Asian Journal of Plant Sciences

ISSN 1682-3974

OPEN ACCESS Asian Journal of Plant Sciences

ISSN 1682-3974
DOI: 10.3923/ajps.2018.1.18

Review Article

Review on Quality Enhancement of Bamboo Utilization: Preservation, Modification and Applications

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Abstract
The properties of bamboo are unique compared to solid wood and other ligno- and non-lignocellulosic materials especially for manufacturing, designing and construction usages. Recent technological advancements for bamboo processing has proven the positive advantages of bamboo for various interior and exterior applications including furniture, bio-composites, packaging, transport, building and so on. The variability in size, length and diameter of bamboo, its growth and production is a big challenge for their applications as bio-based material along with durability. Since bamboo has a low durability, protection against biotic and abiotic degradation. Since it has vital importance for its longer service life. Preservation and modification treatment of bamboo are therefore regarded as a necessity. Those preservation and modification techniques would ensure the quality and durability of bamboo resulting sustainability and advanced engineering utilization of bamboo. This article reviews the preservation and modification techniques of bamboo which are crucial for advanced products manufacturing and utilization. The article also summarizes the importance of preservation and modification process, its principles and the challenges in quality and durability enhancement of bamboo products. At the end of the article, applications specially the modern one has also been discussed along with its further advancement.

Key words: Bamboo, preservation, modification, durability, biocomposites

Received: July 15, 2017 Accepted: October 23, 2017 Published: December 15, 2017

Citation: Aminudin Sulaeman, Rudi Dungani, Nuruddin Nurudin, Sri Hartati, Tati Karliati, Pingkan Aditiawati, Anne Hadiyane, Yoyo Suhaya and Sulistyono, 2018. Review on quality enhancement of bamboo utilization: preservation, modification and applications: A review. Asian J. Plant Sci., 17: 1-18.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Bamboo as the great potential as solid wood substitute materials, their has 1575 species which each particular species has different properties and qualities. Its rapid growth is acknowledged as one of the eco-products on the environment[1]. The bamboo is generally thought to be a plant more associated with growing in subtropical and tropical regions like Southeast Asia[2]. The unique nature of bamboo has attracted researchers to investigate and explore, especially in the field of quality and durability enhancement of bamboo products.

Bamboo is a plant with many advantages and is used for many purposes from cradle to grave and is found in vast areas throughout the world. Because of its fast growing nature, it is an easily renewable raw material which has attractive and unique appearance and toughness[2]. The bamboo dependency could directly reduce the deforestation or degradation of forest because of its short rotation. The woody plants simply take a long time up to 20 years to reach their maturity, while bamboo only takes less than 4 years to reach their maturity. The use of bamboo in some of the tropical countries like Indonesia and Malaysia is still at the minimum level, while in the other countries (China and Japan), it is a source which contributes to the growth of the economy. According to Maoyi and Xiaosheng[3], value of world trade of bamboo has reached 4 billion U.S. dollars and is monopolized by China. Bamboo properties of being lightweight and high-strength are recognized as the source of raw materials that can be processed and shaped into the form of a number of commodities. Advancement in science and technology, has led in terms of its value of diversity in the production of bamboo bio-composite products[4].

In recent years, bamboo use as raw material for various products. This invention had showed the great potential and bright future by using bamboo as raw materials. The laminated products, structural boards, trusses, concrete reinforcement and ply-bamboo has been explored[5-9]. The suitability of bamboo for crushed ply-bamboo for form work (C-Bam for form work) and compressed parallel-orientated bamboo skewer that bound and glued together to form a structurally wood V-Bam was studied by Wahab *et al.*[10]. This raw material has been used for particle board, fiberboard, pulp and paper[11,12].

Research in material processes such as bamboo contributes to various products because it is concerned with factors such as safety, aesthetics, functionality, consumer acceptance and the potential impact on the environment. Many researchers have already shown that modern furniture using material such as bamboo can create something unique, outstanding and biodegradable such laminated, veneer, ply-bamboo, bamboo flooring, bio-composites bamboo, chopstick, tooths ticanel and handicraft[13], etc. (Fig. 1).

Bamboo is a multi-use biological raw material, it is easy to work and in the tropics, is often inexpensive. Its natural durability is however not to be compared with that of

