

EFFECTS OF SURFACE PRETREATMENT ON WETTABILITY OF ACACIA MANGIUM WOOD

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Submitted September 2018; accepted January 2019

Furniture manufacturers using *Acacia mangium* wood often experience difficulties in getting high glossy and attractive finished surface. Such problems may be attributed to poor surface wettability as well as the anatomical structure of the wood itself. This study evaluates the effects of surface treatment on the wettability of *A. mangium* wood. *Acacia mangium* lumber was segregated into sapwood and heartwood prior to sanding. Two types of solvents, methanol and sodium hydroxide (NaOH) at different concentrations (2, 4, 6, 8, 10, 12 and 14%) were used to treat the wood surface. The treated surfaces were evaluated for surface roughness and contact angle according to ISO 4287 and ASTM D7334-08 respectively. The results showed that untreated sapwood of *A. mangium* had significantly rougher surface compared with heartwood after treatment with methanol and NaOH. NaOH-treated surface had relatively lower contact angle than methanol-treated wood and experienced complete wetting within 4.2 s for sapwood and 6.8 s for heartwood. The surface was darker and the grain was less visible. Methanol-treated sapwood and heartwood took 6.4 and 12.1 s respectively to be completely wet but retained its original colour. Their wood grain was clearer and much enhanced. Based on both wettability and appearance, the best results were given by 6% methanol for sapwood and 4% methanol for heartwood.

Keywords: Methanol, sodium hydroxide, wettability, contact angle, sapwood, heartwood

INTRODUCTION

Acacia mangium plantation has been established in Peninsular Malaysia, Sabah and Sarawak since 1980's (Muhamad & Paudyal 1992). Sarawak has the largest *A. mangium* plantation area, with about 289,816 ha in 2012 which makes up 74% of the planted area in Sarawak. To achieve the targeted planted area of 1 million ha by 2020, the remaining 710,000 ha is to be planted at a rate of 88,750 ha per year for the next 8 years (Jusoh et al. 2014). The popularity of *A. mangium* wood is due to its excellent strength and machining properties, making it suitable for medium to high end value-added products such as furniture and indoor components (Lim et al. 2003, Paiman et al. 2018). However, *A. mangium* was reported to be less attractive for wood working due to the presence of knots, cross grain and moderate permeability and wettability (Lim et al. 2011). Such properties are crucial for any wood particularly in finishing process. As a

result, the finished surface often sags and paint tailings occurs due to lack of penetration by the lacquers (Omar AS, personal communication). The low wettability of *A. mangium* wood surface was also experienced in bonding. Alamsyah et al. (2008) reported that *A. mangium* laminated board bonded with resorcinol formaldehyde resin has poor shear bond strength. This problem was associated with poor wettability of *A. mangium* that prevented any liquid to sufficiently penetrate the wood surface. Hence a pretreatment is needed to improve the surface wettability of *A. mangium*.

Surface wettability is an important property for bonding or coating wood. Wettability of *A. mangium* wood can be improved by pretreating the surface before finishing (Alamsyah et al. 2008). Two types of solvents, namely, methanol and sodium hydroxide (NaOH) improves surface wettability of wood due to their ability to

remove extractives and contaminants from the wood surface, thereby lowering surface tension and increasing the penetration of liquid (Hse 1972, Alamsyah et al. 2008). In this study, effects of surface pretreatment on the wettability of *A. mangium* wood were evaluated to determine the treatment that gave the best wettability and appearance.

MATERIALS AND METHODS

Materials preparation

Nine-year-old *A. mangium* wood of size 1000 mm × 60 mm × 20 mm with density of 634 kg m⁻³ and moisture content of 12 ± 3% were provided by Nusantara Kraft Company, Sarawak. The lumbers were cut into 60 mm long × 20 mm wide × 20 mm thick sapwood and heartwood samples prior to surface treatment (Figure 1). Several light strokes were applied sequentially to the surface of each sample using sandpaper of 100, 180 and 360 grits before being dried in an oven at 103 ± 2 °C. The moisture content was determined after 3 hours and the subsequent hours, until it reached 8 ± 2%, a level that is suitable for finishing work (Sonmez et al. 2009). Samples were cooled in a desiccator for 20 min prior to determining their moisture contents.

