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Wettability of Sanded and Aged Fast-growing Poplar Wood Surfaces: I. Surface Free Energy

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The sanding process influences the surface morphology and chemical components of wood, which are two important factors that influence the surface free energy and wettability of wood. The objective of this study was to investigate the roughness of sanded poplar wood and the effects of sanding and aging on the surface free energy using different methods. The roughness parameter (R_a) decreased as the grit number increased, but no change was evident when the grit number increased from 120 to 240. The contact angle of water on the fresh wood samples decreased as the grit number increased. Fresh wood samples were more easily wetted by water than was the aged wood sample, and the contact angles increased as the surface roughness decreased. The surface free energy of sanded, aged wood obtained by the Zisman method may be unsuitable. For the fresh wood samples, the change of surface free energy and its components were not significantly changed when the grit number was higher than 120; for the aged wood samples, the dispersion component appeared to increase slightly as the grit number decreased. The effect of roughness on the acid/base component, acid component, and base component calculated by the vOCG method was unremarkable. The surface free energy of the wood samples (obtained using the liquid parameters provided by Volpe and Siboni (1997)) can effectively balance the relationship between the acid and base components.

INTRODUCTION

Poplar, especially fast-growing poplar, is one of the most productive species used in short-rotation plantations. Poplar wood has many great qualities, such as fast growth, strong adaptability, disease and insect resistance, high yield (yielding up to 24 tons of oven-dry mass per hectare and year of rotation), and easy processing. Uses of poplar include architectural decoration, furniture, wood panels, and pulp and paper (Han *et al.* 2009).

The surface free energy of wood is a useful parameter that provides information on the interaction between the wood surface and an adhesive. Additionally, it has a great influence on the bonding strength of wood composites. These characteristics have been studied recently and in the past (Gardner *et al.* 1991; Liptakova *et al.* 1995; Liu *et al.* 1998; de Meijer *et al.* 2000; Wålinder and Strom 2001; Gindl and Tschegg 2002). Contact angle is the most commonly applied method to calculate surface free energy data for solids using various reference liquids, with several different approaches (Fowkes and Mostafa 1978; Liptakova and Kudela 1994; Gindl *et al.* 2001a,b). Many theories have

been introduced to describe and measure the surface free energy of materials with applications to wood systems. Depending on the surface to be examined and the selected test liquids, several methods are available for calculation of the surface energy of a solid. The earliest studies were based on critical surface tensions (Timmons and Zisman 1968), followed by the two liquids concept of harmonic (Gardner 1996, Maldas and Kamdem 1999) and geometric means (Gardner 1996; Owens and Wendt 1969), the equation of state (Neumann *et al.* 1974), and the Lifshitz-van der Waals/acid-base theory based on three liquids (Van Oss *et al.* 1988; Volpe and Siboni 1997; Wålinder 2002).

Sanding is a crucial process in the woodworking industry, as it determines the surface adhesion strength of coating films and the final perceived wooden esthetic product. A sanded wood surface is characterized by small uniform scratches that are more favorable for stain performance than are planed and sawn surfaces (Tan *et al.* 2012). A good understanding of the sanding effects is essential to achieve the desired surface quality and the optimum bonding strength at machining conditions. The sanding process influences not only the roughness, but also the surface chemistry components, *i.e.*, contact angle and surface free energy (El Abed *et al.* 2012). Multiple studies have reported that smaller contact angles (indication of good adhesion and improved wettability) were obtained after sanding of wood surfaces. (Sinn *et al.* 2004) investigated the chemical and morphological changes that occurred at spruce and beech wood surfaces when they are sanded using different grain sizes. The wettability, coating ability, and bonding strength may be affected by aging time. (Gindl *et al.* 2004) studied the effects of ageing on beech and Norway spruce wood surfaces using contact angle measurements combined with X-ray photoelectron spectroscopy. (Wålinder 2002) studied the Lewis acid-base properties of pine wood by contact angle analysis.

Wood can be viewed as a porous, heterogeneous, complex material comprised of cellulose, hemicellulose, lignin, and extractives, and these polymeric compounds are arranged in a cellular structure resulting in surface roughness on a microscopic scale (Gardner *et al.* 1991), so the equilibrium contact angle of liquid on the wood surface is hard to determine. There are two major effects, Wenzel showed an equilibrium effect of fine-scale roughness; the Wenzel equation shows how the presence of fine-scale roughness tends to amplify differences in contact angle relative to 90-degree angles (Huh and Mason 1977). The other main class of effects is due to contact angle hysteresis (Chibowski 2005). The contact angles assumed as equilibrium contact angle investigated in the study were acquired by linear regression method; the obtained contact angle is quite unlikely to be precisely true on a wood surface. The theory relating contact angle results to roughness was not considered in the present work but might be considered in future studies.

