The Journal of Adhesion

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/gadh20

Finishing performance of *Acacia mangium* wood surface-treated with methanol

Redzuan Mohammad Suffian James , Paridah Md Tahir , Lee Seng Hua , Ummi Hani Abdullah , Mohd Khairun Anwar Uyup , Norwahyuni Mohd Yusof & Izwan Johari

THE JOURNAL OF ADHESION
https://doi.org/10.1080/00218464.2020.1831920

Taylor & Francis
Taylor & Francis Group

Finishing performance of *Acacia mangium* wood surface-treated with methanol

Redzuan Mohammad Suffian James[a], Paridah Md Tahir[a,b], Lee Seng Hua[a], Ummi Hani Abdullah[b], Mohd Khairun Anwar Uyup[c], Norwahyuni Mohd Yusof[a], and Izwan Johari[d]

[a]Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, UPM, Serdang, 43400, Malaysia; [b]Faculty of Forestry, Universiti Putra Malaysia, UPM, Serdang, 43400, Malaysia; [c]Forest Products Division, Forest Research Institute Malaysia, Kuala Lumpur, 52109, Malaysia; [d]School of Civil Engineering, Universiti Sains Malaysia, Nibong Tebal, 14300, Malaysia

ABSTRACT

Evaluation of the effects of 8% methanol (MeOH) pretreatment on the finishing performance of *Acacia mangium* wood was carried out using different coating systems, i.e., nitrocellulose (NC), acid catalysed (AC) and polyurethane (PU). The coated surfaces were tested for adhesion test-cross cut, scratch resistance test, abrasion test, impact resistance test, surface roughness, and gloss measurements test according to the relevant standard. The results have shown that *A. mangium* wood surface treated with 8% methanol resulted in a superior finished surface compared to untreated panels except gloss. Among coating systems, AC and PU appear to be more compatible with MeOH than with NC. Applying 8% of methanol to *A. mangium* surface before coating, application of AC or PU improved the quality of finished *A. mangium* wood and meeting the minimum requirements outlined in the standards.

ARTICLE HISTORY
Received 14 April 2020
Accepted 30 September 2020

KEYWORDS
Acacia mangium wood; surface treatment; wood finishing; coating system; resistance

1. Introduction

In 1966, *Acacia mangium* tree was introduced to Sabah, Malaysia, from its natural range along the margins of tropical moist forests In Queensland, Australia. A. *mangium* wood is a dense, all-purpose hardwood with an attractive, medium-brown colour and has high-quality characteristics similar to black walnut.[1] Many studies have shown that these fast-growing species have potential for further utilisation of other wood products due to their rapid growth rate, availability, renewable nature, high productivity and versatility. [,2,3] Extensive and mass commercialisation and development programmes have been established for Acacia and other species in Sarawak for reforestation and replanting. Approximately 1 million hectares have been planted in the current year in order to meet the current and future needs for raw materials.[,4,5] However, it is known that the wood components, probably

CONTACT Paridah Md Tahir parida@upm.edu.my Lee Seng Hua lee_seng@upm.edu.my Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, Serdang, Selangor Darul Ehsan 43400, Malaysia

extractives, appear to have an effect on the curing of the resin and the wettability of the surface of the wood. Effects of wood extractives as inhibitory components on resin curing and bonding performance have been reported in a number of previous studies.[2,6–8] In the previous study, surface treatment was conducted to overcome this problem and to successfully increase the wettability of *A. mangium* allows the coating material through mechanical bonding to strongly adhere to the wood substrate.[9]

There are three common types of wood finishes in wooden furniture, namely nitrocellulose (NC), acid catalysed (AC) and polyurethane (PU).[10] Nitrocellulose (NC) was made from an alkyd and nitrocellulose resin dissolved and then mixed with solvents that evaporate quickly.[10] This lacquer produces a very hard yet flexible, durable finish that can be polished to a high sheen. This lacquer, however, encompasses the hazardous nature of the solvent, which is flammable, volatile and toxic. The hazardous content also occurs during the manufacturing process.[11] NC lacquer is physically dry as solvents that evaporate from a paint film. NC can also be added to acid-catalysed lacquer to speed up the drying process. This type of lacquer has a moderate resistance to water, but is sensitive to heat and certain solvents. The main drawback is the tendency of the finish to yellow as it ages, which is clearly shown in light-coloured woods.[10] On the other hand, acid catalysed (AC) has a good resistance to household and industrial chemicals and a high resistance to discolouration. Typical AC lacquer is mainly made from alkyd and amino (urea or melamine) resins and is often combined with nitrocellulose. This two-pack acid catalyst is dry by means of a combination of solvent evaporation and chemical reactions, resulting in a hard, tough and mar-resistant film. With the use of heat, the curing time of AC lacquer can be dramatically accelerated. As far as polyurethane (PU) is concerned, this lacquer is typically hard, abrasion-resistant and durable coatings due to its polymerisation reaction on the surface of wood that forms chemical bonding with woof. This lacquer is popular for hardwood flooring, but some consider it difficult or unsuitable for finishing furniture or other details.[11] Polyurethane may be either one-component or two-component. As single-component lacquers dry, the isocyanate they contain reacts with air humidity. In two-component paints, the binder can be either polyester-type or acrylate. Acrylate-based paints dry more quickly than polyester-based paints. It is also stated in the literature that the highest adhesion of polyurethane lacquer is due to its polymerisation reaction on the surface of the wood, which forms a chemical bond with the wood, resulting in a stronger surface adhesion.[12]

As mentioned earlier, *A. mangium* wood has very poor wettability, which makes the application of coating materials a challenging task. As a result, surface treatment must be used to improve the surface wettability of the surface prior to the application of the coating materials. In a study conducted by Redzuan et al.,[9] methanol and sodium hydroxide (NaOH) were used to enhance the surface wettability of *A. mangium* of wood. Methanol proved to be a better option for surface treatment of *A. mangium* wood compared to NaOH because it retained the original-treated wood. Conversely, the darkened colour of the *A. mangium* wood treated with NaOH was undesirable for further application. The objective of this study is therefore to evaluate the finishing properties of *A. mangium* wood surface-treated with methanol and coated with different finishing systems, namely nitrocellulose (NC), acid catalysed (AC) and polyurethane (PU). Adhesion, scratch resistance, abrasion, impact resistance, film thickness, surface roughness and gloss measurement have been assessed because these properties are of great importance in the wood furniture and cabinet manufacturing industry, where the coating surface has had to retain good properties for many years.[13,14]

2. Materials and methods

2.1. Wood samples

A. mangium lumber was obtained from the Nusantara Kraft Company in Sarawak, Malaysia. The sawn lumber was taken out of 9-year-old trees. The lumbers were cut to 1000 mm × 100 mm × 20 mm and had an average density of 634 kg/m^3 at (12 ± 3) % moisture content. This process involved cutting, sanding, surface treatment, drying, spraying, conditioning and testing. The materials used for the finishing were obtained from Polycure (M) Sdn. Bhd without the addition of purification.

