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THERMAL MODIFICATION OF BAMBOO: EFFECTS ON PHYSICAL, MECHANICAL AND CHEMICAL PROPERTIES

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ABSTRACT

All around the world, in both tropical and subtropical climates, bamboo grows to become one of the most plentiful non-timber resources. The fact that it is highly recyclable, has strong mechanical qualities, and is environmentally friendly all add to its growing popularity. The natural hydrophilicity of bamboo, however, poses considerable hurdles, especially when it comes to ensuring the best possible compatibility for uses like building materials. Important methods for enhancing the surface qualities of bamboo have evolved, and they are both cost-effective and eco-friendly. In this post, we will go over every single detail of how thermal treatment circumstances, such as temperature, duration, and medium, affect the structural features of bamboo. Its goal is to provide important information that will spur innovation and increase the use of bamboo-based products.

Keywords: *bamboo; heat treatment; thermal modification; physical, mechanical, & chemical properties*

INTRODUCTION

One of the most important forest products in Indonesia is wood, which is also a significant forest resource. Furniture and building materials are two of its most common uses (Aszahrah *et al.*, 2022; Tjondro, 2014). Also predicted to keep to higher is the demand for wood supply (Mutaqin *et al.*, 2022). Nevertheless, the 45.8 million m^3 of wood available from both natural and plantation forests falls short of the 57.7 million m^3 national demand, as reported by the Ministry of Environment in 2007 (Kaskoyo, 2009; Herwanti, 2015). There has to be a solution to the shortage of wood, and this growing demand is bringing it to light.

Nugroho *et al.* (2022) explained that bamboo has the ability to replace wood. Several previous studies have stated that bamboo also contains lignin, cellulose, and hemicellulose (Hidayat *et al*., 2019; Hariz *et al.*, 2021; Hidayat *et al.*, 2022). The chemical components in bamboo are similar to woods, which make it a good substitute for wood (Hidayat *et al.,* 2022). The bamboo resource is rich in Indonesia. Indonesia bamboo production hit 17,063,847 culms in 2019, as reported by Statistics Indonesia in 2020 (Nugroho *et al.,* 2022).

Sharma *et al.* (2013) indicated that bamboo has numerous benefits, including strong, lightweight, versatile, affordable, environmentally friendly, and high production. In particular, Indonesia extensively uses it due to its fast growth and simplicity of processing (Nugraha *et al.,* 2014). Furniture, animal feed, and construction materials are just a few of the many uses for bamboo

(Murda *et al.,* 2022). Several of bamboo's drawbacks include its sensitivity to water, its weakness against decay and pests (Tang *et al.,* 2019a,b), its lack of dimensional stability, the fact that its physical properties vary greatly across its three sections (base, middle, and tip), and its small diameter (Febrianto *et al.,* 2017; Sharma *et al.,* 2013). Modification strategies can be used to address these issues.

To improve the characteristics of wood while reducing its detrimental impact on the environment is the general goal sought by wood modification (Hidayat and Febrianto, 2018). Among these, higher decay resistance, better dimensional stability, reduction in water absorption levels, and even greater strength can be achieved by employing different means. Chemical, surface, impregnation, and heat treatments are some of the methods employed to modify wood. Heat treatment is a popular method because it is so simple to do that anyone can do it. Among other reasons are that the product has no toxic ingredients and thus can be used even in areas where people live near trees or other plants (Hidayat et al., 2020).

With heat treatment, one can improve the quality of bamboo and wood (Kwan et al., 2014; Li et al., 2015; Shangguan et al., 2016). This process requires specific parameters such as time and temperature (Hendianto et al., 2020). The common range of heat treatment temperature is 180–260℃. Wood quality will deteriorate if it overheats above 260℃ (Hill, 2006; Lee et al., 2018; Hendianto et al., 2020). Ways to implement heat treatment include various media methods, like air, steam, a combination of air and steam, nitrogen, oil, and many others (Esteves et al., 2009; Tian et al., 2021; Feliciano et al., 2011; Hakkao et al., 2005; Abdillah et al., 2020; Suri et al., 2022).

In recent years, five separate approaches have been used commercially in Europe to use heat treatment technology. Thermowood and Dutch Plato Wood are two examples from the Netherlands and Finland that use steam; Bois Perdure and Rectification are two from France that use nitrogen; and Oil Heat Treatment is one from Germany that utilizes oil (Sahin, 2017).

