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Abstract Wettability and bonding quality of exterior coatings on fast-growing wood surfaces were studied. Samples of air-dried flat-grained (tangential surface) and edge-grained (radial surface) pattern of jabon (*Anthocephalus cadamba*) and sengon (*Paraserianthes falcataria*) woods were used. Before application of exterior coatings, the surfaces of the lumber samples were sanded. To provide wood surfaces with various degrees of roughness, abrasive papers of 120, 240, and 360 grits were used for the surface preparation. The wettability of two exterior coatings (water-based acrylic and oil-based alkyd varnishes) on the sanded wood surfaces was measured using a sessile drop contact angle method. The Shi and Gardner (S/G) model was used to evaluate and compare the wettability of the surface coatings on the wood. The sanded wood samples were coated with the two coatings (two layers each). Bonding quality of the coating layers was measured using a crosscut tape test method. Experimental results show that constant contact angle change rate (K value) of the S/G model decreased as the grit number of abrasive paper increased. This indicates that the wettability decreased as the roughness of the surface decreased (surface becomes smoother). There was no evidence of differences in wettability between tangential and radial wood surfaces. The oil-based alkyd coating generated better wettability compared to the water-based acrylic. The crosscut tests showed that the bonding quality of the coating films on both jabon and sengon wood decreased as the surface became smoother. The sengon wood compared to jabon wood provided better coating wettability and bonding quality. Wettability in terms of the K values was a good indication for determining the bonding quality of the two varnish layers.

Keywords Fast-growing wood, Sanding, Surface roughness, Acrylic and alkyd coatings, Contact angle, Wettability, Bonding quality

Introduction

Tropical plantation trees are increasingly seen as a valuable renewable natural resource. Fast-growing trees in the tropics grow in a similar way all year round as a continuous response to favorable environmental conditions (available sun, soil moisture, and nutrients). Plantation trees maintain and improve soil fertility and provide protection from sun, wind, and heavy rain. Among the Indonesian fast-growing tree species, sengon (*Paraserianthes falcataria*) and jabon (*Anthocephalus cadamba*) are widely planted across Java Island by local communities. Sengon and jabon trees have inherently adapted to take advantage of the continuous growing season and suitable growing site of the Java regions in which they grow well. In Java, important artificial regeneration programs and tree improvement research activities have been devoted to these species in recent years. Large-scale reforestation with the fast-growing sengon and jabon are likely to shorten rotations in the near future.[1] This leads to a high percentage of juvenile wood in the tree stems.[2]

The Indonesian wood industry will soon utilize the fast-growing jabon and sengon for pulpwood and also

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for furniture, and wood composites for light construction. Sengon and jabon trees are valuable as both lumber for furniture and veneers for laminated veneer lumber (LVL) attributable to good bonding strength.[3] These species are therefore of vital economic importance for Indonesia. In addition, utilization of the fast-growing jabon and sengon for both interior and exterior purposes can help to solve the problems linked to the decrease in raw material and to the protection of the native forest. However, the fast-growing jabon and sengon wood for exterior uses could degrade at a faster rate because of physical, mechanical, and biological factors, and natural weathering from the combined effects of solar radiation and rain. In this work, surface coating was proposed to improve weathering resistance by considering that the low specific gravity of jabon and sengon would indicate low shrinkage rates which decrease coating failures.

Durability of a coating film is determined by adhesion quality between varnish coatings and the surface of the wood.[4] One important indicator of the quality formation of adhesion is the ease of varnish liquid wetting the wood surface (wettability). Wettability is a term used to describe the adhesion phenomenon of a liquid contacting a solid surface.[5] The wettability of wood is influenced by many factors such as surface roughness,[6] wood species and location of wood (sapwood and heartwood),[7] aging time of exposed surface,[8] machining conditions,[9] treatment and drying methods,[10] amount of extractives,[5,11] and moisture content of wood.[12] In addition to the properties of wood, the properties of the coatings (e.g., viscosity, type of coating, temperature, and surface tension) also influence the wettability.[13]

