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Potential of Wood Modification Technologies on The Physical and Mechanical Properties of *Albizia Falcataria*: A Literature Review

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ABSTRACT

Wood modification treatment has grown in popularity over the last few years and continues to expand as an industrial method for improving certain types of wood. As a result of environmental concerns, the wood sector is under more pressure than ever to develop wood alternatives. Nowadays, fast-growing wood species appear to have increasing potential as substitute wood sources for bridging the supply-demand gap in the wood industry. Albasia (*Albizia falcataria*), sometimes known as sengon wood, is a fast-growing wood widely planted in Indonesia. However, specific characteristics of the wood, such as low density, low hardness, and low strength, have been hindering its end-use applications as a building material. Therefore, numerous technologies enhance wood's physical and mechanical qualities. This paper summarizes the extensive literature on wood modification of *Albizia falcataria* and synthesizes the major publications on wood properties, chemical changes, wood uses, and quality control. Acetylation, furfurylation, thermal modification, and impregnation as wood modification technologies have been utilized in *Albizia falcataria* studies. Based on recent investigations, this article aims to review the current state of knowledge regarding wood modification technologies for improving the Physical and mechanical properties of *Albizia falcataria*. Identifying the research gaps would also aid in accelerating the research activities for deploying these modification technologies on an industrial scale.

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1. Introduction

In 2013, the Indonesian forest product industry consumed more than 64 million m^3 of wood. However, less than 24 million m^3 of natural forest logs were harvested in the same year (Forestry, 2014). Consequently, there is a gap between supply and demand, and wood businesses are compelled to seek alternative sources of raw materials to fulfill the rising need. One source consists of community-owned and -managed forests. Community forests are primarily composed of fast-growing plants with short harvesting cycles (less than ten years).

Albizia falcataria is a fast-growing wood species cultivated extensively in Indonesian forests and community plantations. In 2019, the wood industry was supplied with 57.9 million m^3 of logs, more than 85% of which came from forest plantations. Indonesia produced 5.4 million m^3 of *Albizia falcataria* logs, representing 9.3% of the total national log production (BPS, 2019).

However, the rapid growth of *Albizia falcataria* results in low density, poor hardness and strength, and perhaps a large amount of juvenile wood with numerous knots, which has inferior physical and mechanical qualities to mature wood (Zhang *et al*, 2004; Julian *et al*, 2019). Therefore, increasing the density and characteristics of the wood is essential, as denser wood is frequently selected for commercial applications (Blomberg *et al*, 2005; Laine *et al.*, 2016; Pelİt *et al.*, 2017). Wood modification is a promising strategy for improving the characteristics of fast-growing species (Ratnasingam and Ioras, 2012; Candelier *et al.*, 2015).

This review focuses on how wood modification has been and could be utilized to advance our fundamental understanding of the impact on the physical and mechanical properties of *Albizia falcataria*. First, we briefly describe the current state of knowledge regarding the essential characteristics of Albizia falcataria wood and wood modification technologies. Second, we demonstrate how wood modification can enhance the physical and mechanical properties of *Albizia falcataria*. Finally, the objective is to compile a comprehensive compilation of all literature concerning the impacts and various modification procedures on the physical and mechanical properties of *Albizia falcataria*.

We discuss a focused selection of literature intending to inspire future research in the critical field of *Albizia falcataria* wood modification research to advance the state-of-the-art of *Albizia falcataria* potential. With a greater understanding of the effects of wood modification technologies, it will be feasible to create and refine wood modification procedures to improve the physical and mechanical properties of *Albizia falcataria*.

2. Methods

In this study, we have organized a narrative or semi-systematic review (Wong *et al.*, 2013). The pertinent literature has been analyzed in two sequential steps: (i) identifying literature from selected databases using a set of criteria and (ii) mapping the content of the selected literature using a series of particular queries. These procedures are detailed below.

2.1 Identifying literature

The literature was searched using Google Scholar, ScienceDirect, and ResearchGate portals between April and June 2022. Some terms (in English and Bahasa Indonesia; italics added) were mixed during the literature search, including Acetylation, *Albizia falcataria*, albasia, densification, furfurylation, impregnation, physical properties, plantation, mechanical properties, sengon, thermal modification, wood modification. The articles included were written in English and Indonesian (Bahasa Indonesia). The study review consisted of 23 selected literature on modified Indonesian *Albizia falcataria* wood, which were then classified based on the type of treatment used and properties achieved in each study.

2.2 Mapping of contents

The following questions were utilized to map the contents of the selected studies:

- What wood modification technologies have been implemented in *Albizia falcataria*?
- How is the treatment applied to modified *Albizia falcataria* wood?
- How are wood properties achieved and what are the challenges from different types of treatment on modified *Albizia falcataria*?
- What is the future of wood modification technologies on *Albizia falcataria*?

3. Outline and Current Situation

3.1 *Albizia falcataria*

Albasia or Sengon (*Albizia falcataria*) is a fast-growing tree extensively planted in community forests in Indonesia. The species originated in Indonesia, Papua New Guinea, the Solomon Islands, and Australia (Soerianegara, I. and Lemmens, 1993). As a result of the tree's fast growth, the wood has poor density, strength, and durability, and a large proportion of it is juvenile wood. The wood has a 0.3-0.5 g/cm^3 density and a hardness of 112-122 kg/cm^2, while the trees include up to 100% juvenile wood (Kojima *et al.*, 2009). *Albizia falcataria* has durability and strength classes of IV-V (Martawijaya *et al.*, 2005). *Albizia falcataria* is now utilized in Indonesia for pulpwood, lightweight building, and wood composite. However, its application is limited to original, unaltered wood that is widely distributed in the wood industry sector.