A great deal of research has demonstrated that wood heat treatment can change the chemical properties of timber, and the weight or colour, resulting in weights and colours that are different from their natural states (Hidayat et al., 2018; Suri et al., 2021a,b; Rahmawati, 2022). Hidayat et al. (2018), Suri et al. (2021a, b), Rahmawati (2022) found that jabon wood treated during one period or two units of time changed color and lost weight after air heat treatment (AHT), whereas Suri et al. (2022) demonstrated the effect of AHT on the mechanical strength of Paulownia tomentosa and Pinus koraiensis wood. Ma'ruf et al. (2023) urged treating low-grade wood with oil heat treatment (OHT) to produce better quality timber, an approach described as feasible already by Tang et al. (2019b). Afkar et al. (2023) found after treating modified jabon wood with OHT, there was substantial real change.

Previous research showed that bamboo was heat-sensitive and needed modification. According to Hao et al. (2021), using bamboo (Phyllostachys edulis) timber as the material with orthogonal heat treatment (OHT) increased its dimensional stability and density. After reducing wettability, it became slow, to mention some benefits. Baiti et al. (2021) found that hydrophobicity (water resistance) and darker pigmentation were both improved by AHT modification in betung bamboo (Dendrocalamus asper). This bamboo, being multi-ply in structure and with plenty of cells intertwined so that the water will not escape into the outside layer, will even be more durable and has a blemished surface. It's ideal for ware that must undertake long periods in damp environments and has high aesthetic requirements—whether furniture or craftwork made from laminated wood.

This study aims to systematically review the published literature on the properties of bamboo modified through air heat treatment and oil heat treatment. The specific objectives of this review include: (1) exploring the potential of bamboo, especially in Indonesia, (2) highlighting the importance of heat treatment, (3) reviewing heat treatment methods, and (4) analyzing the effect of heat treatment on bamboo properties.

1. Potential of Bamboo in Indonesia

It is noted that bamboo is an important item of NTFP (non-timber forest produce) with many uses; in addition to lumber, it's also useful in crafts and musical instrument making, for example (Saputra et al., 2022). Its great production capacity, rapid growth, and simple process of treatment make bamboo a versatile resource, particularly in Indonesia (Fahrina and Gunawan, 2014; Nugroho et al., 2022). There is a study emphasizing bamboo's structural superiority. Its flexible, elastic fibers are ideal for bearing loads. When squeezed, bamboo's compressive strength equals that of wood; while in the extension stage, its tensile strength exceeds timber's (Fahrina and Gunawan, 2014; Lestari et al., 2014).

Bamboo belongs to the Gramineae (grass) family and is represented by approximately 200 species in Southeast Asia out of 1,000 species worldwide. Indonesia has approximately 60 bamboo species (Dransfield and Widjaja, 1995). According to a report from Statistics Indonesia 2017, the country produced 14 million bamboo culms. Recognizing its vast potential as a non-wood resource, the Indonesian government has prioritized bamboo’s utilization in daily life while fostering the growth of the bamboo industry (Park et al., 2018). Bamboo has long been used as a construction material due to its availability, lightweight nature, and favorable mechanical properties. It contains cellulose (42.4%-53.6%), lignin (19.8%-26.6%), pentosans (1.24%-3.77%), ash (1.34%-3.75%), silica (0.10%-1.78%), and small amounts of other extractives (Hutapea et al., 2017; Fatrawana et al., 2019)

Bamboo is generally known for its excellent properties, such as strong, straight, smooth, durable culms, ease of splitting, workability, and lightweight nature (Park et al., 2019). Bamboo is primarily used as a secondary construction material for scaffolding, roof battens, walls, and roofing (Fahrina and Gunawan, 2014). This limited usage is largely due to a lack of public awareness regarding bamboo’s mechanical and physical properties. However, bamboo can be used as a primary material in foundations, columns, beams, flooring, and roof trusses (Tang et al., 2019a). Commonly utilized bamboo species in Indonesia include waluh bamboo, legi bamboo, ampel bamboo, and betung bamboo (Irnawan, 2022).

The ability of bamboo to adapt to diverse climates and its superior properties support its widespread cultivation. Its rapid growth cycle is particularly notable. Depending on the species, bamboo matures within 3-6 years, compared to wood, which requires up to 15 times longer to reach harvestable maturity. This fast growth rate is a key factor driving bamboo’s increasing utilization (Hidayat et al., 2024).

2. The Importance of Heat Treatment

In particular, there has been a recent surge of interest in the techniques of bamboo heating treatments because it provides a simple way to modify the physical properties of natural products and has minimal environmental effects. When subjected to temperatures between 160°C and 220°C, bamboo is partially pyrolyzed and condensed. Under this condition of heat and pressure, a chemical reaction is triggered, and bamboo will begin to change. Thus, the chemical composition as well as the structure of bamboo is altered during these processes. These changes make bamboo "compact" (some 50% of the hemicellulose and hydroxyl groups in the cell wall are lost), which improves its properties in physics and chemistry. Particularly, it makes the reduction of water and moisture absorption capacity clear.