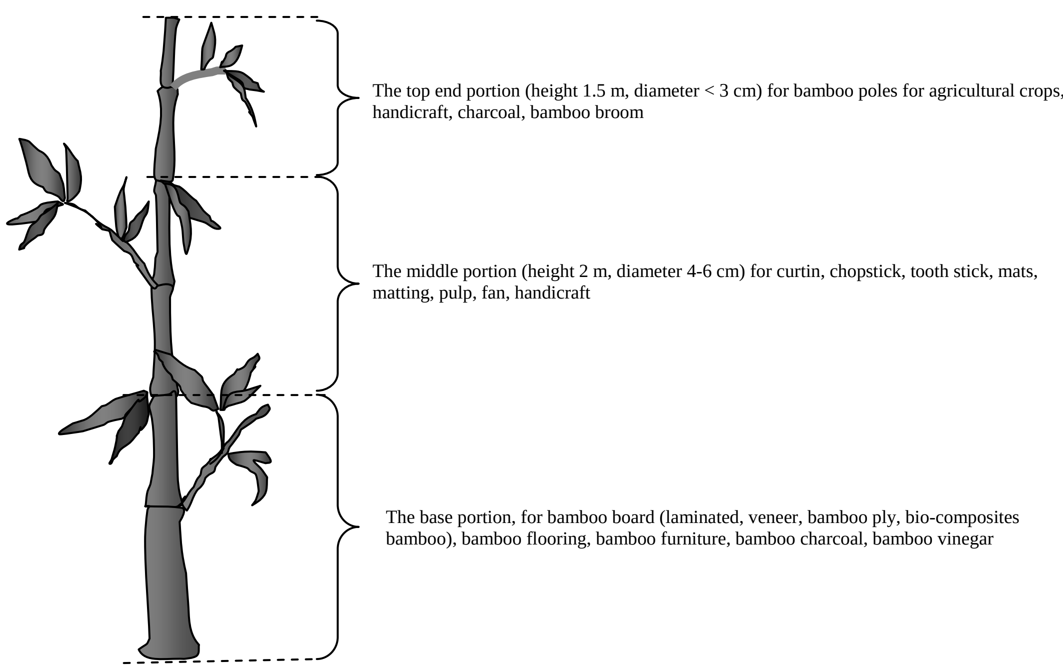

Fig. 1: Potential using of bamboo culm in various application (Van der Lugt *et al.*[14] with modification)

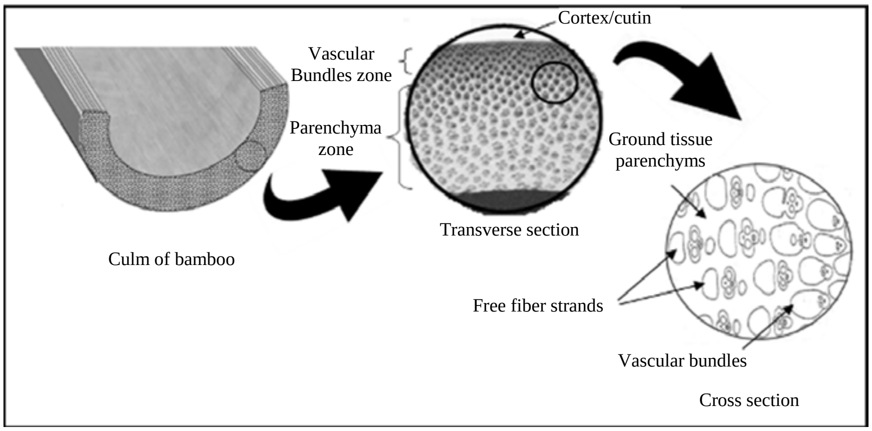

Fig. 2: Schematic drawing of anatomical and fiber morphological of bamboo

materials such as concrete or metal. This has resulted in the bamboo is susceptible to microorganisms (e.g., decay fungi) and xylophaegous boring insects (e.g., termites). Under unfavourable conditions, fungi and insects can greatly curtail its service life. There are many different types which infest and deteriorate bamboo under different environment conditions and which produce various visible changes of the bamboo products attacked. All microorganisms use bamboo and its contents as their energy source, i.e., food[15]. Bamboo consists of 50-70% hemicellulose, 30% pentosans and 20-25% lignin[16]. The lignin present in bamboos is unique and undergoes changes during the growth of the culm[17]. According to Wang *et al.*[18], bamboo is also known to be rich in silica (0.5-4%) but the entire silica is located in the outer layer (1 mm), with hardly any silica in the rest of the wall. Bamboos also have minor amounts of waxes, resins and tannins but none of these have enough toxicity to improve its natural durability[17].

According to Chavan and Attar[15], carbohydrate content of bamboo plays an important role in its durability and service life. Further they mention that, durability of bamboo against mold, fungal and borers attack is strongly associated with the chemical composition. These variations in bamboo durability strongly depend on the species[19-21], the length of the culm, thickness of the wall[22] but also the time of harvesting[23]. Because low durability of bamboo in an exposed environment, the bamboo-protection have long been employed to try and enhance its natural durability. There are various treating method for getting long time use often preservation with chemicals[15,24].

This review effectively summarises the quality enhancement of bamboo utilization, including characterization, properties and its applicability towards sustainable products of bamboo. The need of modification technologies for the production and processing of bamboo as well as principles and importance in designing sustainable bamboo products are also discussed in this study.

NATURE OF BAMBOO

The stem of bamboo is known as a culm and is normally bright green in colour when young and becomes dull green when mature. The bamboo culm is normally cylindrical and smooth in shape and characterized by nodes along its length. Culms arise from underground rhizomes which can be single-stemmed (leptomorh type) or form dense clumps (pachymorph type)[25]. It grows in nature, which makes it a renewable material[26].

Most of the bamboo species show on the transverse section outer layer is known as epidermis as shown in Fig. 2. The culm of bamboo itself is surrounded by outermost layer, the bark, consists of epidermal cells that contain a waxy layer called cutin[27]. The culm bamboo cells consists of parenchymatous cells forming the ground tissue and the vascular bundles are composed of vessels, sieve tubes with companion cells and fibres. There are no radial pathways in the culm tissues. The extent of conducting tissues are only 8% of the culm tissues. Finally, movement of preservative solution for penetration difficult in radial direction and time consuming process[28]. The thickness of the cell-wall and the ratio of cell-wall to cell-volume determines the density. A close correlation exists between density and most of the properties of bamboo like hardness, strength and mechanical properties[29,30]. However, two most important exceptions to this relationship are bamboo's natural durability to resist biological attack and its treat ability, neither corresponds to its density[31]:

- The outer zone of the culm wall is called the cortex/cutin. It consists of epidermis cell covered with cutinized waxy layer. This layer protects against physical damage and preventing loss of moisture[30]. After felling it inhibit rapid drying and thus prevents checks and splits. On the other hand, if bamboo is moist it may be attacked by harmful fungi. Futhermore, cortex/cutin cannot be penetrated by preservatives, thus leading to insufficient treatment[32,33]. On the other hand for sap-displacement methods (Boucherie treatment), the presence of cutin is essential for the process[33]
- Vascular bundles zone are many in numbers and scattered all over any piece of bamboo[34,35]. It reveals that the population of the vascular bundles varies from outer to inner periphery of a piece of bamboo[27]. This part more resistant to attack than tissue parenchyma. At the same it is mostly not permeable for liquids, such as water, organic solvent, etc[36]
- The parenchyma zone consists of longitudinal elongated cells interspersed with small cubical (isodiametric) cells[37]. Numerous small, simple pits connect parenchyma cells to each other[38]. Whereas, a young culm does not contain starch, (since all nutrients are immediately utilized), the parenchyma of older culms is filled with starch grains[32]. Parenchyma zone may be treated with chemicals to get high durability. However, it is often difficult to treat it properly, which has to be considered when using certain bamboo species in fields where attack may occur

The properties of bamboo are mainly determined by the structure of the culms anatomy. It is thus important to understand the structural variability within a culm and possible trends of the characteristics of its features, which may have significant importance on the physical, mechanical and durability properties. Most of the bamboo species have separate fibre strands on the inner or both on the inner and outer side of the vascular bundle[35]. It was concluded by this study that vascular bundle size is larger at the basal and gradually decreases at the top. The total number of vascular bundles decreases steadily with height, whereas their closeness increases. 50-80% of the vascular bundles are located in the outer one third of the culm wall with 10-35% in the middle third and about 10-20% in the inner third[35]. The vascular bundles become progressively more densely packed towards the periphery of the culms[39].

The total culm comprises about 50-52% parenchyma, 40% fiber and 8-10% (cross-sectional area) conducting tissues (vessels and sieve tubes), with some variation according to species[17,40]. Li *et al.*[41] investigated parenchyma cell-walls in *Neosinocalamus affinis*. They were found to consist of about 15 lamellae, which were arranged in broad and narrow layers. The broad lamellae were about 0.2 μm while the narrow lamellae were about 0.04 μm. The parenchyma cell-walls are therefore highly lamellated than fibers.

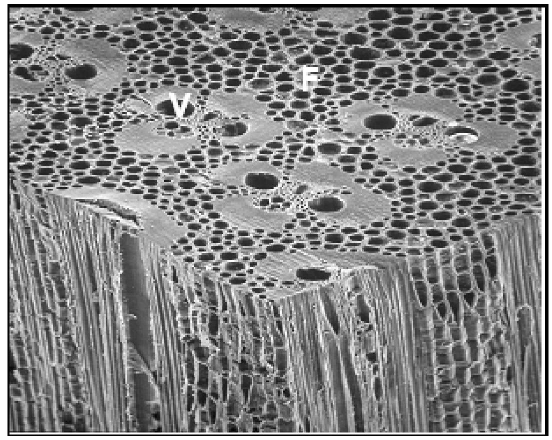

Fig. 3: Fine structure of internode bamboo demonstrating the cross section, radial and tangential phase (photo by Liese[31])
V: Vessel, F: Fibers

The vessel wall has numerous bordered pits in opposite as well as alternate arrangements[17]. The small metaxylem vessels at the nodes possess more perforation. The pits generally have elliptical apertures with a slightly oblique or horizontal orientation. Most of the movement of sap in the culms takes place through the vessels. However, some species produce tyloses in the vessel that might interrupt this movement. The fibre cells differ considerably in size and shape according to their position in the bundle in the culm wall and with species[40]. The fibers are found to be long-living and contain nuclei even after several years of age[41,42]. The fibers often increase in length from the periphery towards the centre of the bamboo culm wall and decrease back towards the inner portion (Fig. 3).

BAMBOO AS PART OF NATURE

Bamboo is a biological product and therefore subject to a continuous cycle of composition and decomposition. In principle, this cycle including decomposition is most important for all life in nature. Various organisms, mainly insects and fungi break down woody substance into organic matter in the soil and the resulting accumulation of nutrients again enables the growth of new plants. Studies reported that the soil biological properties plays effective role in plant growth and development, such as bamboo[43-46].

Bamboo consists of cellulose, hemicellulose, lignin as main constituents and resins, tannins, waxes and inorganic salts as minor constituents[47,48]. The latter being responsible for individual properties of bamboo species, such as colour or natural durability[38,49]. Bamboo culms do not produce any toxic substances during their lifetime, unlike the heartwood of many trees, so that the whole culm can be destroyed. In addition, the culm contains about 50% parenchyma cells, filled with starch as stored energy, which is needed for the development of new culms[32,50-52]. Huang *et al.*[53] reported the starch affects the susceptibility against borers and blue-stain fungi. They also reported the bamboo culms do not produce any toxic substances during their lifetime, unlike the heartwood of many trees, so that the whole culm can be destroyed. Although bamboo is one of the strongest structural materials available, it is often vulnerable to destruction by bamboo deteriorating agents and is then called bamboo deterioration and regarded as a severe disadvantage. During post-harvested period bamboos are prone to fungal and insect attack during storage period as the moisture contents is very high. It is estimated that an average weight loss of 25-40% occurs due to biodeterioration[54]. The correlation of chemical composition of bamboo and damage in bamboo has been investigated in recent years. Dhawan *et al.*[55] found that nitrogen content in bamboo was directly related to termite damage. These authors found also that quantity of lignin, ash and silica present in bamboo influenced termite damage and played a significant role in termite resistance.

