Physical, Mechanical, and Chemical Characterization of Two Sympodial Bamboos (Gigantochloa Ligulata & Gigantochloa Scortechinii) & Their Potential for Construction Purpose

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by
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NaOH	Sodium Hydroxide
M	Molarity
MPa	Megapascal
MC	Moisture content
KOH	Potassium Hydroxide
SEM	Scanning Electron Microscopy

Abstract

Non-traditional lignocellulosic resources, such as bamboo, may be converted into high-value products by utilizing efficient, low-cost, and low-pollution fractionation techniques. The purpose of this study is to determine and compare the physical, mechanical, and chemical characteristics between two bamboo species – Gigantochloa Ligulata and Gigantochloa Scortechinii – as a rapidly increasing resource of major regional relevance. The moisture content, tensile strength, compressive strength, antidecay characteristics, chemical resistance, NaOH solubility, and benzene-ethanol solubility of the samples were determined. This research demonstrates that in terms of compressive strength, bamboo Gigantochloa Ligulata is higher than bamboo Gigantochloa Scortechinii. So, bamboo Gigantochloa Ligulata is more potential to be the building material that always be compressed as the reinforcement of concrete that supports the whole building. In contrast, bamboo Gigantochloa Scortechinii has higher tensile strength than bamboo Gigantochloa Ligulata. Therefore, it is more potential to be the building material that requires to sustain higher tension force. Based on the experiment, it also showed that bamboo in dry condition is always stronger than the bamboo in wet condition. In addition, the higher benzene-ethanol extractives of the bamboo Gigantochloa Ligulata could be an advantage for anti-decay in architecture processing and utilization compared to bamboo Gigantochloa Scortechinii. Finally, bamboo after alkaline treatment will experience damage of fiber structure and then the strength will be decrease significantly as well. However, different bamboo species has different effect of alkaline treatment as well as the alkaline concentration.

Abstrak

Sumber lignoselulosa bukan tradisional, seperti buluh, boleh ditukar kepada produk bernilai tinggi dengan menggunakan teknik pecahan yang cekap, kos rendah dan pencemaran rendah. Tujuan kajian ini adalah untuk menentukan dan membandingkan ciri fizikal, mekanikal dan kimia antara dua spesies buluh - Gigantochloa Ligulata dan Gigantochloa Scortechini - sebagai sumber perkaitan serantau yang semakin meningkat dengan pesat. Kandungan lembapan, kekuatan tegangan, kekuatan mampatan, ciri antireput, rintangan kimia, keterlarutan NaOH, dan keterlarutan benzena-etanol sampel telah ditentukan. Penyelidikan ini menunjukkan bahawa dari segi kekuatan mampatan, buluh Gigantochloa Ligulata adalah lebih tinggi daripada buluh Gigantochloa Scortechini. Jadi, buluh Gigantochloa Ligulata lebih berpotensi untuk dijadikan bahan binaan yang sentiasa dimampatkan sebagai penguat konkrit yang menyokong keseluruhan bangunan. Sebaliknya, buluh Gigantochloa Scortechini mempunyai kekuatan tegangan yang lebih tinggi daripada buluh Gigantochloa Ligulata. Oleh itu, ia adalah lebih berpotensi untuk menjadi bahan binaan yang memerlukan untuk mengekalkan daya tegangan yang lebih tinggi. Berdasarkan kajian, ia juga menunjukkan bahawa buluh dalam keadaan kering sentiasa lebih kuat daripada buluh dalam keadaan basah. Di samping itu, ekstraktif benzena-etanol yang lebih tinggi daripada buluh Gigantochloa Ligulata boleh menjadi kelebihan untuk anti-pereputan dalam pemprosesan dan penggunaan seni bina berbanding buluh Gigantochloa Scortechini. Akhirnya, buluh selepas rawatan alkali akan mengalami kerosakan struktur gentian dan kemudian kekuatan akan berkurangan dengan ketara juga. Walau bagaimanapun, spesies buluh yang berbeza mempunyai kesan rawatan alkali dan kepekatan alkali yang berbeza.