Pretreatment method

Two bleaching reagents were used, namely, methanol and NaOH. These chemicals were analytical grade and were commercially

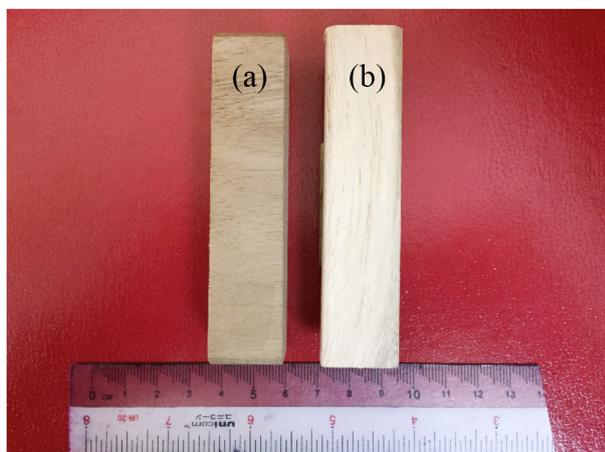


Figure 1 *Acacia mangium* wood sample; (a) heartwood with dark brown colour and (b) sapwood with yellow pale colour

available. Distilled water was used to dilute the solvents to different concentrations, i.e. 2, 4, 6, 8, 10, 12 and 14%. The surfaces of wood samples were wiped with a cloth that was wetted with different concentrations of NaOH or methanol while ensuring sufficient wetting and consistent coverage of the surfaces were attained. The samples were then air dried at ambient temperature for 24 hours prior to testing.

pH and buffering capacity

The buffering capacity was determined following the method described by Paridah et al. (2009) and He and Yan (2005). Untreated *A. mangium* wood sample was ground and dried and 15 g of the dry *A. mangium* particles was boiled in 200 mL flask for 30 min. The mixture was then filtered using glass crucibles with filter porosity 2 (40–100 µm) equipped with an aspirator vacuum. The filtrates were diluted with distilled water to final volume of 200 mL each and cooled at 20 °C for 24 hours. pH values of the diluted solvents were determined before aqueous extraction. Aqueous extract was manually titrated using 0.1 N NaOH and 0.1 N hydrochloride (HCl) solution until pH 10.0 and pH 3.0 respectively. The pH value was recorded after the addition of every 0.2 mL of titrant.

Surface roughness

Surface roughness of sapwood and heartwood samples was determined before and after being wiped with methanol and NaOH. Although there are various roughness measurement techniques including pneumatic, laser and light scattering methods, stylus type of profilometer is the most commonly used technique due to its practicality and accurate numerical results. This test was performed by profile method using stylus device based on standard ISO 4287 (ISO 1998). The measuring speed, pin diameter, and pin top angle of the tool were 5 mm min⁻¹, 5 µm, and 90° respectively. Average surface roughness (Ra) and mean peak-to-valley height (Rz) were two parameters measured. Readings were taken perpendicular to the grain direction using 15-mm tracing length. Five random measurements were collected for each specimen.

Evaluation of contact angle

The wettability measurement was performed according to ASTM D7334-08 (ASTM 2008). Contact angle measurement was taken for different parts of treated and untreated sapwood and heartwood using droplets of 3.0 μL distilled water at 20 °C. Relative humidity in the testing room was $65 \pm 5\%$. Readings were taken until no water droplet was left on the wood surface and five measurements were collected for each specimen.

Statistical analysis

Statistical analysis software was used to analyse the data obtained in the study. An analysis of variance (ANOVA) and mean separation using least significant difference (LSD) were conducted to evaluate the effect of different concentrations of methanol and NaOH on the surface roughness and wettability of *A. mangium* wood.

