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Influence of Abrasive Grit Size on Surface Wettability in Kelempayan (*Neolamarckia cadamba*) and Petai (*Parkia speciosa*) Wood Sanding

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ABSTRACT

The environmental implications of sanding processes, including energy consumption and waste generation, are increasingly significant considerations. Therefore, identifying sustainable sanding practices involves finding ways to minimize energy consumption, reduce waste generation, and mitigate environmental impacts while maintaining or improving product quality. The study aimed to assess the impact of grit size on the surface quality of *Neolamarckia cadamba* and *Parkia speciosa* wood. Three sanding methods with varying grit sizes a) single stage 100-grit, b) two stage 100+150-grit, and c) three stage with 100+150+180-grit were employed, and surface quality was evaluated using three different liquids (water, oil and formamide) medias. SEM analysis was carried out for every grit size sanded sample of both species. The sanding process has been done 30 times on each surface with a constant force. The measurements are carrying out with a view parallel to the grain. Results showed that surfaces sanded with 100+150+180-grit had lower mean contact angle values for water, oil, and formamide for both *Neolamarckia cadamba* and *Parkia speciosa*. The choice of abrasive and grit sequence significantly affects coating absorption time, surface finishing, and wood damage during sanding. Smoother surfaces exhibited higher wettability and absorbency, highlighting the significant influence of sanding on wood surface properties. This study provides valuable insights for bonding and finishing processes in the wood industry, aiming to promote environmentally responsible practices in Malaysia.

Keywords: Wettability; Morphology; Kelempayan; Wood sanding

1. Introduction

Neolamarckia cadamba of the Rubiaceae family, also known as 'kelempayan,' is a large, deciduous, fast-growing tree species. This tree gives early return within 8-10 years. Depending on the soil condition, a 10-year-old of *Noelamarckia cadamba* can achieve 50 cm of diameter, yielding 2.5-3 m^3 of wood [1]. *Noelamarckia cadamba* is one of the good quality raw materials for the plywood industry. Then, its wood is light and hard, which is why it has emerged as a commercial timber, providing the source for plywood and used for lightweight construction works. Meanwhile, it also serves as raw materials for the pulp and paper industry. These species were already selected for planted forest development in Malaysia, especially in Sarawak [2]. Besides, it is frequently grown as an ornamental plant and shade tree in plantations [3].

Parkia speciosa also known as 'petai' is a rainforest tree that can grow up to 40 m high and 100 cm in diameter [4]. This plant belongs to the genus of Parkia and species speciose in the family of Fabaceae but also placed in *Leguminosae and Mimosaceae* [5]. *Parkia speciosa* is usually lightweight, occasionally medium-weight hardwood with a density of 350-810 kg/m^3 at 15 % moisture content [6]. *Parkia speciosa* preservative treatment is easy, while their wood is non-durable, with a service life of about 1 year. The wood of *Parkia speciosa* is used locally for temporary light construction, carpentry, furniture and cabinet making, moulding, interior finish, cladding, concrete shuttering, boxes and crates, matches, clogs, disposable chopstick, and fishnet floats [7]. Generally, utility plywood is manufactured from this wood.

The quality or value of furniture products made from solid wood depends on the finishing quality of the wood. The quality of the surface that will be applied with finishing materials also influences the finishing quality. The roughness and wettability of the wood surface play an important role in determining the surface coating quality before finishing and after finishing the final product [8]. In finishing applications, surface characteristics, including absorption ability, wettability, and surface roughness/smoothness properties, determine the effect of the final product and play important roles in getting the finished product of good quality. Rough wood surfaces limit the wood contact surface in gluing and are also poor finishing quality [9].

Sanding is the most regularly used surfacing method for the first stage of wood covering [10]. The sanding wood main objective is to produce a surface free from visible defects plus to make the surface consistently permeable for wood covering [11]. Sanding wood surfaces using sandpaper or a tiny pebble requires some force to cover the progressively occurring mechanical defects. Sanding wood has its properties and characteristics. Sanded wood surfaces are stronger and smooth, unlike those obtained by planning [12]. Sanding is performed to reduce the roughness of wood surfaces and restore their anatomical properties [13]. It also helps to cover or correct machining imperfections left after wood planning [14].