Wettability can be obtained by measuring the contact angle between the liquid and the surface of the wood. Contact angles less than 90° indicate a high wettability where the liquid wets the wood surface well. Contact angles greater than 90° indicate a low wettability in which the liquid does not wet the wood surface well.[14] Many different models have been used to evaluate the wettability of wood. Both initial contact angle, which is the intercept value of the regression line of the contact angle values over time, and the rate of decrease in contact angle were used to evaluate the wettability of chromated copper arsenate (CCA)-treated wood.[15] A differential method was used for evaluating the contact angle measurement, and the "constant wetting rate angle" (CRWA) was considered as the values determined when the wetting rate becomes constant.[16] Shi-Gardner wetting model (S/G model) was proposed to evaluate the dynamic wetting process.[17] Contact angle from the average of measurements over a 10-s period was obtained to investigate the wettability and surface roughness of natural and plantation-grown narrow-leaved ash wood.[18] A modified wetting model by adding the limitation terms of initial contact angle and equilibrium contact angle was also developed.[19]

The wettability of wood is a useful parameter that provides information about the interfacial phenomenon between the wood surface and coatings and has a great influence on the bonding quality of a coating film. Most studies on wettability have been carried out for adhesives on wood surfaces. Some authors have investigated the wettability between adhesives and the surface roughness of wood panels.[20–22] On the contrary, very few studies on wettability have been carried out for varnish or paint coatings and wood surfaces. Suitable wettability will be an important indication of adequate bonding quality of a varnish or paint coating on jabon and sengon wood surfaces. The objective of this study was to investigate and compare the wettability of water-based acrylic and oil-based alkyd varnishes on jabon and sengon wood with different surface roughness, and to determine the bonding quality of the varnish coating films.

Materials and methods

Materials

Fast-growing jabon and sengon tress used in this experiment were obtained from a plantation forest planted by a local community in 2010. The plantation site was located in the Bogor region of Indonesia. Sengon (*P. falcataria*) and jabon (*A. cadamba*) trees (3 each) were selected from the plantation site as representative specimens. The sample trees of both sengon and jabon were 5 years old. The sample trees had a height of branch-free stem range from 8 to 11 m, and a diameter at breast height level (1.3 m above ground level) varying between 34 and 37 cm. After felling the trees, one log section with a length of 2.5 m was taken from each tree at the bottom part of the tree stem. The sample logs were transported to the wood workshop for preparation of test specimens.

The sample logs were sawn by band saw in such a manner that flat-grained (FG) and edge-grained (EG) lumbers in thickness of 2.5 cm were produced. The lumber was carefully air-dried to prevent warping. The lumber with 12–15% moisture content was surfaced and cut to produce the final sample dimensions of 30 cm × 15 cm × 2 cm. Two replicates were tested, and the total samples prepared for each wood species were 32 pieces (16 pieces of FG and 16 pieces of EG).

An oil-based alkyd and a water-based acrylic varnish were chosen to investigate their dynamic wettability and bonding quality on the jabon and sengon wood surfaces. Both alkyd and acrylic varnishes were obtained from a local paint store in Bogor. A mixture of alkyd varnish (90%) and oil thinner (10%) was prepared and stirred uniformly. Another mixture of acrylic varnish (70%), and water (30%) was also prepared. The two coating mixtures were applied according to the manufacturer's recommended brushing and spreading rate. The viscosity of the alkyd and acrylic mixtures measured by a viscometer was in the average of 0.2 and 1.5 poise, respectively.

Methods

Roughness (Ra) measurement

A set of jabon and sengon samples was kept unsanded as the control. The others were sanded ten times parallel to the length with abrasive papers of P120, P240, and P360 grit. The wood dust produced was carefully cleaned by a standard wood shop air-spray. Roughness values were measured with a diamond tip radius of 5 µm. The tracing length was 15 mm, and the cutoff was 2.5 mm. The measuring force of the scanning arm on the surfaces was 4 mN, which did not significantly damage the surface according to the roughness tester TR200 user manual (Qualitest surface roughness tester 2004). The ten points of roughness measurements were diagonally marked on the surface of the samples. Measurements were made perpendicular to the fiber direction of the samples. Measurements were repeated whenever the stylus tip generated an error during the tests.

Contact angle measurement

Contact angle measurements on the tangential surface of the flat grain samples (FG) and the radial surface of the edge grain samples (EG) were performed with a video measuring system with a high-resolution CCD camera. This system consisted of a CCD camera, and a computer. During measurement, a wood sample was placed on the top of a table in front of the CCD video camera. A 30-µL varnish droplet was placed on the wood surface with a micropipette. Video images of the varnish drop shape on the wood surface were captured by the CCD camera and saved for the duration of 180 s. Five drops per sample were captured for each varnish, two samples were used, and ten measurements of contact angle were obtained. Each of captured video images was cut to an individual image at intervals of 10 s for a total duration of 180 s. Contact angle (θ) of the individual image of the drop was measured by the Motic image software. Fifteen data points were taken for each recorded drop to obtain a curve of contact angle versus time.