3.2 Wood Modification Technologies

Wood modification has been defined by Hill (Hill, 2006) as a procedure that "requires the effect of physical, biological, or a chemical agent on the wood species, resulting in the desired property enhancement during the life span of the modified wood". This is commonly regarded as a different technique from the conventional biocide-based wood preservation treatments (Eaton and Hale, 1993). The wood modification sector is developing significantly, driven partly by environmental concerns.

Four primary types can be constructed as wood modifications (see Figure 1). These wood modifications consist of many advanced procedures now utilized in the wood preservation industry or various stages of development. Several systems are well developed and commercially available, including thermal modification — the method of modifying hygroscopicity by the application of elevated temperatures (160 °C to approximately 230 °C) in an anaerobic environment, steam, or vacuum (Esteves and Pereira, 2009; Lekounougou and Kocaefe, 2014); Acetylation — the esterification of wood with acetic anhydride (Rowell, 2014).

Based on data from Jones and Sandberg, Table 1 summarizes the main wood modification and annual expected commercial volumes worldwide. Thermal modification accounts for a global production volume of 1,608,000 m^3 per year. According to consumer demand, technology licensing, and the relative simplicity of producing thermally treated wood utilizing stand-alone treatment chambers, a rise in production is expected in the future years.

Table 1. Estimated overall global production of modified wood (Jones and Sandberg, 2020)

Treatment	Estimated Volumes (m^3)				
	Europe	China	N America	Oceania/Japan	Other
Thermally modified wood	695,000	250,000	140,000	15,000	10,000
Densified wood	2,000	<1,000	-	<1,000	-
Acetylation	120,000	-	-	-	-
Furfurylation	450,000	-	-	-	-
Other methods	35,000	290,000*	-	5,000	TBD*

(*) Figures combine furfurylation processes other than Kebony® and NobelWood®, DMDHEU, and other resin treatments.
( ) Empty fields indicate that no data are available or that the authors of the cited work are unaware of this type of modified wood in this region.

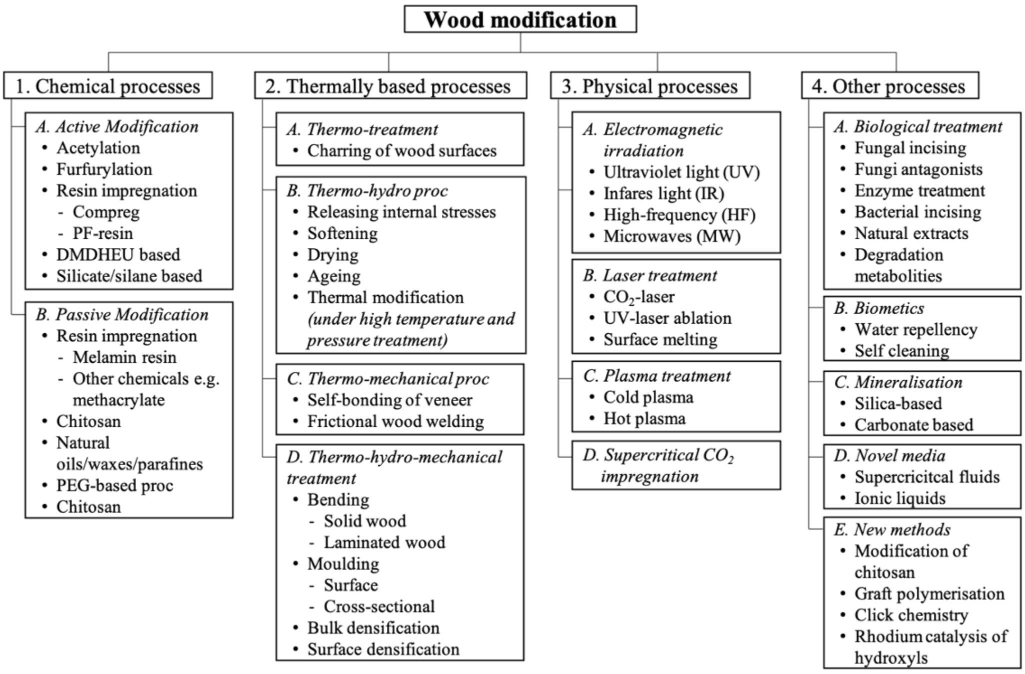

Figure 1. A brief overview of wood modification technology
Source: modified from (Jones *et al*, 2019)

Table 2. Commonly achieved properties of modified *Albizia falcataria* from various wood modification technologies.