2.2. Preparation of surface treatment and coatings

As the bleaching agent, 8% methanol (MeOH) was used. The surfaces of the wood samples were swept 5–6 times by a sponge wetted with 8% MeOH along the grain direction. Subsequently, the samples were air-dried and kept at (25 ± 2) °C for 24 h prior to completion of the application. Nitrocellulose (NC), acid catalysed tall oil fatty acid alkyd backbone resin and a blend of urea and melamine formaldehyde crosslinker (AC) and polyurethane (PU) were used for a 100% clear finish. The lacquer products were blended according to the ratio suggested by the manufacturer. Mixing ratio of lacquer: thinner of 1:1 was used for nitrocellulose and acid-catalyzed while ratio of 2:1:1 (Lacquer: Thinner: Hardener) was used for polyurethane. The properties of the lacquer products used for this study are shown in Table 1.

The ASTM D-3023 specifications were followed during the lacquer applications. Flow time was subjected to the standard test method for the viscosity of the ford viscosity cup no. 4.[15] The coating was applied to the samples in four sequential steps: base coat (2 layers) and top coat (2 layers) in parallel and across the grain by spraying. For each layer, sanding was carried out using sanding paper

Table 1. Properties of the lacquer products used in this study.

Type of lacquer	pH	Solid Content (%)	Application Viscosity (second/DIN Cup 4 mm/20°C)	Amount applied (g/m^2)	Number of lacquer layer applied	Time to cure (minutes)
NC base	4.08	29	18	100	2	30 minutes
NC top	4.2	26	18	100	2	30 minutes
AC base	5.2	35	16	100	2	1 hour
AC top	5.5	35	14	100	2	1 hour
PU base	6.55	55	18	100	2	1 hour and 30 minutes
PU top	6.25	42	16	100	2	1 hour and 30 minutes

Spraying was done at 34°C with 65% RH

of the sizes P100s, P180s and P320s prior to applying the next coating layer. The finishing process was carried out in the water wash spray booth at a temperature of 32 ± 2°C and a relative humidity of 74 ± 5% was achieved with three repeats. The coated sample remained in the conditioned room for another 2 weeks at a temperature of 23 ± 2 °C and a relative humidity of 65 ± 5% for a week.

2.3. Characterization of coating films

2.3.1. Adhesion test

The adhesion test was conducted using a cross-cut tape method.[16] A single-blade cutter was used to create a lattice pattern. The number of cuts for each lattice pattern is six where the space between each cut in each direction is equal and the space is 2 mm. Then, the adhesive tape was placed over the lattice area and removed after 5 min. Afterwards, the percentage of the area cut was examined.

2.3.2. Scratch resistance

The scratch resistance was carried out on the basis of BS EN 180 1518–1:2011.[17] Finished *A. mangium* wood was clamped on the holder of the panel. A weight was then placed on the stylus. Starting with a minimum load of 1000 g, the load was then increased by 100 g until it reached a maximum load of 2000 g. The scratch tester (stylus) creates a scratch on the surface of the sample that can be seen with the naked eye.

2.3.3. Abrasion resistance

Abrasion resistance is particularly important and desirable for the coating formulations used on surfaces, such as flooring, shelving, wall covering, furniture and the like, which are subjected to abrasive contact with other objects during use.[18] The abrasion test was performed on untreated and treated coated *A. mangium* wood panels based on ASTM D 4060–14.[19] The surface of the coated panels was abraded by rotating the panel under weighted

(300 g) abrasive wheels. Abrasion resistance was calculated as a loss of mass at 1000 and 2000 abrasion cycles.

2.3.4. Impact resistance

The relative impact resistance of the finishes was based on BS 3962: Part 6:1980, where the steel ball drops from a height of 1.8 m on the test panel.[20] The area was then examined and assessed on the basis of the assessment code set out in the standard.

2.3.5. Film thickness

The film thickness test was performed to precisely measure the optical thickness (μm) of the transparent thin film form on the substrate.

2.3.6. Roughness

Roughness is the measure of a surface's fine irregularities.[21] Profilometers were used to measure the sample. The measurement was made using a stylus device standard called Mitutuyo Surfest SJ-301 with the profile method. Two parameters were measured for average surface roughness (Ra) and mean peak-to-valley height (Rz). Ra is the average distance from the profile to the mean line, which is the least square average of the profile, whereas Rz can be defined as the average of five consecutive peak-to-valley average heights within the profile. Measuring speed, pin diameter, and pin top angle of the tool are 10 mm/min, 4 μm, and 90°. The roughness measurement points were randomly identified on the surface of the samples. Measurements were conducted in the perpendicular direction of the sample.

2.3.7. Optical properties

Gloss is the measurement of the reflectance of the specular light of the coated surface. In gloss measurement tests, beam light is directed towards the coated surface at certain perpendicular angles. The percentage of the beam which is reflected at the same angle is measured by the photocell. Generally, the wood industry uses the 60° angle of reflection. Other commonly used measurement angles are 20° and 85°. The 20° angle of measurement can be used when measuring gloss units above 70°; the 85° angle is used when measuring gloss below 10°. The classification of lacquers according to gloss ratings depends on the ability of the surface to bounce back a varying amount of light beamed on it, and these readings show the relative reflectivity of the coated surface compared to the smooth, flat mirror.[11]

Table 2. Analysis of Variance (ANOVA) of the effects of coating and treatment on the adhesion.

Source	df	p-value	
Coating	2	<.0001	***
Treatment	1	<.0001	***
Coating*treatment	2	<.0001	***

Note:***Significant different at $p < 0.01$

3. Results and discussion

3.1. Adhesion

Table 2 shows the results of the analysis of variance (ANOVA) of the effect of the coating system and treatment on the adhesion test (cross-cut) of finished *A. mangium* wood. The properties of adhesion of the finished samples were found to be significantly influenced by the coating system, treatment and interaction between coating and treatment.