Chapter 1
Introduction

1.1 Project Background

The globe is now undergoing dynamic changes because of significant growth in population, income, and resource use (Zimmerman et al. 2008), with many natural resource reserves being pressured. Water shortages, deforestation, and mineral depletion have all resulted because of this. One way to a more sustainable future is to increase the use of bamboo, a natural and renewable plant material from the Poaceae family of grasses. Because of its low cost and lack of rivalry with food production, lignocellulosic biomass is predicted to become the most important biomass source in the future. [2,3] Traditional pulp and paper manufacturers, located in tropical and subtropical countries, have current technology, better production capabilities, and cheaper raw material and labor costs in this environment. Due to their quick growth/production, cheap cost, and renewability, a broad variety of annual crops (sisal, bamboo, and others) and agroforestry wastes (sugarcane bagasse, wood sawdust, cereal straws, to name a few) are also accessible in these locations with tremendous promise as a fibrous resource. [4,5] Bamboo is a beneficial and sustainable material owing to its rapid development, with certain species reaching maturity in 2 to 4 years, making it suitable for engineering applications. [25,27] "There could never be enough silver flutes to provide one to everyone in the globe," Cusak (1999) observed.

It is now predicted that the price of forest products will continue to fall owing to global market competitiveness. As a result, forest producers developed novel techniques to boost their revenue by producing bioenergy and biomaterials in addition to wood, pulp, and paper goods. One of these initiatives is to implement the biorefinery idea, which takes use of the forest industry's high concentration of raw materials. Furthermore, it possesses the infrastructure required to develop sophisticated biorefinery programs. [6] Bamboo is an important source of lignocellulosic fibre in many tropical and subtropical locations (principally China). China now has over 4.5 million hectares of Phyllostachys pubescens plants. [7] Since 2005, Peru has pushed Guadua angustifolia or Guayaquil cane plantations across Latin America, employing a Colombian propagation technology that has grown planted area from 3,000 ha to more than 10,000 hectares in 12 years. These plantations are earmarked for the market for whole and rolled cane (6 m long), which sells for roughly USD 0.5 to 3 per cane (without extra value) and is used in building (terrace extensions, country houses, agricultural warehouses etc.). Almost 90% of bamboo originates from farms, and its price per cane can approach USD 10. Despite the 2008 financial crisis, this market has continued to expand, especially in the face of competition from China, which cultivates various species of bamboo. One of the bamboo species, Guadua trinii thrives in Argentina's Misiones or Paranaense jungles, where it forms impenetrable thickets that are hard to penetrate. [8] This species is utilised to build the walls of unstable rural homes (ranchos); it also has a history of usage in the paper industry. [6,11]

Bamboo is the plant which is conventionally associated with the region of Southeast Asia and South America where climate is best suitable for its cultivation. [1] Recently, bamboo is used by human being for the construction of scaffolding, bridges and structures, houses. This is because bamboo as a kind of building material has low weight and high comprehensive strength. Besides, it is also one of the fastest growing plants in the world. They are renewable and extremely versatile resource with multi-purpose usage. [1] Therefore, nowadays, bamboo is being widely used in housing area around the globe. Besides, in many countries, it is used to hold up suspension bridges or simply make places of dwelling. [1] In short, it is important to develop more uses from bamboo in construction to completely replace the use of any non-renewable or environmental unfriendly building material.

Based on the thorough analysis of previous and current bamboo literature, it became obvious that one barrier to employing bamboo for structural applications is a lack of information about bamboo chemical and mechanical characteristics. This led to the first stage of the study, which gathered and analyzed bamboo chemical property values from researchers globally. The goal of this study was to describe two bamboo species (G. Ligulata and G. Scortechinii) physically, chemically, and mechanically. These rapidly developing resources of substantial regional importance might be utilized as non-traditional lignocellulosic resources in a biorefinery system to manufacture high-value products.

1.2 Problem Statement

Some considerable research has been carried out on certain bamboo species, however, there are no study conducted for Bamboo Gigantochloa Ligulata & Bamboo Gigantochloa Scortechinii. Therefore, to encourage the use of bamboo in housing or construction area in Malaysia, the present research paper will choose two famous species of bamboos that existed abundantly in Malaysia, which are Bamboo Gigantochloa Ligulata & Bamboo Gigantochloa Scortechinii. Meanwhile, the present research paper will determine and compare these both bamboos physically, mechanically, and chemically as well as their potential to be used in the field of architecture.