Process	Type	Treatment	Reference	Achieved Properties									
				Density	Mass Loss	Color Changes	Change in Thickness	Moisture	Morphology	Dimensional Stability	Hardness	Compressive Strength	MOR & MOE
Thermally based	Thermo-hydro	Thermal Modification	(Muthmainnah, 2017)	✓	✓	✓	✓	✓					
			(Karlinasari *et al*, 2018)			✓		✓			✓		
			(Karlinasari *et al*, 2018)	✓				✓		✓			
			(Iskandar *et al.*, 2018)	✓			✓	✓			✓		✓
			(Iskandar *et al.*, 2019)	✓						✓	✓	✓	
			(Julian *et al*, 2022)	✓	✓	✓	✓	✓	✓				
			(Iskandar *et al.*, 2021)	✓			✓	✓			✓	✓	
		Drying	(Adzkia *et al*, 2020)	✓				✓					
	Thermo- Mechanical	Bonded	(Karliati *et al.*, 2019)	✓				✓	✓				
Chemical	Active Modification	Acetylation	(Asdar, 1999)	✓				✓					✓
			(Hadi *et al*, 1994)	✓	✓								✓
		Impregnation	(Sumardi *et al.*, 2020)	✓	✓	✓	✓		✓	✓		✓	✓
		Furfurylation	(Hadi *et al*, 2005)		✓								
			(Hadi *et al.*, 2020)		✓								
			(Hadi *et al.*, 2021)	✓	✓	✓		✓					
			(Hadi *et al.*, 2021)	✓	✓	✓		✓					
			(Hadi *et al.*, 2022)	✓	✓	✓		✓			✓	✓	✓
			(Sabrina *et al.*, 2021)		✓	✓		✓					
	Passive Mod	Impregnation	(Nandika *et al*, 2015)	✓			✓	✓	✓	✓	✓		✓
			(Budiman *et al.*, 2020)	✓				✓			✓		✓
			(Rahayu *et al.*, 2020)	✓	✓				✓	✓			
			(Nurhanifah *et al.*, 2020)		✓			✓					
			(Rahayu *et al.*, 2021)	✓	✓				✓	✓		✓	

Empty fields indicate that no benefit is claimed according to the references, to the best of the authors' knowledge

4. Results and Discussion

The effects of *Albizia falcataria* wood modification technology that has been carried out in several studies are summarized in Table 2. Wood modification aims to improve its physical and mechanical properties, including density improvement, wood mass loss, color change, thickness changes, moisture, morphology, dimensional stability, hardness, compressive strength, modulus of rupture, and modulus of elasticity.

4.1. Acetylation

One of the best ways to improve the technical properties of less durable wood species is acetylation, which has been the subject of extensive research (Hill, 2006; Rowell and Dickerson, 2014). Additional research and commercialization have been conducted on the acetylation reaction, and these efforts are still ongoing.

The simplified reaction of *Albizia falcataria* wood components with acetic anhydride is shown in Figure 2. The acetylation of wood is a chemical alteration in which an external pressure forces an electrophilic reagent (often acetic anhydride) to migrate through the wood pits and react with accessible nucleophilic hydroxyl groups, then diffuse and react deeper into the cell wall (Rowell, 1983). Therefore, thickening the cell wall and removing hydrophilic hydroxyl groups decreases the wood's ability to absorb moisture and enhance its resistance to swelling and decay (Hill and Jones, 1996; Hill, 2006). A more detailed description of the acetylation modification of *Albizia falcataria* is shown in Table 3, along with the type of sample and acetylation method.

According to the *Albizia falcataria* acetylation study, older *Albizia falcataria* trees and acetylation conferred more excellent resistance to fungal infection (Hadi *et al*, 1994). The higher the level of acetylating agent (acetic anhydride), the lower the moisture content and swelling of the wood (Asdar, 1999). Moreover, *Albizia falcataria* with a higher WPG (weight percent gain) resulted in increased density, modulus of rupture, modulus of elasticity, and internal bonding; however, this overall score was lower than the control.

4.2. Furfurylation

Another chemical modification technique that enhances the resistance of wood is furfurylation, which has been widely explored and demonstrated to produce high-performing, sustainable wood material (Esteves *et al*, 2011). Furfurylation is a wood modification process that involves impregnating wood with a combination of furfuryl alcohol (FA) and catalysts and then heating the wood to produce polymerization (Sandberg *et al*, 2017). FA can be made by hydrogenating agricultural and timber byproducts containing pentosans (Baysal *et al*, 2004).

The furfurylation aims to enhance resistance to biological degradation and dimensional stability by using a proprietary formula to apply a non-toxic, furfuryl alcohol-based polymer (Sandberg *et al*, 2017). Regarding ecotoxicity, physical and mechanical qualities, dimensional stability, and product durability, the furfurylation of wood has been deemed an exemplary process (Lande *et al*, 2004). The method offers several benefits and is safe for the environment, with a good potential for furfurylation, providing excellent and environmentally friendly material (Dong *et al*., 2014; Gérardin, 2016).

Table 4 provides an overview of furfurylation treatments for selected *Albizia falcataria* wood. Based on subterranean termite field tests conducted in Bogor, Indonesia (Hadi *et al*, 2005), discovered that furfurylated wooden stakes (*Pinus sylvestris*, *Agathis dammara*, and *Albizia falcataria*) experienced a 40% increase in personal weight (WPG) and their condition remained good after a one-year test period in the field, during which termites did not appear to be able to eat the stakes.

Table 3. Summary of selected studies of *Albizia falcataria* acetylation.

Sample	Acetylation method	Reference
Medium-density fiberboard (MDP)	Acetic anhydride, subsequently heated at 120°C for 2 hours	(Asdar, 1999)
Flakeboards	Acetic anhydride, subsequently heated at 120°C for 24 hours	(Hadi *et al*, 1994)

Table 4. Summary of selected studies of *Albizia falcataria* furfurylation.