The percentage of wood detachment as a function of the coating system is shown in Figure 1. As shown in Figure 1, all types of coating differ significantly from one another in terms of wood detachment. The highest percentage of detachment was recorded in NC-coated samples (74%), followed by AC-coated samples (26%) and PU-coated samples (10%). NC samples showed the poorest adhesion due to detachment, even during cross-cut preparation, without adhesion tape. The percentage of layer detached from the adhesion test on different types of coating (Figure 2) did not show a significant difference between untreated and treated panels for both AC and PU coatings. There is, however, a significant difference in the percentage of adhesion for untreated and treated NC coating panels. It indicated that good adhesion was recorded in the treated panel, which showed a lower percentage of detachment compared to the untreated panel. PU-coated samples were extremely good for

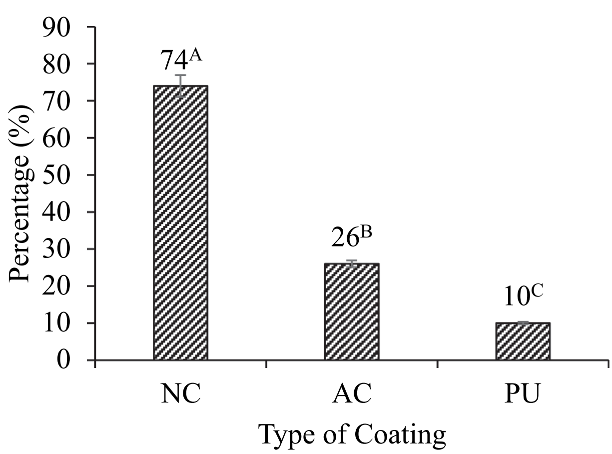

Figure 1. Percentage (%) of wood detached from wood coated with different types of coatings.

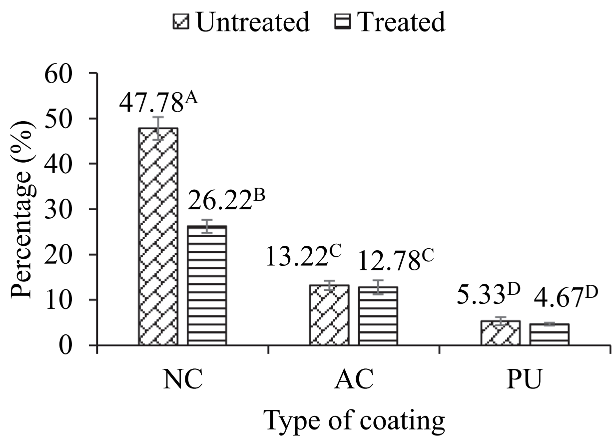

Figure 2. Percentage (%) of wood detached from wood coated with different types of coatings: A comparison between treated and untreated wood.

adhesion, as shown by the low percentage of detached wood. Although the AC-coated sample had fairly good adhesion, the NC-coated sample had relatively high-detached fibres, which is > 70%. The increase of the coating material during the hardening process was accompanied by a decrease in the free interfacial energy at the substrate interface and a good mechanical interlocking.[22]

Table 3 summarises the assessment of coating adhesion of treated and untreated samples coated with different finishes. Coating adhesion may be assessed in terms of the force at which the coating layers detach from the substrate surface or cause serious destruction of the coating layer. Adhesion of high quality to *A. mangium* wood was detected by PU where < 5% was detached. Visual observations of 8% of the MeOH-treated and untreated sample coated with NC, AC and PU are shown in Figures 3–5.

It can therefore be concluded that the coating layer of both untreated and treated PU panels resided along the indentation groove with a slight detachment of small flakes at the intersection of the cuts (rate 1). However, small (rate 2) and slight detachment (rate 1) were detected in the untreated and treated AC sample while high flakes (rate 4) and medium flakes (rate 3) were detected in the untreated and treated NC sample, indicating relatively poor adhesion quality. It is also stated in the literature that the highest adhesion of polyurethane lacquer is due to its polymerisation reaction on the surface of

Table 3. The adhesion (cross cut) assessment on surface of *A. mangium* samples.

Finishing system	Nitrocellulose		Acid catalyzed		Polyurethane	
Rating	Untreated	Treated	Untreated	Treated	Untreated	Treated
	4	3	2	1	1	1

Note: Rating 0–5, where 0 is very good and 5 very poor

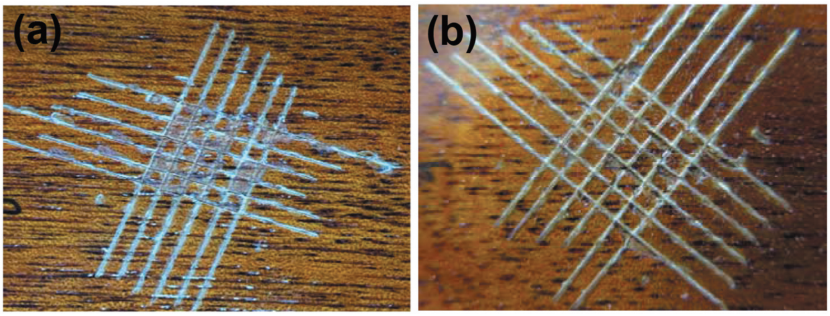

Figure 3. Cross Cut Result for NC Coating; (a) Untreated, (b) Treated.

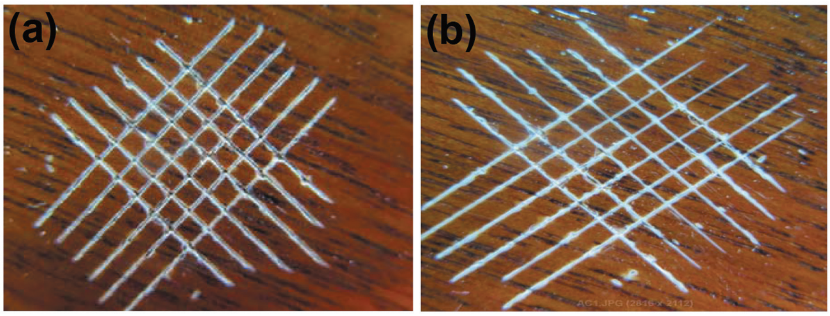

Figure 4. Cross Cut Result for AC Coating; (a) Untreated, (b) Treated.

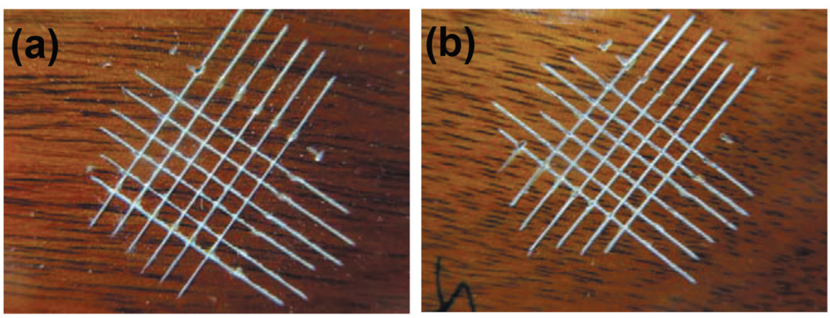

Figure 5. Cross Cut Result for PU Coating; (a) Untreated, (b) Treated.

wood, which forms a chemical bonding to wood, resulting in a stronger surface adhesion.[12]

3.2. Scratch resistance

The results of the scratch test revealed that all the coating samples had the highest scratch resistance of 19.7 N. Coating scratches can be assessed in terms of the total load at which the coating layers detach from the surface substrate.