1.3 Project Objectives

To determine the physical, mechanical, and chemical characteristics of Bamboo Gigantochloa Ligulata and Bamboo Gigantochloa Scortechinii as well as their potential to be used in construction area. The present paper will discuss the problem in terms of moisture content, tensile strength, compressive strength, anti-decay characteristics, and chemical resistance of these both bamboos. To determine these terms, physical, mechanical, and chemical characteristics of Bamboo Gigantochloa Ligulata and Bamboo Gigantochloa Scortechinii is determined in prior in this research.

The objectives of the present paper include:

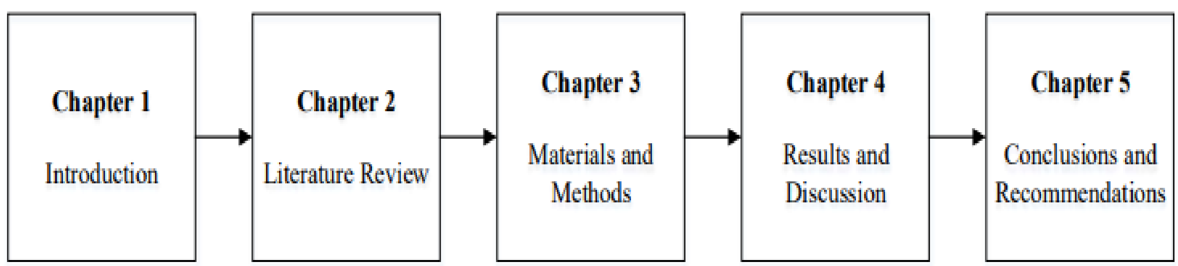
i) To determine the physical, mechanical, and chemical characteristics as well as the chemical composition of Bamboo Gigantochloa Ligulata as well as Bamboo Gigantochloa Scortechinii with respect to their moisture content, tensile strength, compressive strength, anti-decay characteristics and chemical resistance.

ii) To determine the effect of using strong alkaline, NaOH to treat Bamboo Gigantochloa Ligulata and Bamboo Gigantochloa Scortechinii.

iii) To determine and compare the potential of using Bamboo Gigantochloa Ligulata and Bamboo Gigantochloa Scortechinii in construction area.

1.4 Thesis Organization

The thesis has been organized in a rather straightforward and standard manner presentation of project report. The project report is divided into five chapters which is containing an introduction to the entire project, a literature analysis on related studies, and materials and equipment to be utilized in the research, results and discussion on the data gained, and conclusion to summarize the full project. To make things easier, the flow of the thesis organization is provided below as the illustrations.



Chapter 2
Literature Review

2.1 Chemical and Physical Analysis of Bamboo

In their study, Tomalang et al. [18] discovered that the primary elements of bamboo culms include holocellulose (60-70%), pentosans (20-25%), hemicellulose, and lignin (each 20-30%), as well as minor compounds such as resins, tannins, waxes, and inorganic salts. Bamboo's chemical makeup is comparable to that of hardwoods, except for increased alkaline extract, ash, and silica content. Bamboo's carbohydrate content has a significant impact on its durability and service life. The chemical makeup of bamboo is significantly linked to its resistance to mold, fungal, and borer assault [16]. According to Chew et al. [17], bambusa vulgaris contains 2.37 percent glucose, 2.07 percent fructose, and 0.5 percent sucrose. Before and after soaking, the total sugar content was 4.94 percent and 0.28 percent, respectively. The sugar content may be lowered below 0.5 percent using the soaking process, which is a permissible threshold for cement-bonded particleboard manufacture. Unless handled, a bamboo sample containing more than 0.6 percent total sugar will create low-quality cement-bonded particleboard, according to this report.