Most of the studies have focused on the surface free energy calculation of sanded wood or the aged wood, however, the surface free energy of fresh and aged wood (fast-grown poplar wood, especially) after sanding with varying grit numbers has rarely been studied. The aim of this work is to investigate the roughness of sanded poplar wood and the effects of sanding with different grit number and aging on the surface free energy of fast-growing poplar wood. Additionally, the different methods used to calculate the surface free energy were compared using contact angle measurements.

EXPERIMENTAL

Materials

Fast-growing poplar used in the experiment was obtained from a local woodworking factory (Hebei, Wen'an County). The average poplar density was 408 kg/m^3, with a standard deviation of 26 kg/m^3.

Samples were cut parallel to the grain direction and under control conditions of temperature and relative humidity of 20 °C and 65%, respectively. The samples were first planed and then sanded with varying grit numbers (60, 120, 180, and 240) 40 times parallel to the sample. After sanding, the wood dust was carefully cleared. The sanded samples were then left to age for 10 days in air, and the fresh wood samples were only sanded without ageing. Only heartwood was used to avoid experimental error between the sapwood and heartwood. The final dimensions of the samples were 100 mm × 25 mm × 3 mm.

Methods

Surface roughness

According to DIN 4768 (1990), the roughness parameter R_a (arithmetic mean of the deviations from the absolute values of the mean line profile) was measured using a Surtronic 3+ roughness tester (Taylor/Hobson Company, England) with a 20-μm-radius diamond stylus tip. The measurement angle used was 90º, and the evaluation length was 12.5 mm. The measurement results were processed using a digital Gaussian filter. Eight to ten wood samples were used for roughness measurement, and the unevenness error did not exceed ± 10%.

Image Analysis

Images of the surfaces of sanded wood samples parallel to the grain direction were obtained using scanning electron microscopy. An S-3400N (Hitachi, Japan) scanning electron microscope (SEM) operating at a 10-kV acceleration voltage was used to visualize the surfaces. Prior to imaging, samples were coated with gold-palladium in a sputter coater (E-1010, Hitachi, Japan)

Contact angle measurement

The contact angle measurements on the tangential surfaces of the samples were performed with an optical contact angles apparatus (OCA 20 DatapPhysics Instruments GmbH, Filderstadt, Germany) equipped with a video measuring system that included a high-resolution CCD camera and a high-performance digitizing adapter that enables instantaneous and frequency registration. SCA 20 software (DatapPhysics Instruments GmbH, Filderstadt, Germany) was used for data acquisition. Sessile droplets (3 μL, measured with a microsyringe) of liquids (for diiodomethane, 1.5 μL) were placed on the wood surface; the right and left angles of the drops on the surface were collected at intervals of 0.1 s for a total duration of 60 s, and the average of the angles was calculated. A minimum of 10 droplets was examined for each wood sample. In this study, three reference liquids were used. All the contact angles were observed parallel to the macroscopic fiber orientation. The contact angles of fresh wood were detected within 10 min after sanding treatment; therefore, the possible treated surface aging is minimized.

A direct determination of the contact angle on solid surfaces is difficult when the angle soon starts to change because of the interaction between the solid and the liquid. Because of the fast absorption of the reference liquids into the wood samples, a break point (constant contact angle, constant volume and height) was difficult to distinguish for the samples studied. Because both the absorption and spreading occur simultaneously, care must be taken to separate these processes. Different methods for determination of equilibrium contact angle and the contact angle used to calculate the surface free energy of wood have been presented (Liptakova and Kudela 1994). In this study, contact angle evolution after the initial wetting was fitted with a linear function, as we assumed that at the transient time of 0 to 0.5 s, spreading is forceful compared with absorption of samples; after that, the spreading and absorption are synchronous, and the function was extrapolated to t = 0. The value at t = 0 was taken to simulate the value of the equilibrium contact angle that would be observed on a non-absorbing and non-porous material (Nzokou and Kamdem 2004; Cao *et al.* 2005; Mamiński *et al.* 2009). This value was utilized to calculate the surface free energy of the wood samples following Young's equation (Eq. 1),

$$\gamma_S = \gamma_L Cos\theta + \gamma_{SL} \tag{1}$$

where γ_L is the surface tension at the liquid-air interface, θ is the contact angle (drawn through the liquid phase), and γ_{SL} is the solid-liquid interfacial tension.