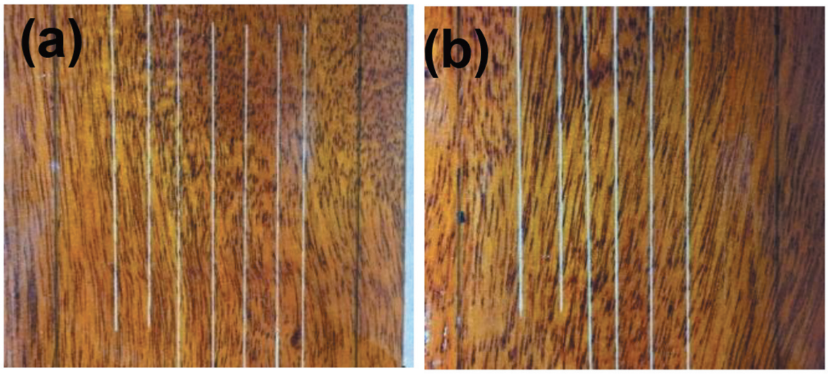

Figure 6. Scratch on the NC Coating; (a) Untreated, (b) Treated.

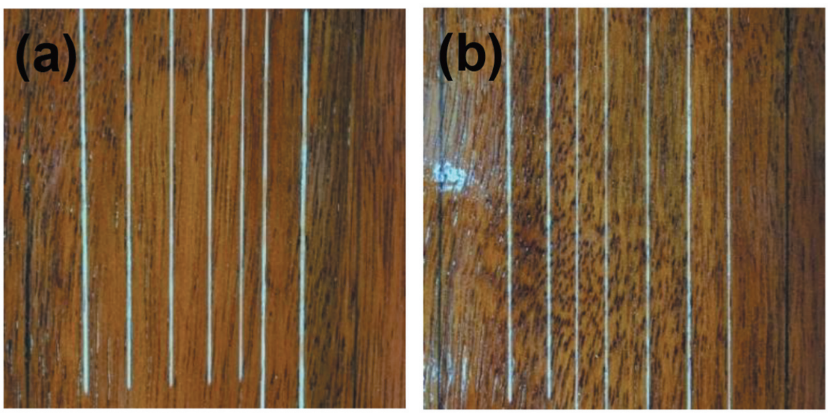

Figure 7. Scratch on the AC Coating; (a) Untreated, (b) Treated.

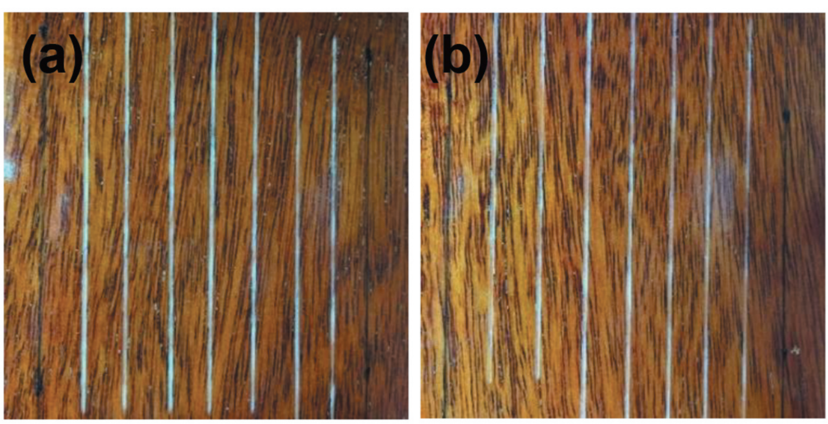

Figure 8. Scratch on the PU Coating; (a) Untreated, (b) Treated.

Table 4. Analysis of variance (ANOVA) of the effects of coating, cycle, and treatment on the abrasion.

Source	df	p-value	
Coating	2	<.0001	***
Cycle	2	0.6333	ns
Treatment	1	0.0888	*

Note: ns No significant different at $p > 0.1$
*Significant different at $p < 0.1$
***Significant different at $p < .0001$

After cleaning the sample surface with a soft cloth, the surface was checked by a naked eye under 100-lx lamps. All panels were then examined using a microscope image to approve the validation of the naked eye. The values of scratch resistance were similar for all types of coating used. Although the scratch line was varied (Figures 6–8), it can withstand the highest load of the scratch test machine, which is 19.7 N. According to a study by Jevtic,[23] all of these coatings could be classified as high-resistance coatings.

3.3. Abrasion

Table 4 shows ANOVA for the effects of coating, cycle and treatment on the abrasion resistance of the finished *A. mangium* wood. As indicated in Table 4, no significant differences were observed for all parameters except the coating system and treatment. From the table, the parameters that influence the result appear to be the coating system itself as having a high significance of $p \leq 0.0001$.

The abrasion resistance test of the coatings was performed where weight loss was recorded after 2000 cycles. As shown in Table 5, the results showed that NC had the highest weight loss ranged from 32.89 g to 32.61 g (0.28 g weight loss) and 34.27 g to 33.97 g (0.30 g weight loss) for untreated and treated panels, respectively. PU panels have good abrasion resistance with the slightest weight loss of 31.42 g to 31.26 g (0.16 g weight loss) and 31.53 to 31.33 g (0.20 g weight loss), respectively, for untreated and treated panels, followed by AC panels with medium decrease in weight loss, from 32.04 to 31.84 g (0.20 g weight loss) for untreated and 31.62 to 31.37 g (0.25 g weight loss) for treated panels. However, there is no significant difference between AC and PU coatings (denoted by the same letter ‘B’). PU is known as a hard,

Table 5. The abrasion resistance test of the finished films for *A. mangium* samples.

	Nitrocellulose (g)		Acid catalyzed (g)		Polyurethane (g)	
Finishing system/Number of cycles	Untreated	Treated	Untreated	Treated	Untreated	Treated
Net weight	32.89^{B}	34.27^{A}	32.04^{B}	31.62^{C}	31.42^{C}	31.53^{C}
1000 cycles	32.66^{B}	34.12^{A}	31.92^{B}	31.46^{C}	31.36^{C}	31.41^{C}
2000 cycles	32.61^{B}	33.97^{A}	31.84^{B}	31.37^{C}	31.26^{C}	31.33^{C}
Loss in weight	0.28^{A}	0.30^{A}	0.20^{B}	0.25^{B}	0.16^{C}	0.20^{C}

*Loss in weight = weight of 0 cycle − weight after 2000 cycles
Mean follow by the same letters ^{A,B,C} in the same row are not significant different at $p \leq 0.005$

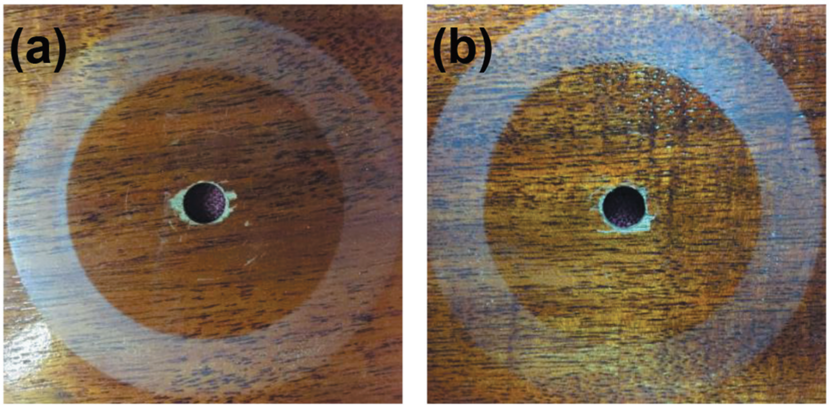

Figure 9. Abrasion Mark on the NC Coating; (A) Untreated, (B) Treated.