Determination equilibrium contact angle and constant contact angle change rate

When a liquid drop of coating is placed on the wood surface, the liquid will spread, penetrate, and form a contact angle. As time elapsed, the drop shape tends to stabilize in which an equilibrium contact angle (θ_e) will be obtained. A segmented regression model was used to determine the equilibrium contact angle. It is assumed that development of contact angle during wetting process can be described by two functions in a curve (Fig. 1). The first function is a steep slope (quadratic) of the curve over the first second beginning of spreading and penetration, and the second function is a constant slope (plateau) for the later part of the curve (constant contact angle). The fitted regression model for the functions takes the form of a quadratic model with plateau. The transition point between the two functions ($\boldsymbol{t_e}$) was directly obtained by using nonlinear least-squares procedures (PROC NLIN) in SAS STAT.[23]

Contact angle change rate depends on the contact angle at a particular time. Several models have been applied to evaluate contact angle change rate measurement by employing differential methods. The constant contact angle change rate (K value) on the S/G model[17] (Shi and Gardner, 2001) was used to quantitatively evaluate the wettability in this work. The K value measures how fast the liquid spreads and penetrates. Higher K values correspond to a shorter time required for the contact angle to reach relative equilibrium and for the liquid to spread and penetrate. The S/G model is described in equation (1).

$$\theta = \frac{\theta_i x \theta_e}{\theta_i + (\theta_e - \theta_i) e^{\left[K\left(\frac{\theta_e}{\theta_e - \theta_i}\right)t\right]}}, \tag{1}$$

where θ_i is the initial contact angle, θ_e is the equilibrium contact angle, θ is the contact angle at a certain time, t is the wetting time, and K is a constant contact angle change rate. The K values were calculated using defined functions of nonlinear regression model to fit the S/G equation by XLSTAT.[24]

Coating application and bonding quality test

The unsanded and sanded sengon and jabon wood samples were coated by the above-mentioned varnish types for bonding quality evaluation. Two coats were

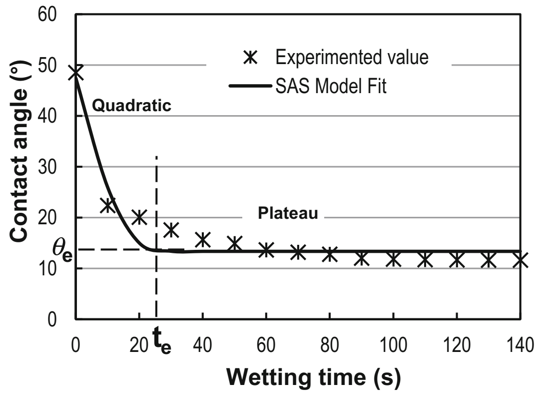

Fig. 1: Determination of the equilibrium contact angle (θ_e) from a plot of the contact angle as a function of time, by segmented regression model

applied on the wood surfaces to achieve a total application of 150 g/m^2 wet film and a dry film thickness of 60 ± 5 μm. The required weight of each coat to achieve these spread rates was calculated based on the surface area of the samples. The varnishes were applied by brush on the front face and the back of the samples. Twenty-four hours drying time was allowed before the second coat was applied. When the second coat had dried, the coated samples were conditioned for one week in a clean room at approximately 25°C temperature and 75% relative humidity.

A crosscut tape test method was applied to evaluate the resistance of the coating films to separation from wood surfaces.[25] A crosscut pattern was made through the film with a sharp cutter head. Pressure-sensitive tape was applied over the cut. Tape was smoothed into place by using a pencil eraser over the area of the incisions. Tape was removed by pulling it off rapidly back over itself close to an angle of 180°. Adhesion was assessed on a 0–5 scale. The scale 5 is 0% area removed, and scale 0 is greater than 65% area removed. Five crosscut patterns per sample were made for each varnish coating, two samples were used, and ten measurements of crosscut were obtained. The scales of the adhesion were averaged.

Statistical analysis

An analysis of variance, ANOVA, was conducted ($p < 0.05$) to evaluate the effect of the varnish coating type and grit size of the abrasive paper (the surface roughness) on the wettability (equilibrium contact angle, and K value), and bonding quality between the varnishes and wood samples. Significant differences among the average values of the factors were determined using Duncan's multiple range tests.