Surface free energy

After calculation using Young's equation, the surface free energy of different wood samples was calculated by the Zisman method (Eq. 2) (Timmons and Zisman 1968), the OWRK method (Eq. 3) (Owens and Wendt 1969), and the vOCG method (Eq. 4) (Van Oss *et al.* 1988).

Zisman method

The Zisman method (Timmons and Zisman 1968) uses the following equation,

$$\cos\theta = 1 - b(\gamma_L - \gamma_S) \tag{2}$$

where *b* is the slope of the regression line. Zisman introduced the concept of critical surface energy (γ_C), which is defined as the surface tension of a reference liquid that fully wets the surface ($\gamma_L = \gamma_C$). If the experimentally determined values of the reference liquids lie in a straight line, then the full wettability of the surface is obtained by extrapolation to $\cos\theta = 1$ ($\theta = 0$). The critical surface tension can be calculated from at least two liquids.

OWRK method

The OWRK method (Owens and Wendt 1969) uses the following equation,

$$\gamma_L(1 + \cos\theta) = 2\sqrt{\gamma_S^d \gamma_L^d} + 2\sqrt{\gamma_S^p \gamma_L^p} \tag{3}$$

where γ_S is the surface tension of a solid, γ_L is the surface tension of a liquid, γ_{SL} is the surface tension of the solid-liquid interface, and θ is the contact angle between a solid

(S) and a liquid (L). γ_S^d and γ_S^p are the dispersion and polar components, respectively, in the surface free energy of a solid (mJ/m^2), and γ_L^d and γ_L^p are the dispersion and polar components, respectively, in the surface free energy of a liquid (mJ/m^2). Because of the presence of the polar term, the minimum number of liquids required to calculate the solid surface components is two, of known surface tension.

vOCG method

The vOCG method (Van Oss *et al.* 1988) uses the following equation:

$$\gamma_L(1+\cos\theta) = 2\sqrt{\gamma_S^{LW}\gamma_L^{LW}} + 2\sqrt{\gamma_S^+\gamma_L^-} + 2\sqrt{\gamma_S^-\gamma_L^+}$$

(4)

Instead of the polar component (hydrogen bond component) being described as γ^p, it is now described as γ^{AB}, where AB refers to the acid-base interactions. The non-polar (dispersion) term was described as γ^d; this was changed to γ^{LW}, where LW describes all the London-van der Waals forces. Thus, the surface free energy could be described as $\gamma = \gamma^{LW} + \gamma^{AB}$. Because the polar term was redefined to take into account the acid-base interactions, the component γ^{AB} is a combination of contributions from electron donors (γ^-) and electron acceptors (γ^+). The sum of the acid-base components can then be redefined as $\gamma^{AB} = 2\sqrt{\gamma^+\gamma^-}$. Because there are three terms that relate to the solid surface, at least three known liquids are used for contact angle measurements, two of which must be polar liquids.

The vOCG method (Van Oss *et al.* 1988) is critical because almost all surface free energy of solids calculated by the method had a much higher γ^- value than γ^+ value; the reason is that all the surface free energy components were determined on the assumption that the water component is $\gamma^+ = \gamma^-$, whereas water is a stronger Lewis acid than a Lewis base. Volpe and Siboni (1997) recalculated test liquid acid-base balances, resulting in a decrease in the base component compared to the vOCG method (Van Oss *et al.* 1988). The acid-base values of reference liquids used according to vOCG and DVS are list in Table 1.

**Table 1.** Surface Tension and Component Data for Test Liquids

Type of the Liquid Reference	γ_L	γ_L^{LW}	γ_L^{AB}	γ_L^+	γ_L^-
Van Oss (1988)					
Distilled water	72.8	21.8	51.0	25.5	25.5
Formamide	58.0	39.0	19.0	2.28	39.6
Diiodomethane	50.8	50.8	0.0	0.0	0.0
Volpe and Siboni (1997)					
Distilled water	72.8	21.8	51.0	65.0	10.0
Formamide	58.0	35.6	22.6	1.95	65.7
Diiodomethane	50.8	50.8	0.0	0.0	0.0

RESULTS AND DISCUSSION

Morphology and Contact angle

Surface roughness is an important property in terms of surface quality, particularly in finishing treatments (Buyuksari *et al.* 2011). The surface roughness of the wood surface could be affected by sanding treatment. The roughness parameter (R_a) was used to examine the surface roughness of poplar wood samples (Nemli *et al.* 2007; Sulaiman *et al.* 2009; Nadir Ayrilmis 2010). The contact angle of water and measured roughness parameter are shown in Table 1 and Fig. 2, and Fig. 1 shows the surface structure morphology.

