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PHYSICAL PROPERTIES AND NATURAL DURABILITY OF INDONESIAN COMMERCIAL WOODS MODIFIED BY SURFACE CHARRING AND COATING APPLICATION

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ABSTRACT

This study evaluated the characteristics of Indonesian commercial wood species modified through the yakisugi surface finishing technique combined with coating application. Four wood species, teak (*Tectona grandis*), pine (*Pinus merkusii*), mindi (*Melia azedarach*), and mahogany (*Swietenia mahagoni*), were treated using a mini butane torch to produce charred surfaces either with or without the removal of carbon layers, followed by transparent exterior coating. The treatments were assessed for volumetric swelling, water absorption, and termite resistance through a 12-week graveyard test. Results showed that combining surface charring and coating improved dimensional stability and termite resistance compared to untreated wood. The durability class of teak and pine increased to class II, while mindi and mahogany showed no significant changes. The findings suggest that surface charring combined with coating provides a simple, practical, and effective finishing method to enhance the performance of tropical commercial woods.

KEYWORDS: Durability, dimensional stability, wood commercial, wood finishing, yakisugi.

INTRODUCTION

Wood is increasingly used as a construction and decorative material for both indoor and outdoor applications. Compared to metal-based materials such as steel and aluminum, wood offers advantages in terms of sustainability and environmental friendliness (Kalt 2018). The growing awareness of environmental issues has boosted the use of wood in furniture, construction, and other value-added products. However, the limited supply of high-quality timber from natural and plantation forests has raised concerns about the efficient use and optimization of wood resources. As a result, various modification technologies have been developed to improve wood performance and extend service life, thereby contributing to climate change mitigation (Kutnar et al. 2016; Kymäläinen et al. 2017).

Among these technologies, thermal modification has been widely applied to enhance the dimensional stability and biological resistance of wood. Heat treatment reduces hygroscopicity (Peterson et al. 2008; Widyorini et al. 2014) and increases resistance to fungal and termite attacks (Sivrikaya et al. 2015; Pratiwi 2018). However, this process also leads to a significant loss of mechanical strength at higher temperatures and longer durations (Korkut & Hiziroglu 2009; Martha et al. 2021), along with high energy consumption (Fahrussiam et al. 2023). These limitations have encouraged the development of alternative surface modification techniques that are more efficient while still improving wood performance.

In recent years, surface thermal modification through the traditional Japanese *yakisugi* (charred wood) technique has gained renewed attention. The *yakisugi* method involves burning the wood surface to create a thin carbonized layer that protects it from weathering and biological degradation (Kymäläinen et al. 2022). Apart from its protective function, *yakisugi* produces a unique natural appearance valued for its aesthetic appeal (Ebner et al. 2021; Žigon & Pavlič 2023). However, several studies reported that excessive burning during *yakisugi* may cause microcracks and high surface porosity, leading to increased water absorption (Ebner et al. 2023). To address this, some researchers have combined charring with post-treatments such as linseed oil coating to improve dimensional stability (Ibanez et al. 2023; Soytürk et al. 2023).

Most previous studies on *yakisugi* have focused on temperate species such as cedar and spruce, which possess light-colored wood and distinct annual rings. The application of this technique to tropical fast-growing hardwoods, however, remains limited. Moreover, earlier works mainly investigated physical–mechanical properties, weathering performance, or fungal resistance (Kymäläinen et al. 2022; Tenorio et al. 2024a,b; Hasburgh et al. 2021), while resistance to subterranean termites has received little attention. Therefore, this study aims to evaluate the effects of *yakisugi* surface charring combined with coating application on the physical properties and termite resistance of selected Indonesian commercial wood species.

MATERIAL AND METHODS

Materials

This study utilized four Indonesian commercial wood species that are still readily available in local timber markets and commonly used as raw materials for both industrial and household wood-based products. The selected species were teak (*Tectona grandis*), mahogany (*Swietenia mahagoni*), mindi (*Melia azedarach*), and pine (*Pinus merkusii*). All samples were procured from a wood distribution center in Klaten, Central Java Province, Indonesia. The boards were obtained in a planed surface with sanding paper grit P320, measuring 2 × 15 × 100 cm (radial × tangential × longitudinal) and free from visible defects. The boards were then air-dried for approximately one week to reach a moisture content below 14%. The basic physical characteristics of each species are presented in Tab. 1.