Sample	Furfurylation method	Reference
Wood stakes	Vacuum-pressure impregnation (30-L capacity), 92, 48, and 15% FA, vacuum (45 min), pressure 12 bars (2 h), wrapped in aluminum foil, and heated 103 °C (16 h & 8 h)	(Hadi *et al*, 2005)
Flat sawn lumber	FA + tartaric acid (20:1, v/v), streamed into the tank during vacuum release, and pressure at 10 kg·cm−2 (30 min)	(Hadi *et al*., 2020)
Flat sawn timber	FA + 5% tartaric acid (5%), vacuum 600 mmHg (30 min), pressure 10 kg·cm−2 (30 min), wrapped in aluminum foil, and heated 100 °C (24 h)	(Hadi *et al*., 2021)
Flat sawn timber	Tartaric acid + FA (1:20; v/v), pressure 9.81 bars (30 min), wrapped with aluminum (30 min), and heated 100 °C (24 h)	(Hadi *et al*., 2021)
Flat sawn timber	Tartaric acid + FA (5:100 by weight), vacuum 600 mmHg (30 min), immersion in FA, pressure 10 kg/cm^2 (30 min), wrapped with aluminum foil, and heated 100 °C (24 h)	(Hadi *et al*., 2022)
Flat sawn timber	FA + tartaric acid 5% (b/v), oven-dried 60±2°C (48 h), pressure at 5 atm (30 min), wrapped with aluminum foil (30 min), and heated 100 °C (24 h)	(Sabrina *et al*., 2021)

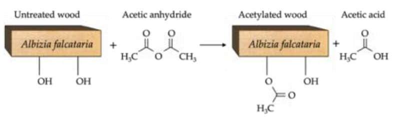

Figure 2. Schematic view of the acetylation of *Albizia*

Figure 3. Control and furfurylated wood samples

In Figure 3 (Hadi *et al.*, 2021), furfurylation increases the resistance of wood to subterranean termites, as shown by a lower amount of termite damage, a higher wood resistance class (from class IV to class I, according to Indonesian standards), and a substantially lower percentage of weight loss (control wood lost 17.30 % of weight loss, while furfurylated wood lost 1.92 %).

4.3. Thermal Modification

Thermal modification of wood has a long history, dating back to the 1920s (Esteves and Pereira, 2009), and since the 1990s, Europe has developed new technologies for producing these types of products, resulting in increased industrial production and commercialization of wood species (Sandberg *et al*, 2017).

It has been thoroughly studied that wood that has been thermally modified will typically experience beneficial changes in properties such as decreased equilibrium moisture content, increased dimensional stability (Srinivas and Pandey, 2012; Uribe and Ayala, 2015), and enhanced durability (Esteves and Pereira, 2009). In addition, thermal modification can reduce hygroscopicity (Bal and Bektaş, 2013) and cause hydrophobic alteration of wood (Wang and Piao, 2011). Hydrophobicity is associated with surface qualities and influences wood's coating, absorbency, adhesion, and finishing properties (Esteves and Pereira, 2009; Hubbe *et al*, 2015). A summary of recent thermal modification studies into *Albizia falcataria* species is given in Table 5.

Among the physical properties of wood, color is crucial for wood applications because it determines its aesthetic market value (Huang *et al.*, 2012). The high demand for *Albizia falcataria* wood supplied by the Indonesian processing industry is due to the wood's bright colors and rough texture (Nemoto, 2002). In addition, the wood's original color may change during processing and thermal modification. As seen in Figure 4, the thermally modified *Albizia falcataria* was darker than its control. As the density of the wood grows, its chemical components, specifically hemicellulose, decompose, darkening its color (Julian *et al*, 2022). In general, the temperature and time of exposure to the modified thermally treatment performed on *Albizia falcataria* caused color changes in all studies. Nevertheless, based on the thermal treatment set, the interaction of pre-treatment factors, temperature, and time of heat treatment had no significant effect on the color and hardness changes of the wood (Karlinasari *et al*, 2018; Adzkia *et al*, 2020; Julian *et al*, 2022).

The morphology structure of *Albizia falcataria* before and after thermally modified is presented in Figure 5. Scanning Electron Microscopy (SEM) analysis revealed that the treatment increased wood morphology (Julian *et al*, 2022). Comparing the control without treatment to the thermal modification and subsequent compaction, the cavity's microscopic structure changes are visible (Muthmainnah, 2017). This alteration in cell shape does not reduce the strength of the wood; in fact, it increases its strength. This is because the cell structure becomes denser, and the lignin remains undamaged, which increases the strength of the wood, decreases its moisture content, and enhances its dimensional stability.

4.4. Impregnation Modification

One way to overcome the low physical and mechanical properties of fast-growing wood is to modify it by impregnating it with impregnation material, which modifies the properties of the wood by intervening at the level of the cell wall (Hill, 2006).

Table 5. Summary of selected examples of thermal modification of *Albizia falcataria*.