RESULTS AND DISCUSSION

Buffering capacity of *A. mangium*

Resistance of wood material to the change in its pH level is called buffer capacity. The pH value and buffering capacity information are fundamental to understanding the curing behaviour of resin (He & Yan 2005, Paridah et al. 2009). Both pH and buffering capacity influence the effectiveness of surface treatment. *Acacia mangium* appeared to be more stable in

acidic than in alkaline condition since it required higher amount of HCl (8.8 mL) to reach pH 3 while it takes only 2.0 mL NaOH for the *A. mangium* to reach pH 10 from the initial pH of 5.08 (Figure 2). In a similar study, Nurhazwani et al. (2015) found that bamboo (*Dendrocalamus asper*) required 5.5 mL of HCl to change its pH from 4.3 to 3.0, while rubberwood needed only 4.5 mL to change its pH from 4 to pH 3. On the other hand, the amount of NaOH required to change the initial pH to 10 for both bamboo and rubberwood were approximately the same, i.e. between 74.5 and 77 mL, which was much higher than the amount needed for *A. mangium*. Wood that requires a large amount of acid to decrease its pH is considered as having high buffering capacity (Maloney 1977). Hence *A. mangium* had low buffering capacity in alkali as shown by the sudden increase in pH after a small addition of NaOH (2.0 mL).

This study suggested that there will be difficulties with *A. mangium* wood when using basic coating system as pH of the wood surface will change once it is associated with any alkali-based system. Such behaviour will change the curing rate of the coating material itself or of the coating material on the wood surface as well as in the cells. As a result, the rate of curing can be altered to be slower to faster. However, such changes are troublesome particularly in achieving good adhesion between the finishing and wood (Johns & Niazi 2007). High buffering capacity in bamboo had slowed down the curing time of melamine formaldehyde, melamine urea phenol formaldehyde and phenol formaldehyde

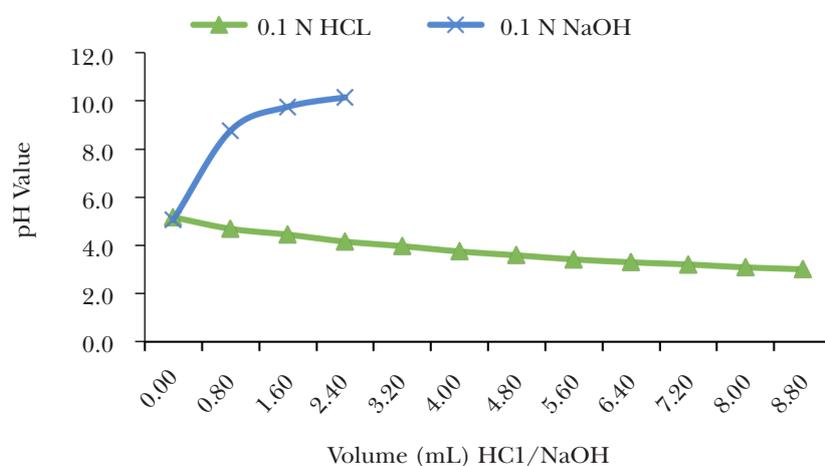


Figure 2 Stability of *Acacia mangium* in acidic and alkaline condition

resin adhesives resulting in lower bond strength of the bamboo composites (Malanit et al. 2009). Meanwhile, as *A. mangium* had high acid buffering capacity, it is recommended that some amount of acid catalyst should be added when applying acid-based coatings such as nitrocellulose, acid catalyst or polyurethane lacquers (pH ranges from 4–6).

Appearance of *A. mangium*

According to Tenorio et al. (2012), *A. mangium* has distinct coloration between sapwood and heartwood. Sapwood is often white or yellowish-white and the heartwood is yellowish brown to golden brown when fresh, and change to dull brown upon long exposure to light and air as shown in Figure 3a. Natural wood pattern provides artistic enjoyment and colours and patterns significantly differ from one wood species to another. The colour of furniture is so important for its appearance and must remain as uniform as possible to ensure aesthetic effect (Keey 2005). NaOH-treated *A. mangium* wood has darker colour compared with methanol-treated sample. However, NaOH-treated wood also has poor wood appearance (water mark) as shown in Figure 3. Surface treatment with high pH occasionally darkens wood as tannin in the wood is brought to the wood surface by solvents. Dark iron tannate discoloration occurs once the tannin reacts with microscopic metals particles, resulting in darkened wood surface. On the other hand, methanol-treated samples retained its original light colour and therefore was more favourable for finishing application compared with NaOH-treated samples.