Test specimens were subsequently cut according to the required dimensions for each evaluation parameter. In addition to the surface modification process, a transparent exterior alkyd-based coating (Propan Ultran Lasur Exterior, Indonesia) was applied in combination with the surface charring treatment. For comparison, a conventional finishing technique was also included, consisting of the application of a colored coating of the same brand (*classic teak* tone) to represent standard finishing commonly used in Indonesian woodworking industries.

Tab. 1: Physical properties of Indonesian commercial wood samples before treatment.

Wood species	Moisture content (%)	Density (g/cm^3)	Specific gravity
Pine	10.40	0.50	0.46
Mindi	10.22	0.52	0.47
Mahogany	11.01	0.61	0.55
Teak	10.87	0.63	0.57

Surface charring process

Surface charring was performed using a flame charring technique with a handheld butane gas mini torch. All sides of the specimen surface was manually exposed to the flame at a distance of approximately 10–15 cm from the wood surface. The exposure time for each area (≈70 cm²) was about 30–40 s, until a uniform thin carbonized layer was formed across the surface. Žigon & Pavlič (2023) reported that surface temperature during the charring process from torch flame ranged between 530–680°C, measured indirectly using a thermocouple-based infrared thermometer. Two surface types were prepared from surface charring: Ch (Charred), surface left intact a full carbonized layer and Ch + B (Charred + Brushed), surface lightly brushed with a wire brush to remove loose char residue.

Coating application

The coating material used was a transparent exterior alkyd-based finish (Propan Ultran Lasur Exterior, Indonesia). The coating was applied twice using a flat brush, with an interval of 8 h between applications, following the manufacturer’s recommendations. The coating rate was approximately 5–6 m² per liter. Five surface treatment variations were prepared (Tab. 2) with 3 replicants for durability test and 5 for dimensional stability. An example of the resulting charred and coated surface on mindi wood (*Melia azedarach*) is shown in Fig. 1, illustrating the distinct texture and color contrast between the carbonized and brushed areas.

Tab. 2: Code and description of surface treatment variations.

Code	Surface treatments description
Ref	Control, untreated (sanded only)
Co	Conventional coating without charring
Ch+B	Charring followed by brushing to remove loose char
Ch+Co	Charring followed by coating
Ch+B+Co	Charring, brushing, and coating combination

J- *Tectona grandis*, M-*Melia azedarach*, N-*Swietenia mahagoni*, P-*Pinus merkusii*.

Fig. 1: Melia azedarach (mindi) samples: (a) untreated, (b) coating without charring, (c) charring and brushing (Ch+B), (d) charring, brushing and coating (Ch+B+Co), and (e) charring and coating (Ch+Co).

Dimensional stability test

Dimensional stability was evaluated following the procedure described by Rowell and Ellis (1978) using specimens with dimensions of 2 × 2 × 2 cm. For each treatment, the samples were oven-dried at 103 ± 2°C for 24 h until a constant weight was achieved. The initial volume (V_0) was determined by measuring the length, width, and height, while the initial dry weight (W_0) was also recorded. After drying, each specimen was immersed in distilled water for 24 h, with a small weight placed on top to ensure full submersion. Upon completion of the soaking period, the final volume (V_1) and wet weight (W_1) of each sample were measured. Excess surface water was carefully removed with tissue paper before weighing to avoid measurement errors. Water absorption (WA) and volumetric swelling (S_v) were calculated using Eqs. 1 and 2:

$$WA\ (\%) = \frac{(W0-W1)}{W1} x100 \quad (1)$$

$$Sv\ (\%) = \frac{(v1-v0)}{v0} x100 \quad (2)$$

where: WA is the percentage of water absorption; W_0 is the oven-dry weight before immersion; W_1 is the weight after 24 h immersion; S_v represents the percentage of volumetric swelling; V_0 is the initial volume before immersion; and V_1 is the volume after immersion.