Sample	Temperature (°C)	Duration	Others	Reference
Board	170	3 min	Hot oil	(Muthmainnah, 2017)
Board	120, 150, 180	2 h, six h	-	(Karlinasari *et al*, 2018)
Lumber	120, 150, 180	2 h, 6 h	-	(Karlinasari *et al*, 2018)
Board	100	45 min	Pressure	(Iskandar *et al.*, 2018)
Board	100	45 min	Pressure	(Iskandar *et al.*, 2019)
Tangential board	100, 120, 140	30 min	Vacuum, Pressure	(Julian *et al*, 2022)
Board	100	45 min	Pressure	(Iskandar *et al.*, 2021)
Board	165	2 h, 6 h	Drying	(Adzkia *et al*, 2020)

Figure 4. Color differences of *Albizia falcataria* thermally modified at different temperatures and pressures
Source: (Julian *et al*, 2022)

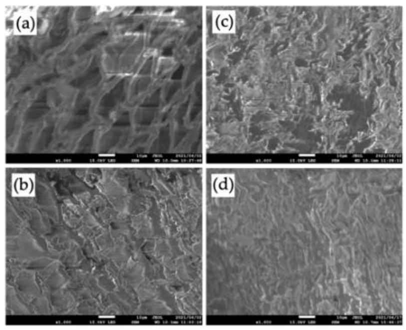

Figure 5. Morphology of *Albizia falcataria* thermally modified by SEM micrographs 500 µm:
(a) control; (b) 100 °C; (c) 120 °C; (d) 140 °C
Source: (Julian *et al*, 2022)

Table 6. Summary of selected examples of impregnation modification of *Albizia falcataria*.

Sample	Impregnation	Compregnation	Reference
Tangential board	Chitosan solution 0.5% under 100 °C, 120 °C, 140 °C	Compressed to be 1.5 cm thickness under 150 °C, 170 °C, 190 °C	(Nandika *et al*, 2015)
Tangential board	Polystyrene under vacuum 600 mmHg (30 min)	Immersion in monomer styrene pressure at 10kg/cm^2 (30, 60, 90 min)	(Budiman *et al.*, 2020)
Small wooden block	Mono-ethylene glycol (MEG) and nano-SiO2	Pressure 10 and 400 Pa, under a low vacuum mode	(Rahayu *et al.*, 2020)
Glulam	Polystyrene, made into 2 layers using isocyanate adhesives	Cold pressing with specific pressure of 10 kg/cm2.	(Nurhanifah *et al.*, 2020)
Small wooden block	MEG and nano-silica originated from betung bamboo leaves	0.5 bar of vacuum (60 min), 2.5 bar of pressure (120 min)	(Rahayu *et al.*, 2021)

The impregnation method includes treating wood with a monomer solution, which diffuses through the cell wall, followed by polymerization. The bulking of the cell wall by the impregnation is the primary cause of property enhancements.

Chemical compounds containing formaldehyde, such as PF, MF, and UF, have typically been utilized as wood impregnation materials (Deka and Saikia, 2000; Gabrielli and Kamke, 2010; Fukuta *et al.*, 2011). Due to the potential health concerns posed by formaldehyde emissions generated by these items, their use must be restricted. Therefore, alternative chemical substances that are less harmful to the environment are required. The use of chitosan as a preservative and to improve the dimensional stability of wood has increased during the past decade (Guo *et al.*, 2006; Arinana *et al.*, 2009). According to studies conducted on this species of timber, many physical and mechanical properties of *Albizia falcataria* wood can be enhanced by impregnation with chitosan (Nandika *et al*, 2015)(Usman *et al*, 2007).

Monoethylene Glycol (MEG) and Silica (nano-SiO2) materials are other environmentally friendly alternatives for the impregnation process. Silica is a chemical that has several applications in a variety of industries, notably as a polymer in wood impregnation. According to research (Dirna *et al.*, 2020), silica can be acquired from commercial marketplaces or natural substances such as bamboo leaf ash. MEG is fully soluble in water, colorless, odorless, liquid, and volatile, and it has a molecular weight of 62.07 g/mol. The impregnation of sengon wood with MEG and nano-SiO2 also significantly affects dimensional stability and density (Rahayu *et al.*, 2020, 2021). Furthermore, it can be concluded that low-density species, such as *Albizia falcataria*, are typically easier to impregnate (Budiman *et al.*, 2020).

5. Conclusion

According to recent studies, Numerous technologies are used to modify *Albizia falcataria*, an indigenous Indonesian wood. The modification processes include acetylation, furfurylation, thermal modification, and impregnation treatments. The acetylation process involves the migration and reaction of acetic anhydride through the wood pores of *Albizia falcataria*. Another chemical technique, furfurylation, involves impregnating wood with a combination of FA and a catalyst and then heating the wood for polymerization. In addition, thermal modification requires heating with varying heat settings and durations. Furthermore, the impregnation procedure involves the diffusion of a monomer solution into the cell wall, followed by polymerization. Based on the study of acetylation of *Albizia falcataria*, the wood's moisture content and swelling decrease as the acetylating material (acetic anhydride) level rises. Meanwhile, the furfurylation of *Albizia falcataria* boosted the wood's resistance to subterranean termites and its class according to Indonesian standards. On the other hand, thermal modification is the most used method for modifying *Albizia falcataria* wood since it is environmentally friendly, increases wood density, and darkens its color. Finally, the modification of wood by impregnation and compregnation improves the dimensional stability of the wood with non-hazardous, alternative chemicals such as chitosan, MEG, and silica. Even though the results of wood modification on *Albizia falcataria* have not yet achieved market acceptance in the wood industry, current research shows that it can potentially improve the physical and mechanical properties of *Albizia falcataria* wood.

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7. References

Adzkia, U., Priadi, T. and Karlinasari, L. (2020) 'Evaluasi Cacat Pengeringan Dan Pemesinan Pada Empat Jenis Kayu Cepat Tumbuh Termodifikasi Panas', *Jurnal Penelitian Hasil Hutan*, 37(7), pp. 204–216. doi: 10.20886/jphh.2019.37.3.204-216.