Figure 2 indicates that the roughness parameter (R_a) decreased as the grit number increased. The changes in R_a values sanded by grit numbers of 120, 180, and 240 were slight. The sample sanded with the grit number of 180 had the smoothest surface, with an R_a value of 4.57 μm. Conversely, the control sample, with a R_a value of 8.43 μm, was the roughest surface. Figure 1 shows that the sample sanded with a grit number of 180 had the smoothest surface, the control sample was found to have a large number of destroyed vessels compared to the sanded samples, and fibrillation was seen on the samples, especially for samples sanded with grit numbers of 120 and 240. The sanding process can effectively reduce the wood surface roughness, although the change was not evident when the grit number increased from 180 to 240, which might be due to the irregularities from planing not being totally removed by the very fine grit number of 240.
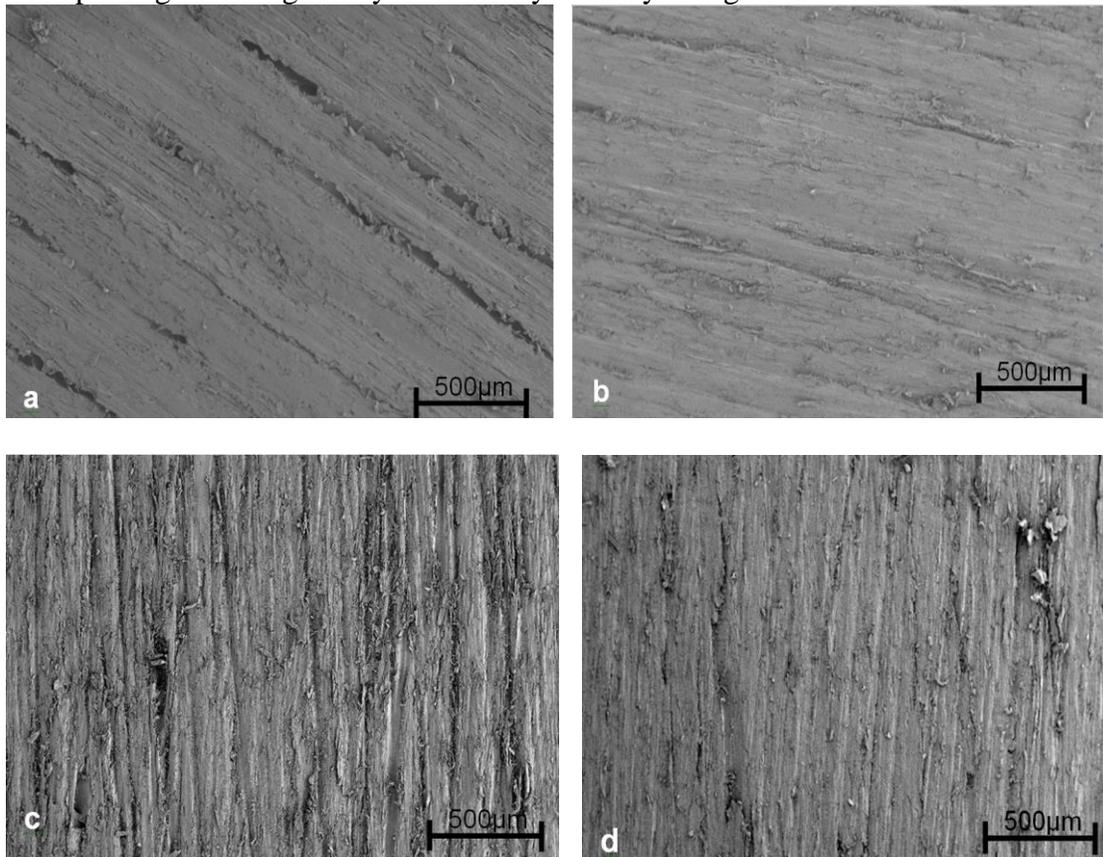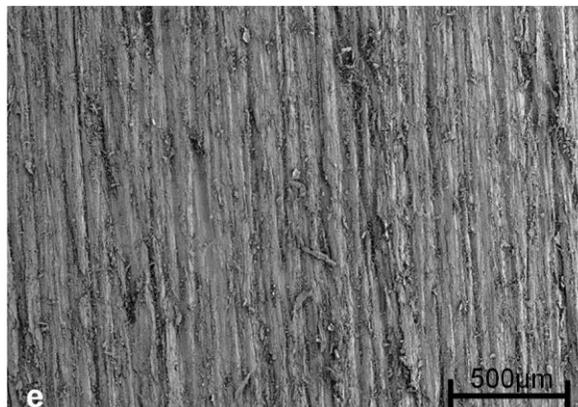
Fig. 1. SEM micrographs of sanded poplar wood samples. (a) Control, (b) 60, (c) 120, (d) 180, and (e) 240