Termite resistance test

The graveyard test for evaluating natural durability was conducted in Perina Village, Jonggat District, Central Lombok Regency, West Nusa Tenggara, Indonesia. The test site was selected based on local reports indicating high subterranean termite activity. Wood specimens measuring 45 × 2 × 2 cm (longitudinal × radial × tangential) from each surface treatment were oven-dried at 103 ± 2°C for 24 h to obtain a constant weight (M_0), and then weighed. The specimens were buried vertically, with two-thirds of their length inserted into the soil and one-third remaining above ground. Graveyard points were randomly assigned among treatments, maintaining a spacing of approximately 30 × 30 cm between samples (Fig. 2).

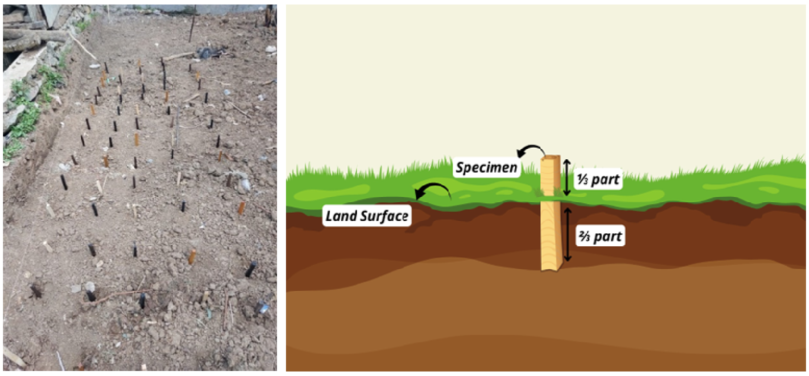

Fig. 2: Graveyard test layout showing the sampling points (left) and schematic sketch of specimen placement in the soil (right).

The exposure period lasted for 12 weeks (approximately three months). After the test, all specimens were carefully removed, cleaned under running water using a soft brush to eliminate adhering soil and debris, oven-dried again at 103 ± 2°C for 24 h, and reweighed (M_1). The weight loss percentage (WL) was calculated according to Eq. 3:

$$\text{WL (\%)} = \frac{M0-M1}{M0} x100 \qquad (3)$$

where: WL is the percentage of weight loss, M_0 is the initial oven-dry weight before graveyard, and M_1 is the oven-dry weight after the test.

The degree of termite attack and durability classification were determined based on Indonesian National Standard (SNI) No. 7207: 2014 (Tab. 3).

Tab. 3: Wood durability against subterranean termite attack based on SNI 7207: 2014.

Class	Durability rating	Weight loss (%)
I	Very durable	<3.52
II	Durable	3.52-7.50
III	Moderate	7.50-10.96
IV	Not durable	10.96-18.94
V	Very intolerable	18.94-31.89

RESULTS AND DISCUSSION

Dimensional stability

The dimensional stability of the wood samples for each treatment was evaluated based on volumetric swelling (S_v) and water absorption (WA) values. The results of volumetric swelling are presented in Fig. 3. Among the tested species, pine exhibited the highest swelling values, followed by mindi, mahogany, and teak, which showed the lowest. The relatively low density and homogeneous anatomical structure of pine, a softwood species, largely contributed to its greater dimensional change upon water exposure. In contrast, the higher density and extractive content in teak contributed to its superior dimensional stability.

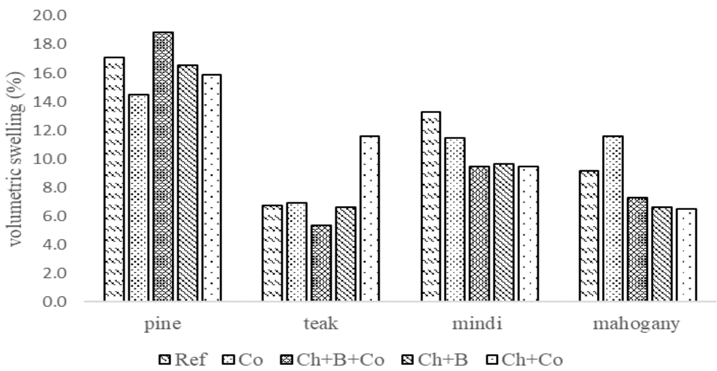

Fig. 3: Volumetric swelling of the treated wood samples after 24 h of water immersion.