Arinana, R. *et al.* (2009) 'Development of Termite Formulation Baiting for Building Protection', 2(1), pp. 32–39.

Asdar, M. (1999) 'Physical and mechanical properties of medium density fibreboard from the acetylated sengon (Paraserianthes falcataria (L.) Nielsen) wood pulp', *Buletin Penelitian Kehutanan (Indonesia)*, (ISSN : 0853-9197).

Bal, B. C. and Bektaş, I. (2013) 'The Effects of Heat Treatment on Some Mechanical Properties of Juvenile Wood and Mature Wood of Eucalyptus grandis', *Drying Technology*, 31(4), pp. 479–485. doi: 10.1080/07373937.2012.742910.

Baysal, E., Ozaki, S. K. and Yalinkilic, M. K. (2004) 'Dimensional stabilization of wood treated with furfuryl alcohol catalysed by borates', *Wood Science and Technology*, 38(6), pp. 405–415. doi: 10.1007/s00226-004-0248-2.

Blomberg, J., Persson, B. and Blomberg, A. (2005) 'Effects of semi-isostatic densification of wood on the variation in strength properties with density', *Wood Science and Technology*, 39(5), pp. 339–350. doi: 10.1007/s00226-005-0290-8.

BPS (2019) *Statistic of Forestry Production 2019*. Jakarta, Indonesia.

Budiman, I. *et al.* (2020) 'Physical and mechanical properties of five Indonesian wood treated with polystyrene', *IOP Conference Series: Earth and Environmental Science*, 572(1). doi: 10.1088/1755-1315/572/1/012039.

Candelier, K. *et al.* (2015) 'Utilization of temperature kinetics as a method to predict treatment intensity and corresponding treated wood quality: Durability and mechanical properties of thermally modified wood', *Maderas: Ciencia y Tecnologia*, 17(2), pp. 253–262. doi: 10.4067/S0718-221X2015005000024.

Deka, M. and Saikia, C. N. (2000) 'Chemical modification of wood with thermosetting resin: effect on dimensional stability and strenght property', *Bioresource Technology*, 73(2), pp. 179–181.

Dirna, F. C. *et al.* (2020) 'Nanosilica synthesis from betung bamboo sticks and leaves by ultrasonication', *Nanotechnology, Science and Applications*, 13, pp. 131–136. doi: 10.2147/NSA.S282357.

Dong, Y. *et al.* (2014) 'Wood/polymer nanocomposites prepared by impregnation with furfuryl alcohol and Nano-SiO2', *BioResources*, 9(4), pp. 6028–6040. doi: 10.15376/biores.9.4.6028-6040.

Eaton, R. A. and Hale, M. D. C. (1993) 'Wood: decay, pests and protection.', p. 546. Available at: http://www.cabdirect.org/abstracts/19940606334.html;jsessionid=770A55932A7376C4D023914856569567?freeview=true.

Esteves, B. M. and Pereira, H. M. (2009) 'Wood modification by heat treatment: A review', *BioResources*, 4(1), pp. 370–404. doi: 10.15376/biores.4.1.370-404.

Esteves, B., Nunes, L. and Pereira, H. (2011) 'Properties of furfurylated wood (Pinus pinaster)', *European Journal of Wood and Wood Products*, 69(4), pp. 521–525. doi: 10.1007/s00107-010-0480-4.

Forestry, M. of E. and (2014) *[Direktorat BPPHH Ditjen BUK] Forestry Statistics of Indonesia. 2013*. Jakarta, Indonesia.

Fukuta, S. *et al.* (2011) 'Bending properties of compressed wood impregnated with phenolic resin through drilled holes', *European Journal of Wood and Wood Products*, 69(4), pp. 633–639. doi: 10.1007/s00107-010-0506-y.

Gabrielli, C. P. and Kamke, F. A. (2010) 'Phenol-formaldehyde impregnation of densified wood for improved dimensional stability', *Wood Science and Technology*, 44(1), pp. 95–104. doi: 10.1007/s00226-009-0253-6.

Gérardin, P. (2016) 'New alternatives for wood preservation based on thermal and chemical modification of wood— a review', *Annals of Forest Science*, 73(3), pp. 559–570. doi: 10.1007/s13595-015-0531-4.

Guo, Z. *et al.* (2006) 'Novel derivatives of chitosan and their antifungal activities in vitro', *Carbohydrate Research*, 341(3), pp. 351–354. doi: 10.1016/j.carres.2005.11.002.

Hadi, Y. S. *et al.* (2020) 'Termite resistance of furfuryl alcohol and imidacloprid treated fast-growing tropicalwood species as function of field test', *Applied Sciences (Switzerland)*, 10(17). doi: 10.3390/app10176101.

Hadi, Y. S., Nawawi, D. S., *et al.* (2021) 'Evaluation of discoloration and subterranean termite resistance of four furfurylated tropical wood species after one-year outdoor exposure', *Forests*, 12(7). doi: 10.3390/f12070900.

Hadi, Y. S., Mulyosari, D., *et al.* (2021) 'Furfurylation of wood from fast-growing tropical species to enhance their resistance to subterranean termite', *European Journal of Wood and Wood Products*, 79(4), pp. 1007–1015. doi: 10.1007/s00107-021-01676-4.