2. Materials and Methods

2.1 Raw Materials

2.1.1 Neolamarckia cadamba and Parkia speciosa wood

In this research, wood samples from *Neolamarckia cadamba* and *Parkia speciosa*, each measuring 200 mm in length, 100 mm in width, and 15 mm in thickness were used. The trees were sourced from the 'Agropark' at Universiti Malaysia Kelantan. The abrasive sandpapers used had grit sizes of 100, 150, and 180, all composed of silicon carbide grains. Water, oil, and formamide were the liquids used to measure the contact angle.

2.2 Methods

2.1.1 Wood sample sanded

72 wood samples which means 36 wood samples for *Neolamarckia cadamba* species and 36 wood samples for *Parkia speciosa* were used for sanding treatment. Wood samples were subjected to sanding using hand sanding [15]. According to Hawks, using a wood block as a sanding support ensures better results when sanding wood surfaces. The size of the wood block is also crucial for making the sanding process easier to handle [16]. Wood samples were sanded 30 times using three different ranges of sandpaper grit sizes: first-stage 100-grit, second-stage 100+150-grit, and third-stage 100+150+180-grit. The grit sizes of the sandpaper were fixed at 180, 150, and 100, as per DIN 4768 (1990). These three ranges of grit sizes were selected to start with rough sandpaper and progressively move to finer grits.

2.1.2 Contact angle measurement

The contact angle measurements were performed based on 3 different liquids (water, oil, and formamide) using the sessile drop method. The contact angle was defined as the angle through the liquid phase formed between the surface of a solid and the line tangent to the droplet radius from the point of contact with the solid. A minimum of 5 droplets was examined for wood samples [17]. Twelve wood samples, each measuring 200 mm x 100 mm x 15 mm, were used for contact angle measurements with different types of liquids. The contact angle measurements were obtained manually, as shown in Fig. 1, and calculated using in Eq. 1 below.

$$\tan \theta = \frac{h}{r} \rightarrow \theta = 2 \arctan \frac{h}{r} \qquad \text{(Eq. 1)}$$

Where: r: radius

h: height

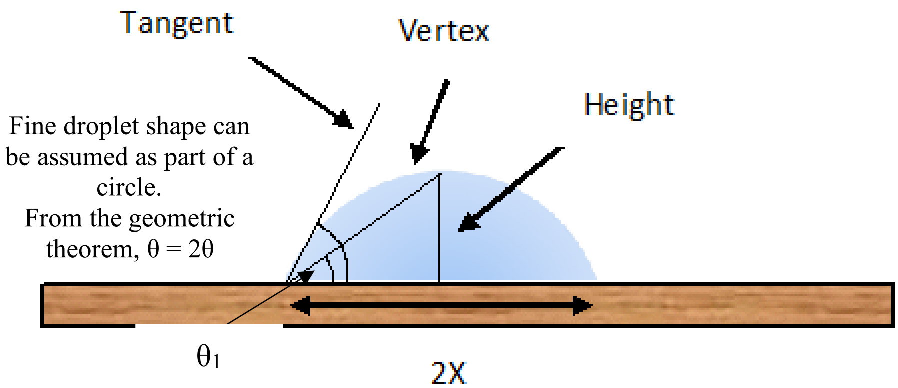

Fig. 1: Contact angle measurement formula

2.1.3 Scanning Electron Microscopy (SEM) analysis

After the sanding treatment of *Neolamarckia cadamba* and *Parkia speciosa* wood samples, the samples untreated and treated were observed parallel to the grain direction by using an SEM analysis machine. SEM was utilized to observe the morphology of the sanded surface [18]. Particular attention was given to surface fiber damage and wood cells by studying the samples' grain across their entire width (1 cm to 5 microns) [19]. Observations were collected without using replicate samples, with four samples each for *Neolamarckia cadamba* and *Parkia speciosa*.