As proved by Wang et al. (2020) and Meng et al. (2016), changes that can improve surface properties, raise dimensional stability, and obviously improve resistance against biodegradation are taken. Its chemical composition and mechanical performance are changed by bamboo heat treatment in various methods. This makes efforts at achieving bamboo materials capable of being put to use for all kinds of product needs. To solve the problem of wood supply and demand, promoting environmental sustainability, and expanding the use of fiber composites from bamboo, heat treatment of bamboo material is absolutely necessary.

3. Heat Treatment Methods

Heat intensity (time and temperature) and treatment medium (vacuum, gas, air, or oil) are the most important variables in determining how heat treatment processing affects bamboo properties. All these things matter regarding how heat treatment turns out and how bamboo acts once heated (Suri *et al.,* 2022).

Oil, air, and steam treatments are the main methods of treating bamboo with high-temperature heat. Despite their great usefulness in improving the physical and chemical qualities of bamboo, the first two approaches have only had limited industrial application globally (Hidayat and Febrianto, 2018).

Heat treatments using air or oil, on the other hand, are laborious and intricate. It becomes more difficult to process and use bamboo after it absorbs a lot of water and oil during processing. There are a number of problems with these systems, including increased complexity in waste management and high operational expenses (Yang *et al.,* 2021; Wang *et al.,* 2021).

4. The Effects of Heat Treatment on Bamboo Properties

a. Heat treatment impact on bamboo's physical properties

There is as study reported that betung bamboo (Dendrocalamus asper) becomes more hydrophobic if it is kept heated after boiling for some time. Baiti et al. (2021) reported that when bamboos are treated with heat, the surface wettability of bamboo changes between 100°C and 180°C. Under experimental conditions, at a temperature of 140 degrees Celsius, water drops on bamboo stick like small beads (Shao et al., 2009). The glass transition temperature of lignin, an amorphous thermoplastic polymer, is 150°C (Zheng et al., 2020). Bamboo loses hygroscopicity as it gets hotter. This is because the hydroxyl groups in cellulose microfibrils break down (Meng et al., 2016). As Baiti et al. (2021) explained, hygroscopicity is the ability of surface materials to absorb and retain water molecules.

Previous studies on bamboo have shown that heating affects surface wettability and coloring. When bamboo is left under hot conditions for long enough, it turns black. On the other hand, when cellulose, hemicellulose, and lignin undergo oxidation and condensation, the red-green chromaticity parameter (a*) increases (Baiti *et al.,* 2021). Cademartori *et al.* (2014) found that by-products of lignin condensation intensify the color redness.

In their study, Chen *et al.* (2019) found that bamboo subjected to dry heat treatment with a moisture content of 5% did not experience any changes in color intensity (ΔE). On the other hand, significant changes in color (higher ΔE values) were seen when wood with a high moisture content was heated. Sundqvist (2004), Cademartori *et al.* (2014), and Pelit (2017) reported that the surface of wood darkening, it could be caused by the amorphous microfibril degradation and higher lignin levels. Wood loses some of its surface brightness when heated at 220°C (Huang *et al.,* 2012).

Cell wall components, layer orientation, microfibril alignment, chemical compounds within the cell walls, and environmental growth conditions are among the factors that affect the physical properties of bamboo (Fahrina and Gunawan, 2014). Dimensional stability, acoustic properties, insulating capacity, density, and moisture content are the primary physical qualities of bamboo.

b. Heat treatment impact on bamboo's mechanical properties

Factors such as species, harvesting age, culm moisture distribution, culm section, and node arrangement and spacing affect bamboo's mechanical qualities (Fahrina and Gunawan, 2014). Important metrics for assessing the mechanical and physical properties of bamboo include the modulus of elasticity (MOE), proportional and elastic limits, shear strength, compressive strength, tensile strength, and the stress-strain relationship (Ndale, 2013).

Tung oil heat treatment enhanced modulus of rupture (MOR) and modulus of elasticity (MOE) when temperatures were kept below 140°C, according to Tang *et al.* (2019b). These values remained higher than untreated samples even after being heated to 200°C, indicating that heat treatment in tung oil below 200°C helps preserve desirable mechanical qualities.