As a matter of fact, bamboo deterioration causes much loss if a long-term use of bamboo products is intended and for many types of utilization, like constructional bamboo, poles or furniture, it is essential to avoid an early decomposition[53]. There are of treatment have been applied to long time service life for protect bamboo from deterioration process such as heat treatment[56-58], preservative chemical treatment[14,59-61], microwave modification[62], fumigation techniques[63], pressure impregnation[64], traditional water leaching method and smoking[65] etc.

Time of attack: It is essential for effective bamboo preservation to know the time when bamboo may be infested by deleterious organisms. In practice the 1st signs of attack are often neglected and much bamboo is treated which is already badly infested or even deteriorated. This is not only an economical waste but it may cause danger if the strength properties are already reduced. A prophylactic treatment in due time will enhance quality.

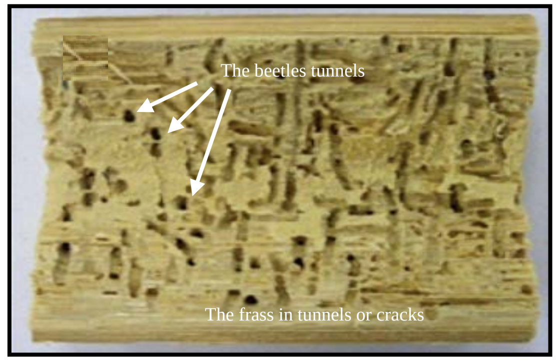

Fig. 4: Boring tunnels by adult beetle and larva (Photo by Norhisham)[76]

Freshly cut stem of bamboo can be attacked within few hour of felling by certain insects and by spores of blue stain fungi[66]. Furthermore, the harvested and stored bamboos, if not protected adequately are often seriously infested by insect borers, termites and fungi:

- The bamboo borer beetle, belongs to powder-post beetles and long-horned beetles are small family with approximately 650 species in 7 subfamilies and 80 genera[67-70]. They are all important insects damaging post-harvest bamboo[69,71-73]. Thapa *et al.*[74] reported that a bamboo stack may be lost approximately 40 % within a period of 8-10 months due to borer attack. Muthukrishnan *et al.*[75] considered that *Dinoderus brevis*, *D. minutus* and *D. ocellaris* are the serious pests of felled bamboos. Acda[76] reported that infestation by *D. minutus* on bamboo is mainly associated with the availability of carbohydrate content. According to Garcia and Morrell[77], the physical properties are mainly moisture content and density of the bamboo is an important factors that determines the rate of development of *D. minutus* in bamboo. Study by Norhisham *et al.*[78] shown the beetles will deposit their eggs into the bark/cutin and the larvae penetrate into the bamboo of moisture contents between 12 and 30% (Fig. 4)
- Termites are the most aggressive insect enemy of bamboo and are therefore of considerable economic significance[54]. The main food of most termite species is bamboo, wood and other plant material. They are among the few insects capable of utilizing cellulose as a source of food[79]. Bamboo susceptibility towards biodegradation agents, particularly termite has been studied by many

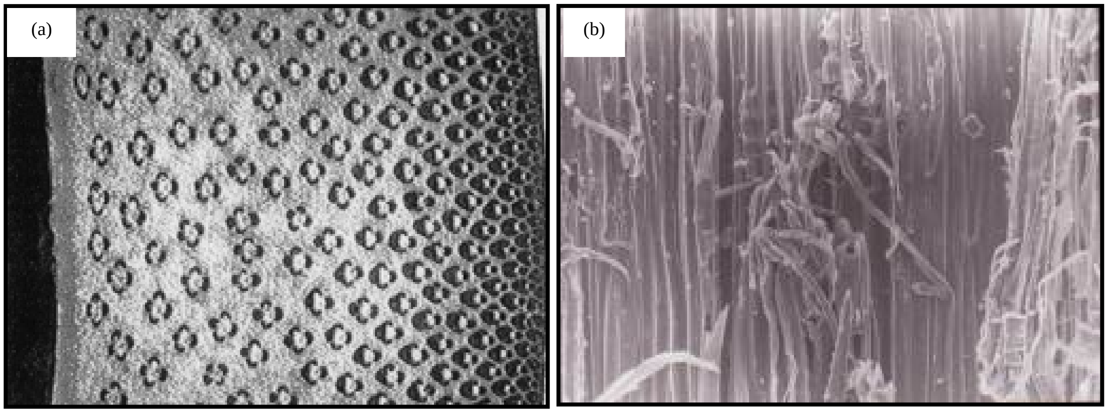

Fig. 5(a-b): SEM micrograph showing termite attack on bamboo culm (a) Before termite attack (Photo by Amada and Untao[82]), (b) After termite attack