Results and discussion

Equilibrium contact angle

The results in Fig. 2 show the decrease in the contact angle as a function of time for different wood surfaces and varnish coating systems. Oil-based alkyd exhibited lower instantaneous contact angles than water-based acrylic varnish, and this can be attributed to the lower surface tension of the oil-based versus water-based coating. The oil-based alkyd also appeared to generate an equilibrium contact angle faster than the water-based acrylic (Fig. 2). The equilibrium contact angles (θ_e values) of the model fit for all experimental data in Fig. 2 were calculated using a segmented regression model, and the results are presented in Table 1. The θ_e of water-based acrylic on tangential and radial surface of sengon wood was between 13.4°–24.5° and 15.6°–26.0°, respectively, then on tangential and radial of jabon wood was between 17.8°–32.7° and 18.1°–32.6°, respectively. For the oil-based alkyd, the θ_e was calculated to be 0. In order to understand the surface properties of the jabon and sengon woods, the θ_e values of distilled water on the surfaces of unsanded and sanded tangential surfaces of jabon and sengon were measured and were calculated to be 0°, respectively. These results indicate that the surface tension of the acrylic resin would be larger than that of distilled water. It also appears from Table 2 that the oil-based alkyd reached equilibrium contact angle at a faster rate compared to water-based acrylic. The changes in θ_e with increasing grit number for P120, P240, and P360 were observed for the water-based acrylic in both jabon and sengon. However, the effect of roughness on the θ_e for the oil-based alkyd on the jabon and sengon wood surfaces was not different.

Table 2 shows the analysis of variance result for the equilibrium contact angle by using a factorial in block (wood species) design. It is seen from Table 2 that varnish type and sanding treatments showed a significant effect (p value < 0.05) on the equilibrium contact angle. For the wood surface factor, no significant difference was observed in equilibrium contact angle, indicating that the effect of FG sample (tangential surface) and EG sample (radial surface) on the equilibrium contact angle was not different. The θ_e value for acrylic and alkyd varnishes on the wood surfaces was significantly different. Alkyd varnish had a lower viscosity compared to the acrylic varnish. In addition, surface tension and molecular weight (2000–8000 g/mol) of alkyd resin is lower compared to surface tension and molecular weight (10^5–10^6 g/mol) of the acrylic resin.[26] The formation of a continuous film from an alkyd resin is less critical than in the case of an acrylic resin because of the lower molecular weight and lower viscosity of an alkyd. Alkyd resin spreads completely during film formation even without the presence of solvent. The ease of spreading of the alkyd leads to beneficial substrate wetting and penetration in wood. The lower θ_e of the oil-based alkyd indicates that it should create more intimate contact on the wood surface than that of the water-based acrylic.

Surface roughness is an important property in terms of surface quality, particularly in finishing treatments. The increasing in grit number from P120 to P360 in this work contributed to a decrease in surface roughness parameter (Ra) of both jabon and sengon wood across the grain from 14.37 to 11.46 μm, and 15.08 to 12.36 μm, respectively. The Ra values across the grain for unsanded jabon and sengon were 14.77 and 15.89 μm, respectively. The increase in the grit number which caused the decrease in the surface roughness of jabon and sengon leads to the significant increase in the θ_e of varnish coatings (Table 2). Duncan's multiple range tests showed that the θ_e value was significantly different among the unsanded and sanded surfaces of different samples. It was described that the surface roughness of wood decreases as grit number increased.[6] With an increase in grit number of abrasive paper from P80 to P240, the Ra surface roughness