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2.3 Statistical analysis

The surface wettability data for *Neolamarckia cadamba* and *Parkia speciosa* wood species, tested with three different liquids, were analyzed using descriptive analysis for various sandpaper grit sizes. The recorded data were then entered into SPSS Statistics Version 20.0 for Windows for further statistical analysis.

3. Results and Discussion

3.1 Surface Wettability Test Using 3 Different Liquid

3.1.1 Mean contact angle for Neolamarckia cadamba and Parkia speciosa

Water, oil, and formamide droplets spread over the wood surface and soaked into its porous structure immediately upon contact. Each liquid test was repeated five times on different parts of the same wood sample. The mean contact angle decreased across all sandpaper grit sizes, as shown in Fig. 2 and Fig. 3. During the initial stage of sanding, the rates of liquid spreading and soaking were lower, but these rates increased by the third stage. The most rapid change in contact angle was observed with formamide, followed by oil and water. This variation in liquid behavior is attributed to their differing surface viscosities.

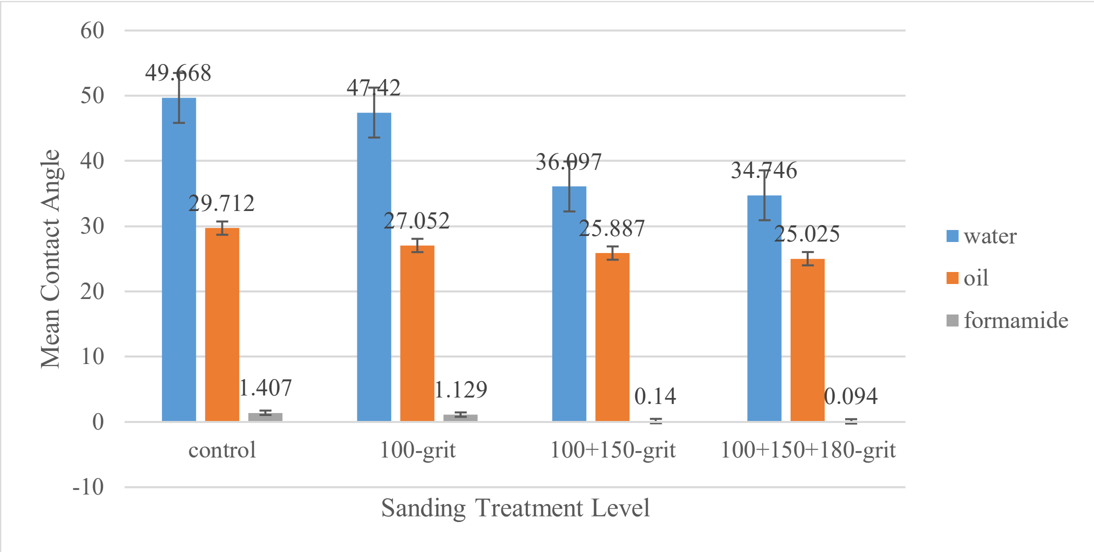

Fig. 2: The effect of sanding treatment on the mean contact angle of *Neolamarckia cadamba*