Zhang et al. (2013) conducted a heat experiment in air at a temperature of 100–220°C for 1-4 hours. Several results were reported in this study. MOR started to increase first and then began to fall off. 160°C was the temperature point at which MOR began to decline. Its rate of decline also increased with time: 80 hours at 160°C would see MOR drop to about one-twentieth of that at 10 hours at the same temperature. As the treatment temperature ascended above 200°C, even more MOR was lost. However, the MOE after heat treatment had a smaller impact. 140°C represented the maximum MOE value; at 200°C, an inflection point was reached, and this began to fall away rapidly. Dense materials and greater crystallinity in the cellulose all served to increase MOE and MOR at first. Lower mechanical values than before were found for bamboo samples heated to 200-210°C using a muffle furnace (or equivalent treatment method per the conditions). The main reason behind this loss was due to cellulose destruction. Bamboo heat treatment resulted in a reduction of the hydroxyl group peak, soon followed by a continued decline in cellulose and other moisture-absorbing groups as the heat grew more severe. Chemical changes, such as those reported in several studies (Fazita et al., 2016; Zhang et al., 2016; Yang et al., 2016; Yang et al., 2019b), caused the low degree of crystallinity in bamboo, leading to damage to its mechanical properties. Although mechanical intensity was reduced, how much was lost varied greatly from treatment medium to medium (Yang et al., 2016).

Hemicellulose, a component that binds to cellulose, plays a crucial role in imparting structural stability to the cell wall. As it breaks down, you compromise the reinforcing material, and that then affects how well the composite as a whole performs. The stiffness of a material can be measured as the Modulus of Elasticity (MOE), and the addition of lignin results in harder and stiffer matrices. Note that the relative content of lignin increases with respect to polysaccharide content during heat treatment. So, MOE is unaffected by this adjustment (Zhang *et al.,* 2013; Meng *et al.,* 2019).

Additional research by Suri *et al*. (2022) compared the effects of air and oil heat treatments on Korean white pine and royal paulownia woods. At 180 °C, the axial compressive strength of the wood samples that were heat-treated in either oil or air was found to be the highest, according to their research. After that, they went downhill as the treatment time and temperature went up. Unlike *Paulownia tomentosa* wood, *Pinus koraiensis* wood became harder when heated in oil. After being heated in the air, the two wood samples became less hard. They said that hemicellulose degradation and oxidation reactions in wood might be to blame for the altered mechanical qualities.

c. Heat treatment impact on bamboo’s chemical properties

According to Murda *et al.* (2018), hemicellulose and low-molecular-weight extractives are reduced when subjected to heat. A weakening of the bamboo's structure is caused by the breakdown of cellulose and hemicellulose chains, which increases the relative lignin concentration (Meng *et al.,* 2016; Shao *et al.,* 2009; Baiti *et al.,* 2021). The mechanical properties of bamboo strands are improved due to an autocatalytic reaction within the cell walls. This process increases the polymer crystallinity (Nishida *et al.,* 2017; Yun *et al.,* 2016; Baiti et al., 2021).

Water loss and volatilization of extractive components occur in lignocellulosic materials, including wood, when continually subjected to heat below 140°C (Baiti *et al.,* 2021). The alignment of polymer chains improves mechanical qualities when bamboo is heated to a temperature close to its glass transition temperature (Tg), seen at the macroscopic level. According to Baiti *et al.* (2021), this process causes the bamboo structure to become denser and less porous, making it more resistant to liquid penetration and diffusion.

Bamboo fibers are chemically and anatomically identical to other raw materials used to make pulp and paper, and their length is about 3 to 4 mm. Bamboo has strands that are longer than pine and about the same length as red spruce. Cellulose makes up 42.4% to 43.6% of bamboo. Lignin (19.8%–26.6%), pentosans (1.24%–3.77%), ash (1.24%–3.77%), silica (0.10%–1.78%), and extractives (0.9%–6.9% benzene-alcohol solubility, 4.5–9.9% cold water solubility, and 5.3%–11.8% hot water solubility) are among the other components found in bamboo (Nafitri and Lukmandaru, 2014). The distribution of bamboo's chemical properties coincides with the vertical location along the culm of *Dendrocalamus asper* (Nafitri and Lukmandaru, 2014).

CONCLUSIONS

Bamboo is a promising alternative to wood due to its sustainability, rapid growth, and strong mechanical properties. However, its high water absorption, susceptibility to degradation, and dimensional instability limit its broader applications. Heat treatment has proven to be an effective and eco-friendly modification technique that enhances bamboo’s physical, mechanical, and chemical properties. Thermal treatment addresses many of bamboo's inherent weaknesses by reducing moisture absorption, increasing dimensional stability, and improving surface hydrophobicity. Moderate heat treatment temperatures improve mechanical strength, but excessive heating above 200°C can degrade cellulose and reduce structural integrity. Chemically, heat treatment alters bamboo’s composition by breaking down hemicellulose and extractives while increasing lignin content, affecting both stiffness and hardness.