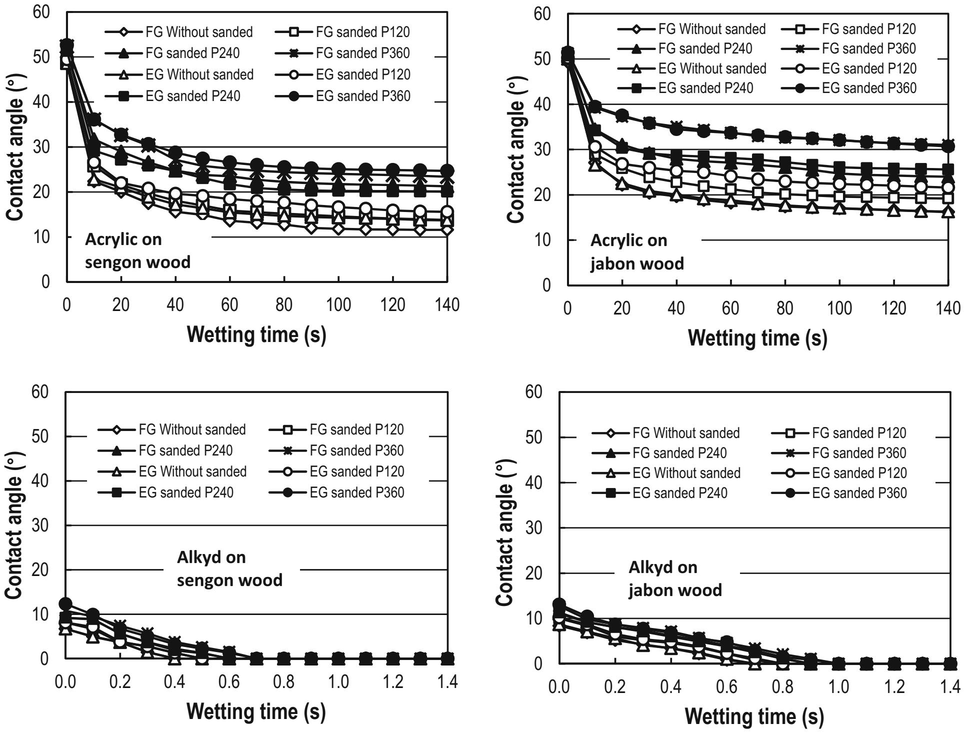

Fig. 2: Progress of contact angle and wetting time for water-based acrylic and oil-based alkyd varnish on the sengon and jabon wood surfaces

Table 1: Equilibrium contact angle (θ_e) for acrylic and alkyd varnishes on the sengon and jabon wood surfaces

Wood	Surface pattern and sanding treatment	Water-based acrylic		Oil-based alkyd	
		θ_e (°)	Time at equilibrium (s)	θ_e (°)	Time at equilibrium (s)
Sengon	FG without sanded	13.4	25.6	0	0.6
	FG sanded P120	15.7	27.7	0	0.7
	FG sanded P240	22.9	29.7	0	0.8
	FG sanded P360	24.5	47.5	0	1.0
	EG without sanded	15.6	18.8	0	0.6
	EG sanded P120	17.7	24.4	0	0.7
	EG sanded P240	21.7	25.1	0	0.8
	EG sanded P360	26.0	39.9	0	0.8
Jabon	FG without sanded	17.8	25.4	0	1.0
	FGl sanded P120	20.7	26.4	0	1.1
	FG sanded P240	25.9	31.9	0	1.4
	FG sanded P360	32.7	38.4	0	1.5
	EG without sanded	18.1	23.7	0	1.0
	EG sanded P120	23.5	23.8	0	1.1
	EG sanded P240	27.2	25.3	0	1.3
	EG sanded P360	32.6	39.7	0	1.4

parameter of ash and birch wood across the grain decreased from 8.64 to 3.88 μm, and from 8.43 to 3.87 μm, respectively. A similar occurrence was observed on the θ_e between adhesive and roughness of wood surfaces.[27,28] The θ_e is lower when the wood surface is rougher.

Wettability

The S/G model is the most commonly used wood wetting model.[17] The varnish coating or adhesive wettability on different wood surfaces can be quantitatively evaluated by applying the S/G model. The

Table 2: Analysis of variance for the equilibrium contact angle

Source	DF	Sum of squares	Mean squares	*F*	*Pr* > *F*
Model	16	4397.021	274.814	63.793	<0.0001
Varnish type	1	3960.500	3960.500	919.354	<0.0001
Surface pattern	1	2.420	2.420	0.562	0.465
Sanding	3	188.088	62.696	14.554	0.000
Wood species	1	52.531	52.531	12.194	0.003
Varnish and surface pattern interaction	1	2.420	2.420	0.562	0.465
Varnish and sanding interaction	3	188.088	62.696	14.554	0.052
Surface pattern and sanding interaction	3	1.488	0.496	0.115	0.950
Varnish, surface pattern, and sanding interaction	3	1.488	0.496	0.115	0.950
Error	15	64.619	4.308		
Corrected total	31	4461.640			