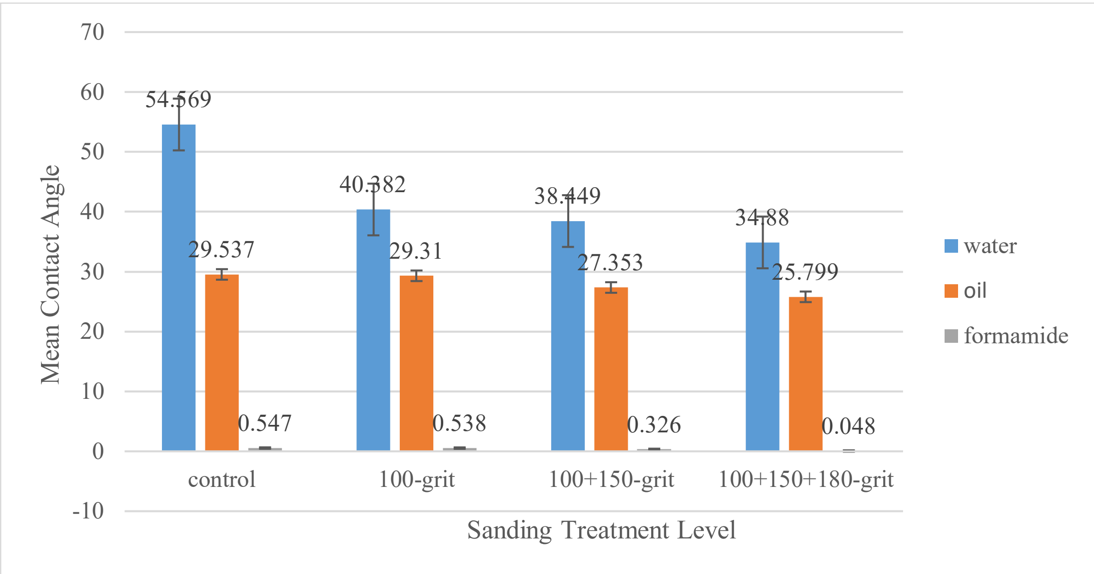

Fig. 3: The effect of sanding treatment on the mean contact angle of *Parkia speciosa*

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As shown in Fig. 2 and Fig. 3, the measured and calculated contact angle values were listed, indicating that the contact angle decreased with higher levels of sanding treatment. The surface with a lower sanding grit size had a higher contact angle value. The wood sample surface's smaller contact angle indicates greater wettability and hydrophilicity. The contact angle is directly influenced by surface roughness and reflects the average wettability of the surface [8]. For example, the wood samples of *Neolamarckia cadamba* sanded with 100-grit size have a 47.42 contact angle on the water liquid test, 27.052 contact angle on the oil liquid test, and 1.129 contact angle on the formamide liquid test. The surface sanded with 100+150+180-grit size showed a contact angle of 34.746 for the water liquid test, 25.025 for the oil liquid test, and 0.094 contact for the formamide liquid test.

Wood samples of *Parkia speciosa* sanded with 100-grit sandpaper had contact angles of 40.382 for water, 29.31 for oil, and 0.538 for formamide. When sanded with 100+150+180-grit sandpaper, the contact angles were 34.88 for water, 25.799 for oil, and 0.048 for formamide. The surfaces of *Neolamarckia cadamba* and *Parkia speciosa* sanded with 100+150+180-grit sandpaper were more wettable than those sanded with 100-grit sandpaper. The contact angles for water, oil, and formamide decreased significantly with higher grit sizes. The different behaviours of liquids at the wood phase boundary were reflected in the varying contact angle values [20]. These differences in contact angle values also highlight the distinctions between the wood phase boundary and non-polar and polar liquids [21]. The results indicate that increasing surface roughness decreases the surface absorption of the wood samples. These findings emphasize the impact of surface roughness on wettability, with increased roughness leading to decreased wood surface absorption. This underscores the importance of sanding treatments in modifying wood surface properties for various applications.

3.1.2 Comparison of contact angle of Neolamarckia cadamba and Parkia speciosa after liquid test

Tables 1 and 2 display the outcomes of the analysis of variance (ANOVA) and Duncan's multiple range test for the contact angle measurements of *Neolamarckia cadamba and Parkia speciosa* in water, oil, and formamide liquids. In the water liquid test, the contact angle of *Neolamarckia cadamba and Parkia speciosa* wood exhibited significant differences across grit sizes for water treatment (sig=0.000) at a significance level of ≤ 0.05, as shown in Table 1. However, no statistical significance was observed between the species and the interaction term species*grit size (sig=0.965 and sig=0.203, respectively) at the same significance level. The variation in grit size is attributed to the distinct quality levels represented by different grades of sandpaper [22].

