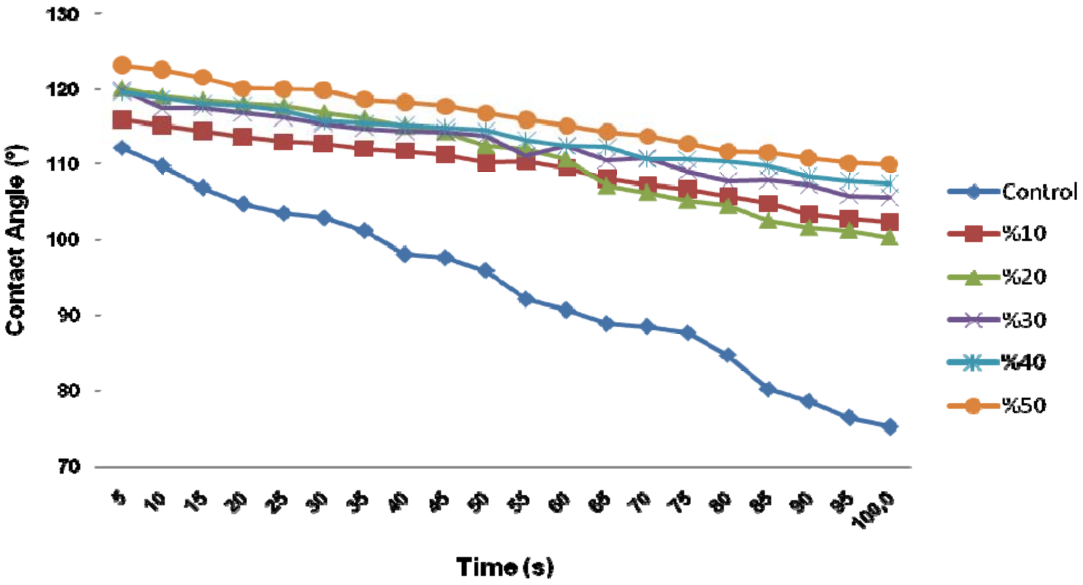

Fig. 3. Time-dependent variations in the contact angle values of the particleboards

CONCLUSIONS

1. Particleboards made from 100% wood particle had the lowest average contact angle, but it was highest for the particleboards containing 50% pine cone. The surface of particleboards containing cone particle was less polar and thus repelled water, resulting in a lower wettability compared with control panels made from 100% wood particles.
2. The average CA value of the produced panels increased as the pine cone ratio in the mixture increased.
3. In case of time-dependent variations of the CA values, the decrease in the CA values of samples containing pine cone was less than those of the control group.
4. Surface roughness of the particleboards was adversely influenced as pine cone ratio increased in the mixture.
5. The average R_a value of the produced panels increased with increasing the pine cone ratio in the mixture.
6. The worsening of wettability and surface roughness of particleboard should be considered if particleboards containing cone particles of stone pine are used in manufacturing overlaid panels for the furniture industry.

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