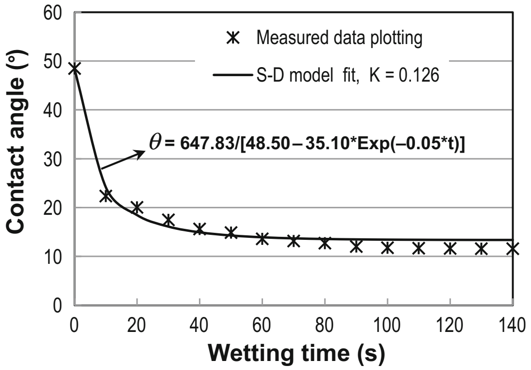

Fig. 3: Determination of the constant contact angle change rate (*K* value) according to the S-D model

constant contact angle change rates (*K* values) for all experimental data in Fig. 2 were calculated using the least-squares method to fit the S/G equation by XLSTAT. As a sample of *K* value calculation, the wetting progress of water-based acrylic on the tangential surface of unsanded sengon wood using the S/G model is shown in Fig. 3. The average *K* values of five measurements for all varnish coatings and wood samples are shown in Table 3. Table 3 shows that the R squared values of the wetting model were over 0.96 for all wood surfaces examined. Coefficients of variation (CV) of the calculated *K* values were less than 10%. Therefore, the S/G wetting model could accurately be used to describe the varnish wetting process on the jabon and sengon wood surfaces. The results in Table 3 also show that the unsanded wood samples had the highest *K* value and the *K* value for sanded wood decreased as the grit number of the abrasive paper increased both for the acrylic and alkyd varnish coatings. Compared to jabon wood samples, sengon wood surfaces were more wettable. The oil-based alkyd generated larger *K* values compared to water-based acrylic.

Varnish coating type

Analysis of variance results in Table 4 shows that varnish type and sanding factors had a significant effect (p value < 0.05) on the *K* value. The effect of tangential (FG samples) and radial (EG samples) surfaces on the *K* value was not significant (p value > 0.05). The *K* value of alkyd on sengon wood along the unsanded tangential surface (10.847) was greater than that of acrylic resin (0.126), also the *K* value of alkyd on jabon wood along the unsanded tangential surface (6.360) was greater than that of acrylic resin (0.104). The greater *K* values of alkyd resin indicated its faster penetration and spreading on the wood surface compared to the acrylic resin. By considering the fact that the acrylic and alkyd in this study were prepared and applied at the manufacturer's recommended use, it can be concluded that alkyd resin exhibits better wettability than acrylic resin and should form more intimate contact with the jabon and sengon wood surfaces.

Sanded wood surface

Surface roughness of the wood samples decreased with increasing grit number of the abrasive paper. The lower roughness of the wood samples sanded by higher grit number rather than lower grit number was attributed to the smaller particle size of the higher grit number of the paper. The wood samples sanded by higher grit paper could produce shallower ridges and valleys as compared to the wood samples sanded by lower grit paper. The surface sanded with lower grit number had a higher *K* value. A higher *K* value means that the surface is more wettable. Both sengon and jabon wood surfaces that were sanded with 120-grit size were more wettable compared to those that were sanded with 240 and 360-grit size. Duncan's multiple range tests showed that the *K* value was significantly different among the sanded surfaces using different grit number papers. However, the *K* values of wood surfaces for the unsanded and

Table 3: Constant contact angle change rate (*K* value) for water-based acrylic and oil-based alkyd varnishes on sengon and jabon wood surfaces

Wood	Surface pattern and sanding treatment	Water-based acrylic		Oil-based alkyd	
		K value	R^2	*K* value	R^2
Sengon	FG without sanded	0.126	0.984	10.847	0.880
	FG sanded P120	0.104	0.990	8.907	0.939
	FG sanded P240	0.070	0.985	6.892	0.880
	FG sanded P360	0.049	0.990	6.013	0.869
	EG without sanded	0.132	0.983	10.719	0.905
	EG sanded P120	0.106	0.985	8.762	0.915
	EG sanded P240	0.084	0.971	7.167	0.877
	EG sanded P360	0.050	0.986	5.343	0.913
Jabon	FG without sanded	0.104	0.993	6.360	0.864
	FGI sanded P120	0.087	0.985	5.358	0.897
	FG sanded P240	0.055	0.976	3.812	0.872
	FG sanded P360	0.032	0.963	3.790	0.890
	EG without sanded	0.110	0.988	6.121	0.898
	EG sanded P120	0.083	0.980	5.215	0.878
	EG sanded P240	0.064	0.979	4.088	0.882
	EG sanded P360	0.033	0.965	4.058	0.907

Table 4: Analysis of variance for the constant contact angle change rate (*K* value)