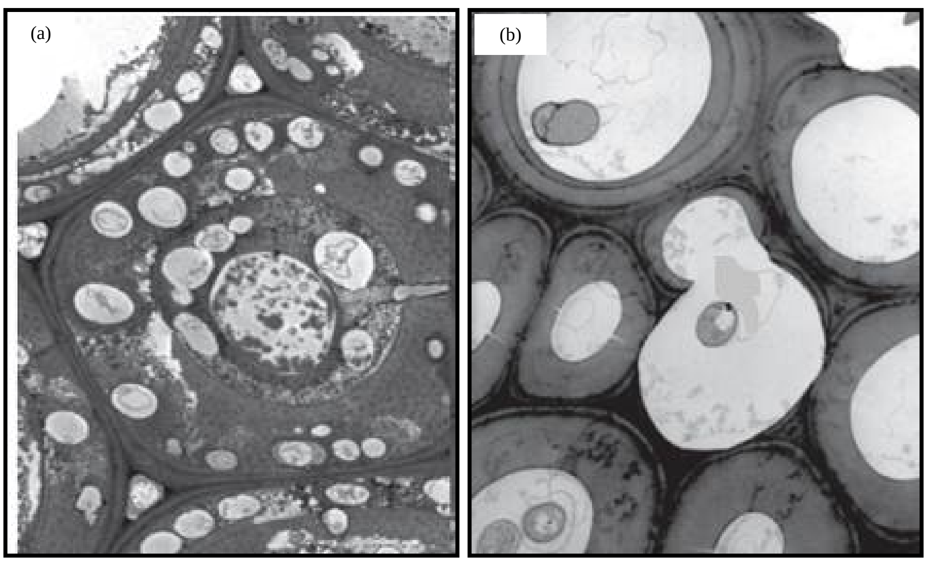

Fig. 6(a-b): TEM image of decay in Bamboo fibers (a) Decay soft-rot by *Chaetomium globosum*, (b) Decay white-rot by *Pleurotus ostreatus* (Photo by Wahab *et al.*[88])

researcher. Hapukotuwa and Grace[80] conducted laboratory evaluations of the natural resistance of different bamboo species using *Coptotermes formosanus* and *Coptotermes gestroi*. They report that none of them were highly resistant to termite attack. Mishra and Rana[81] and Mishra and Thakur[82] has been carry out on studies of bamboo natural resistance against termites. They reported that natural resistance of bamboos was more or less comparable to that of some of the moderately durable commercially important timber species. Furthermore, they also observed that the outer layer of bamboo is highly resistant and that termites normally invade bamboo from the cut end portion only. The mechanism of termite attack on bamboo is described by Dungani *et al.*[83] using scanning electron microscope. They investigated that termites began by attacking the samples from the middle and then progressed to attacking the bamboo meal, which was the bamboo culm. Termite attacked the center of the culm by making a hole, thereby penetrating inside of the culm (Fig. 5)

- Fungi are the microbial decomposition of biomaterial. Attack fungi in bamboo have found that the initial fungal pathways for penetration are via the vascular bundles. Furthermore, based on Fig. 6, the mycelium spreads characteristically in an axial direction in the parenchyma adjacent to the vessel elements. The development of decay cavities caused by growth of the soft rot fungus. According to the many studies of natural decay resistant of bamboo on several fungi were belonged to little decay resistance[18,48,85,86]. Liese[54] have been reported that the bamboo is considered as susceptible to fungi. However, in the further study, Norul-Hisham *et al.*[87] found that the resistance of bamboo related by the bamboo age. Suprapti[19] suggested that, the resistance of Indonesian bamboo decayed by fungi was not significantly different by the culm portions but studied by Schmidt *et al.*[20] found that the bamboo culm aged 6 months decayed more than the older. Schmidt[88] investigated bamboo degradation by white-rot fungi and Kim *et al.*[89] by soft-rot fungi. They provided morphological changes of the cell wall structure during decay using TEM (Fig. 6)

The hyphae of white rot penetrated into the metaxylem vessel. Furthermore, from the lumen, the hyphae further penetrated into the parenchyma cell, where starch was mostly deposited[86].

Natural durability of bamboo: The ability of bamboo species to resist biological deterioration is called natural durability or natural resistance[91]. This property varies depends on bamboo species, the inner part, outer part and among the butt end and the top of culm and also climatic condition.

Low durability of bamboo against bio-deterioration ranges between 1-36 months[91-93] investigated that untreated bamboo has a service life of only 2-5 years. They reported that fungi, bacteria and subterranean termite as well as one or more of these organisms attacking the bamboo culms in succession. Material of bamboo (quantity) gets degraded during transportation, storage in the depots as well as in mill yards due to stain fungi and insects. Dhawan and Mishra[23] did study on natural durability of bamboos against termites based the felling season and moon phase. They found bamboos felled during moon phase were less durability to termites than those felled in dark phase.

Most countries have started to establish research and development-based bamboo products such as in rural community to substitute wood for housing material. Bamboo products is susceptible to termite and powder post beetle. Consequently, bamboo and its derivative products have relatively short service life. Many researcher have been observe and report that natural durability of bamboos against *Coptotermes cynocephalus* and *Anobium* sp.[94] and white rot fungus[95] were resistant to poor. They also observed effect of the starch content of the bamboo and concluded that the higher starch content of bamboo species reduce the degree of caused by insects and fungi attacks.

In India, found 13 bamboo species have the termite resistance was more or less comparable to that of some of the moderately durable commercially important timber species[81,82]. In addition, Hapukotuwa and Grace[80] analyzed the resistance levels of 6 bamboo species in Hawaii by *Coptotermes formosanus* and *C. gestroi*. They provide evidence none of them were highly resistant to termite attack and most should be considered perishable. The durability of bamboo against fungi also have been studied. Wei *et al.*[21] investigate 5 bamboo species against brown rot, white rot and soft-rot fungi. They found *Guadua angustifolia* was rather resistant to *Trametes versicolor* and *Dendrocalamus asper* against *Chaetomium globosum*. Previous study by Kim *et al.*[96] found the major fungi causing serious damage on bamboo are *Trametes versicolor* and *Arthrinium arundinis*, which caused the largest weight losses of approximately 21.6 and 17.9%, respectively. Furthermore, this investigation confirms that the natural durability of bamboo in outdoor utilization is low.