Table 1: Analysis of variance (ANOVA) for water, oil, and formamide liquids test of *Neolamarckia cadamba and Parkia speciosa* between species, grit size, and interaction species*grit size

Treatments	Source	Sum of Square	df	Mean Square	F	Sig.
Water	Species	0.046	1	0.046	0.002	0.965
	Grit size	1079.979	3	359.993	15.684	0.000
	Species*Grit size	118.612	3	39.537	1.723	0.203
Oil	Species	7.009	1	7.009	0.556	0.467
	Grit size	27.292	3	9.097	0.722	0.554
	Species*Grit size	38.149	3	12.606	1.009	0.415
Formamide	Species	0.644	1	0.644	3.070	0.990
	Grit size	2.635	3	0.878	4.184	0.023
	Species*Grit size	1.954	3	0.651	3.102	0.056

The analysis of variance (ANOVA) conducted on the oil liquid test for determining the contact angle of *Neolamarckia cadamba and Parkia speciosa* wood revealed significant differences across various grit sizes ($p < 0.001$), as indicated in Table 1, with no significance observed between species, grit size, and their interaction ($p = 0.467$, $p = 0.554$, and $p = 0.415$, respectively) at the 0.05 significance level. This outcome is consistent with the findings of Amorim et al., who noted the heterogeneous nature of superficial roughness in wood due to its cellular structure and grain type, which consequently affects wettability [23]. Similarly, ANOVA results for the formamide liquid test also showed significant differences among grit sizes ($p < 0.001$) for both wood species, as illustrated in Table 1. However, there were no significant differences observed between species and the interaction of species with grit size ($p = 0.990$ and $p = 0.056$, respectively), while significance was found solely within the grit size variable ($p = 0.023$) at the 0.05 significance level. This finding underscores the influence of sandpaper grades on abrasive quality, backing material, and bonding agents, thereby impacting the results of the formamide liquid test.

In Table 2, Duncan's multiple range test reveals distinct mean values of water-liquid test contact angles for various wood samples across different grit sizes: 34.81a, 37.27a, 43.90b, and 52.12c, respectively. Notably, mean values sharing a different letter indicate significant differences. Similarly, the analysis unveils mean values of oil liquid test contact angles: 25.84a, 27.17a, 28.29a, and 28.53a, respectively, with consistent significance as indicated by differing letters. Furthermore, the investigation displays mean values of contact angles: 0.09a, 0.32ab, 0.87b, and 0.83b, representing distinct levels of significance across the wood samples and grit sizes.

Table 2: Duncan's multiple ranges test for Water, Oil and Formamide liquids test

Treatments	**Contact angle (°)**			
	Grit Size			
	100+150+180	**100+150**	**100**	**Control**
Water	34.81a	37.27a	43.90b	52.12c
Oil	25.84a	27.17a	28.29a	28.53a
Formamide	0.09a	0.32ab	0.87b	0.83b

*different letters in the same column and the same type of binder showed significant differences at α value of 0.05

During the post hoc test, strong significance was observed in the water liquid test between the control group and the 100+150-grit size ($p=0.00$), as well as between the control group and the 100+150+180-grit size ($p=0.00$). Additionally, there was marginal significance between the control group and the 100-grit size ($p=0.40$), along with the control group and itself ($p=0.40$). In contrast, no significant differences were found between any grit sizes in the oil liquid test at a significance level of $p \leq 0.05$. Regarding the formamide liquid test, there was a slight significance observed between the 100-grit and 100+150+180-grit sizes ($p=0.45$), while the other grit sizes showed no significance across all stages at a significance level of $p \leq 0.05$.