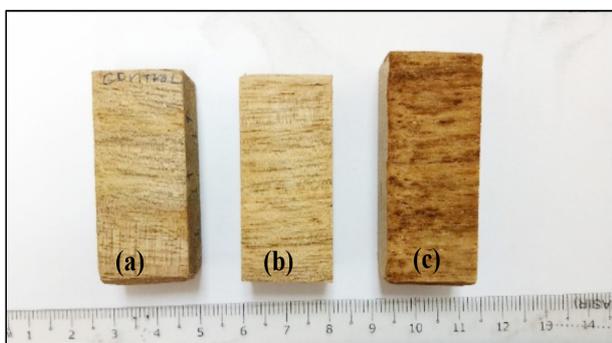


Figure 3 Appearance of *Acacia mangium* wood; (a) control, (b) methanol-treated and (c) NaOH-treated samples

Surface roughness

Surface roughness is influenced by cross grain, annual growth ring width, rays, knots, reaction wood, and ratio of earlywood and latewood (Sulaiman et al. 2009). Surface roughness of *A. mangium* prior to finishing is very crucial in determining the quality of the finished product. Ra and mean Rz were considered for evaluation of different per cent of concentration of methanol and NaOH samples. Ra is the average distance from profile to the mean line, which is the least square average of the profile, whereas Rz can be defined as an average of five consecutive mean peak-to-valley height within the profile (Hiziroglu & Graham 1998). Lower rates of Ra and Rz are favourable because a smooth surface needs relatively little paint for coverage, and paint performance is improved (Jakub & Martino 2005).

Table 1 tabulates the ANOVA and mean separation using LSD method of the effect of different concentrations of methanol and NaOH towards two parts of wood, sapwood and heartwood. The results showed that there were significant differences for Ra and Rz in terms of parts of wood (sapwood and heartwood), types of treatment (methanol and NaOH) and percentages of concentrations, but there was no difference between the interaction of part of wood and type of treatment, part of wood and concentration, type of treatment and concentration, and part of wood and type of treatment and concentration.

Different parts of wood gave different outcomes to the surface roughness (Ra and Rz) values. Sapwood had higher Ra and Rz than heartwood. The surface profile of sapwood is easily affected by sanding due to the capillary-porous nature of wood itself. Therefore, during surface treatment process, the surface of the sapwood and a thin layer below it are in movement, causing surface distortion (raised grain) and changes in surface roughness (Csanády et al. 2015). With increasing surface roughness, the spreading and penetration of liquids/water on the surface of wood increase (Sulaiman et al. 2009). Rough surface can promote over penetration by increasing true surface area and increase the tendency in capturing higher amount of water (Neese et al. 2004, Ratnasingam & Scholz 2006). Sapwood may have greater ability to absorb liquid/water

Table 1 Analysis of variance for the effects of different variables on surface roughness of *Acacia mangium*

Source	df	Ra		Rz	
		p-value		p-value	
Part of wood (P)	1	< 0.0001	***	< 0.0001	***
Treatments (T)	1	0.0037	***	0.0140	**
Concentration (C)	6	0.0011	***	0.0003	***
P*T	1	0.0910	ns	0.0926	ns
P*C	6	0.9500	ns	0.9065	ns
T*C	6	0.9988	ns	0.9946	ns
P*T*C	6	0.9987	ns	0.9914	ns

*** = significant difference at $p < 0.01$, ** = significant difference at $p < 0.05$; ns = no significant difference

compared with heartwood. The highest Ra for part of wood was recorded in sapwood at $5.11 \mu\text{m}$ followed by heartwood at $3.31 \mu\text{m}$, while the highest Rz for part of wood was recorded at $31.84 \mu\text{m}$ for sapwood followed by $22.77 \mu\text{m}$ for heartwood (Figure 4a). NaOH produced rougher surface (higher Ra and Rz values) than methanol (Figure 4b). The highest Ra was recorded by NaOH at $4.75 \mu\text{m}$ followed by methanol at $3.66 \mu\text{m}$. The highest Rz values was recorded by NaOH at $29.89 \mu\text{m}$ and followed by methanol at $24.72 \mu\text{m}$ respectively.