Overall, surface charring treatment effectively reduced volumetric swelling across all species. This result aligns with previous findings on the physical characteristics of charred temperate woods (Čermák et al. 2019; Ibanez et al. 2023; Kymäläinen et al. 2014; Kymäläinen et al. 2017), where surface carbonization led to a reduction in hydrophilic hydroxyl groups, improving dimensional stability. Moreover, the addition of a coating layer on charred wood surfaces further enhanced the dimensional stability for most treatments. For teak, mahogany, and mindi, the Ch+B+Co treatment (charring, brushing, and coating) resulted in lower volumetric swelling values compared to Ch+B or Ch treatments. This improvement can be attributed to the sealing effect of the coating, which fills microcracks and reduces capillary water diffusion through the carbonized surface. Similar findings were reported by Ibanez et al. (2023) and Soytürk et al. (2023), who observed that applying a coating layer on carbonized wood surfaces significantly decreased water diffusion rates by sealing microcapillaries formed during the thermal degradation process.

Another indicator of dimensional stability is the percentage of water absorption (WA), as shown in Fig. 4. In all wood species, the untreated control samples exhibited the highest water absorption values compared to those subjected to surface charring or combined charring–coating treatments. Among the tested species, pine showed the greatest water absorption, followed by mindi, mahogany, and teak, which consistently exhibited the lowest values.

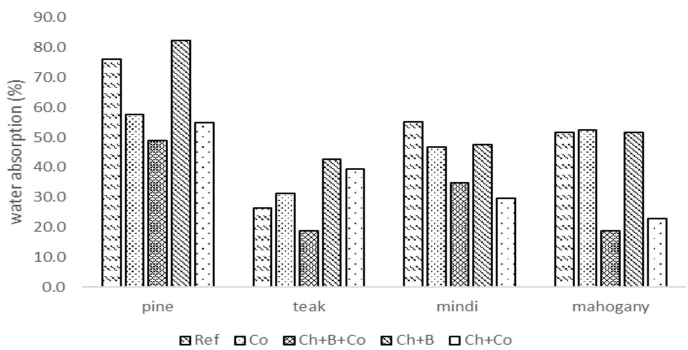

Fig. 4: Water absorption (%) of surface-treated wood samples after 24 h immersion.

The results indicate a positive correlation between water absorption and volumetric swelling. Lower water absorption in the treated samples is attributed to the formation of a carbonized surface layer, which increases hydrophobicity by reducing the number of hydrophilic sites (Kymäläinen et al. 2022). The enhanced hydrophobic behavior is also associated with the reduction of hydroxyl (-OH) groups, an increase in cellulose crystallinity, and the formation of cross-links within lignin (Čermák et al. 2019). Additionally, thermal degradation of hemicellulose, which is highly reactive to moisture, further contributes to the reduction in water uptake (Kymäläinen et al. 2017).

The Ch+B treatment (charring followed by brushing) showed higher water absorption compared to other surface treatments across nearly all wood species. This can be attributed to the mechanical brushing process using a wire brush, which increases surface roughness and opens the cellular structure, thereby facilitating water penetration. Similar results were reported by Darmawan et al. (2018), who found that wood surfaces sanded with lower-grit abrasives (coarser texture) exhibited higher wettability, leading to increased water absorption.

Termite resistance

The resistance of each wood species to termite attack, as determined from the graveyard test, is presented in Tab 4. Higher percentages of weight loss indicate lower resistance to subterranean termite attack. Overall, surface charring treatment improved the durability class of pine and teak (Tab. 4), while mahogany and mindi exhibited greater variation among treatments. The highest weight loss was observed in untreated pine, confirming its inherent susceptibility to termite attack and its classification as durability class V (Muslich & Rulliaty, 2016). This was further supported by the severe physical deterioration visible after 12 weeks of exposure (Fig. 5).