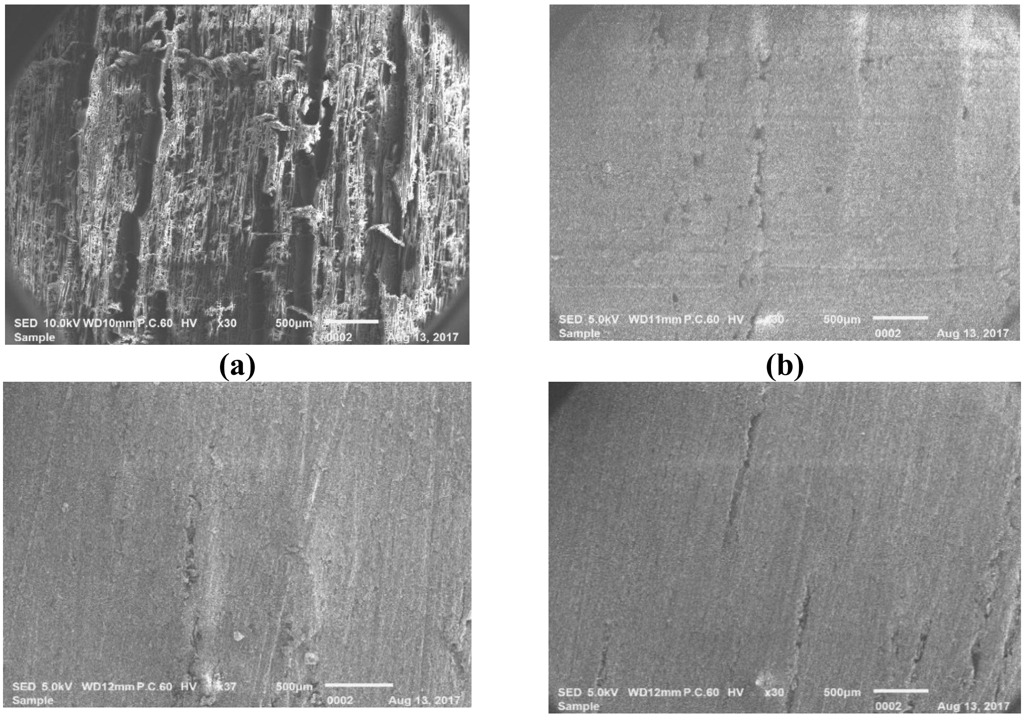
According to Saloni et al., the sanding process involves altering the surface using abrasive materials [24]. The choice of abrasive and the sequence of grit sizes influence factors such as coating absorption time, surface finish quality, and potential damage to the sanded wood. Studies on the effect of grit size on the surface quality of *Neolamarckia cadamba* and *Parkia speciosa* have concluded that smaller abrasive grains result in superior surface finishes. Regarding the type of abrasive used, most studies suggest that silicon carbide provides better surface finishing compared to other abrasives such as flint, garnet, and aluminum oxide [25]. It is important to note that wood exhibits significant variability due to its physical, chemical, and anatomical properties, leading to variations among different wood species.

In conclusion, the analysis of variance (ANOVA) and Duncan's multiple range test provided valuable insights into the contact angle measurements of *Neolamarckia cadamba* and *Parkia speciosa* in water, oil, and formamide liquids across different grit sizes. Significant differences were observed in contact angles among grit sizes for water, oil, and formamide treatments, underscoring the influence of sandpaper grades on surface properties. Notably, the post hoc test revealed specific significance levels between grit sizes in the water and formamide liquid tests, emphasizing the nuanced effects of sanding treatments on wood surface interactions with different liquids. Furthermore, the findings highlight the importance of selecting appropriate abrasives and grit sizes in the sanding process to optimize surface finishing and wettability. Studies suggest that smaller abrasive grains, particularly silicon carbide, contribute to superior surface finishing, further emphasizing the need to carefully consider abrasive materials in wood surface engineering. Overall, these findings contribute to a better understanding of how sanding treatments influence wood surface properties and offer valuable insights for improving surface quality in various wood applications.

3.2 Morphology of wood to SEM analysis

3.2.1 Morphological view of Neolamarckia cadamba

In the other objective, the morphology of the wood after and before sanding was examined. Untreated (control) and treated (sanded) wood samples were analyzed using scanning electron microscopy (SEM). The SEM images of the Neolamarckia cadamba wood surface are shown in Fig. 4. The samples were sanded using 100-grit, 100+150-grit, and 100+150+180-grit silicon carbide sandpaper in longitudinal directions. Additionally, two samples were left unsanded, serving as untreated or control samples.