Table 2. Contact Angles of Sanded and Aged Wood Samples

Wood samples	Water	Formamide	Diiodomethane
Fresh Control	48.1 (5.8)	26.9 (0.9)	33.8 (4.8)
Fresh 60	47.2 (5.1)	12.1 (1.4)	22.0 (3.4)
Fresh 120	40.3 (5.3)	13.6 (1.1)	14.8 (2.8)
Fresh 180	34.75 (2.1)	13.0 (1.7)	17.8 (4.2)
Fresh 240	37.1 (1.5)	15.3 (2.3)	20.8 (1.3)
Aged control	66.6 (4.5)	31.4 (4.2)	32.0 (2.8)
Aged 60	74.3 (5.5)	27.7 (1.1)	27.5 (2.1)
Aged 120	92.2 (12.7)	30.8 (5.8)	24.8 (2.9)
Aged 180	95.4 (6.5)	36.4 (2.8)	20.1 (3.8)
Aged 240	93.6 (9.8)	32.6 (5.9)	18.1 (4.4)

Standard deviation in parentheses

When sanded with 60 grit, the depth of vessels on the wood surface became shallower than the control wood, and the vessels disappeared when the grit number increased from 120 to 240. The wood surface sanded with 180 grit had the smoothest surface, and no fibrillation was found on the wood surface. Generally, the larger grit number corresponded with smaller roughness. It is commonly reported and agreed that grit size affects the surface roughness *i.e.*, a higher grit size produces a finer sanded surface (Fujiwara *et al.* 2005; Hendarto *et al.* 2005; Gurau *et al.* 2007).
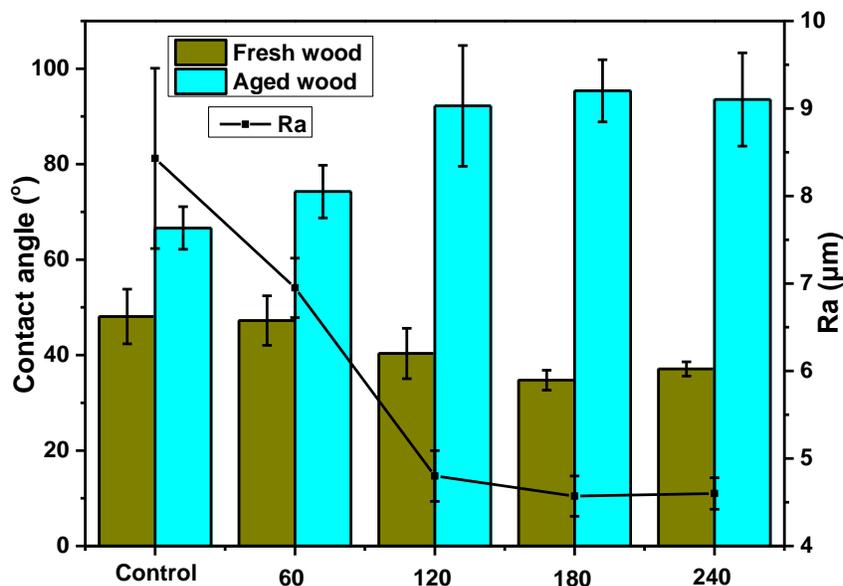
Fig. 2. Contact angle of water on sanded fresh and aged wood surface wood

To investigate the effect of the sanding process on the wood surface wettability the initial contact angles were acquired by the linear regression method. As shown in Table 2, for the fresh wood, the highest contact angles were obtained with water, whereas formamide gave the lowest contact angles. The contact angle of water decreased as the grit number increased, which means that the R_a value decreased with decreasing contact angle; the contact angle of the control sample was 48.1°. A similar occurrence was reported in cases of planed and sanded beech surfaces (Liptakova *et al.* 1995). Grit numbers of 180 and 240 yielded contact angles of 34.8° and 37.1°, respectively. The contact angle of the wood surface sanded by a grit number of 180 was 2.3° lower than that at 240; this followed the same trend as the R_a values. Because of the sanding process, the wood surface became smoother and more hydrophilic active groups (hydroxyl groups) were exposed on the surface, so the contact angle of water decreased. The wood flour created from the sanding process caused the water to spread more easily on the wood surface. These results were confirmed by other researchers, who found that smooth surfaces display hydrophilic characteristics (El Abed *et al.* 2012).