Despite these benefits, challenges such as treatment cost, efficiency, and variations in processing outcomes remain. Future research should focus on optimizing heat treatment methods to maximize bamboo’s performance while ensuring economic viability. Exploring hybrid treatments and alternative processing techniques could further enhance bamboo’s mechanical and physical properties, expanding its applications in construction, furniture, and engineered composites. Bamboo can become a more competitive and sustainable material in the global market by refining thermal treatment strategies.

REFERENCES

Abdillah, M., Ma'ruf, S. D., Kaskoyo, H., Safe'i, R., and Hidayat, W. (2020). Modifikasi sifat fisis dan mekanis kayu sengon (*Falcataria moluccana*) dan kelapa (*Cocos nucifera*) melalui perlakuan panas dengan minyak. *Prosiding Seminar Nasional Konservasi 2020*. Bandar Lampung. 564-569.

Afkar, H., Febryano, I. G., Duryat, D., Suri, I. F., and Hidayat, W. (2022). Pengaruh perlakuan panas *oil heat treatment* terhadap perubahan warna kayu jabon (*Anthocephalus cadamba*). *Warta Rimba: Jurnal Ilmiah Kehutanan* 10(5): 97-104.

Aszahrah, H., Anraeni, S., and Darwis, H. (2022). Penerapan metode K-nearest neighbor untuk mengidentifikasi jenis kayu sebagai bahan furniture. *Buletin Sistem Informasi dan Teknologi Islam (BUSITI)* 3(4): 284-292.

Baiti, R. N., Maulana, S., Sipahutar, W. S., Murda, R. A., Julyatmojo, F. A., Suwanda, A. A., and Fadlan, M. S. (2021). Evaluation of surface properties of betung bamboo (*Dendrocalamus asper*) strands under various heat treatment duration and temperature. *Journal of Science and Applicative Technology* 5(2): 411-417.

Cademartori, P. H. G. D., Mattos, B. D., Missio, A. L., and Gatto, D. A. (2014). Colour responses of two fast-growing hardwoods to two-step steam-heat treatments. *Materials Research* 17: 487-493.

Chen, Q., Fang, C., Wang, G., Ma, X., Chen, M., Zhang, S., Dai, C., and Fei, B. (2019). Hygroscopic swelling of moso bamboo cells. *Cellulose* 27(2): 611- 620.

Dransfield, S., and Widjaja, E. A. (1995). *Bamboos*. Leiden: Backhuys Publishers.

Esteves, B.M., and Pereira, H. (2009). Wood modification by heat treatment: A review. *BioResources* 4(1): 370-404.

Fahrina, R., and Gunawan, I. (2014). Pemanfaatan bambu betung bangka sebagai pengganti tulangan balok beton bertulangan bambu. *Forum Profesional Teknik Sipil* 2(1): 56-68.

Fatrawana, A., Maulana, S., Nawawi, D. S., Sari, R. K., Hidayat, W., Park, S. H., and Kim, N. H. (2019). Changes in chemical components of steam-treated betung bamboo strands and their effects on the physical and mechanical properties of bamboo-oriented strand boards. *European Journal of Wood and Wood Products* 77: 731-739.

Fazita, M. R. N., Jayaraman, K., Bhattacharyya, D., Haafiz, M. K. M., Saurabh, C. K., and Hussin, M. H. (2016). Green composites made of bamboo fabric and poly (lactic) acid for packaging applications – a review. *Materials* 9(6): 435. doi: 10.3390/ma9060435.

Febrianto, F., Sumardi, I., Hidayat, W., and Maulana, S. (2017). *Papan untai bambu berarah: material unggul untuk komponen bahan bangunan struktur*. Bogor: IPB Press.

Hakkou, M., Pétrissans, M., Zoulalian, A., and Gérardin, P. (2005). Investigation of wood wettability changes during heat treatment on the basis of chemical analysis. *Polymer Degradation and Stability* 89(1): 1–5.

Hao, X., Wang, Q., Wang, Y., Han, X., Yuan, C., Cao, Y., and Li, Y. (2021). The effect of oil heat treatment on biological, mechanical and physical properties of bamboo. *Journal of Wood Science* 67(26): 1-14.

Hardianto, A.H., Ma'ruf, S.D., and Hidayat, W. (2020). Oil heat treatment kayu sengon (*Falcataria moluccana*) dan Kelapa (*Cocos nucifera*) pada berbagai durasi perlakuan. *Seminar Nasional Konservasi 2020*. Bandar Lampung. 287-292.