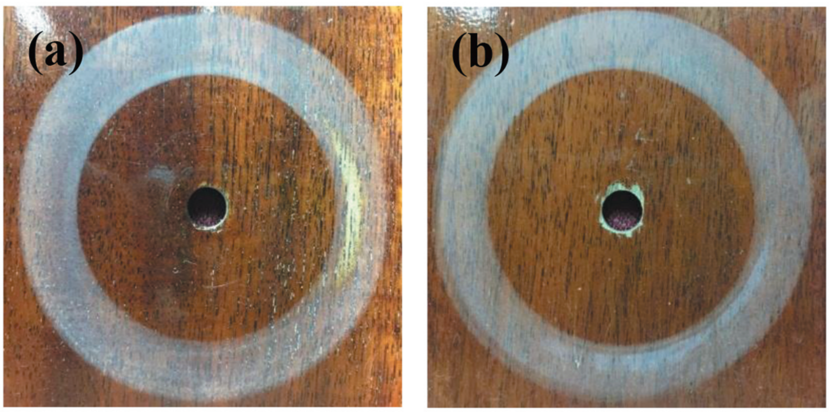

Figure 10. Abrasion Mark on the AC Coating; (A) Untreated, (B) Treated.

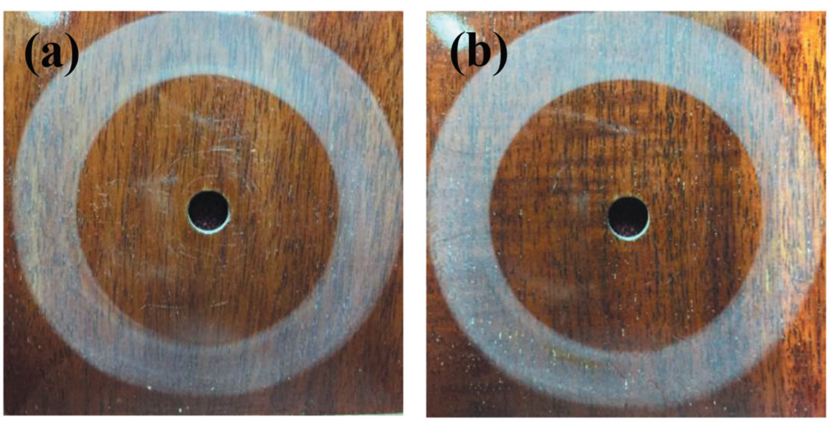

Figure 11. Abrasion Mark on the PU Coating; (A) Untreated, (B) Treated.

Table 6. Analysis of variance (ANOVA) of the effects of coating and treatment on the impact resistance.

Source	df	p-value	
Coating	2	<.0001	***
Treatment	1	0.2631	ns
Coating*treatment	2	0.9501	ns

Note: ns No significant different at $p > 0.1$
*** Significant different at $p < 0.01$

abrasion-resistant and durable wood coating and therefore it can withstand the highest abrasive damage.[24] When the wood surface was treated with 8% MeOH, all samples improved slightly. The visual appearance of samples after the abrasion test is shown in Figures 9–11.

3.4. Impact resistance

Table 6 shows the impact of coating and treatment on the impact resistance of finished *A. mangium* wood based on variance analysis (ANOVA). There is no significant difference either in interaction or treatment with impact resistance. The type of coating system was found to be the only factor that influenced the impact resistance of finished wood.

As can be seen in Figure 12, both AC (3.44) and PU (3.61) coatings have significantly higher impact resistance compared to NC (2.22). As shown in Table 7, higher resistance was achieved by PU and AC (rate 4) for treated panels with slight cracking, e.g. one or two circular cracks around the edge of

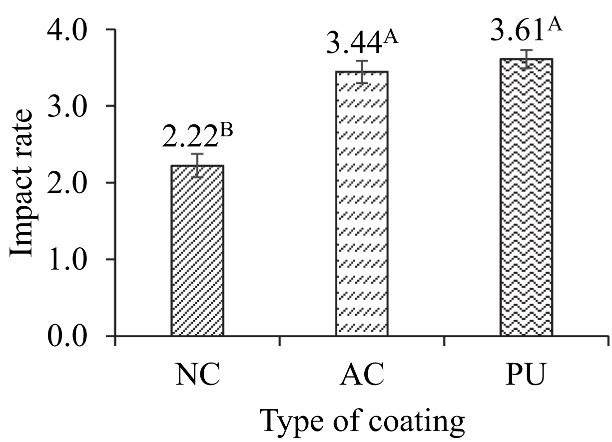

Figure 12. The Impact Rate from Impact Test on Different Type of Coating.

Table 7. The impact resistance of the finished films for *Acacia mangium* samples.

Finishing system	Nitrocellulose		Acid catalyzed		Polyurethane	
Rating	Untreated	Treated	Untreated	Treated	Untreated	Treated
	1	2	3	4	3	4

Note: Rating 1–5, where 5 is very good and 1 very poor

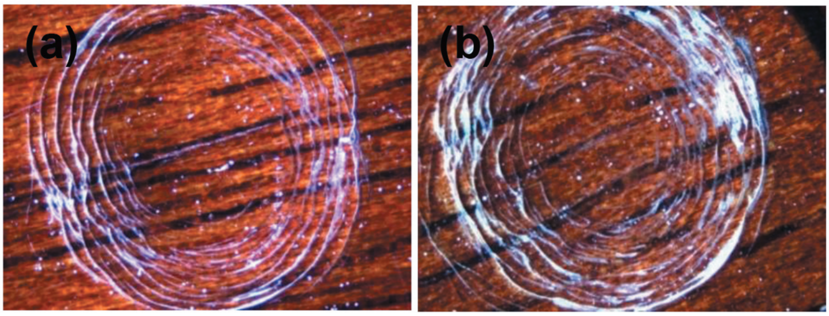

Figure 13. Crack Impact on the NC Coating; (A) Untreated, (B) Treated.