It is not surprising that fresh wood surfaces are more easily wetted by water than the aged wood samples, as consistently found in the literature (Gardner *et al.* 1991, Gindl *et al.* 2004). Figure 2 shows that the contact angle trend for aged wood surfaces was opposite that of the fresh wood surfaces; the contact angle increased as the surface roughness decreased. The contact angle of wood surface sanded by a grit number of 180 was 84.1°, and that for the aged control sample was 66.6°, approximately 26.0% lower than the aged and sanded wood. From Fig. 2, the conclusion can be made that all of the contact angles of aged wood were higher than those of fresh wood. For the control sample, the initial contact angle increased by 38.6%, and the contact angle increased by 142% for a grit number of 180. The hydrophobicity of the sanded wood after aging increased remarkably (Nussbaum 1999; Santoni and Pizzo 2011). Santoni and Pizzo (2011) found that the contact angle of fresh sanded poplar wood was 47.0°, while the contact angle was 86.0° for an aged sanded surface. The migration of extractives and

hydrophobic groups from the interior to the exterior may be the primary reason for this. At an R_a value of over 120, the contact angle changes were not evident.

Surface Free Energy Components

Figure 3 depicts the surface free energy of fresh and aged wood samples calculated by the Zisman method (Timmons and Zisman 1968). It can be seen that the surface free energy of control wood (fresh and aged) was smaller than the sanded wood samples, and the surface free energy of aged wood increased with increasing grit number, but the change was not remarkable.

As seen in Fig. 3, one can also conclude that the surface free energy of aged wood was larger than that of fresh wood, in accordance with the contact angle trend, in which the contact angle for aged wood samples was larger than that for fresh wood samples. Therefore, the data obtained by the Zisman method (Timmons and Zisman 1968) might be unsuitable, as indicated in many studies (Gardner 1996; Gindl *et al.* 2004; Maldas and Kamdem 1998) and by the following empirical statement: "Lower surface free energy would have a higher contact angle, and meanwhile, higher surface free energy would have a lower contact angle" (Baldan 2012).

There is no doubt that the surface free energy calculated from the contact angle using the Zisman method (Timmons and Zisman 1968), OWRK method (Owens and Wendt 1969), and vOCG method (Van Oss *et al.* 1988) showed wide variations. Zisman (Timmons and Zisman 1968) himself always emphasized that the critical surface free energy is not the surface free energy, but only an empirical parameter related closely to this quantity (Baldan 2012). For fresh wood, the critical surface free energy according to the Zisman method (Timmons and Zisman 1968) is systematically 30 to 40% lower than that calculated by the OWRK method (Owens and Wendt 1969). A similar occurrence was observed by Maldas and Kamdem (1998) and Gindl *et al.* (2001a). However, for aged wood, the changes in surface free energy among the Zisman method (Timmons and Zisman 1968), OWRK method (Owens and Wendt 1969), and vOCG method (Van Oss *et al.* 1988) were not evident (Fig. 4 and Table 3).
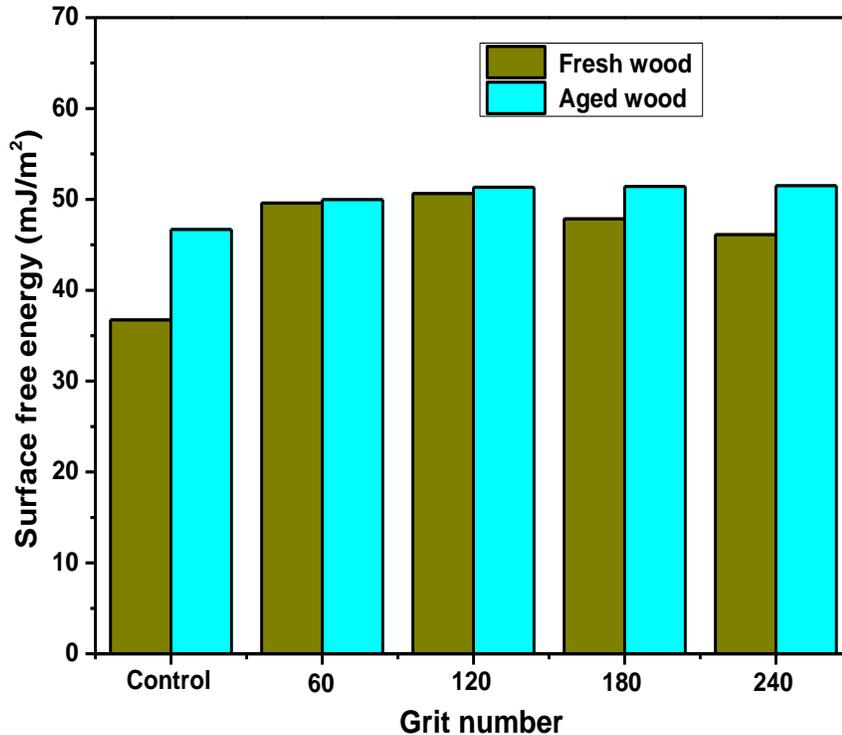
Fig. 3. Surface free energy of fresh and aged wood samples (calculated by the Zisman method)
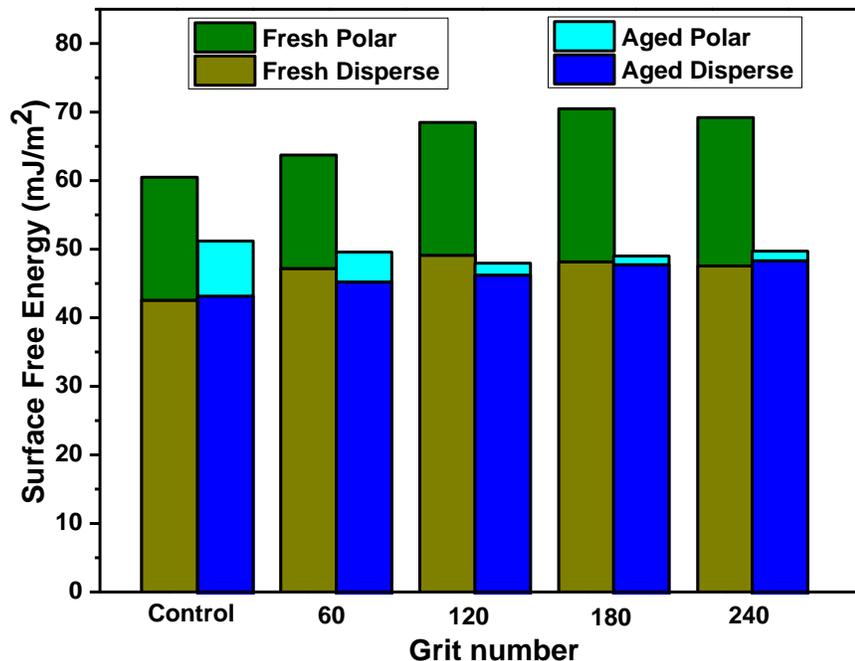