Besides, bamboo includes various organic compounds. It has a starch content of 2-6 percent, a deoxidized saccharide content of 2%, a fat content of 2-4 percent, and a protein content of 0.8-6 percent. Bamboo's carbohydrate content has a significant impact on its durability and service life. Bamboo's resistance to mold, fungal, and borer assault is intimately linked to its chemical makeup. Bamboo has a history of being attacked by fungi and insects. Depending on the species and environmental conditions, bamboo's natural endurance ranges from 1 to 36 months [25]. Bamboo is extremely sensitive to staining fungi and powder-post beetles due to its high starch content [26]. Starch was found throughout the culm, particularly in the longitudinal cells of the ground parenchyma, even in 12-year-old culms [27]. Some bamboo species with higher benzene-ethanol extractives may have an advantage in terms of decay resistance [28].

The species, site/soil and climatic conditions, silvicultural treatment, harvesting technique, age, density, moisture content, location in the culm, nodes or internodes, and biodegradation all influence the physical and mechanical characteristics of bamboo [21]. Much research has been conducted to emphasize and monitor these basic qualities, as well as to enhance bamboo consumption [19, 20, 21, 23]. The influence of anatomical parameters on the physical and mechanical qualities of B.bluemeana was investigated by Abd.Latif et al. [19]. According to this research, age and height have no bearing on moisture content. The green moisture content ranged from 57 percent to 97 percent. When compared to an older bamboo, younger bamboo had a greater moisture content. It might be due to the older bamboo's strong wall fiber and larger concentration of vascular bundle, according to the report. The density along the culm height of the 3-year-old culm did not alter significantly. B.bluemeana's radial and tangential shrinkage did not alter substantially with age or height. The radial and tangential shrinkage, respectively, vary from 5.4 percent to 9.5 percent and 6.4 percent to 20.1 percent. In comparison to the young bamboo, the elder bamboo (3 years old) is more dimensionally stable (1-year-old). The 1-year-old bamboo was found to decline by 15% to 22% on average. At the basal height of a 2-year-old B.bluemeana culm, radial and tangential shrinkage range from 8% to 19%, with top location shrinkage ranging from 6% to 12%.

Most mechanical parameters changed considerably with age and culm location in this investigation. With increasing age and height, shear, compression parallel to grain, and bending stress at proportionate limit all increased. MOR diminished as people became older and taller. Age, on the other hand, had no effect on MOE. The insensitivity of MOE to age, according to this study, might be a benefit in the usage of B.bluemeana in a product where it is difficult to pre-select old and young bamboo. As soon as bamboo loses moisture, it begins to shrink in both wall thickness and diameter, according to Tewari [24]. This contrasts with wood, which begins to change most of its qualities once it achieves fiber saturation.

The specific gravity of bamboo varies between 0.5 and 0.79, resulting in a density of 648 kg/m3 (40.5 lb/ft3) [22]. According to another article, the typical specific gravity of bamboo varies between 0.3 to 0.8 [21]. B.vulgaris has a density of 630 kg/m3 according to Chew et al. [17], which is low compared to other bamboo species. The percentage of vascular bundles is directly connected to density, which is a key component that determines mechanical qualities. Density and moisture content are connected to shear, compression parallel to grain, bending at proportional limit, and

MOE. The observation is that mechanical qualities rise when moisture content drops, while mechanical properties decrease as density decreases. This behavior is comparable to wood's mechanical characteristics. Except for MOR, vascular bundle distribution is favorably linked with all strength attributes. According to Abd.Latif et al. [19] this behavior might be attributed to a rise in the number of sclerenchyma and conductive cells, which leads to an increase in density. Compression strength, bending stress at proportional limit, and MOE are all positively linked with vascular bundle size (radial/tangential ratio) and fiber length.

The rise in strength qualities was accompanied by a reduction in tangential size of the vascular bundle (mature stage or greater radial/tangential ratio). Longer fibers, according to Abd.Latif, reduce shear strength, which is mostly attributable to cell wall thickness or density rather than the percentage of parenchyma fibers. Compression strength, bending stress at proportional limit, and MOE all have positive correlations with cell wall thickness, whereas MOR has a negative association. Fiber dimensions, except for lumen diameter, were shown to have a high correlation with mechanical qualities in this investigation. Bamboo is as strong as wood in terms of tension, bending, and compression, however it is weaker in terms of parallel grain shear.