Hariz, T. M. R., Santosa, I. A., Maulana, M. I., Marwanto, M., Prasetia, D., Hidayat, W., Lubis, M. A. R., Kim, N. H., and Febrianto, F. (2021). Effect of resin content on characteristics of bamboo oriented strand board prepared from strand of betung, ampel, and their mixtures. *Jurnal Sylva Lestari* 9(3): 454-464. DOI: 10.23960/jsl.v9i3.520

Herwanti, S. (2015). Potensi kayu rakyat pada kebun campuran di Desa Pesawaran Indah Kabupaten Pesawaran. *Jurnal Sylva Lestari* 3(1): 113-120.

Hidayat, W., and Febrianto, F. (2018). Teknologi Modifikasi Kayu Ramah Lingkungan: Modifikasi Panas dan Pengaruhnya Terhadap Sifat-sifat Kayu. Pusaka Media. Bandar Lampung.

Hidayat, W., Ma'ruf, S. D., Abdillah, M., Prayoga, S., Zevan, R., Prihastono, G. B. A., Hardianto, A. H., and Ridjayanti, S. M. (2020). *Perlakuan minyak panas (hot oil treatment) pada kayu*. Bandar Lampung: Pusaka Media.

Hidayat, W., Pah, J. M., Suryanegara, L., Hasanudin, U., Haryanto, A., and Wulandari, C. (2022). Production and characterization of andong bamboo (*Gigantochloa pseudoarundinacea* (Steudel) Widjaja) pellets from various stem parts. *Jurnal Teknik Pertanian Lampung* 11(4): 713-723.

Hidayat, W., Suri, I. F., Safe'i, R., Wulandari, C., Satyajaya, W., Febryano, I. G., dan Febrianto, F. (2019). Keawetan dan stabilitas dimensi papan partikel hibrida bambu-kayu dengan perlakuan steam dan perendaman panas. *Jurnal Ilmu dan Teknologi Kayu Tropis* 17(1): 68-82.

Hidayat, W., Wijaya, B., Saputra, B., Rani, I., Kim, S., Lee, S., Yoo, J., Park, B., Suryanegara, L., and Lubis, M. (2024). Torrefaction of bamboo pellets using a fixed counter-flow multi-baffle reactor for renewable energy applications. *Global Journal of Environmental Science and Management* 10(1): 169-188.

Hill, C. A. S. (2006). *Wood Modification: Chemical, Thermal and Other Process*. Chicester: John Wiley and Sons Ltd. 99-127.

Huang, X., Kocaefe, D., Kocaefe, Y., Boluk, Y., and Pichette, A. (2012). A Spectrocolorimetric and Chemical Study on Color Modification of Heat- Treated Wood During Artificial Weathering. Applied Surface Science. 258(14): 5360-5369.

Hutapea, E. M., Iwantono, I., Farma, R., Saktioto, S., and Awitdrus, A. (2017). Pembuatan dan karakterisasi karbon aktif dari bambu betung (*Dendrocalamus asper*) dengan aktivasi KOH berbantuan gelombang mikro. *Komunikasi Fisika Indonesia* 14(2): 1061-1066.

Irnawan, D. (2022). Bambu sebagai material konstruksi yang mudah dibentuk pada konstruksi bangunan menara penangkap embun. *Jurnal Teknosains Kodepena* 2(2): 27-31.

Kaskoyo, H. (2009). Potensi dan kerapatan jenis pohon di hutan rakyat Desa Tanjung Rusia Kecamatan Pardasuka Kabupaten Tanggamus. *Seminar Agroforestry sebagai Pemanfaatan Lahan Berkelanjutan di Masa Depan (Agroforestry as the Future Sustainable Land Use)*. Bandar Lampung, 7 Mei 2009. Lembaga Penelitian Universitas Lampung.

Kwon, J. H., Shin, R. H., Ayrilmis, N., and Han, T. H. (2014). Properties of solid wood and laminated wood lumber manufactured by cold pressing and heat treatment. *Materials and Design* 62: 375-381.

Lee, S.H., Ashaari, Z., Lum, W.C., Halip, J.A., Ang, A.F., tan, L.P., Chin, K, L., and Tahir, P.M. (2018). Thermal Treatment of Wood Using Vegetable Oils: A Review. *Construction and Building Materials* 181(1): 408-419.

Lestari, D., Suwanda, A. A., Murda, R. A., Maulana, M. I., Augustina, S., Rianjanu, A., Taher, T., Hidayat, W., Maulana, S., and Lubis, M. A. R. (2024). Durability to natural weathering of methylene diphenyl diisocyanate-bonded bamboo oriented strand board. *Jurnal Sylva Lestari* 12(1): 143–157.