Fig. 4. Surface free energy and its components for sanded and aged wood (calculated by the OWRK method)

The effects of sanding and aging on the surface free energy and its components as calculated by the OWRK method (Owens and Wendt 1969) are shown in Fig. 4. For the fresh wood samples, the surface free energy of fresh wood increased as the grit number increased from 60 to 180. The dispersion component, and the polar component of sanded

wood samples were all higher than these of control sample. The change of surface free energy and its components were not remarkable when the grit number was higher than 120, the surface free energy change was attributed to an increase in the disperse component.

After sanding, the increased surface free energy may be due to the active functional groups exposed (*i.e.,* hydroxyl groups), which caused the surface to become more hydrophilic. Lower surface free energy was observed for the control sample compared with the sanded samples. For the aged wood surfaces, contrary to the surface free energy obtained by the Zisman method (Timmons and Zisman 1968), the surface free energy decreased as grit number increased, the disperse component increased as the grit number decreased but not remarkably. The reduction of the polar component caused the surface free energy to decrease. At a grit number over 120, the effect of grit number on the changes of the surface free energy, polar component, and disperse component were all not obvious. The decreased polar component caused the surface free energy to decrease in spite of the increase in the dispersion component. The dispersion component increased, but the change was not distinct, which indicated that part of the extractives migrated to the surface.

As shown in Table 3, the total surface free energy (γ_S) of the fresh wood samples was higher than that of aged wood samples, which is caused by the presence of extractives (Gindl *et al.* 2004; Santoni and Pizzo 2011). In the case of the fresh wood samples, the surface free energy of the control wood sample was lower than that of sanded wood samples; the surface free energy was highest at a grit number of 60, but the change was insignificant.