Source	DF	Sum of squares	Mean squares	*F*	*Pr* > *F*
Model	16	380.531	23.783	14.339	<0.0001
Varnish type	1	326.165	326.165	196.640	<0.0001
Surface pattern	1	0.007	0.007	0.004	0.949
Sanding	3	17.187	5.729	3.454	0.044
Wood species	1	21.127	21.127	12.737	0.003
Varnish and surface pattern interaction	1	0.009	0.009	0.006	0.942
Varnish and sanding interaction	3	15.882	5.294	3.192	0.059
Surface pattern and sanding interaction	3	0.081	0.027	0.016	0.997
Varnish, surface pattern, and sanding interaction	3	0.074	0.025	0.015	0.997
Error	15	24.880	1.659		
Corrected total	31	405.411			

sanded with 120-grit were not significantly different. With increasing surface roughness, the spreading and penetration of coatings on the surface of the wood samples increased. It should be noted that the higher wettability of rougher surfaces could be attributed to the higher amount of peaks and valley points on the surface where liquid can be captured by capillary force. It was stated that a rough surface provides paints several possibilities to penetrate and create ''fingers of resin,'' which helps in developing strong joints.[29,30] On the other hand, high roughness has the negative effect of high cost, due mainly to the excessive volume of paint necessary to give surfaces smooth appearances.

Jaban and sengon wood

Significant differences in *K* values between sengon and jabon were found in the three-way ANOVA with *p* values less than 0.05 (Table 4). As shown in Table 3, both the alkyd and acrylic coatings exhibited a greater *K* value on sengon than on jabon wood surface. The effect of wood species on the spreading and penetration could strongly depend on the texture and structure of the wood surface. The sengon and jabon woods have well-known differences in texture and structure. Sengon wood is normally rough in texture compared to the fine texture in jabon.[31] Sengon is significantly different in vessel and fiber structure than jabon wood. Vessel area of sengon (average 30,428 μm^2) is larger than that of jabon (average 14,960 μm^2), and lumen fiber diameter of sengon (average 21.67 μm) is larger than that of jabon (18.86 μm).[32] In addition, it was observed in this work that the average surface roughness (*Ra* value) of sengon (15.89 μm) was larger than that of jabon (14.77 μm). Therefore, the sengon wood is considered to have higher liquid spreading and penetration than that of jabon wood.

Bonding quality of varnish coatings

Average values of bonding quality according to varnish type, grit size, and wood species are presented in Fig. 4. Bonding quality decreased from the unsanded surface to 360-grit sanded surface. According to coating type, bonding quality was higher for the alkyd coating. Sengon wood retained slightly better bonding quality compared to jabon wood. It is seen from Fig. 4, no remarkable differences were found between bonding quality determined from the tangential and radial surfaces for both jabon and sengon wood. The highest bonding quality value of 4.8 was determined for unsanded sengon samples using alkyd varnish. The lowest bonding quality value of 2.4 was determined for jabon sample sanded with 360-grit paper using acrylic varnish.

The results in Fig. 4 also indicate that the bonding quality had a positive correlation, in which the surface roughness decreased when the bonding quality also tended to decrease. The increase in grit number of the abrasive paper resulted in the smoother surfaces. When the surface became smoother, a coating lacked mechanical interlocking with the substrate, thus weakening the adhesion. As can be displayed in Fig. 4, bonding quality of alkyd varnish on sengon wood decreased to be 4.2 for sanding 120-grit (*Ra* 15.08 μm), 4.1 for sanding 240-grit (*Ra* 14.17 μm), and 3.2 for sanding 360-grit (*Ra* 12.36 μm). It appears also that the bonding quality of alkyd varnish on jabon wood decreased to be 3.6 for sanding 120-grit (*Ra* 14.37 μm), 3.1 for sanding 240-grit (*Ra* 13.09 μm), and 2.6 for sanding 360-grit (*Ra* 11.46 μm). Adhesion was thought to occur only by the coating liquid flowing and filling pores, holes, crevices, and microvoids on the wood substrate to achieve a strong bond between coatings and material surface. A rough surface was proposed to enhance intrinsic adhesion by providing greater interfacial area and some mechanical interlocking mechanism. By considering that the interfacial or intermolecular attraction was the basis for the varnish adhesion, increasing the actual area of contact would increase the total energy of surface interaction.