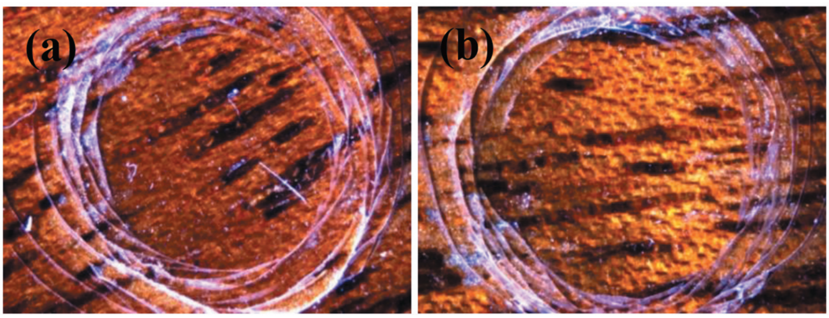

Figure 14. Crack Impact on the AC Coating; (A) Untreated, (B) Treated.

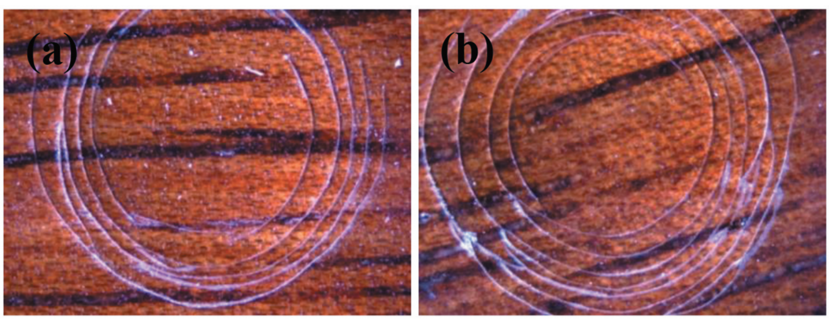

Figure 15. Crack Impact on the PU Coating; (A) Untreated, (B) Treated.

the indentation and the lowest resistance was NC (rate 1) for untreated panels with more than 25% of the finish removed from the indentation area. Other than that, the second lowest impact resistance was NC (rate 2) for the treated panel, due to cracking outside the indentation area and slight flaking of the finish, and the same rate (rate 3) for AC and PU for the untreated panel due to moderate or severe cracking within the indentation area. It can be said that the impact strength of the panel was improved following the MeOH treatment of

Table 8. Analysis of variance (ANOVA) of the effects of treatment, coating and layer on the film thickness.

Source	df	p-value	
Treatment	1	<.0001	***
Coating	2	<.0001	***
Layer	3	<.0001	***
Treatment*Coating*Layer	6	<.0001	***

the panel. The visual appearance of the wood following an impact test can be seen from Figures 13–15. The findings were in agreement with Chang et al.[25] who found that NC coating had lower impact resistance than PU coating when applied to Japanese cedar and Formosa acacia.

3.5. Film thickness

Table 8 presents the analysis of variance (ANOVA) effects of the coating and treatment on the film thickness of finished *A. mangium* wood. There was a significant difference in all parameters, including methanol treatment (treated and untreated), coating system, layer and interaction between methanol treatment, coating and layer.

The thickest layer of film from Table 9 is PU (221.33 µm & 224.28 µm) followed by AC (194.28 µm & 178.17 µm) and NC (124.56 µm & 112.83 µm)

Table 9. The film thickness of the finished films for *A. mangium* samples.

	Nitrocellulose (µm)		Acid catalyzed (µm)		Polyurethane (µm)	
Finishing system/Number of layers	Untreated	Treated	Untreated	Treated	Untreated	Treated
1st layer	43.81	21.50	64.21	54.37	79.63	64.21
2nd layer	72.63	56.72	126.35	101.71	134.67	126.35
3rd layer	90.83	87.53	153.48	143.22	179.29	173.48
4th layer	124.56	112.83	194.28	178.17	221.33	224.28

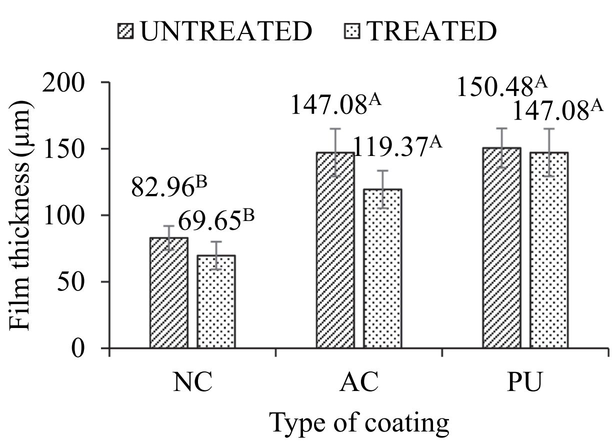

Figure 16. Film Thickness for Untreated and Treated Panel for All Types of Coating.

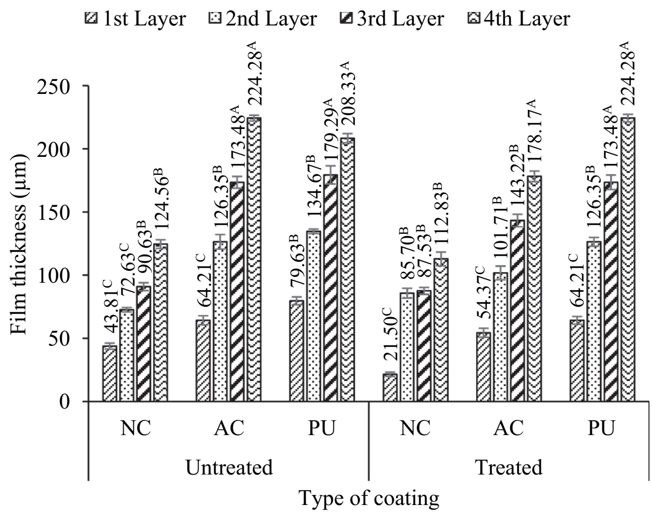

Figure 17. The Film Thickness for Each Layer for Untreated and Treated Panel for All Type of Coating.

for both untreated and treated samples. The findings contradicted those of Shukla et al., [26] where the authors observed that NC had a higher film thickness than PU. In the meantime, Figure 16 shows that there is no significant difference between the thickness of the untreated film and the treated panel for all types of coating, even though some variations were present. In addition, each layer resulted in a film thickness of between 100 and 230 μm for all types of coating as shown in Figure 17. The thickness of the film varied for untreated and treated panels. The treated panel, coated with all types of coatings, appears to have absorbed a lot of coating material compared to the untreated panel. This is expected as MeOH increases surface roughness and reduces surface tension, thus encouraging higher fluid penetration into the wood. Therefore, only a partial amount of lacquer left on the surface to form the film. In addition, the solid content of each type of coating also provided different thickness of the film. The exact amount of film thickness is related to good finishing properties for the adhesion test, scratch resistance test, impact resistance test, etc. Too much thickness of the coating may, however, cause the coating to become brittle and reduce the transparency of wood.

Table 10. Analysis of variance (ANOVA) of the effects of coating and treatment on the surface roughness.

		Ra		Rz	
Source	df	p-value		p-value	
Coating	2	0.0737	*	0.0896	*
Treatment	1	0.3183	ns	0.6618	ns
Coating*treatment	2	0.8020	ns	0.6953	ns

Note: *significant different at $p < 0.1$
ns no significant different

Table 11. Means of surface roughness of finished panel for untreated and treated *A. mangium* wood.

	Untreated		Treated	
Finishing system	Ra	Rz	Ra	Rz
NC	1.09	4.67	0.72	3.19
AC	0.74	2.93	0.51	3.21
PU	0.29	1.32	0.25	1.33

3.6. Surface roughness

Table 10 shows that the types of coating, treatment and interaction between the type of coating and treatment had very little effect on the surface roughness of the finished sample. Table 11 shows that these values were lower in the treated sample than in the untreated sample. For example, surface roughness (Ra) decreased by 51.39% in NC-treated panels, 45.10% in AC-treated panels, and 16% in PU-treated samples. This reduction is very important for many applications of wood furniture that want a smooth surface for good glossiness, boost aesthetic values and make it easier to coat.[27]

3.7. Effect of surface treatment on appearance

3.7.1. Gloss

The analysis of variance (ANOVA) for the effects of treatment with methanol (untreated and treated), the form of coating and the angle of glossiness is given in Table 12. All variables have a major impact on the glossiness. However, there is no major or low incidence of interaction between methanol treatment, type of coating and angle.

Table 12. Analysis of variance (ANOVA) of the effects of treatment, coating and angle on the gloss.

Source	df	p-value	
Treatment	1	0.003	**
Coating	2	<.0001	***
Angle	2	<.0001	***
Treatment*Coating*Angle	4	0.233	ns

Note: ns No significant difference at $p > 0.1$
** Significant difference at $p < 0.05$
*** Significant difference at $p < 0.01$

Table 13. Average of gloss for MeOH-treated *A. mangium* coated with different type of coating.

	NC		AC		PU	
Angle	Untreated	Treated	Untreated	Treated	Untreated	Treated
20°	44.67^{A}	46.33^{A}	30.77^{B}	17.33^{C}	54.13^{A}	53.10^{A}
60°	77.97^{B}	75.55^{B}	66.87^{B}	48.07^{D}	78.87^{C}	88.17^{A}
85°	80.23^{A}	82.97^{A}	67.10^{B}	51.20^{C}	79.50^{A}	83.43^{A}

Note: Mean follow by the same letters ^{A,B,C,D} in the same row are not significant different at $p \leq 0.05$

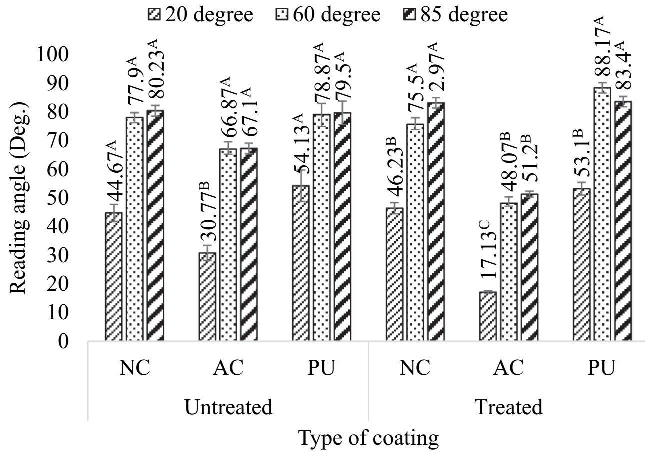

Figure 18. The Glossiness of Different Angle of Untreated and Treated Panel for Different Type of Coating.

The average glossiness of NC, AC, and PU coatings for both untreated and treated samples is shown in Table 13. The more direct light is reflected in the gloss assessment, the glossier the impression will be. Figure 18 shows that the highest percentage of light reflection is PU followed by NC. No significant difference was detected between untreated and treated samples. The lowest AC sample was recorded where both the untreated and the treated sample differed significantly. This is probably due to the roughness of the textured surface after treatment.[28] Taking the 60° reflecting angle as a general use in the wood industry, it can be seen that the NC sample was marked as a gloss finish for both untreated and treated samples with a gloss measuring unit of 77.97 and 67.97, respectively. The AC panel has a significantly high gloss and semi-gloss unit for both untreated and treated samples with 69.83 and 55.83, respectively. The PU panel was labelled as a high-gloss unit for both untreated and treated samples with 84.93 and 87.78, respectively. Figure 18 shows that all samples have a higher level of gloss when the angle of reflection is set at 60° and 85°. In this reflection, however, there is no significant difference between the two angles. The glossiness of the AC was relatively lower than that of the NC sample, despite having higher adhesion, scratch resistance, impact and abrasion. On the basis of a comparison of the percentage between untreated and treated samples for NC and AC, MeOH should not be applied to the wood surface for a better gloss effect.

4. Conclusion

The findings of this study can be summarised as follows:

(i) MeOH was effective in the treatment of surface *A. mangium* improved the mechanical properties of the finished surface in adhesion, abrasion and impact, except for scratching.
(ii) MeOH surface treatment has the ability to increase the absorption of the coating in comparison to the untreated sample.
(iii) MeOH treatment is not suitable for the production of high-gloss surface.
(iv) The PU coating system has provided good properties for both mechanical and physical characteristics. In ascending order, the overall coating result sequence is NC < AC < PU.
(v) MeOH treatment requires a few steps of preparation and it takes longer time to complete the finishing process.
(vi) Further studies should consider the optimisation of the coating layer (base and top layer). Moreover, the economic aspects should be studied, as they could potentially reduce the costs of wood-finishing operations.

Acknowledgements

The authors express their gratitude to the Higher Institutions Centre of Excellence, Ministry of Higher Education for the financial support (project no. 6369109). We would like to thank Wood Finishing Laboratory, Forest Research Institute Malaysia for the facilities used during the study.

References

[1] National Research Council. *Mangium and Other Fast-Growing Acacias for the Humid Tropics*; National Academy Press: Washington, D.C., 1983.
[2] Alamsyah, E. M.; Yamada, M.; Taki, K. Bondability of Tropical Fast-Growing Tree Species III: Curing Behavior of Resorcinol Formaldehyde Resin Adhesive at Room Temperature and Effects of Extractives of *Acacia Mangium* Wood on Bonding. *J. Wood Sci*. 2008, *54*(3), 208–213. DOI: 10.1007/s10086-007-0945-1.
[3] Alamsyah, E. M.; Nan, L. C.; Yamada, M.; Taki, K.; Yoshida, H. Bondability of Tropical Fast-Growing Tree Species I: Indonesian Wood Species. *J. Wood Sci.* 2007, *53*(1), 40–46. DOI: 10.1007/s10086-006-0821-4.
[4] Bakri, M. K. B.; Jayamani, E.; Hamdan, S.; Rahman, M. R.; Kakar, A. Potential of Borneo Acacia Wood in Fully Biodegradable Bio-Composites' Commercial Production and Application. *Polym. Bull.* 2018, *75*(11), 5333–5354. DOI: 10.1007/s00289-018-2393-z.
[5] Parti Bumiputera Perkasa Malaysia (PERKASA). Seminar on Viability Assessment of Indigenous Tree Species and Propagation Techniques for Planted Forest Development in Sarawak. Sarawak Timber Ind. *Dev. Corp. Newslett*. 2009, *5*, 6–8.
[6] Tohmura, S. I.;. Acceleration of the Cure of Phenolic Resin Adhesives VII: Influence of Extractives of Merbau Wood on Bonding. *J. Wood Sci.* 1998, *44*(3), 211–216. DOI: 10.1007/BF00521965.

[7] Hirabayashi, Y.; Nakano, T. Adhesive and Coating Properties on Tropical Woods. *Mokuzai Gakkaishi*. 1997, *43*, 356–363.

[8] Hse, C. Y.; Kuo, M. L. Influence of Extractives on Wood Gluing and Finishing-A Review. *For. Prod. J.* 1988, *38*, 52–56.

[9] Redzuan, M. S. J.; Paridah, M. T.; Anwar, U. M. K.; Juliana, A. H.; Lee, S. H.; Norwahyuni, M. Y. Effects of Surface Pretreatment on Wettability of *Acacia Mangium* Wood. *J. Trop. For. Sci.* 2019, *31*, 249–258. DOI: 10.26525/jtfs2019.31.2.249258.

[10] Jewitt, J.; 2004. Selecting a Finish. https://www.finewoodworking.com/2004/11/01/selecting-a-finish (accessed January 18, 2020).

[11] Çakıcıer, N.; Korkut, S.; Korkut, D. S. Varnish Layer Hardness, Scratch Resistance, and Glossiness of Various Wood Species as Affected by Heat Treatment. *BioResources*. 2011, *6*, 1648–1658.

[12] Sonmez, A.; Budakci, M.; Bayram, M. Effect of Wood Moisture Content on Adhesion of Varnish Coatings. *Sci. Res. Essays*. 2009, *4*, 1432–1437.

[13] Sow, C.; Riedl, B.; Blanchet, P. UV-Waterborne Polyurethane-Acrylate Nanocomposite Coatings Containing Alumina and Silica Nanoparticles for Wood: Mechanical, Optical, and Thermal Properties Assessment. *J. Coat. Technol. Res.* 2011, *8*(2), 211–221. DOI: 10.1007/s11998-010-9298-6.

[14] Vu, C.; La Ferté, O.; Eranian, A. 'High Performance UV Multi-Layer Coatings Using Inorganic Nanoparticles. Presented at the RadTech Europe 2005 Conference and Exhibition: Trends Continue, UV/EB Technologies Advance, Innovations Show High Potential, Barcelona, Spain, October 18-20, 2005.

[15] ASTM D1200-10. *Standard Test Method for Viscosity by Ford Viscosity Cup*; ASTM International: West Conshohocken, PA, 2018.

[16] BS EN ISO 2409. *Paints and Varnishes – Cross-Cut Test*; BSI Standard Limited: London, 2013.

[17] BS EN ISO 1518-1. *Paints and Varnishes. Determination of Scratch Resistance. Constant-Loading Method*; BSI Standard Limited: London, 2011.

[18] Safta, E.; Chen, F. B. H.; Forrest, H. R.; Muselman, G. D. Abrasion Resistant Coatings. US6641629B22002, March 20, 2003.

[19] ASTM D4060-19. *Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser*; ASTM International: West Conshohocken, PA, 2019.

[20] BS 3962: Part 6. *Finishes for Wooden Furniture-Assessment of Surface to Mechanical Damage*; BSI Standard Limited: London, 1980.

[21] Hiziroglu, S.;. Surface Roughness Analysis of Wood Composites: A Stylus Method. *For. Prod. J.* 1996, *46*, 67–72.

[22] Kúdela, J.; Liptáková, E. Adhesion of Coating Materials to Wood. *J. Adhes. Sci. Technol.* 2006, *20*(8), 875–895. DOI: 10.1163/156856106777638725.

[23] Jevtić, P. J.;. Quality of Wood Surface Finished with Polyurethane Coating. *Zaštita Materijala*. 2013, *54*, 189–192. DOI: 620.197.6:674.5.

[24] Poaty, B.; Riedl, B.; Blanchet, P.; Blanchard, V.; Stafford, L. Improved Water Repellency of Black Spruce Wood Surfaces after Treatment in Carbon Tetrafluoride Plasmas. *Wood Sci. Technol.* 2013, *47*(2), 411–422. DOI: 10.1007/s00226-012-0505-8.

[25] Chang, C. W.; Kuo, W. L.; Lu, K. T. On the Effect of Heat Treatments on the Adhesion, Finishing and Decay Resistance of Japanese Cedar (*Cryptomeria Japonica* D. Don) and Formosa Acacia (*Acacia Confuse* Merr. (Leguminosae)). *Forests*. 2019, *10*(7), 586. DOI: 10.3390/f10070586.

[26] Shukla, S.; Pandey, K. K.; Kumar, K. V. S. Chemical and Application Properties of Some Solvent and Water Based Coatings on Wooden Substrate. *Drv. Ind.* 2019, *70*(2), 107–114. DOI: 10.5552/drvind.2019.1809.

[27] Li, H.; Jiang, X.; Ramaswamy, H. S.; Zhu, S.; Yu, Y. High-Pressure Treatment Effects on Density Profile, Surface Roughness, Hardness, and Abrasion Resistance of Paulownia Wood Boards. *Trans. ASABE.* 2018, *61*(3), 1181–1188. DOI: 10.13031/trans.12718.

[28] Veigel, S.; Grüll, G.; Pinkl, S.; Obersriebnig, M.; Müller, U.; Gindl-Altmutter, W. Improving the Mechanical Resistance of Waterborne Wood Coatings by Adding Cellulose Nanofibres. *React. Funct. Polym.* 2014, *85*, 214–220. DOI: 10.1016/j.reactfunctpolym.2014.07.020.