Tab. 4: Weight loss (%) of wood samples after 12-week graveyard test.

Treatments	Pine	Teak	Mindi	Mahogany
Ref	68.0 ± 12.6^{c}	7.7 ± 1.3^{a}	10.0 ± 3.9^{ab}	7.4 ± 0.5^{a}
Co	8.3 ± 3.3^{ab}	8.5 ± 2.4^{ab}	8.9 ± 1.4^{ab}	9.3 ± 2.9^{ab}
Ch+B+Co	13.4 ± 7.0^{ab}	7.2 ± 1.4^{a}	9.4 ± 2.8^{ab}	8.5 ± 1.6^{ab}
Ch+B	6.1 ± 1.3^{a}	5.7 ± 0.2^{a}	11.5 ± 0.9^{ab}	12.2 ± 4.7^{ab}
Ch+Co	7.4 ± 0.6^{a}	6.7 ± 1.0^{a}	16.1 ± 7.0^{b}	7.0 ± 0.2^{a}

Note: Values followed by the same letter(s) are not significantly different, whereas values followed by different letters indicate significant differences according to the post hoc test at $p < 0.05$.

Fig. 5: Subterranean termite attack on wood samples after 12-week burial test.

Conversely, the lowest weight loss was recorded in teak wood under the Ch+B treatment, with a mean value of 5.7%, although it remained statistically within the same durability class as the Ch+Co and Ch+B+Co treatments (Tab. 5).

Tab. 5: The durability class of the wood samples after a 12-week graveyard test.

Treatments	Pine	Teak	Mindi	Mahogany
Ref	V	III	III	II
Co	III	III	III	III
Ch+B+Co	IV	II	III	III
Ch+B	II	II	IV	IV
Ch+Co	II	II	IV	II

Statistical analysis revealed that combining surface charring and coating application (top coat) resulted in significantly lower weight loss compared to treatments involving charring or coating alone for all wood species. This indicates a synergistic effect between the carbonized surface layer and the protective coating in reducing termite activity. These findings are consistent with those of Hassan et al. (2020), who reported that applying linseed oil after surface charring reduced termite-induced mass loss by creating an additional barrier against biological degradation. However, other studies have reported that surface charring does not significantly affect the resistance of wood to subterranean termite attack (Peterson et al. 2008). This phenomenon has been attributed to the thermal decomposition of volatile extractive compounds, which are naturally toxic to termites. The evaporation of these substances during charring reduces the chemical defense capacity of the wood, thereby making charred wood more susceptible to termite infestation.

Similarly, several studies on thermal modification have shown that control (untreated) wood exhibits greater termite resistance than heat-treated wood at various temperature levels (Unsal et al. 2009; Surini et al. 2012). These findings support the results of the present study, where the Ch+B treatment (charring and brushing) on mindi and mahogany resulted in higher weight loss values compared to the untreated control, likely due to the loss of termite-repellent extractives during the charring process.

CONCLUSIONS

This study revealed the physical and biological characteristics of Indonesian commercial wood species following surface modification through surface charring, coating application, and their combinations. Charring-based surface treatments significantly improved dimensional stability and reduced water absorption, particularly in mindi and pinus, with reductions up to −29.7% and −50.4%, respectively. Mahoni also responded positively, whereas Jati showed only moderate improvement. Overall, the charring–brushing–coating combinations proved to be the most effective approach for enhancing the hygroscopic performance of the tested wood species.

The durability test results based on weight loss after the graveyard test showed that surface charring increased the durability class of pine from class V to class II and teak from class III to class II. In contrast, mindi and mahogany exhibited no significant improvement in durability class following surface modification.

Overall, these findings indicate that the combination of surface charring and coating can effectively enhance both dimensional stability and termite resistance of tropical commercial woods, particularly for species with naturally moderate or low durability.

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