Li, T., Cheng, D. L., Wålinder, M. E., and Zhou, D. G. (2015). Wettability of oil heat-treated bamboo and bonding strength of laminated bamboo board. *Industrial Crops and Products* 69: 15-20.

Ma'ruf, S.D., Bakri, S., Febryano, I.G., Setiawan, A., Haryanto, A., Suri, I.F. and Hidayat, W. (2023). Effects of Temperature during Oil Heat Treatment on the Quality Improvement of Mindi (*Melia azedarach*) and Sengon (*Falcataria moluccana*) Woods. *Jurnal Teknik Pertanian Lampung* 12(1): 255-267.

Meng, F., Yu, Y., Zhang, Y., Yu, Y., and Gao, J. (2016). Surface chemical composition analysis of heat-treated bamboo. *Applied Surface Science* 371: 383-390.

Meng, F. D., Wang, C., Xiang, Q., Yu, Y.L., and Yu, W.J. (2019). Effect of hot dry air treated defibering bamboo veneer on the properties of bamboo-based fiber composites *Scientia Silvae Sinica* 55(9):142–8.

Murda, R. A., Maulana, S., Fatrawana, A., Mangurai, S. U. N. M., Muhamad, S., Hidayat, W., and Bindar, Y. (2022). Changes in chemical composition of betung bamboo (*Dendrocalamus asper*) after alkali immersion treatment under various immersion times. *Jurnal Sylva Lestari* 10(3): 358-371.

Murda, R. A., Nawawi, D. S., Maulana, S., Maulana, M. I., Park, S. H., and Febrianto, F. (2018). Perubahan kadar komponen kimia pada tiga jenis bambu akibat proses steam dan pembilasan. *Jurnal Ilmu dan Teknologi Kayu Tropis* 16(2): 102-114.

Mutaqin, D. J., Nurhayani, F. O., and Rahayu, N. H. (2022). Performa industri hutan kayu dan strategi pemulihan pascapandemi Covid-19. *Bappenas Working Papers* 5(1): 48-62.

Ndale, F. X. (2013). Sifat fisik dan mekanik bambu sebagai bahan konstruksi. *Agrica: Journal of Sustainable Dryland Agriculture* 7(2): 22-31.

Nafitri, M., and Lukmandaru, G. (2014). Sifat kimia bambu hitam (*Gigantochloa* sp.) pada perbedaan arah aksial dan ketinggian tempat tumbuh. *Prosiding Seminar Nasional Masyarakat Peneliti Kayu Indonesia (MAPEKI) XVI*. pp. 318-324. Bogor.

Nishida, M., Tanaka, T., Miki, T., Ito, T., and Kanayama, K. (2017). Multi-scale instrumental analyses for structural changes in steam-treated bamboo using a combination of several solid-state NMR methods. *Industrial Crops and Products* 103: 89-98.

Nugraha, H. (2014). Pengolahan material bambu dengan menggunakan teknik laminasi dan bending untuk produk furniture. *Widyakala: Journal of Pembangunan Jaya University* 1(1): 1-9.

Nugroho, N., Bahtiar, E. T., and Lelono, A. B. (2022). Kekuatan bambu betung (*Dendrocalamus asper* Backer ex K. Heyne) menahan gaya normal tekanan dan tarikan. *Jurnal Penelitian Hasil Hutan* 40(1): 37-48.

Park, S., Jang, J., Wistara, I., Hidayat, W., Lee, M., and Febrianto, F. (2018). Anatomical and physical properties of Indonesian bamboos carbonized at different temperatures. *Journal of the Korean Wood Science and Technology* 46(6): 656-669.

Pelit, H. (2017). The effect of different wood varnishes on heat-treated wood materials' surface color propes. *Journal of the Faculty of Forestry Istanbul University* 67(2): 262-274.

Poncsak, S., Kocaefe, D., and Younsi, R. (2011). Improvement of the heat treatment of jack pine (*Pinus banksiana*) using thermowood technology. *European Journal of Wood and Wood Products* 69(2): 281-286.

Rahmawati, L. (2022). *Peningkatan sifat fisis dan mekanis kayu jabon (Anthocephalus cadamba) melalui perlakuan panas air heat treatment*. Doctoral Dissertation. Universitas Lampung. Bandar Lampung.

Sahin, H. I. (2017). Heat treatment application methods and effects of heat treatment on some wood properties. *III International Conference on Engineering and Natural Sciences (ICENS)*. Budapest. Hungary.

Saputra, B., Tambunan, K. G. A., Suri, I. F., Febryano, I. G., Iswandaru, D., and Hidayat, W. (2022). Effects of torrefaction temperature on the characteristics of betung (*Dendrocalamus asper*) bamboo pellets. *Jurnal Teknik Pertanian Lampung* 11(2): 339-353.