Considering the comparison on varnish type (Fig. 4), the alkyd varnish retained higher bonding quality compared to acrylic varnish in both sengon and jabon woods. Alkyd resin exhibited better wettability than acrylic resin and should form more intimate contact with the sengon and jabon wood surfaces. The better wettability of the alkyd resin contributed to the higher bonding quality. It was noted in another study that oil-based alkyd varnish completes its polymerization reaction on the surface of wood which allows for chemical bonding with wood, so it creates a stronger adhesion on wood surface.[12] Lower bonding quality of water-based acrylic varnish is considered because the water used as a solvent in waterborne varnishes causes swelling of wood fibers and decreases penetration near the wood surfaces which lead to a weakening of the interface of the wood material and filling coat.[33] It was stated in another study that swelling reduces the brightness of the layer.[34] For this reason, it could be necessary to pay extra attention to surface preparation of the wood, especially while applying waterborne varnishes.

According to the wood species, the bonding quality of sengon wood was slightly higher than jabon wood. There are a lot of factors that may cause this difference between the species, e.g., intensity, cell structure, basic and secondary compounds of wood, texture, extractive substances.[35] However, it is a well-known fact that anatomical structure is one of the major parameters influencing overall interaction between varnish coating and substrate. Sengon wood, being a porous structure would result in better absorption of the coating causing higher magnitude of interface which enhanced bonding quality characteristics.

Wettability and bonding quality

Wettability should be an important factor in determining bonding quality. Therefore, a relationship between wood surface wettability and bonding quality should also be discussed. A multiple linear regression analysis was conducted to describe the effect of

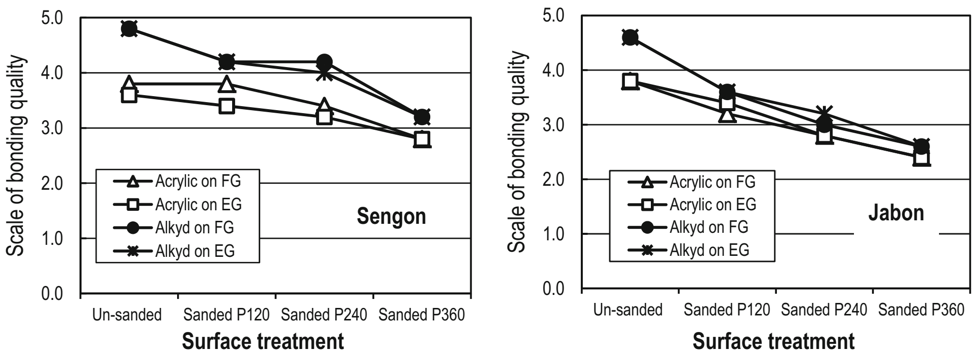

Fig. 4: Progress of the bonding quality of acrylic and alkyd varnishes on unsanded and sanded surfaces of sengon and jabon

Table 5: Analysis of variance for significance of multiple linear regression in determining the effect of equilibrium contact angle (θ_e) and constant contact angle change rate (*K*) on the bonding quality

Source	DF	Sum of squares	Mean squares	*F*	*Pr* > *F*
Model	2	6.943	3.471	11.780	0.000
Error	29	8.546	0.295		
Corrected total	31	15.489			

Model parameters

Source	Value	Standard error	*t*	*Pr* > |*t*|
Intercept	3.032	0.337	8.998	0.0001
θ_e	0.000	0.015	0.026	0.979
K value	0.132	0.051	2.602	0.014*

* Significant at $\alpha = 5\%$

equilibrium contact angle (θ_e) and constant contact angle change rate (*K* value) on the bonding quality. The analysis of variance result in Table 5 shows that no significant effect ($Pr > 0.05$) was found for the equilibrium contact angle and the bonding quality of the coating. However, a significant effect was found for the *K* on the bonding quality values. It is concluded that wettability in terms of the *K* value could be used to evaluate the adhesion between varnish coating and wood surface and could be a good indicator for the bonding quality.

Conclusions

Based on the findings in this work, the following general conclusions were drawn. Sanding with higher grit number increased the surface smoothness of the wood surfaces. Tangential (FG sample) and radial (EG sample) grain orientations of both jabon and sengon woods do not make any remarkable differences in their roughness, *K* values and bonding quality values. The jabon and sengon wood surfaces that were sanded with lower grit number generate better wettability and bonding quality compared to those sanded with higher grit number. Wood structure and texture of the jabon and sengon are considered as the factors influencing roughness, wettability, and development of bonding between varnish coating and the wood samples. Sengon wood with porous structures is more wettable and provides better adhesion compared to jabon wood. The varnish type has a significant impact on the wettability and bonding quality. Oil-based alkyd is more wettable and generates better bonding quality compared to water-based acrylic. The wettability in terms of *K* value is a good indicator for the bonding quality.

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