(a) **(b)** **(c)** **(d)**

Fig. 4: SEM images showing the surface of *Neolamarckia cadamba* sanded using different techniques
Note: (a) control; (b) 100-grit size; (c) 100+150-grit size; (d) 100+150+180-grit size

The surface sanded with 100+150+180-grit sizes, as shown in Fig. 4(d), is smoother compared to the surfaces sanded with 100+150-grit (Fig. 4(c)) and 100-grit sizes (Fig. 4(b)). It seems that sanding fills the available pores in the cells. The structure and arrangement of the cells determine the surface roughness. Sanding is essential to improve or smoothen a surface. The influence of anatomical structure on roughness has also been mentioned by Gurau et al. [26], *Neolamarckia cadamba* growth rings are moderately distinct and marked by layers of thicker fibers. According to Cartenì et al., growth ring formation shows a period of dominance between January and March or May [27]. The growth rings exhibit differences in cell wall thickness between earlywood and latewood, resulting in different lumen sizes, particularly for vessels. These lumen sizes influence surface roughness and contact angle. It is expected that the surface of *Neolamarckia cadamba* that was not sanded shows lower surface roughness and contact angle than those that were sanded.

In conclusion, examining *Neolamarckia cadamba* wood surfaces before and after sanding reveals significant morphological changes. Utilizing scanning electron microscopy (SEM), it was observed that sanding with progressively finer grit sizes leads to smoother surfaces, with the 100+150+180-grit sandpaper producing the smoothest finish. This smoothing effect is attributed to the sanding filling pores within the wood cells. The anatomical structure of the wood, including distinct growth rings characterized by variations in fiber thickness and lumen sizes, influences surface roughness. Untreated samples exhibited lower surface roughness and contact angles compared to sanded samples. These findings underscore the importance of sanding processes in improving surface smoothness and highlight the role of wood anatomy in determining surface characteristics.

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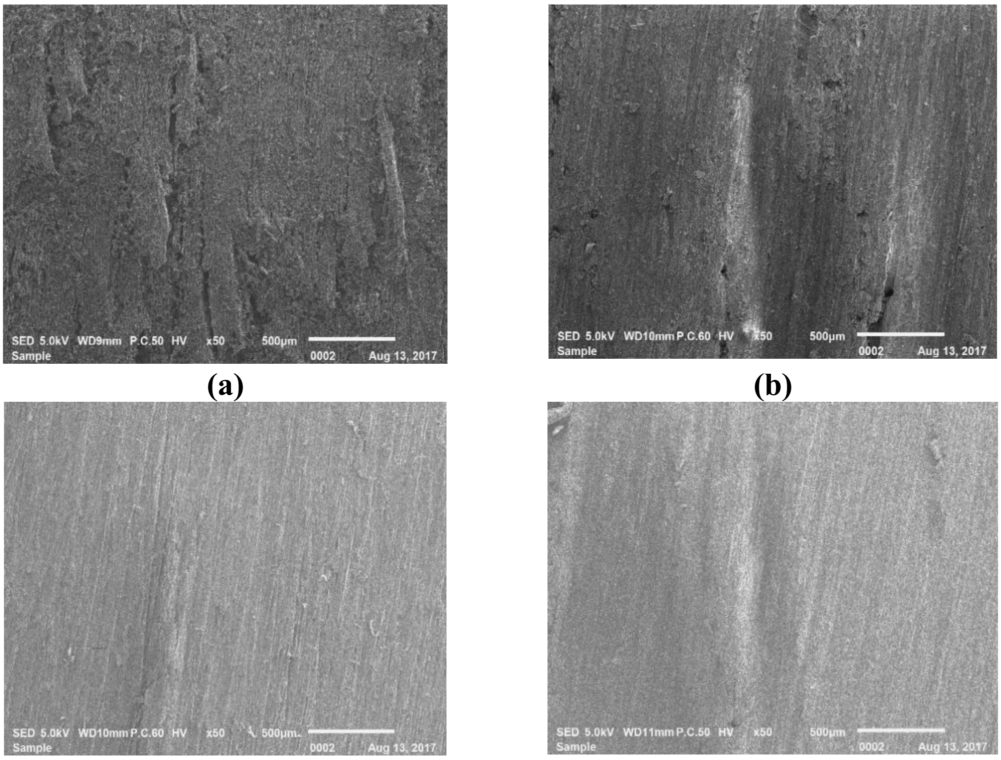
3.2.1 Morphological view of Parkia speciosa