Hadi, Y. S. *et al.* (2022) 'Furfurylation Effects on Discoloration and Physical-Mechanical Properties of Wood from Tropical Plantation Forests', *Journal of the Korean Wood Science and Technology*, 50(1), pp. 46–58. doi: 10.5658/WOOD.2022.50.1.46.

Hadi, Y. S., Rosyadi, A. and Darma, G. K. T. (1994) 'Acetylated Flakeboard Resistance to Schizophyllum Commune Fungus Attack', *Folia Forestalia Polonica*, B, p. 25.

Hadi, Y. S., Westin, M. and Rasyid, E. (2005) 'Resistance of furfurylated wood to termite attack', *Forest Products Journal*, 55(11), pp. 85–88.

Hill, C. (2006) *Wood Modification: Chemical, Thermal, and Other Processes*. West Sussex: John Wiley & Sons, Ltd.

Hill, C. A. S. and Jones, D. (1996) 'The dimensional stabilisation of Corsican pine sapwood by reaction with carboxylic acid anhydrides: The effect of chain length', *Holzforschung*, 50(5), pp. 457–462. doi: 10.1515/hfsg.1996.50.5.457.

Huang, X. *et al.* (2012) 'A spectrocolorimetric and chemical study on color modification of heat-treated wood during artificial weathering', *Applied Surface Science*, 258(14), pp. 5360–5369. doi: 10.1016/j.apsusc.2012.02.005.

Hubbe, M. A., Gardner, D. J. and Shen, W. (2015) 'Contact Angles and Wettability of Cellulosic Surfaces: A Review of Proposed Mechanisms and Test Strategies', *BioResources*, 10(4), pp. 8657–8749. doi: 10.15376/biores.10.4.8657-8749.

Iskandar *et al.* (2018) 'Physical and Mechanical Properties on Densified Boards of Sengon (Paraserianthes Falcataria)', in *International Conference on Applied Science and Technology (ICAST) Physical*, pp. 730–736.

Iskandar *et al.* (2019) 'Comparison of Densified Sengon and Mahang Boards At 43% Densification Target, 150°c Temperature, and 6.0 Minute Pressing Time', *Russian Journal of Agricultural and Socio-Economic Sciences*, 91(7), pp. 341–348. doi: 10.18551/rjoas.2019-07.40.

Iskandar *et al.* (2021) ' Optimal Thickness and Heating Time Based on Physical and Mechanical Properties of Densified Sengon Board ', *Proceedings of the Joint Symposium on Tropical Studies (JSTS-19)*, 11, pp. 205–210. doi: 10.2991/absr.k.210408.034.

Jones, D. and Sandberg, D. (2020) 'A Review of Wood Modification Globally – Updated Findings from COST FP1407', *Interdisciplinary Perspectives on the Built Environment*, 1, pp. 1–31. doi: 10.37947/ipbe.2020.vol1.1.

Jones, D., Sandberg, D. and Gicomo, G. (2019) *Wood modification in Europe: A state-of-the-art about processes, products, applications.*

Julian, T. C., Fukuda, H. and Bohoshevych, I. B. (2019) 'The Potential of Albasia Wood (Albizia Falcataria) as Indonesian Local Wood: Fast-Growing Wood for the Use in the Construction Field', *IEREK*. doi: 10.1109/mwc.2020.9316637.

Julian, T. C., Fukuda, H. and Novianto, D. (2022) 'The Influence of High-Temperature and -Pressure Treatment on Physical Properties of Albizia falcataria Board', *Forests*, 13(2), p. 239. doi: 10.3390/f13020239.

Karliati, T. *et al.* (2019) 'Properties of laminated wood bonded with modified Gutta-Percha Adhesive at various surface roughness profile of Laminae', *BioResources*, 14(4), pp. 8241–8249. doi: 10.15376/biores.14.4.8241-8249.

Karlinasari, L., Lestari, A. T. and Priadi, T. (2018) 'Evaluation of surface roughness and wettability of heat-treated, fast-growing tropical wood species sengon (Paraserianthes falcataria (L.) I.C.Nielsen), jabon (Anthocephalus cadamba (Roxb.) Miq), and acacia (Acacia mangium Willd.)', *International Wood Products Journal*, 9(3), pp. 142–148. doi: 10.1080/20426445.2018.1516918.

Karlinasari, L., Yoresta, F. S. and Priadi, T. (2018) 'Karakteristik Perubahan Warna dan Kekerasan Kayu Termodifikasi Panas pada Berbagai Suhu dan Jenis Kayu (Color Changes and Hardness Properties of Thermally Modified Wood at Various Temperatures and Wood Species)', *Jurnal Ilmu Teknol. Kayu Tropis*, 16(1).

Kojima, M. *et al.* (2009) 'Effect of the lateral growth rate on wood properties in fast-growing hardwood species', *Journal of Wood Science*, 55(6), pp. 417–424. doi: 10.1007/s10086-009-1057-x.

Laine, K. *et al.* (2016) 'Wood densification and thermal modification: hardness, set-recovery and micromorphology', *Wood Science and Technology*, 50(5), pp. 883–894. doi: 10.1007/s00226-016-0835-z.

Lande, S., Westin, M. and Schneider, M. (2004) 'Properties of furfurylated wood', *Scandinavian Journal of Forest Research*, 19(1596), pp. 22–30. doi: 10.1080/0282758041001915.

Lekounougou, S. and Kocaefe, D. (2014) 'Effect of thermal modification temperature on the mechanical properties, dimensional stability, and biological durability of black spruce (Picea mariana)', *Wood Material Science and Engineering*, 9(2), pp. 59–66. doi: 10.1080/17480272.2013.869256.