Shangguan, W., Gong, Y., Zhao, R., and Ren, H. (2016). Effects of heat treatment on the properties of bamboo scrimber. *Journal of Wood Science* 62(5): 383- 391.

Sharma, B., Harries, K. A., and Ghavami, K. (2013). Methods of determining transverse mechanical properties of full-culm bamboo. *Construction and Building Materials* 38: 627-637.

Shao, S., Jin, Z., Wen, G., and Iiyama, K. (2009). Thermo characteristics of steam-exploded bamboo (*Phyllostachys pubescens*) lignin. *Wood Science and Technology* 43: 643-652.

Sundqvist, B. 2004. *Colour changes and acid formation in wood during heating*. Lulea University.

Suri, I. F., Kim, J. H., Purusatama, B. D., Yang, G. U., Prasetia, D., Lee, S. H., Hidayat, W., Febrianto, F., Park, B. H., and Kim, N. H. (2021a). Comparison of the color and weight change in *Paulownia tomentosa* and *Pinus koraiensis* wood heat-treated in hot oil and hot air. *BioResources* 16(3): 5574-5585.

Suri, I. F., Purusatama, B. D., Lee, S., Kim, N., Hidayat, W., Ma'ruf, S. D., and Febrianto, F. (2021b). Characteristic features of the oil-heat treated woods from tropical fast growing wood species. *Wood Research* 66(3): 365-378.

Suri, I.F., Purusatama, B.D., Kim, J.H., Yang, G.U., Prasetia, D., Kwon, G.J., Hidayat, W., Lee, S.H., Febrianto, F., and Kim, N.H. (2022). Comparison of physical and mechanical properties of *Paulownia tomentosa* and *Pinus koraiensis* wood heat-treated in oil and air. *European Journal of Wood and Wood Products* 80(6): 1389-1399.

Tang, T., Chen, X., Zhang, B., Liu, X., and Fei, B. 2019a. Research on the physico-mechanical properties of moso bamboo with thermal treatment in tung oil and its influencing factors. *Materials* 12(4): 599-610.

Tang, T., Zhang, B., Liu, X., Wang, W., Chen, X., and Fei, B. 2019b. Synergistic effects of tung oil and heat treatment on physicochemical properties of bamboo materials. *Scientific Reports* 9(1): 1-11.

Tian, M., Zhang, B., Wu, Z., Yu, L., Li, L., and Xi, X. (2021). Effects of steam heat-treatment on properties of *Pinus massoniana* wood and its bonding performance. *Journal of Renewable Materials* 9(4): 789-801.

Tjondro, J.A. (2014). *Perkembangan dan prospek rekayasa struktur kayu di Indonesia.* Seminar dan Lokakarya Rekayasa Struktur, Universitas Petra, Surabaya. 24 p.

Wang, Q., Wu, X., Yuan, C., Lou, Z., and Li, Y. (2020). Effect of saturated steam heat treatment on physical and chemical properties of bamboo. *Molecules* 25(8): 1999. doi: 10.3390/molecules25081999.

Yang, T. C., Yang, Y. H., and Yeh, C. H. (2021). Thermal decomposition behavior of thin makino bamboo (*Phyllostachys makinoi*) slivers under nitrogen atmosphere. *Mater Today Communication* 26: 102054.

Yang, T. H., Lee, C. H., Lee, C. J., and Cheng, Y. W. (2016). Effects of different thermal modification media on physical and mechanical properties of moso bamboo. *Construction Building and Materials* 119: 251–9. doi: 10.1016/j. conbuildmat.2016.04.156.

Yun, H., Li, K., Tu, D., Hu, C., and South, G. C. (2016). Effect of heat treatment on bamboo fiber morphology crystallinity and mechanical properties. *Wood Research* 61(2): 227-234.

Zhang, Y., and Yu, W. (2015). Changes in surface properties of heat-treated *Phyllostachys pubescens* bamboo. *BioResources* 10(4): 6809–6818.

Zhang, Y., Zhang, X., Yu, Y., Che, W., Zhang, X., and Hou, J. (2020). Evaluating the comprehensive influences of heat treatment and polydimethylsiloxane on integrated performance of bamboo timber. *RSC Advances* 10(71): 43438-43446.

Zhang, Y., Yu, Y., and Yu, W. (2013). Effect of thermal treatment on the physical and mechanical properties of *Phyllostachys pubescen* bamboo. *European Journal of Wood and Wood Products* 71: 61–67. doi: 10.1007/s00107- 012-0643-6.