PRESERVATION VERSUS MODIFICATION

In order to overcome the natural defects, there have been many attempts in research on the bamboo modification. As well, there have been many studies on preservation of bamboo against termite and fungal attack and weathering, with increasing needs for structures and products. Based on a review of the literature, the modification of chemical into bamboo has been studies starting in 1936[97]. On the other hand, modification by non-chemical was reported in the early 1950s[98].

To protect the lignocellulosic of bamboo material from biodegradation and enhance its service life. Protection method of treating bamboo material has been using various preservation such as mineral oil, coal tar and preservative other[99-101]. Studies were also carried out to improve other performance properties of bamboo through modification treatment, such as steam treatment[56,102,103], smoking[65,56], treating with various etherifying and esterifying agents[104,105], acetals, alkylene oxide and alkoxysilane-coupling agents[106]. Several treatments methods have been developed to prolong bamboo's usefulness using irradiation into bamboo surface. The irradiation is treatment by hydrogen ions, He^+ and Ar^+ for improve wettability of outer surface of bamboo[107]. They reported that hydrogen ion bombardment, vascular bundles

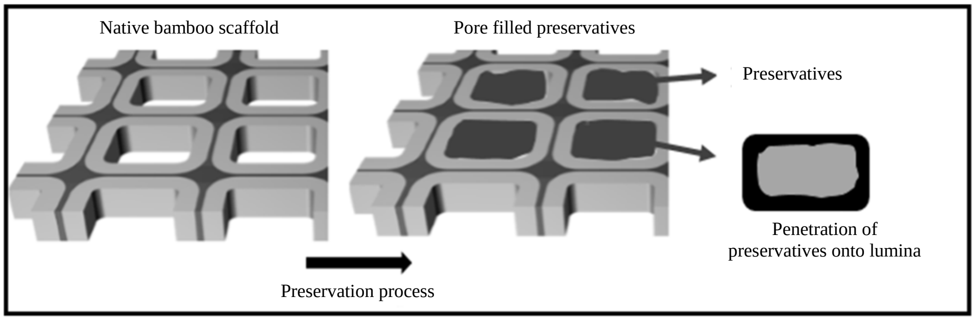

Fig. 7: Schematic drawing of presence of preservatives within the bamboo lumina after preservation process

were etched faster than parenchyma lignin. The dipping modification was studied to improve the tensile performance of bamboo fiber by sulfate process. Wang *et al.*[108] considered that sulfate isolated fiber surface cause increase of tensile strength, modulus of elasticity and elongation at break.

Preservation method to protection of bamboo: Similar to wood, bamboos have a low resistance to biological degrading organisms, therefore, need bamboo preservation techniques during storage and use. The sap-replacement pressure technique, the pressure impregnation, soak and diffusion process can be used[23]. Bamboo preservation is the process by which bamboo is preserved. Proper preservative treatment will enable to enhance durability of bamboo. Therefore, it is very essential to use bamboo after proper preservative treatments. Preservation method with boraks is the other way to improve quality of bamboo betung (*Dendrocalamus asper*). Its influence on the mechanical properties indicate that bamboo was preserved has a higher strength than the strength of bamboo without preservatives[109]. Optimum increasing of tensile strength of bamboo betung (*Dendrocalamus asper*) acquired at borax and 60% boric acid preservative. Immersion time increase the tensile strength of bamboo betung and optimum increasing of tensile strength acquired at 24 h of immersion time[110]. The effects of preservative treatment on the durability properties of bamboo strips have been studied by Hanim *et al.*[111]. They observed that the water borne preservative gave the best protection against termite.

Once harvested the bamboo turn yellow and the color starts to decay cause their degrade their performance. The protection based preservatives, is also an effective method of fresh bamboo for green-color conservation[112]. Chang and Wu[104] protected fresh bamboo under treated with chromated copper phosphate (CCP) or chromated phosphate (CP). They reported that appropriate chemical reagents were CrO_3 and H_3PO_4. They reported that, treated with 1% CrO_3, 1% H_3PO_4 had the best green color conservation. Chang and Yeh[105] and Zhang *et al.*[113] considered that an alkali pretreatment was required removed the waxes and silica on bamboo surface. They suggested that pretreatment was caused by a penetration and reaction with the green color protector in the cellulose bamboo.

The main purpose of bamboo preservation was applied to protect culm tissue against biological agents of deterioration. Based on a review of the literature, starting in 1957/58, Dr. Ashtakala Purushotham had already begun to use chemical preservative for preservation bamboo[24]. The preservation by chemical treatment must considered of characteristics of bamboo as described by Liese and Kumar[24] and Jansen[114] are: (i) The outer skin is high in silica and waxy layer content, (ii) The absence of ray cells, (iii) The refractory nature of bamboo culms and (iv) Thin culms. They reported that the flow of preservative was restricted into the culm. They also reported that the flow of preservative on longitudinal direction will be constrained. Meanwhile, radial flow of the preservative is hindered due to the refractory (Fig. 7).

Disadvantages of many these preservatives are the toxic effects on environment and human hearth, researcher are attempting to develop botanical extract-based preservatives. Several studies of these preservatives have been such as neem oil[63,115,116], oil nut of kukui plant[117], cashew nut shell oil[118], cedar oil[119,120], oil camphor[93,121] and resin from Guayule[122].

Meanwhile, many attempts have been made to protection bamboo by non-chemical method. Magel *et al.*[123] and Othman *et al.*[124] investigated the lowering starch and sugar in bamboo culms by harvesting of bamboo during the low-sugar content season. Sulthoni[125] and Nguyen[126], protected fresh bamboo using submersion in running or stagnant water for 1-3 months.

Modification of bamboo: The modifications in bamboo can use many kinds of the wood modification techniques, such as thermal modification[127,128], chemical modification[129], surface

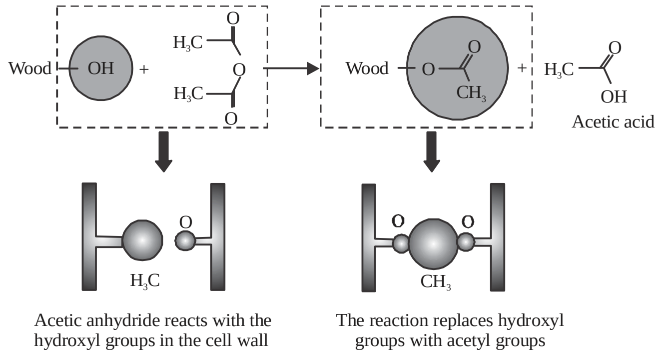

Fig. 8: Schematic principle of acetylation reaction in the bamboo cell wall

modification[130] and impregnation modification[131]. The chemical modification using acetylation method is a chemical treatment which depends on the amount of compounds in the bamboo which can be extracted during the treatment. The bamboo modification using chemicals that produce formation of chemical bonds between the acetyl groups of the chemical reagent with hydroxyl groups of bamboo constituents[132]. The chemical modification of bamboo using acetylation reaction can be represented in Fig. 8.

Sugiyanto[133], bamboo acetylated using acetic anhydride on species *Dendrocalamus asper*. He reported that the bamboo strip in acetic anhydride improving the liquid uptake. The study has been previously conducted on bamboo modification through acetylation reaction without a catalyst using supercritical carbon dioxide[134]. Other research has been conducted by Chang and Wu[104], Wu *et al.*[135] and Chang and Yeh[105] on modification of green bamboo culms with chemical reagents without arsenic. They reported that treated chromated phosphate (1% CrO_3, 1% H_3PO_4) had the best green color conservation on the bamboo. Wu *et al.*[136,137] investigated the appropriate method and process treatment to achieve the green colour protection of bamboo culms. They showed that green colour protection was obtained treated with methanol-borne copper chloride ($CuCl_2$), copper phosphorous salt and under 60°C condition in water bath for 2 h.

Furthermore, the chemical other using such as, acetic acid and propionic acid inhibited mould growth on *Buddleja stenostachya* and *Thorea siamensis*. The bamboo species *Bambusa procera* and *D. asper* can full protection with 10% propionic acid[60]. Silviana[138] investigated the chemical modification of bamboo using acetic anhydride and silicone oil assisted by supercritical CO_2 as medium. They showed that the acetylated bamboo can be categorized as a durable material with hydrophobic. They also reported that the silicone oil-modified bamboo is still degrading during the assessment.

Many studies on thermal modification results in several physical and mechanical changes and chemical composition to the bamboo[56,139,142]. They reported that correlation between chemical and physical properties after thermal modification produce increased dimensional stability, reduced hygroscopic characteristics and improved decay resistance. Starke *et al.*[143] investigated the thermal modification of African alpine bamboo by heat treatment under temperature 160-220°C. This study shown that, thermally modified bamboo reflected the decomposition of hemicelluloses and correlated with the deterioration of impact resistance. They also observed the treatment temperatures had a stronger effect than the time of modi cation.

Bremer *et al.*[57] investigated effect of thermal modification on the properties of 2 Vietnamese bamboo species (*Dendrocalamus barbatus* and *Dendrocalamus asper*). From their studied considered that in thermal modification process depending on the treatment parameter like atmosphere, temperature and duration. They reported that treatment at 130°C cause only slight changes and significant changes occur by modification above 180°C. Meanwhile, the thermally-modified *Dendrocalamus asper* on the termite resistance were investigated by Manalo and Gracia[144]. The results showed that heating bamboo under heat conditions at high temperature (140°C) is effective method for improved bamboo's resistance to termites.

ADVANCEMENT IN UTILIZATION

Bamboo as a sustainable material has been well-accepted in the global market for its many applications as an alternative to traditional timber resources. Recent advancements in bamboo technology has proven the positive advantages of bamboo for innovative design and product in various applications for interior and exterior, which include in furniture, bio-composite products, automotive, building and construction and so forth. The utilization of bamboo is on as materials renewable fiber based products, that is particularly in building and construction, furniture, reinforcement material, automotive and so forth.

Furniture design: Bamboo furthermore, is a material that replaces the wood used in furniture manufacturing. Bamboo furniture have to integrate technology, science, art, and humanism to create more possibilities for the future products[145]. Many countries have started to establish technique combining-based furniture such as Malaysia, China and Taiwan to produce of bamboo furniture. Bamboo-based furniture products have been produced using bamboo bio-composite. Nowadays, application of ceramic furniture and material in furniture design have been studied by Huang *et al.*[146]. The combination between bamboo and ceramics complements each other to bring about the new modern furniture designs. Furthermore, they suggested that this technique combination needs understanding of ceramic and bamboo culture and rational innovations on superiority of two kinds of material.

Bamboo based furniture uses round or split bamboo and glue-laminated bamboo panels. The new design as 'pack-flat,' 'knockdown' furniture can improving the various characteristics bamboo such as physical, mechanical and aesthetic[13,147]. In recent years, recombinant bamboo developed with makes use of bamboo waste as raw materials. This technology of recombinant bamboo through compressed bamboo ties or bamboo slices into a mold[148]. They reported that the application of recombinant bamboo in furniture industry is still in the initial stage of exploration.

Automotive components: In the past decade, the use of natural fibers in composite plastics is gaining popularity, particularly the automotive industry. The natural fibers such as flax, jute, bamboo, kenaf, hemp, roselle, banana and sisal offer such benefits as natural-fiber composites with thermoplastic and thermoset matrices. The use of these composites as automotive parts production such as the interior of the car, rear seats, door panels, dashboards, headliners and package trays[149,150]. Davoodi *et al.*[151] reported that fiber bamboo materials has several advantage, such as high strength and stability, sound insulation, resistance to dampness, pressure resistance and flexibility.

Earlier studies by Ismail *et al.*[152] and Cobonpue and Birkner[153], shown that bamboo has been used to build boats, aircraft and zeppelins. They suggested that natural fiber bamboo materials have highly potential to be used in automotive parts. They also reported that, the aircraft bamboo were built in Philippines and Chinese.

Application of bamboo based products in housing: In Asian countries, bamboo is extremely important material for Traditional houses. The various applications of bamboo utilization, such as traditional bamboo houses using a bamboo frame and prefabricated houses made of bamboo laminated boards is easy to find in China, India, Thailand and other Asia areas[154].

There are many uses of culms of bamboo for housing and construction purpose such as glue-laminated bamboo, laminated woven bamboo mat panel, bamboo pole, woven bamboo mat and flattened bamboo[155-159]. In several countries have been application of these materials integrated into engineered constructive systems[160,161].

Towards consumer product, bamboo fibers based composites play the most important role in enhancement of product. The composites of polymer and bamboo fiber are expected will many applications. They are used for girder, purlin, post, rafter, ceiling, flooring, roofing, partitions, doors and window frames[162-166]. Further applications of bamboo products include its use as scaffolding, water piping and as shuttering, reinforcement for concrete and concrete formwork[167-171].

Further, hybrid bamboo-based products have been used as the home decorative accessories was studied by Suhaily *et al.*[172]. Based on the studies by Abdul Khalil *et al.*[29], it was proved that hybrid bamboo material have aspects aesthetic as well as physical and mechanical. With the treatment such as heating and clamping, the bamboo can be bent or straightened. This is further proving that hybrid bamboo material can overcome other types of materials. One of more example of applications on the industry for interior decoration was Madrid Barajas International Airport, Spain. This international airport was built using laminated bamboo laths from all walks of bamboo veneer[173].

Others applications: Bamboo has been widely recognized for excellent production of fiber and has great potential in the bio-composite industries. Bamboo fiber is longer than wood fiber, these fibers are approximately 12.91-42.32 μm in diameter[15] with length of the fibers is 2.98-5.63 mm and cell wall thickness were 2.41-13.32 μm[174-175]. The extraction of fiber from bamboo is done in 3-4 years old bamboo. Several of studies have reported bamboo fiber is produced through sulphuric acid hydrolysis[176-179], autohydrolysis[180], alkaline treatment[181], phosphoric acid[182] and oxalic acid[183].

Over the past 2 decades, numerous studies have been performed to application bamboo fiber as a reinforcement material in polymer composites. These cellulose fibers are an interesting alternative to synthetic fibers because of its clean emissions and biodegradability[184-186]. Several investigators have producing the polymer composites from bamboo fibers, such as medium density fiberboard[101,187], bamboo fibers in combination with wood veneer as bamboo mat veneer composites product[188,189], bamboo-glass fibres composites[190,191], bamboo fibres as reinforcement material, such as in thermoplastic polypropylene[162,191], polyester[192], vinyl ester[193], epoxy[194-196], elastomer polymer matrix[197,198] and rubber matrix[199] to be used in many applications. Meanwhile, utilization of bamboo fibers as cement replacement also become a new approach in bamboo development progress[200]. However, few studies shown that bamboo fiber is brittle compared with other natural fibers[49,199-204]. They investigated that, the bamboo fibers are covered with lignin. Therefore, fiber surface modifications via various chemical treatments to improve the fiber-matrix interface adhesion on mechanical has become crucial for the development and design products[153].

CONCLUSION

The utilization of bamboo as a resolution to the problem of resources reduction of natural forests and also can generate new economic resources for future generations. Bamboo as a sustainable material has been well-accepted for its many applications as an alternative to traditional timber resources. Recent advancements in bamboo technology has proven the positive advantages of bamboo for innovative design and product in various applications for particularly in building and construction, furniture, bio-composite products, automotive and so forth. Bamboo requires innovative processing technology to realize the quality product development. Many attempts have been made to quality enhancement of bamboo by preservation. Chemical or physical modification is another effective method of the advancements in the technology. However, various in properties from bamboo require treatments and application of bamboo products in various categories. Furthermore, chemical and physical treatment resulted products are with high performance.

SIGNIFICANCE STATEMENTS

This study discovers the preservation and modification techniques of bamboo that can be beneficial for advance products manufacturing and utilization. This study will help the researcher to uncover the critical areas of quality and durability enhancement of bamboo products that many researchers were not able to explore. Thus a new theory on Preservation, modification and applications of bamboo may be arrived at.

ACKNOWLEDGMENTS

The authors would like to thank Institute Teknologi Bandung, Indonesia (ITB), for providing Research Grants of Increase Citation for ITB World Class University Ranking No. 1355/SK/11.B03.2/KU/2016. The authors would also like to thank Forestry Research and Development Agency (FORDA) Indonesia, for providing the necessary facilities.

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