Martawijaya, A. *et al.* (2005) *Indonesian Wood Atlas Volume 1*. Jakarta, Indonesia: Ministry of Forestry Republik of Indonesia.

Muthmainnah (2017) 'SIFAT FISIK KAYU SENGON (Paraserianthes falcataria (L) Nielsen) TERPADATKAN', *J. ForestSains*, 23(4), pp. 1–10. Available at: https://www.proquest.com/scholarly-journals/discerns-special-education-teachers-about-access/docview/2477168620/se-2?accountid=17260%0Ahttp://lenketjener.uit.no/?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ%3Aed.

Nandika, D., Darmawan, W. and Arinana (2015) 'Quality Improvement of Sengon Wood Through Compregnation Process', *Jurnal Teknologi Industri Pertanian*, 25(2), pp. 125–135.

Nemoto, A. (2002) 'Farm Tree Planting and the Wood Industry in Indonesia : a Study of Falcataria Plantations and the Falcataria Product Market in Java', *Policy Trend Report*, pp. 42–51.

Nurhanifah *et al.* (2020) 'Shear strength and subterranean termite resistance of polystyrene impregnated sengon (Falcataria moluccana) glulam', *IOP Conference Series: Materials Science and Engineering*, 935(1). doi: 10.1088/1757-899X/935/1/012052.

Pelİt, H. *et al.* (2017) 'the Effects of Densification and Heat Treatment on Thermal Conductivity of Fir Wood', *Journal of Science and Technology*, 7(3), pp. 117–122.

Rahayu, I. *et al.* (2020) 'Characteristics of fast-growing wood impregnated with nanoparticles', *Journal of Forestry Research*, 31(2), pp. 677–685. doi: 10.1007/s11676-019-00902-3.

Rahayu, I. *et al.* (2021) 'Dimensional stability of treated sengon wood by nano-silica of betung bamboo leaves', *Forests*, 12(11), pp. 1–9. doi: 10.3390/f12111581.

Ratnasingam, J. and Ioras, F. (2012) 'Effect of heat treatment on the machining and other properties of rubberwood', *European Journal of Wood and Wood Products*, 70(5), pp. 759–761. doi: 10.1007/s00107-011-0587-2.

Rowell, R. M. (1983) *Chemical Modification of Wood*. Forest Products Abstracts 6. doi: 10.3139/9783446442504.022.

Rowell, R. M. (2014) 'Acetylation of wood - A review', *International Journal of Lignocellulosic Products*, 2014(1), pp. 1–28. Available at: http://ijlp.gau.ac.ir.

Rowell, R. M. and Dickerson, J. P. (2014) 'Acetylation of wood', *ACS Symposium Series*, 1158, pp. 301–327. doi: 10.1021/bk-2014-1158.ch018.

Sabrina, P. A. *et al.* (2021) 'Color Changes and Resistance against Subterranean Termites Attack of Furfuryl Alcohol Impregnated Pine and Sengon Woods through Graveyard Test', *IOP Conference Series: Earth and Environmental Science*, 891(1). doi: 10.1088/1755-1315/891/1/012014.

Sandberg, D., Kutnar, A. and Mantanis, G. (2017) 'Wood modification technologies - A review', *IForest*, 10(6), pp. 895–908. doi: 10.3832/ifor2380-010.

Soerianegara, I. and Lemmens, R. H. M. . (1993) 'Plant resources of South-East Asia', *Timber trees: major commercial timbers*, (Pudoc Scientific Publishers).

Srinivas, K. and Pandey, K. K. (2012) 'Effect of heat treatment on color changes, dimensional stability, and mechanical properties of wood', *Journal of Wood Chemistry and Technology*, 32(4), pp. 304–316. doi: 10.1080/02773813.2012.674170.

Sumardi, I. *et al.* (2020) 'Quality enhancement of falcataria-wood through impregnation', *Journal of the Korean Wood Science and Technology*, 48(5), pp. 722–731. doi: 10.5658/WOOD.2020.48.5.722.

Uribe, B. E. B. and Ayala, O. A. (2015) 'Characterization of three wood species (Oak, Teak and Chanul) before and after heat treatment', *Journal of the Indian Academy of Wood Science*, 12(1), pp. 54–62. doi: 10.1007/s13196-015-0144-4.

Usman, F., HMS, S. and Nandika, D. (2007) 'Sifat Fisis dan mekanis kayu sengon yang diaplikasikan dengan senyawa khitosan dari cangkang udang', in *Proceeding Seminar Nasional MAPEKI X*. Pontianak.

Wang, C. and Piao, C. (2011) 'From Hydrophilicity to Hydrophobicity: A critical review - Part II: Hydrophobic Conversion', *Wood and Fiber Science*, 43(1), pp. 41–56. Available at: http://swst.metapress.com/index/46W6818741X24533.pdf.

Wong, G. *et al.* (2013) 'RAMESES publication standards: Meta-narrative reviews', *Journal of Advanced Nursing*, 69(5), pp. 987–1004. doi: 10.1111/jan.12092.

Zhang, S. Y., Yu, Q. and Beaulieu, J. (2004) 'Genetic variation in veneer quality and its correlation to growth in white spruce', *Canadian Journal of Forest Research*, 34(6), pp. 1311–1318. doi: 10.1139/X04-015.