Table 2 shows the surface roughness values of *A. mangium* treated with different concentrations of methanol and NaOH. Untreated *A. mangium* had smoother surface compared with treated samples for both sapwood and heartwood. Treatment using NaOH and methanol increased the roughness of wood surface but was pronounced in the sapwood. Surface roughness of the sapwood changed significantly when $\geq 6\%$ NaOH was used while the significant change in surface roughness for heartwood was already observed when only 2% NaOH were applied (Table 2). Nevertheless, methanol-treated sapwood and heartwood surface behaved differently. For sapwood, changes in roughness were quite similar to those of NaOH-treated samples. For heartwood, changes in surface roughness were opposite to that of NaOH-treated samples. The surface roughness changed significantly after treatment with 12% methanol. Heartwood contains substantial amount of extractives that accumulate in the lumen. Unlike methanol, NaOH can easily dissolve some of these extractive components, making NaOH

easier to penetrate into several cell layers. Sample surface were rougher when using methanol and more amount of solvent was needed to dissolve the extractives. ‘Roughing’ wood surface is common during wood finishing as it helps to increase surface area for the bonding of coating material. However, rougher surface will contribute to excessive volume of liquid/water penetration, thus increasing the finishing cost. Surface topography is an important criterion that affects good penetration and aesthetic value of wood in terms of touch and appearance (Jakub & Martino 2005).

Evaluation of surface wettability

In the wettability study, contact angle formed between the surface and liquid provides useful information on how well the adhesives wet, spread and penetrate the wood (Paridah et al. 2009). Table 3 summaries the ANOVA results of the effects of different parts of wood (sapwood and heartwood), solvents (methanol and NaOH) and their concentrations on the contact angles of *A. mangium*. The results showed that all the parameters studied had significant influence on the contact angle and wettability of *A. mangium*. Surface treatment minimised surface area so that the number of intermolecular bonds in the surface might be reduced and penetration could occur. The continuous contact between the adhesive and adherend is called wetting. Adhesion occurs by the penetration of adhesives into pores of the substrate and the coating with better penetration and substrate wetting show superior adhesion (Lu 2006).

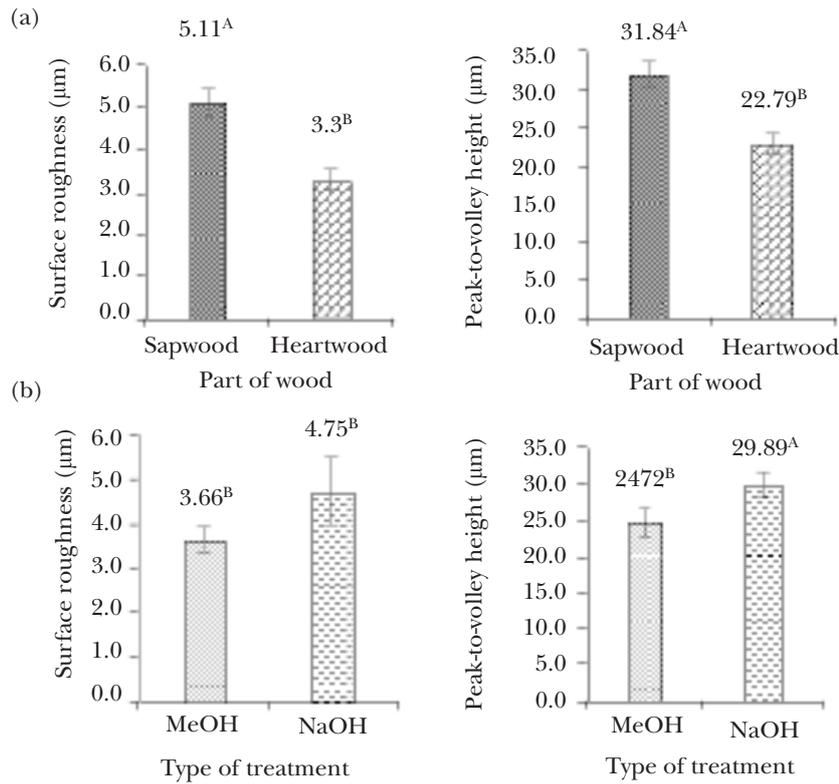


Figure 4 Comparison of average surface roughness and mean peak-to-valley height between (a) sapwood and heartwood and (b) methanol and NaOH; bars having the same letters are not significantly different at $p \leq 0.05$

Table 2 Average surface roughness (Ra, μm) and mean peak-to-valley height (Rz, μm) of *Acacia mangium* wood treated with methanol and NaOH

Concentration (%)	Methanol		NaOH	
	Sapwood			
	Ra	Rz	Ra	Rz
Control	2.41 ^b (0.24)	17.65 ^b (1.68)	2.41 ^b (0.24)	17.65 ^b (1.68)
2	3.26 ^b (1.11)	20.97 ^b (5.96)	3.60 ^b (1.50)	25.57 ^b (10.49)
4	3.97 ^b (1.37)	24.75 ^b (7.81)	3.89 ^b (0.28)	25.08 ^b (2.36)
6	4.69 ^a (1.19)	33.38 ^a (9.50)	5.02 ^a (3.35)	31.27 ^a (12.05)
8	4.75 ^a (2.17)	28.82 ^b (13.40)	5.99 ^a (2.62)	33.39 ^a (12.85)
10	4.80 ^a (1.34)	30.95 ^a (7.63)	5.60 ^a (1.49)	33.82 ^a (4.70)
12	5.99 ^a (2.62)	33.39 ^a (12.85)	6.27 ^a (3.75)	37.72 ^a (21.23)
14	6.63 ^a (1.95)	44.72 ^a (12.33)	7.04 ^a (0.68)	41.88 ^a (3.78)
	Heartwood			
	Ra	Rz	Ra	Rz
Control	1.32 ^b (0.30)	9.06 ^b (1.08)	1.32 ^b (0.30)	9.06 ^b (1.08)
2	1.41 ^b (0.41)	10.25 ^b (4.99)	3.35 ^a (0.84)	21.12 ^a (9.67)
4	1.81 ^b (0.81)	13.85 ^b (7.55)	3.44 ^a (1.41)	21.38 ^a (10.71)
6	2.07 ^b (0.63)	15.06 ^b (6.99)	3.47 ^a (1.37)	25.20 ^a (6.47)
8	2.19 ^b (0.90)	20.02 ^b (8.13)	3.77 ^a (1.53)	24.94 ^a (10.45)
10	2.58 ^b (0.65)	17.63 ^b (5.28)	4.38 ^a (1.50)	27.10 ^a (8.79)
12	3.57 ^a (0.52)	26.74 ^a (7.17)	5.14 ^a (1.89)	36.11 ^a (5.58)
14	3.49 ^a (0.75)	25.59 ^a (4.15)	5.60 ^a (1.49)	33.82 ^a (4.70)

Means followed with the same letter in the same column are not significantly different at $p \leq 0.05$

Table 3 Analysis of variance of the effects of part of wood, treatment and concentrations on the contact angle of *Acacia mangium*

Source	df	p-value	
Part of wood (P)	1	< 0.0001	***
Treatment (T)	1	< 0.0001	***
Concentration (C)	6	< 0.0001	***
P*T	1	0.0034	***
P*C	6	< 0.0001	***
T*C	6	< 0.0001	***
P*T*C	6	< 0.0001	***