(c) **(d)**

Fig. 5: SEM images showing the surface of *Parkia speciosa* sanded using different techniques
Note: (a) control), (b) 100-grit size; (c) 100+150-grit size; (d) 100+150+180-grit size

The examination of *Parkia speciosa* wood surfaces before and after sanding revealed significant morphological changes. Using scanning electron microscopy (SEM), this study observed the effect of grit size on surface characteristics. SEM images, as shown in (Fig. 5(b-d)), of the sanded surfaces with various grit sizes along the longitudinal direction demonstrated distinct differences. The 100+150+180-grit sandpaper as shown in Fig. 5(d) produced a much smoother surface than the 100+150-grit sanded surface as presented in Fig. 5(c). The sanding process appears to fill the available pores within the wood cells, resulting in improved smoothness. Similar to *Neolamarckia cadamba*, cell structures and arrangements play a crucial role in determining surface roughness. *Parkia speciosa* growth rings are indistinct or visible due to colour differences. Growth rings represent annual growth patterns and are influenced by environmental factors. These rings affect the fiber thickness and overall wood structure. Sanding on either radial or tangential surfaces contributes to surface smoothing. The sanding action breaks the surface and forms small particles (dust) that fill the pore area. As a result, the cell structure was no longer visible as debris and dust occupied the available pores. The roughness along the grain direction was lower when sanded with finer sandpaper grit size. Smaller grit sizes lead to more effective pore-filling and smoother surfaces. In summary, understanding the impact of sanding processes on wood surfaces is essential for achieving the desired characteristics. SEM analysis provides valuable insights into the intricate details of surface changes influenced by both grit size and wood anatomy. These findings underscore the importance of sanding in enhancing surface quality and highlight the role of growth rings in shaping wood properties.

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4. Conclusion

This study aimed to investigate the contact angle and evaluate the surface quality of *Neolamarckia cadamba* (Kelempayan) and *Parkia speciosa* (Petai) wood using water, oil, and formamide as testing liquids. A lower contact angle indicates greater wettability of the wood surface. The analysis in Fig. 2 and 3 shows that larger grit sizes resulted in lower contact angle values, whereas smaller grit sizes led to larger contact angles. The 100+150+180-grit sandpaper stage was particularly effective in reducing wood wool and achieving a smoother surface. Sessile droplets of water, oil, and formamide spread rapidly along the wood grains, indicating enhanced wettability. SEM images further illustrated distinctions between the control (untreated) and treated wood surfaces. Control samples exhibited more pronounced wood wool, whereas treated samples displayed smoother surfaces. Notably, the 100+150+180-grit size yielded the smoothest wood surface due to the finer sandpaper grit, effectively reducing surface irregularities and pore filling. The second objective, examining wood morphology before and after sanding, was successfully achieved. The analysis in Fig. 4 and Fig. 5 indicates that higher grit sizes produce smoother surfaces than lower grit sizes, with the anatomical structure of growth rings and cell arrangement influencing surface characteristics. This study highlights the importance of sanding processes in enhancing wood surface quality, particularly the effectiveness of the 100+150+180-grit sandpaper stage in reducing wood wool and achieving smoother surfaces. SEM analysis confirmed the impact of grit size on surface morphology. A comprehensive understanding of these factors is pivotal for attaining desired wood properties and optimizing their applications across various domains. In summary, this study offers valuable insights into wood surface treatment and the pivotal role of sanding in enhancing surface quality, thereby contributing significantly to the field of wood science and offering practical implications for woodworking and material applications.

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