Table 3. Surface Free Energy of Different Wood Samples (Obtained by the vOCG Method using Liquid Parameters from Van Oss *et al.* (1988))

Sample	Surface Energy components (mJ/m^2)				
	γ_S	γ_S^{LW}	γ_S^{AB}	γ_S^{+}	γ_S^{-}
Control	53.04	42.56	10.48	1.13	24.29
Fresh 60	58.16	47.18	10.98	1.46	20.65
Fresh 120	58.13	49.12	9.01	0.70	29.00
Fresh 180	57.58	48.41	9.17	0.60	35.06
Fresh 240	57.10	47.54	9.56	0.69	33.08
Aged control	50.45	43.20	7.25	1.96	6.72
Aged 60	49.43	45.24	4.19	2.96	1.48
Aged 120	46.23	46.23	0.00	3.26	0.00
Aged 180	48.16	47.76	0.40	2.03	0.02
Aged 240	48.64	48.33	0.31	2.47	0.01

Table 4. Surface Free Energy of Different Wood Samples (Obtained by the vOCG Method using Liquid Parameters from Volpe and Siboni (1997))

Sample	Surface Energy components (mJ/m²)				
	γ_S	γ_S^{LW}	γ_S^{AB}	γ_S^{+}	γ_S^{-}
Control	50.32	42.56	7.76	1.38	10.84
Fresh 60	54.96	47.18	7.78	1.56	9.71
Fresh 120	56.46	49.12	7.34	1.11	12.14
Fresh 180	56.37	48.41	7.96	1.11	14.29
Fresh 240	55.54	47.54	8.00	1.17	13.69
Aged control	48.14	43.20	4.94	1.49	4.09
Aged 60	48.77	45.24	3.53	1.79	1.74
Aged 120	47.93	46.23	1.70	1.69	0.43
Aged 180	48.98	47.76	1.24	1.07	0.36
Aged 240	49.67	48.33	1.34	1.28	0.35

A similar occurrence was found by Sinn *et al*. (2004) in the case of spruce and beech. They found that an increase in roughness leads to a higher surface free energy up to a specific roughness, after which the surface free energy decreased. As for the aged wood samples, the surface free energy of the aged control wood sample was higher than that of sanded aged wood. As the grit number increased, the total surface free energy initially decreased, followed by an increase. This trend was opposite to the change of fresh sanded wood samples. Table 3 shows that the effect of roughness on the acid-base components, acid component, and base component was unremarkable. Compared to the fresh wood samples, the acid component increased and the base component decreased in the aged wood samples. This may be due to the oxidation of extractives on the wood surface (Wålinder and Gardner 2000). The surface free energy calculated by the vOCG method (Van Oss *et al*. 1988) was similar to the data calculated by the OWRK method (Owens and Wendt 1969).

As indicated from Table 3, the base components were distinctly higher than the acid components for the fresh wood samples, and the acid components were distinctly higher than the base components for the aged samples. This finding, inconsistent with that of Gindl that the base components were higher than the acid components (Gindl *et al.* 2004), may be due to the different reference liquids and/or the different species of wood; more work is necessary to determine the basis of this discrepancy. As shown in Table 4, the base-acid component ratios for fresh wood obtained by the vOCG method (Van Oss *et al.* 1988) using liquid parameters from Volpe and Siboni (1997) were considerably lower than those ratios obtained from Van Oss *et al.* (1988). Table 4 shows that no notable difference was observed in the total surface free energy obtained from the two different liquid parameters. The total surface free energy of aged wood samples (obtained using liquid parameters from Volpe and Siboni (1997)) were not significantly different. The acid-base components of aged wood samples decreased with increasing grit number.

From Tables 3 and 4, comparing the fresh wood and aged wood, the acid component of fresh wood increased while the base component decreased, which may be

due to the reorientation of functional groups in the wood-air interface and oxidation. These results agreed with results from Wålinder *et al.* (2002). The surface free energy of wood samples obtained using the liquid parameters from Volpe and Siboni gave a better balance between the acid component and base component (Volpe and Siboni 1997; Wålinder 2002).

CONCLUSIONS

1. The roughness parameter (R_a) decreased as grit number increased. Therefore, the sanding process can effectively reduce the wood surface roughness; no change was evident for a grit number increase from 120 to 240.

2. The contact angle of water on the fresh wood samples decreased as the grit number increased. The fresh wood surface was more easily wetted by water than was the aged wood sample. The contact angles increased as the surface roughness decreased.

3. The surface free energy of sanded aged wood obtained by Zisman model may not be relevant.

4. For the fresh wood samples, the change of surface free energy and its component were not remarkable when the grit number was higher than 120; for the aged wood samples, the disperse component increased as the grit number decreased but not remarkably.

5. The effect of roughness on the acid-base components, acid component, and base component (calculated using the vOCG method) were unremarkable. The surface free energy of wood samples (obtained using the liquid parameters given by Volpe and Siboni (1997)) can effectively balance the relationship between the acid and base components.

ACKNOWLEDGMENTS

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