***highly significant difference at $p < 0.01$

Methanol and NaOH-treated samples experienced some enhancement in wetting compared with untreated samples (control) irrespective of the concentration used. *Acacia mangium* wood had high resistance towards acid but less resistance towards alkaline. Surface wettability values of *A. mangium* sapwood and heartwood treated with different concentrations of NaOH and methanol as indicated by the time needed for the contact angle of the water droplet to reach 0° are shown in Figures 5–8. The largest contact angle recorded by untreated sapwood (Figures 5 and 6) and heartwood (Figures 7 and 8) was 83.0° and 80.8° respectively which took 92.2 and 130.3 s to reach 0° (not shown in the figure). Sapwood and heartwood samples treated with 2% NaOH only needed 4.22 and 6.81 s to reach 0° as shown in Figure 5 and Figure 7 respectively. Meanwhile, 6 (Figure 6) and 4% (Figure 8) methanol were the most effective in increasing the wettability of *A. mangium* sapwood and heartwood respectively. To reach 0° , the fastest times for both types of wood were 6.41 s shown by sapwood treated with 6% methanol (Figure 6) and 12.11 s (Figure 8) by heartwood treated with 4% methanol.

The surface wettability did not show significant improvement when higher concentration of NaOH ($\geq 10\%$) was used as the times needed for the contact angles to reach 0° were longer as shown in Figures 5 and 7. However, when the concentration of NaOH was $< 10\%$, the improvement was obvious. Concentration had much larger influence on contact angle as higher concentration of solvents only gave slight increment in wettability while at lower concentration, the time needed to reach 0° was shortened especially for NaOH $\leq 6\%$. On

the other hand, for methanol-treated samples, solvent concentrations ranged from 4–12% gave good results in improving the surface wettability, where the best concentration was 6% for sapwood and 4% for heartwood as mentioned before. Too low (2%) or too high (14%) of the methanol concentration did not bring significant improvement in surface wettability of *A. mangium*. Wettability of sapwood was relatively higher because it had higher surface roughness compared with heartwood. Sapwood contains living cells hence usually have thinner cell wall and larger lumen diameter that is filled with water while heartwood contains mainly dead cells with high amount of extractives in the lumen (Hoadley 2000, Taylor et al. 2007). Upon drying, the cell wall and lumen of sapwood will form greater number of voids compared with heartwood. During machining, these voids will be cut through, exposing the empty lumen and creating open grains which are responsible for the rough surfaces which significantly affect the wettability (Busscher et al. 1984, Petrič 2013). Wettability is also determined by type of liquid, extractives, time and wood species (Wälinder & Johansson 2001).

CONCLUSIONS

This study investigated the influence of surface treatment using methanol and NaOH at different percentages as a way to enhance the surface wettability of *A. mangium* towards its use as a high-end product. *Acacia mangium* appeared to be more stable in acidic than in alkaline condition. It has low buffering capacity in alkali as shown by a sudden increase in pH after a small addition of NaOH. Overall, the type of solvent

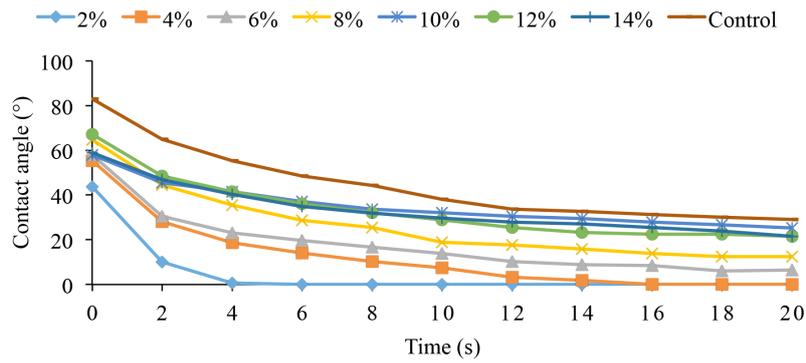


Figure 5 Surface wettability (time needed in s for the water droplet to reach 0°) of *Acacia mangium* sapwood treated with different concentrations of NaOH