The physical and mechanical parameters of big timber bamboo (Phyllostachys bambusoides) growing in South Carolina, USA, were studied by Lee et al. [21]. The mechanical and physical qualities of the culm are affected by moisture content, height position in the culm, presence of nodes, and orientation of the outer bark, according to this study. The most significant shrinkage occurred in the radial direction, which was nearly twice as high as shrinkage in the tangential direction, while longitudinal shrinkage was minimal, according to this study. The bamboo species investigated had an average green moisture content of 137.6% and a green specific gravity of 0.48. There were no significant changes in moisture content or specific gravity between the different regions of the culm and between the different stems, according to the findings.

On the other hand, there is one paper [11], published in 2020, carried out few experiments to determine the chemical composition and fiber characteristics for two types of sympodial bamboos. They are called Yunnanicus bamboo and Whangee bamboo respectively. These bamboos were collected from Yunnan Province in Southwest China. Experiment had been done to develop the bamboo and fully utilize these kinds of bamboos. The characteristics and content of bamboo investigated by this paper including moisture content, ash content, hot water solubility, percentage of NaOH solubility, the benzene-ethanol extractives, holocellulose, acid insoluble lignin, Pentosans, fiber length, fiber width, thickness of fiber cell wall as well as lumen diameter.

Based on the result and analysis, in aspect of chemical composition, the research report showed that the Whangee bamboo contains the higher 1% NaOH solubility and benzene-ethanol extractive, lower ash and lignin content than Yunnanicus bamboo. In addition, report showed that both bamboos contain almost the same cellulose and hemicellulose. However, the higher 1% NaOH solubility in Whangee bamboo would cause higher alkali-consumption in alkali pulping but, as for wood pressing, higher benzene-ethanol extractive in Whangee bamboo will be one kind of anti-decay. This property will provide good strength in fiber processing due to its higher specific gravity.

On the other hand, the report showed that Whangee bamboo has higher fiber width than YUNNANICUS bamboo, and higher length/width ratio. Therefore, Whangee bamboo has the better fiber characteristics. Result of the experiment did also indicate that Yunnanicus bamboo fiber has bigger lumen and thinner cell wall than Whangee bamboo, whereas Whangee bamboo fiber has higher wall to lumen ratio. Therefore, in overall, Whangee bamboo has higher fiber strength than Yunnanicus bamboo.

2.1.1 Effect of Moisture Content on Mechanical properties of Bamboo

Based on the study by Hao et al. (2013) [14], it was discovered that the compressive strength declined linearly by roughly 51%, from 7.27 GPa to 3.58 GPa, whereas the moisture content grew from 0.44 percent to 23 percent. It also suggested that as the moisture content increased from 4.3% to the 23%, the *elastic modulus* decreased nearly linearly by 34%, from 23.17 GPa to 15.43 GPa. Meanwhile, when the moisture content increased from 4.3% to 23%, the hardness decreased by 48% between 604.85 MPa and 316.80 MPa. Hao et al. (2013) also hypothesized that bamboo parenchyma cells are more sensitive to changes in MC during compression than bamboo fibers.

On the other hand, based on the study by Dinie et al. (2017) [40], the average compressive strength was taken for the bamboo at 1^{st} month and 5^{th} months. Meanwhile, same bamboo was used. The result showed that the bamboo at 1^{st} month recorded the lower compressive strength that the one at 5^{th} month. The reason is that the bamboo, which was dried for five months, its moisture content was decreased, therefore, the compressive strength increased.

In conclusion, based on the previous studies, the lower the moisture content, the higher the compressive strength. In other word, the bamboo will be stronger or more resisted to the compression when their moisture content is low. Thus, further studies on the effect of moisture content on different species of bamboo is worthy as bamboos are potential to be used in construction area to replace steel or other metals.

2.1.2 Effect of Moisture Content on Tensile Strength

Based on the study [41], it was discovered that the average tensile strength of Tonkin Cane and Bamboo Ku Zhu in wet condition is 17.9% and 19.75% lower than that in dry condition respectively. Meanwhile, Tan et al. (2011) also stated that the formation of cracks along inter-laminar borders as moisture may impair fiber connections in the tensile test, causing quicker crack propagation along inter-laminar boundaries and, eventually, specimen breakage. [42]

Besides, it shown that tensile modulus linearly decreased with the increase in moisture content [43]. The impact of MC on the elastic modulus of lignin [44–46] and hemicellulose, which were isolated chemically from wood, revealed that the stiffness of both hemicelluloses and lignin decreased dramatically as MC increased.