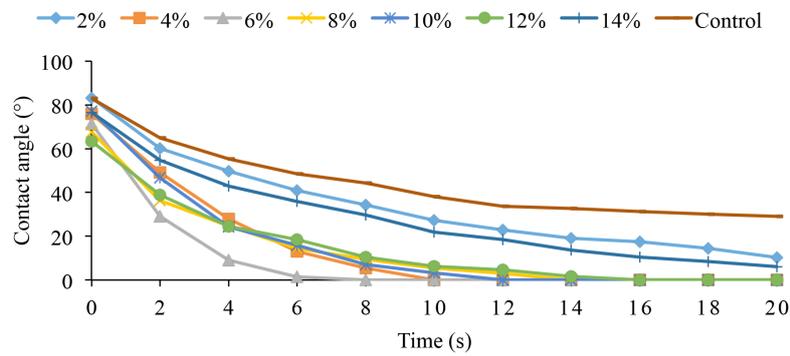


Figure 6 Surface wettability of *Acacia mangium* sapwood treated with different concentrations of methanol

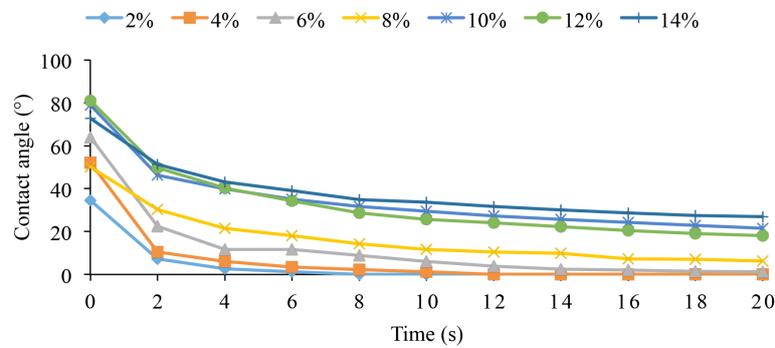


Figure 7 Surface wettability of *Acacia mangium* heartwood treated with different concentration of NaOH

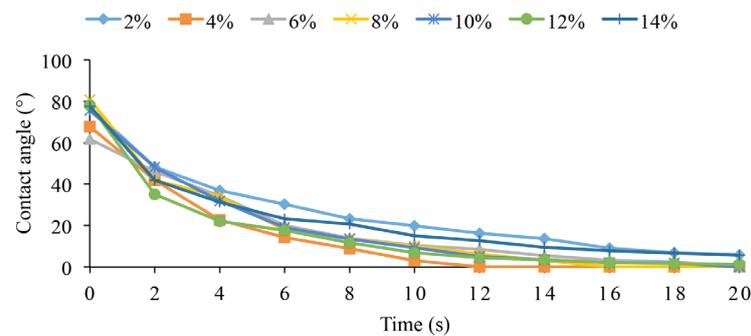


Figure 8 Surface wettability *Acacia mangium* heartwood treated with different concentration of methanol

and its concentrations had significant effect on the surface roughness and wettability of *A. mangium* wood. Methanol and NaOH were able to increase the wettability of *A. mangium* wood surface, irrespective of sapwood or heartwood. Heartwood responded better to surface treatment compared with sapwood. Between NaOH and methanol, the former was more effective in improving the surface wettability of wood but it caused unfavourable change in colour of the wood. Treatment with 6% methanol for sapwood and 4% methanol for heartwood significantly improved the wettability of *A. mangium* wood. Surface treatment with alkali (NaOH) darkened the wood as the tannin in the wood was brought to the wood surface by the solvent. Meanwhile, methanol-treated samples retained its original light colour and therefore was more favourable for finishing application.

ACKNOWLEDGEMENTS

The authors wish to thank the Higher Institutions Centres of Excellence, Ministry of Higher Education for the financial support (project no. 6369109) and Wood Finishing Laboratory, Forest Research Institute Malaysia for the facilities used during the study.

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