To sum up, to understand more about the tensile strength of other species (Gigantochloa Ligulata & Gigantochloa Scortechinii), further study was conducted.

2.1.3 Test of NaOH Solubility

Water-soluble extractives include tannin, gum, low molecular weight carbohydrates, colors, and starch. A solution of 1% NaOH dissolves extractive substances, some part of lignin, and low molecular weight hemicellulose. TAPPI/ANSI T-212 ISO. (2012) stated that the degree of fungal decay or degradation of wood can be indicated by solubility in 1% NaOH solution [47]. The study by Maulana et al. (2020) [48] stated that solubility in 1% NaOH solution of seven bamboo species were 21.64-30.99%. Meanwhile, Tali bamboo has the lowest value and Sembilang bamboo has the highest value of solubility in 1% NaOH solution. Shortly to say, analysis of variance showed that bamboo species significantly influence the solubility in 1% NaOH and 1% NaOH will reflect the anti-decay characteristics of the bamboo. Therefore, 1% NaOH solubility will be conducted on bamboo Gigantochloa Ligulata and Gigantochloa Scortechinii to determine and to compare their alkaline consumption in alkali pulping process if it should be used in pulping and paper-making process.

2.1.4 Effect of Alkaline Treatment on Bamboo

Alkali hydrolysis is a well-known method. It is a chemical method for delignifying and removing amorphous areas from raw cellulose fiber. It roughens the fiber surface, activates hydroxyl groups, and increases the tensile strength of the fiber. This method begins with the application of an alkali solution (NaOH) to remove not only cellulosic but also non-cellulosic components such as hemicellulose, lignin, and pectin from the plant fiber [20]. The alkali-treated fibers are next bleached in a multi-phase process. Most manufacturers utilize this approach since it not only takes less time to produce bamboo fibers, but it also costs less money, especially when compared to mechanical methods.

Based on the study [49], it was discovered that the tensile strength of all alkali treated individual bamboo fibers decreased as compared to untreated fiber. The result showed that comparing the untreated bamboo with the bamboo which was treated using alkaline solution with concentrations of 6, 8 and 10%, the tensile strength was decreased from 0.83 GPa to 0.64, 0.68, and 0.59 GPa respectively. That might be caused by the damage and the change in the structure of fine fiber after treated using strong alkaline.

However, [50] showed that the composites with the bamboo fibres treated with 6% NaOH exhibited the highest tensile strength, which is 10% higher than untreated composites. Compared to untreated composites, the tensile strength of specimens treated with 4% NaOH increased by 2.6%. Whereas the results also showed that there is an obvious drop in tensile strength at 8% NaOH, with a 15% reduction compared to untreated composites. Therefore, high alkali concentration which causes an excess removal of covering materials from the cellulose surface, which results in weakening or damaging of the fiber structure.

Based on the previous studies, we can see that some bamboos will have higher tensile strength after alkaline treatment but some of them will be lower tensile strength after alkaline treatment. The hypothesis is that different bamboo has different effect after treating using alkaline. Therefore, to study the effect of alkaline treatment on different bamboo species, a study will be conducted using 1M NaOH to treat the bamboo.

Chapter 3
Material & Methodology

3.1 Material & Methodology

In this experiment, there will be few experiments to be carried out for identifying the chemical, physical and mechanical characterization of Bamboo Gigantochloa Ligulata and Bamboo Gigantochloa Scortechinii. This is to determine if these bamboos suitable to be used in architecture. In addition, there is also an experiment to be carried out for improving the strength of the bamboo using suitable kind of chemical mostly alkaline. This is to increase the strength of these bamboo for better use and support in construction.

The physical and chemical characterization of Bamboo Gigantochloa Ligulata and Bamboo Gigantochloa Scortechinii can be identified in terms of their moisture content, %NaOH solubility, and benzene-ethanol extractives. Meanwhile, mechanical characterization will be conducted in term of tensile strength and compressive strength. For deeper research, there was also an experiment to determine the compressive strength of bamboo which was treated using alkaline. The overall research methodology will be simplified as below: