CHEMICALLY TREATED BAMBOO WITH SODIUM HYDROXIDE AND POTASSIUM HYDROXIDE

by

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UNIVERSITI SAINS MALAYSIA

2022

CHEMICALLY TREATED BAMBOO WITH SODIUM HYDROXIDE AND POTASSIUM HYDROXIDE

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THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF BACHELOR OF CHEMICAL ENGINEERING

July 2022

ACKNOWLEDGEMENT

The thesis was completed as part of the requirements for a Bachelor of Engineering (Honours) in Chemical Engineering degree. The completion of a thesis was impossible without the mental and technical help and encouragement of a number of people, including the supervisor, laboratory technicians, family members, and friends. I would even want to utilize this opportunity to appreciate all who have been mentioned.

First and foremost, I want to start by expressing my sincere gratitude and appreciation to the person who oversaw my final year project which is Dr. Muhammad Nazri Murat, for his precious guidance and technical advices throughout the final year project. At first, he has provide a clear direction on the assigned project and kept directing me to strive in the correct pathway. Moreover, despite his tight schedule, he has always showed a desire to spend time with me and make meaningful research ideas.

In addition, I am grateful to the technical personnel at USM's School of Chemical Engineering for their tremendous assistance during my investigations. Pn. Nor Zalilah Ahmad, Pn. Yusnadia Mohd. Yusoff, and En. Osmarizal Osman deserve special thanks. They have given up precious research time to show me how to operate laboratory equipment properly and to share their important experience of project approach. Their courteous guidance and helpful recommendations helped me complete my job successfully.

In addition, I'd want to express my heartfelt thanks to Professor Dr. Mohd. Roslee Ahmad, the coordinator of EKC 499, for his tireless efforts in planning and organising during the COVID-19 epidemic.

Thank you to all of the professors and people I've met over the last four years. Every one of them has provided me with memorable and enjoyable learning opportunities. The celebration would never be meaningful without expressing my heartfelt thanks to my family for their constant support throughout my degree years. Without their assistance and encouragement, I would be unable to continue my academic studies at USM. Today, I am grateful for my parents' hard work and goals coming true.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

NaOH	Sodium hydroxide
KOH	Potassium hydroxide
FTIR	Fourier Transform Infrared Spectroscopy
PF	Phenol Formaldehyde
CCA	Chromated copper arsenate
CCB	Chromate-copper-boron
ACC	Acid copper chromate
HCl	Hydrochloric acid
SEM	Scan Electron Microscopy
M	Molarity

ABSTRAK

Penggunaan buluh dalam sektor bangunan bukanlah perkembangan terkini. Oleh kerana kekuatan, ketahanan dan kapasitinya untuk menggantikan keluli dalam konkrit, buluh merupakan sumber semula jadi dengan populasi yang besar dan berpotensi untuk digunakan dalam bangunan. Walau bagaimanapun, kandungan kanji yang tinggi pada buluh menjadikannya sangat terdedah kepada kesan unsur-unsur apabila tahap sap atau kelembapan adalah tinggi. Buluh yang dituai mungkin cepat dicederakan oleh serangga, kulat, reput, dan api jika ia tidak dicincang, dikendalikan dan disimpan dengan betul. Oleh itu, kesan rawatan alkali terhadap ciri mekanikal dan fizikal buluh tempatan telah dinilai dalam penyelidikan ini. Objektifnya adalah untuk merawat buluh tumpat dan buluh semantan dengan alkali dan menentukan cirinya sebagai sumber yang mampan untuk pembinaan bangunan. Selain itu, kesan rawatan kimia dengan NaOH dan KOH yang digunakan pada buluh yang dimaksudkan untuk digunakan sebagai bahan binaan telah disiasat.

Larutan NaOH dan larutan KOH digunakan untuk mencari alkali terbaik untuk merawat buluh. Selepas direndam dalam larutan alkali selama 24 jam, buluh tersebut dikeringkan. Fourier Transform Infrared Spectroscopy (FTIR) digunakan untuk menganalisis kedua-dua buluh yang dirawat dan tidak dirawat, dan meter kelembapan digunakan untuk menentukan kandungan lembapan. Selain itu, sifat mekanikal buluh ditentukan menggunakan mesin ujian tegangan dan juga mesin mampatan. Menurut penyelidikan, buluh yang dirawat mungkin merupakan pengganti praktikal untuk kayu dalam pembinaan bangunan, lebih baik daripada buluh asli dari segi rintangan. Buluh yang dirawat dengan natrium hidroksida (NaOH) menunjukkan kekuatan mampatan dan kekuatan tegangan tertinggi yang menjadikannya sesuai digunakan sebagai bahan binaan.

ABSTRACT

The usage of bamboo in the building sector is not a recent development. Due to its strength, durability, and capacity to substitute steel in concrete, bamboo is a natural resource with a large population and potential for usage in building. However, the high starch content of bamboo makes it particularly susceptible to the effects of the elements when sap or humidity levels are high. Harvested bamboo may be quickly harmed by insects, fungi, rot, and fire if it is not chopped, handled, and stored properly. Thus, this study evaluated how alkaline treatment affected the mechanical and physical features of local bamboo. The objective is to treat bamboo *Gigantochloa Ligulata* and bamboo *Gigantochloa Scortechinii* with alkali and determine its characteristic as a sustainable resource for building construction. Additionally, the effects of chemical treatment with NaOH and KOH applied to bamboo intended for use as a construction material were investigated.

NaOH solution and KOH solution were used to discover the best alkali for treating bamboo. After being submerged in the alkali solution for 24 hours, the bamboo was dried. Both treated and untreated bamboo were examined using Fourier Transform Infrared Spectroscopy (FTIR), and the moisture content was measured using a moisture meter. Besides, the mechanical properties of the bamboo was determined using tensile testing machine and also compression machine. According to the research, treated bamboo may be a practical replacement for wood in the construction of buildings, better to those natural bamboo in terms of resistance. The bamboo treated with sodium hydroxide (NaOH) show the highest strength in compression and tensile strength which make it suitable to use as building material.

CHAPTER 1

INTRODUCTION

1.1 Background

Bambusoideae, subfamily of the Poaceae family of grasses includes the quickly growing bamboo plant. It comprise of more than 115 genera and also 1400 species. Malaysia has 59 kinds of bamboo, 25 of which are imported, and 34 of which are native to the country. It can grow as fast as 30cm per day and its culm may attains heights more than 40 meters in some species. It takes only three to four years to achieve its peak strength, and it takes five years to reach maturity (Ghavami, 2005). It is also a resource that is renewable, adaptable, and has a high strength to weight ratio (Saikia et al., 2015). Furthermore, it is abundant in tropical and subtropical places across the world.

Because of its mechanical durability, bamboo is a great material for use in construction in the world of engineering (Pantawane et al., 2020). While the strength to specific weight ratio of certain bamboo species is six times that of steel, its maximum tensile strength is really rather equal to the yield strength of mild steel. Bamboo has a bright future as a source of cost-effective materials and modules that may be used in both structural and non-structural applications in construction. It presents similar potential as steel, for being used as alternative construction element.

Besides, bamboo fibres are regarded as "natural glass fibre" because of its remarkable mechanical qualities, which are attributed to the inner double-helical structural components (Abdul Khalil et al., 2012). Their strength is ten times greater than that of ordinary wood (Shin et al., 1989). Due to its advantages over normal composites, such as cheap cost, acceptable specific characteristics, weather resistance, dimensional stability, and biodegradability, composites containing bamboo fiber reinforcements are becoming important construction materials in the structural community.

Nevertheless, there are some challenges in using bamboo in construction. The intrinsic defects in bamboo fibres, which diminish their compatibility with composite materials and lead to poor mechanical qualities, provide a significant obstacle to their use. Besides, there are also presence of components like cellulose, hemicellulose, lignin and wax substances which will cause the natural fibres to exhibit hydrophilic properties, thus water and other polar molecules are easily attracted to them, which will increase the moisture content.(Sugiman et al., 2019) Natural fibres with high moisture content have a difficult time binding to the composite, resulting in mechanical degradation. However, chemical treatments given to the fibre surface may be able to ameliorate the poor compatibility between the fibre and the composite matrix.

Hence, in this final year project we are going to find out is the chemical treated bamboo has the potential to adopt in construction project. To enhance the bamboo's mechanical qualities, sodium hydroxide (NaOH) and potassium hydroxide (KOH) are suggested as treatments. This is because alkali treatment successfully dignifies cellulose and chemically expands cellulose, enzymatically scarifies bamboo, breaks down the chemical bond connecting hemicellulose and lignin, and completely eliminates most lignin and hemicellulose.

1.2 Problem Statement

Governments, non-governmental organisations (NGOs), and industry are seeking for sustainable options to fulfil the growing demand for housing as the world's population grows. Natural bamboo could be one of the alternative to be used as a building material but it has some drawbacks. One improvement of this drawback would be treating natural bamboo with chemicals. It has been investigated by reseachers that there are certain type of bamboos which have been treated by alkali leads to overall improvement of the performance and utilization value. Therefore in this research paper, sodium hydroxide (NaOH), potassium hydroxide (KOH) and also mixture of both alkali are used to improve the properties of local bamboo.

1.3 Objectives

The objective of this research:

1. To treat bamboo *Gigantochloa Ligulata* or bamboo *Gigantochloa Scortechinii* with alkali and determine its characteristic as a sustainable material for building construction.

2. To investigate the effects of applying NaOH and KOH chemical treatments on bamboo to use as building material.

CHAPTER 2

LITERATURE REVIEW

2.1 Physical and Mechanical Properties of Bamboo

Bamboo has strong mechanical properties along its fiber direction, including tensile and flexural strength. It is a naturally occurring hierarchical cellular material. Since bamboo is a functionally graded natural composite, the interfaces between its numerous components, such as its fibers, parenchyma cells, and lignin matrix, may significantly impact its mechanical properties (Wegst and Ashby, 2007). The supporting cellulose fibers that encircle the vascular bundles in the parenchyma matrix give bamboo its hierarchical structure. Bamboo's major mechanical qualities are provided by these fibres. Furthermore, the cellulose fibers serve as reinforcement to fortify the lignin matrix, much like fiber reinforced polymer matrix composites. In bamboo's microstructure, this arrangement makes straight chains of glucose and hydrogen bonds, which make up the crystalline parts, and irregular hydrogen bonds, which make up the amorphous parts (Gibson, 2012; Youssefian and Rahbar, 2015).

Because of the particular microstructural qualities of natural bamboo in relation to its mechanical capabilities, it forms a good renewable material for composites in high-performance applications. In the inner layers of the wall cross, bamboo has a lower density compared to the outer surface (Kaur et al., 2015; Lakkad and Patel, 1981a; Murphy and Alvin, 1992; Ray et al., 2004a; Zou et al., 2009). Therefore, the bamboo culms' exterior layers need to have greater mechanical qualities (Bamboo and 1985, n.d.; Lo et al., 2008; Yu et al., 2008). Nevertheless, there is no full and systematic evaluation of the properties of bamboo. The identification of sections with enhanced fibre densities and subsequently improved quality in terms of physical and mechanical characteristics has the potential to have a considerable influence on manufactured composite material performance.

2.2 Bamboo as a Building Material

The increased awareness of excessive energy consumption and hence greater levels of pollution has increased the number of academic studies on natural-source construction materials that might replace manufactured items used in civil construction.(Rodrigues Moura et al., n.d.) Since of its unique rhizome-dependent structure, bamboo is one material that will have a considerable cost advantage because it matures quickly and achieves its maximal mechanical resistance quickly. Compared to most other plant species, bamboo grows three times as quickly. In the field of engineering, bamboo exhibits mechanical resistance properties that are highly desirable for use in composite materials. Bamboo's strength is one of the qualities that would make it a suitable steel alternative in reinforced concrete (Rahim et al., 2020).

A renewable resource, bamboo may be utilized for a number of things. Housing is one of the most significant uses for bamboo, particularly in view of the worldwide housing scarcity. Southeast Asia and South America, where the environment is best for cultivating bamboo, are historically associated with the plant. In several nations, bamboo is used to build dwellings or to support suspension bridges.

Everything in the house, including the structural walls and columns as well as the woven roofs, doors, and windows, may be made of bamboo (McClure, 1981). Bamboo was formerly used with other organic building materials including wood, clay, lime, and grass in ancient architecture. Currently, it has been blended with cement or adhesives to provide far more durable and visually pleasing materials that are appropriate for modern lives. Bamboo is a natural substance, thus it might deteriorate with time. If properly handled and industrially processed, bamboo components may last a respectable 30 to 40 years, although natural bamboo durability varies depending on species and method of treatment (Gichohi, 2014; Oprins et al., n.d.).

Typically, bamboo may be used without any further processing or finishing since it is a strong and light material (Gichohi, 2014). Although bamboo's naturally round and hollow shape poses certain construction difficulties, especially for connections, its structural qualities and advantages for the environment make it a top choice for sustainable building. Building challenges have been the subject of a great deal of research and experimentation, ranging from composite materials to inventive connecting details. Because it is strong, flexible, and adaptable, bamboo is a good structural and engineering material that can be used to build houses. According to decades of research by bamboo practitioners, bamboo is a strong structural and engineering material that, because of its strength, flexibility, and adaptability, is a suitable material for use in houses (Kibwage et al., 2014).

For traditional building, the culms of bamboo can be used whole, split lengthwise, flattened, or woven into mats (Bystriakova et al., 2003). Vines, split bamboo, or rattan are commonly used to connect bamboo poles (Ham and Shroyer, 1993; Larasati et al., n.d.), resulting in a fairly weak connection between bamboo poles. In many vernacular contexts, the joints are created solely using knotted ropes or bamboo incisions, which are easy to make but insufficient to convey the whole bamboo component's bearing capability (Sassu et al., 2016). Indonesia was the birthplace of the plastered bamboo home, which had a wooden frame and a mat made of bamboo woven outside. The outside of the woven mat resembled a brick wall, while the inside revealed the timber frame, which was plastered.

Dendrocalamus strictus bamboo from India was examined by Wakchaure and Kute for its dimensional changes, tensile and compressive strength, as well as tensile and compressive strength at various heights, moisture content, specific gravity, water absorption (Wakchaure and Kute, 2012). Those who discovered no observable differences between the bottom and middle portions in terms of tensile, compressive, or elastic modulus. The moisture content reduced as the specific density went from the bottom to the top. Unfortunately, no research has been done to ascertain how the culm wall's diameter and thickness impact its mechanical and physical qualities.

An essential quality for applications in architecture, building, and composite fabrication is the moisture content of raw bamboo. According to research by Chen et al., 2009; Kushwaha and Kumar, 2009; Okubo et al., 2004, moisture content may reduce the bonding power of bamboo fibres in composite items and bamboo laminates. As a consequence, it is predicted that the functioning and service life of new bamboo composite materials would be significantly impacted by the moisture content.

In the construction and automotive sectors, natural fibres have attracted a lot of interest as a potential replacement for synthetic fibres in composite applications as a result of growing awareness of environmentally friendly biomaterials (Tran et al., 2019; Wang et al., 2018). Natural lignocellulose fibres provide a number of advantages over standard inorganic fibres generated from fossil fuels, including biodegradability, low density, superior thermal properties, cheap cost, high specific features, and light weight.

In addition to influencing raw bamboo's mechanical qualities, moisture content affects a material's geometrical characteristics, such as dimensional stability, along with physical characteristics like tensile and flexural strength. No studies have examined the connection between water absorption and the mechanical properties of green bamboo, despite several research looking at how water absorption affects raw bamboo and bamboo composite specimen dimensional stability (Nugroho and Ando, 2001, 2000; Rowel et al., 1988). Rapid moisture changes may lead to significant bamboo layer shrinkage or expansion, which can result in layer-bond failure, particularly in laminates or composites (Lee et al., n.d.; Malanit et al., 2010). Therefore, it is necessary to detect the moisture content of various sections of raw bamboo and classify the moisture content according to its position within the culm length before processing the raw bamboo fibres into composites or laminates.

Compared to steel, bamboo is more durable in reinforcement. This is because steel is a metal which will corrode. From Ghavami (2005) the first bamboo-reinforced concrete beam is exhibited and contrasted with the steel-reinforced concrete column. The bamboo portion of the beam reinforcement, which was treated for both concrete bonding and insect resistance, is in excellent condition after 15 years until now. However, the column's steel reinforcing bars are extensively corroded and must be replaced. Because it releases oxygen into the air, which is something industrial materials like steel, plastic, and concrete cannot accomplish, bamboo is also a sustainable construction material.

2.3 Sustainability of Bamboo

Bamboo is recognized as a sustainable building resource because, when harvested properly, compared to other forms of building materials, it has less of an influence on the environment. The 20% of mature stems that will be replaced annually by an equal emergence of new shoots may be harvested responsibly by maintaining a stable population of current live stems and carefully choosing the 20% of mature stems that will do so (Minae, 1989). Depending on the anticipated logistical costs of transportation and harvesting, the technical implications of potentially harvestable bamboo, the effect of bamboo harvesting on soil erosion and water conservation, and the intended use of bamboo stems, various harvesting cycles can be advised, such as in India where a four-year cutting cycle is advised. Different from other types of wood, bamboo may be harvested three to four years after it is planted, and then every year after that. In actuality, annual bamboo harvesting keeps the clump or bamboo forest in good condition. Bamboo can be used for a long time because the roots are not damaged and are always ready to send up new shoots (Asif, 2009).

Because of its quick growth, bamboo is a fantastic choice for reforestation (Basumatary et al., 2015; Mohamed, 2003). However, problems include species extinction (due to unimpeded bamboo growth producing a thick canopy that only allows for very little development beneath it), loss of species diversity (due to unimpeded bamboo growth producing a thick canopy that only allows for very little development beneath it) (Minae, 1989) and locations with insufficient nutrients have had poor bamboo growth rates (Shibata et al. 2001). However, a research indicated that bamboo may be grown alongside other crops for soil conservation and reforestation due to the quantity of leaves it generates that fall to the ground, feeding the vegetative system with new nutrients continuously (Basumatary et al., 2015; Minae, 1989). Bamboo may be grown in flood plains as well as areas that have been damaged by deforestation (Basumatary et al., 2015). The majority of bamboos need rather humid and warm circumstances (mean annual temperatures at minimum 15-20°C and at least 1000-1500 mm of precipitation every year), while other bamboos may adapt to a range of habitats (Minae, 1989; Scurlock et al., 2000), there are still a few bamboo species that can withstand drought and develop in semi-arid areas.

As it develops, bamboo absorbs carbon dioxide, which it then stores for use in building. Although bamboo only lives for two to three years in its natural condition, chemical treatments to ward off natural pests and appropriate design elements to shield it from climate effects may increase its lifespan to thirty to forty years. As a consequence, when bamboo is used in construction, carbon is captured and delayed until after the structure has been demolished. Bamboo has rates of carbon sequestration and storage of 30 to 121 mg per hectare and 6 to 13 mg per ha per year, respectively (Nath et al., n.d.).

Because bamboo is a quick renewable material, it is considered environmentally beneficial (Gichohi, 2014). By making better use of wasteland, abandoned land, and river banks, as well as by encouraging new and existing farmers to plant more bamboo, increased bamboo usage might reduce deforestation and enhance soil conservation and flood catastrophe mitigation (Nwoke and B. O. Ugwuishiwu, 2011). This will help the environment since bamboo reduces the amount of carbon in the air and soil, which contributes to the greenhouse effect, as well as the local population's socioeconomic position because it will provide many work possibilities (Ham, 1990; Ham and Shroyer, 1993; Singh et al., 2003).

According to reports, bamboo may last for two to three years if it isn't treated (Asif, 2009; Bystriakova et al., 2003). This is because of untreated bamboo's susceptibility to the invasion of wood-eating insects and rot fungus (Asif, 2009; Bystriakova et al., 2003; Kyakula and Gombya, 2008); it may also include insects that spread illness (Bystriakova et al., 2003; Deka et al., n.d.; Ham, 1990; Kyakula and Gombya, 2008). Bamboo may be treated chemically or without chemicals (Asif, 2009; Larasati et al., n.d.; Liese, n.d.). Smoke or immersion in water have long been employed as alternative treatment options. Other non-chemical techniques for treatment include paint with diesel, motor oil, and phenol formaldehyde (PF) resin. Chemical treatment includes delivering or dispersing pharmaceuticals by injection or diffusion techniques into the bamboo. Creosote oil, chromated copper arsenate (CCA), chromate-copper-boron (CCB), acid copper chromate (ACC), boron, and a combination of boron and boric acid may all be used as treatment chemicals. The handling of treated commodities and the application of preservatives in bamboo might affect people, environment and animals (Liese, n.d.; Nurdiah, 2016). To reduce this risk, strict laws on the use of chemicals, public awareness of the hazards of their use and disposal, and precautions during use and disposal are required.

2.4 Chemical Treatment of Bamboo

The basic bamboo fibres structure is made up of hemicellulose, cellulose and lignin. It possesses a high-volume fraction of cellulose fibres compared to wood and grass. The major component of natural fibre resistance and stiffness is cellulose. Natural fibres are commonly used in nature, but some researchers have investigated methods to improve the conditions of these materials, primarily to be incorporated into composites. The chemical approach is the most commonly used technique for unwinding fibre bundles in order to recover textile fibres for later wet processing (V et al., 2018). Alkaline solutions including caustic soda, sodium triphosphate, sodium sulphate, sodium carbonate, sodium hydrogen phosphate, and sodium silicate are widely used for this. Alkaline treatment encourages the breaking of lignin in the fibres without harming the cellulose. It may also remove hemicellulose and lignin, therefore increasing the cellulose content as well.

By roughening the surface and exposing more cellulose, alkaline treatments encourage these hydrophilic fibres attach to the hydrophobic matrix. Because alkali treatments make it possible to break down hydrogen bonds in network structures, increase surface roughness, and remove hemicellulose and lignin from the fibre surface, they are effective at producing high-quality fibres on both an experimental and a commercial scale. The chemical composition of the fibres is altered by the alkali treatment, which also affects their mechanical characteristics, surface roughness, crystallinity, and heating behaviour.

The paper by (Rodrigues Moura et al., n.d) discussed the effects of a bamboo subjected to a chemical process using sodium hydroxide (NaOH) fibres, which concrete blocks will employ as reinforcement. The bamboo used in the paper is Bambusa Vulgarise (Rodrigues Moura et al., n.d.). NaOH was used to treat the bamboo before it was calendered into fibres. In the future, optical microscopy and SEM were used to characterize the fibres. The bending tests were used to characterise the composite material. The findings demonstrate the reinforcing supplied by treated fibre's contribution to the concrete blocks' bending-related tensile strength, demonstrating the importance of using the chemical treatment. The study's findings demonstrate that processed bamboo fibre, which has better resilience than natural bamboo fibre, may be utilized as a feasible substitute for concrete block reinforcement.

Natural fibres may vary in surface quality and chemical composition by chemical processing to attain desired qualities. This is because alkaline treatments can remove hemicellulose and lignin thereby increasing the cellulose content as well. From Jähn et al. (2002) chemical treatment on natural fibres with alkaline solutions can increase the resistance and stiffness of the fibre and improve the increase on the composite resistance. Based on Li et al. (2007), the network structure's hydrogen bonds will be broken by alkaline treatment, increasing surface roughness. This process will remove some of the lignin, oils, and wax that had been applied to the outside of the fibre cell wall. The cellulose will also depolymerize, exposing the short-length crystallites.

Additionally, adding aqueous NaOH to bamboo fibre encourages the hydroxyl group in the alkoxide to become ionized.

Wood products are acetylated using acetic anhydride to increase their strength and stability. This treated wood can be used outside because it stabilizes the wood, makes it less absorbent of water, makes it more stable in size, and makes it resistant to organisms (Hill, 2007; Rowell, 2012). Similar to the acetylation process, wood or other lignocellulosic materials may undergo chemical modification via the esterification process, which employs citric acid as the primary solution. This method has been employed as a binder for particleboards (Widyorini et al., 2014), wood veneers (del Menezzi et al., 2018), and the esterification of hydroxyl groups from wood after heat treatment between 100-140 ℃ (Despot et al., 2008; Essoua et al., 2016; Šefc et al., 2009).

Citric acid has the capacity to act as a cellulose cross-linking agent (Widsten et al., 2014). Additionally, polymers in wood cell walls may react with it (Feng et al., 2014). Citric acid is used in the wood sector to improve products and lessen the total environmental impact of buildings (Essoua et al., 2017). Additionally, it may be used to improve the wood's dimensional stability and biological endurance. Although parallel to the grain compression strength remains unchanged (Despot et al., 2008), tensile strength and modulus of rupture are reduced in citric acid treated wood (Feng et al., 2014; Guo et al., 2019).

Citric acid reactions with cellulosic materials have been studied using FTIR. It seems that a five-membered cyclic anhydride intermediate is created when the two neighbouring carboxylic acid groups dehydrate, which may then undergo an esterification reaction with a hydroxyl group of cellulose (Feng et al., 2014).

In Manalo et al. (2015) to create the composites, bamboo fibres were subjected to varying degrees of alkali solution treatment before being injected with polyester resin. Bamboo fibre, according to Takagi and Ichihara (2004), is among the most alluring options for usage as a natural fibre that provides strength. Bamboo offers a number of benefits, including a minimal environmental effect due to its yearly renewal and rapid growth, as well as better strength than jute and cotton fibres. In addition, according to Rao and Rao (2007), compared to sisal fibres and banana, two of the most popular natural fibres, are stiffer yet weaker.

According to Mohanty et al. (2000), among the most well-liked and affordable chemical treatments for natural fibres is alkaline treatment. This process removes a few lignin, wax, and oil from the outside of the fibre cell wall, exposing more cellulose to the fibre's surface. The alkaline treatment improves surface roughness as well, which encourages fibre-matrix interaction and reduces fibre aggregation in the matrix. (Aziz and Ansell, 2004; Gomes et al., 2007).

From Manalo et al. (2015) the mechanical properties of the composites were enhanced by treating the bamboo fibres with NaOH. This enhancement is the result of the bamboo fibres' increased adhesion to the polyester resin. 6% was found to be the ideal alkali concentration for bamboo composites, producing the optimum mechanical properties. Bamboo composites treated with this alkali concentration increased their tensile, bending, compressive, and stiffness by 7, 10, 81, and 25%, respectively, compared to untreated composites.

CHAPTER 3

MATERIALS AND METHOD

3.1 Materials and Equipment

The required materials and equipment in conducting the experiment for the project are listed in Table 1 and Table 2 together with their respective purposes.

Table 3.1: List of materials required

Materials	**Purposes**
Bamboo *Gigantochloa Ligulata* / bamboo *Gigantochloa Scortechinii*	Raw material
Sodium hydroxide (NaOH)	Chemical used to treat bamboo
Potassium hydroxide (KOH)	Chemical used to treat bamboo
Distilled water	Diluting agent

Table 3.2: List of equipment required

Equipment	**Purposes**
Oven	Fasten the drying of wet product
Moister meter	To measure the moister content of bamboo
Scanning electron microscopy	Image the surface morphology and properties of samples
Fourier transforms infrared spectroscopy (FTIR)	To analyse the changes in the chemical structure after treatment
Compressive strength machine	To perform compressive test
Tensile testing machine	To perform bending test
Electric saw	To chop down the bamboo
Weighing machine	To measure the humidity content of bamboo

3.2 Flow Chart of Methodology

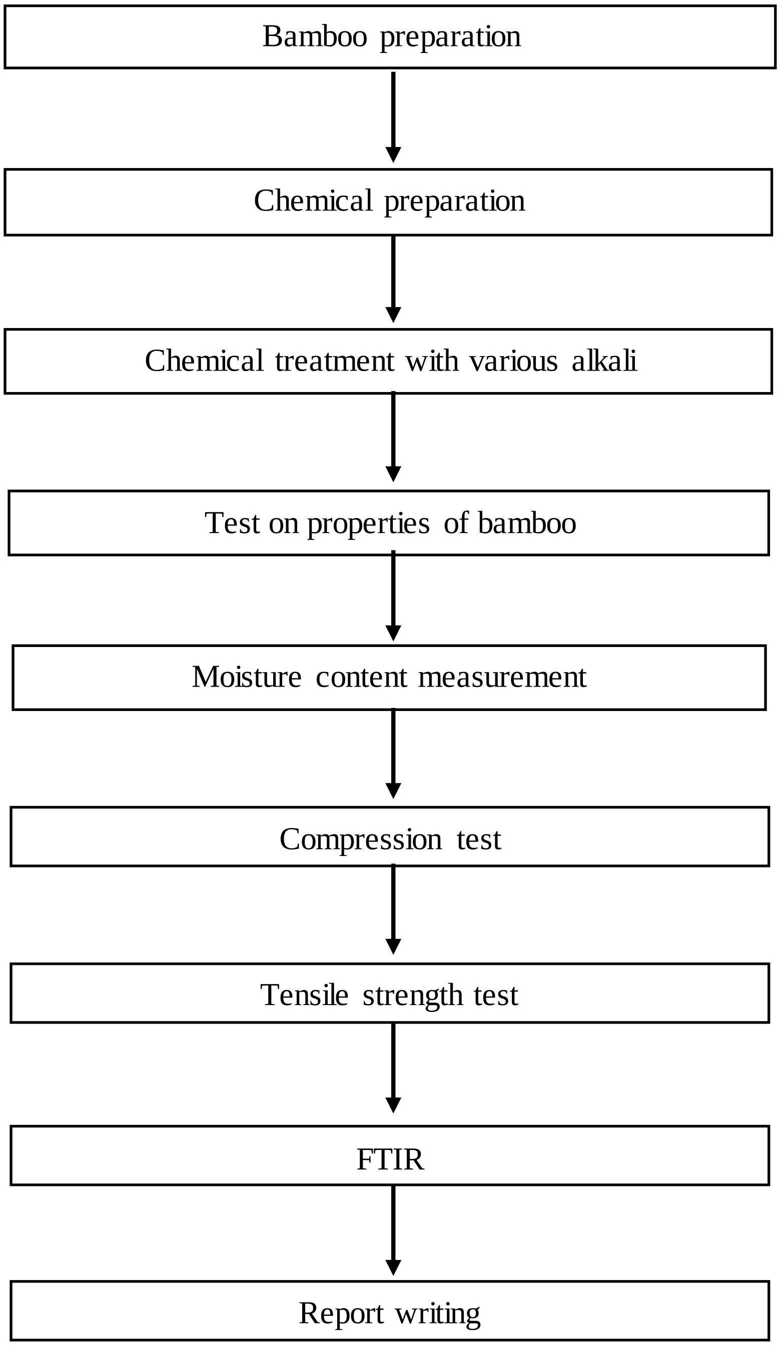

Figure 3.1: Proposed workflow for project

3.3 Experimental Procedure

3.3.1 Bamboo preparation

The bamboo *Gigantochloa Ligulata* and bamboo *Gigantochloa Scortechinii* were picked with the age of approximately 5 years. 5 samples were taken from bottom to top section of bamboo culm for the experiments.

3.3.2 Chemical preparation

The solution of sodium hydroxide (NaOH) was prepared with concentration of 1M. In order to make 1M NaOH solution, 40 g of sodium hydroxide pellets is dissolved in 1000 mL distilled water. It is added with phenolphthalein and titrate with 1.0M HCl to confirm the concentration of NaOH prepared. The formula used to calculate is $M_A V_A = M_B V_B$. The steps are repeat with KOH solution.

3.3.3 Chemical treatment with various alkali

The bamboo were soaked in the solution for 24 hours. The solution were NaOH solution, KOH solution and NaOH + KOH mixture. After the alkali treatment, it is then washed for few times with water to remove any alkali solution attach on the bamboo surface. It was dried at 90ºC for 4 hours.

3.3.4 Moisture content measurement

The moisture content of the bamboo after treatment are measured by using moister meter. It is measured within the culm wall thickness. The measurement should not be made on the surface of the culm wall but to take by driving deep, sharp probes into the wall from the side. The area at which measurement are made shall not contain any dirt or visible defects. The electrodes were drove into the culm wall cross-section so that the line between the tips of the needles intersects only bamboo material. Three measurements are made in each measuring area which is 10mm to 15mm apart. This is to avoid any error due to the electrodes piercing an invisible defect.

3.3.5 Preparation of tests specimens for compression test

The length of the specimen should be deemed to be 10 times the wall thickness, 10δ or less than the outer diameter, D. However, if D is 20mm or less, the height may be taken as twice the outer diameter, 2D, irrespective of δ. The specimens' end planes must be flat with a maximum variation of 1% of the diameter, parallel to each other, and parallel to the specimen's length axis.

3.3.6 Procedure for compression test

With an accuracy of 0.01 mm, the specimen's length, L, and wall thickness, δ, were measured. The specimen was positioned such that the axis is aligned with the loading axis of the machine. A small load, not exceeding 1% of the expected failure load, was initially applied to seat and hold the specimen in position. The maximum load, at which the specimen failed was recorded. If ductile behaviour is observed, the maximum load is considered to occur at a strain of 0, 1.

3.3.7 Preparation of tensile strength test

Radially oriented specimens with rectangular cross-sectional dimensions, breadth equal to the culm wall thickness, δ, and width, b, equivalent to one-half the culm wall thickness or less, underwent tensile tests parallel to the fibre. The maximum specimen width should be 20 mm. One node, which must be in the gauge portion, must be present.

The test piece's gauge portion's longitudinal axis should be parallel to the fibres' general direction of orientation. The gauge length must range from 50 to 100 mm.

To make it easier for the test machine to grasp the grasped ends of radially oriented test parts, softwood (or a similar material) "tabs" should be bonded to their width dimension, δ. To guarantee that the failure occurs inside the gauge part of the specimen and to reduce stress concentration in the transition region, the tabs must be concentric and adequate.

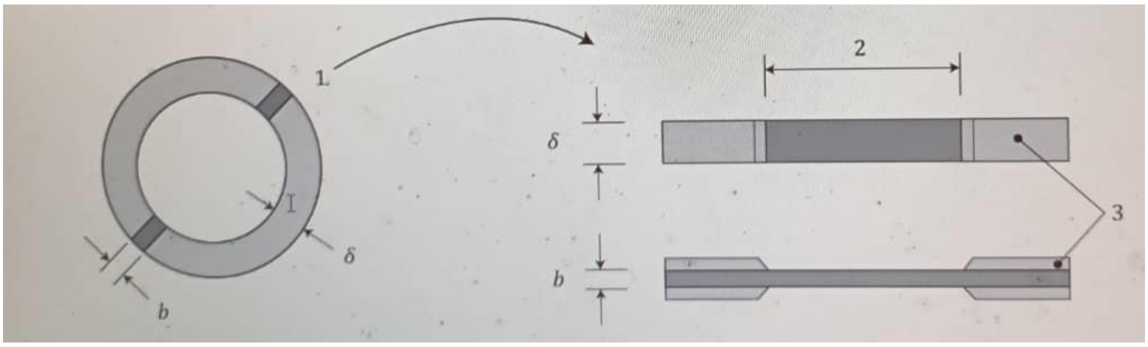

Figure 3.2: Specimen dimension

Key

δ wall thickness

B width of specimen (b < (δ /2) < 20mm)

1 culm section

2 gauge length = 50 mm to 100 mm

3 tabs

3.3.8 Procedure for tensile strength test

At three points along the length of the gauge component, the specimen's cross-sectional dimensions, δ and n, were measured with an accuracy of 0.1 mm, and the mean cross-sectional area was determined. The test piece's end was clamped between the testing device's grips such that the clamping force was directed via the specimen's thinner dimension. The failure mode was noted and the maximum load was read. Test specimens must be removed from the strength analysis if they fail anywhere other than the gauge area.

3.3.9 Procedure for FTIR

The FTIR spectrometer was filled with the sample. The sample is exposed to IR beams from the spectrometer, which measures how much of the beam and at what frequencies the sample absorbs. The sample must be cut into a thin enough slice or have a tiny layer of material removed in order for the infrared light to pass through. During data processing, the sample spectrum's absorption frequency bands are matched to the molecules' normal modes of vibration.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Moisture Content

Moisture content is an essential parameter of bamboo. It controls the mechanical characteristics of bamboo and is crucial in determining its lifespan. Green bamboo typically has high moisture content, depending on age, season, geographic region, species, and watering practises. Insect attack are strongly linked to the quantities of starch and humidity in bamboo culms. For a variety of reasons, drying bamboo is essential to its preservation. The moisture content of green and bamboo always decreases from bottom to top. Figure 4.1 depicts the fluctuation in moisture content along with each sample taken from different internode from bottom to top. According to the findings, moisture content in the bottom region of both natural and chemically treated bamboo culms was somewhat higher than in the middle and top sections. The lowest moisture content was found in the top portion. From the bottom to the top of the bamboo culm, the moisture content reduced. The top section of bamboo *GigantochloaLigulata* treated with NaOH record the lowest moisture content (11.71%) while the bamboo treated with KOH record the highest moisture content (14.10%) among those treated bamboo. This goes the same with bamboo *Gigantochloa Scortechinii* which record lowest moisture content (12.24%) for bamboo treated with NaOH and highest moisture content (14.84%) for bamboo treated with KOH.

Low humidity bamboo is less susceptible to mould assaults, especially when the humidity level is less than 15%. Bamboo's physical and mechanical characteristics improve as its humidity level decreases (Lakkad and Patel, 1981b).

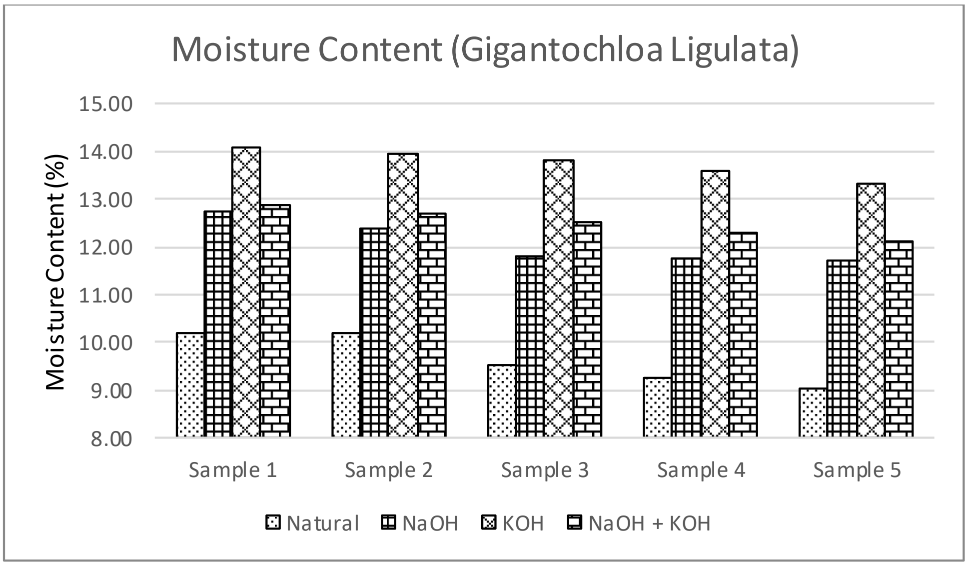

Figure 4.1: Moisture content of bamboo Gigantochloa Ligulata

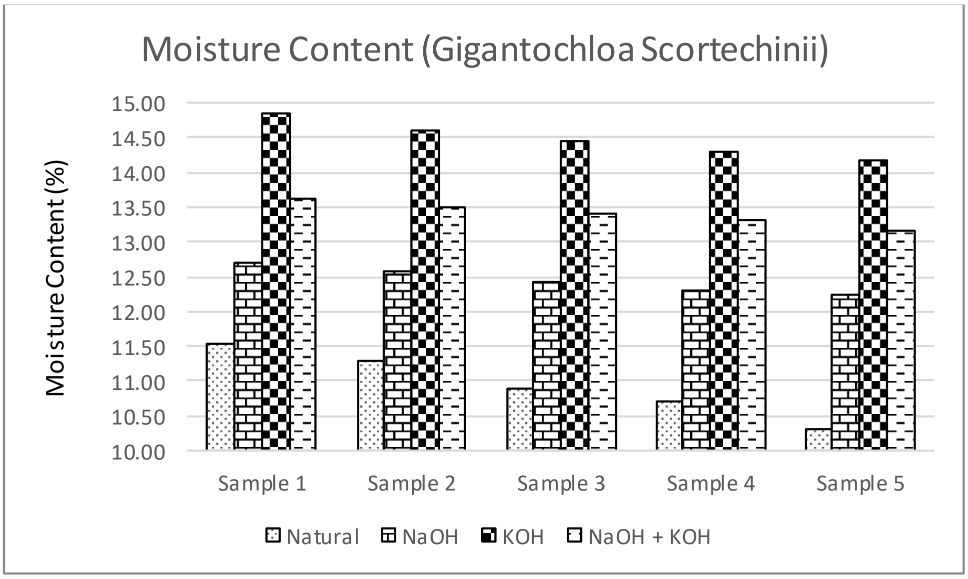

Figure 4.2: Moisture content of bamboo Gigantochloa Scortechinii

4.2 Compression Test

When a material or product is put through a mechanical test called a compression test, it is subjected to forces that push, compress, squash, crush, and flatten the test specimen. Fundamental mechanical tests like tensile and bend tests are similar in nature to compression tests. Compression tests identify the stiffness and strength of a material or product under applied crushing loads. In order to perform these tests, a testing machine that generates compressive loads is typically used in conjunction with platens or other specialized fixtures to apply compressive pressure to a test specimen. In the study, the maximum compression strength was found in the top part of both natural and chemically treated bamboo. This is owing to the bamboo wall's thicker thickness and larger cross-sectional area when compared to the middle and bottom sections. Bamboo treated with NaOH recorded the highest ultimate compression strength which is 89.56 N/mm^2 which was the top section for the bamboo culm while 87.31 N/mm^2 was recorded for the bottom part. For natural bamboo, the highest ultimate compression strength is 58.65 N/mm^2 for the top section of bamboo while 47.15 N/mm^2 was recorded for the bottom part. There are two types of failure modes occurring during the compression test of the specimens, which is splitting and end bearing failure. The figure 4.4(b) showed the splitting failure mode while in Figure 4.6(b) it showed end bearing failure. The splitting failure appeared due to the distinctive splitting cracks initiated along the specimen's culms. This phenomenon might be due to the low moisture content. The kind of compressive failure is generally determined by the moisture content of the material. Specimens with significant moisture content revealed failure in the end bearing. Specimens with low moisture content, on the other hand, revealed a failure in fibre splitting (Chung and Yu, 2002). Among the 2 bamboo species, it was found that the average compressive strength was highest at the top, followed by the centre, and finally the bottom. The specimens obtained close to the base of the culm were somewhat older and weaker than the ones taken further from the base. The existence of large vascular bundles in bamboos is thought to be the cause of this property's distinction. Throughout the life of a bamboo plant, vascular bundles are in charge of transferring all the nutrients from the culm's base. The reduced fibre concentration at the base of the culm as opposed to the top of the culm is an indirect outcome of these vascular bundles.

(a) (b)

Figure 4.3: Bamboo Gigantochloa Ligulata before compress (a) Top view (b) Front view

(a) (b)

Figure 4.4: Bamboo Gigantochloa Ligulata after compress (a) Top view (b) Front view

(a) (b)

Figure 4.5: Bamboo Gigantochloa Scortechinii before compress (a) Top view (b) Front view

(a)

(b)

Figure 4. 6: Bamboo Gigantochloa Scortechinii after compress (a) Top view (b) Front view

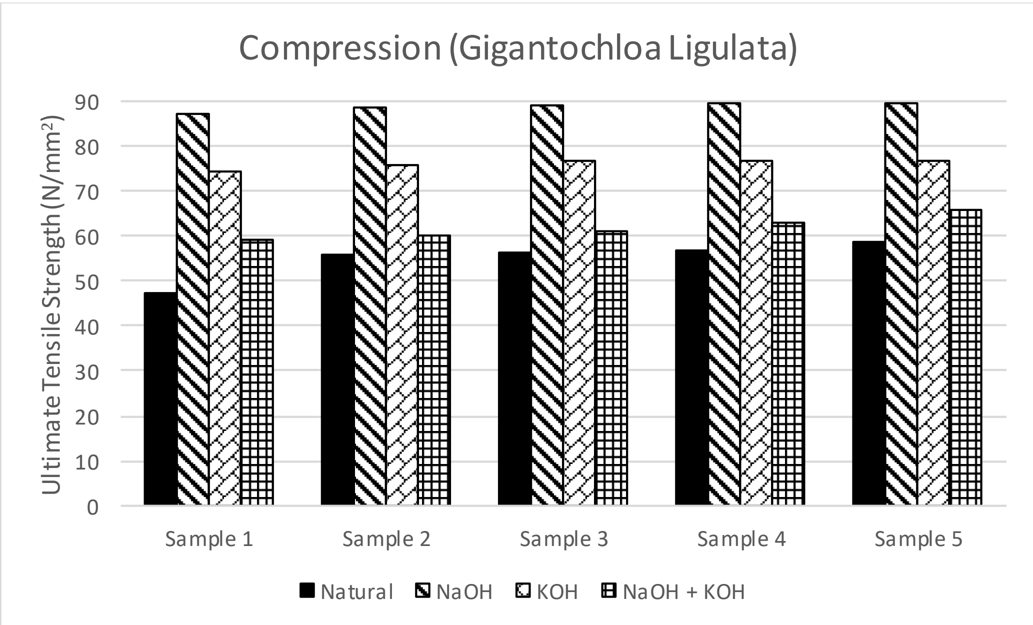

Figure 4.7: Compression test for bamboo Gigantochloa Ligulata

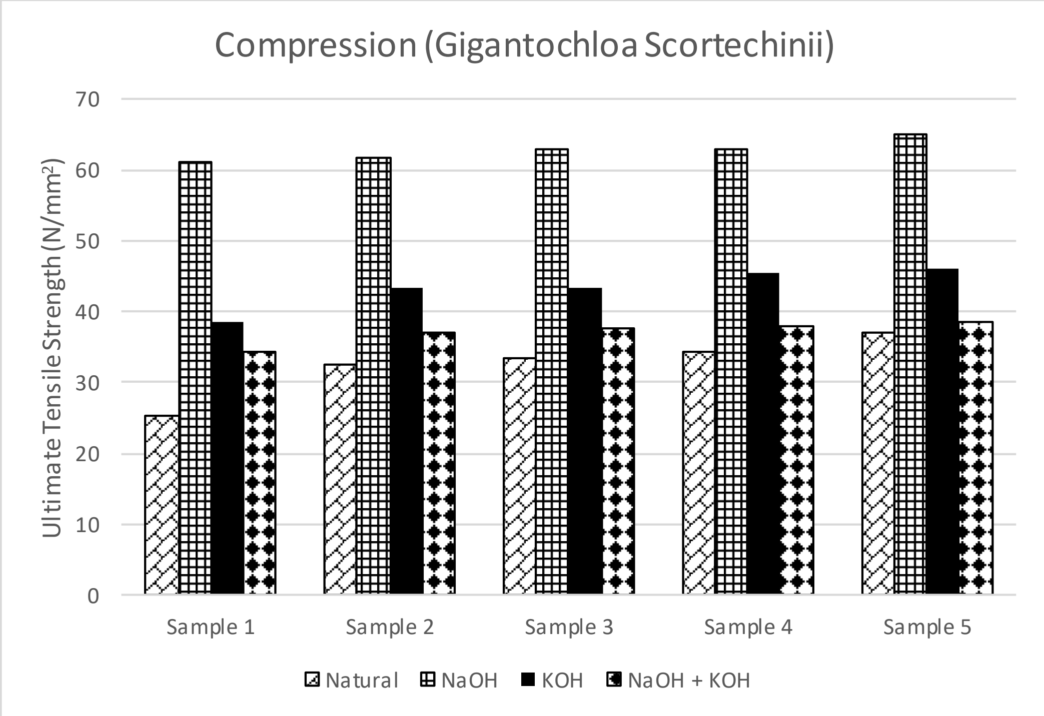

Figure 4.8: Compression test for bamboo Gigantochloa Scortechinii

4.3 Tensile Strength Test

The tensile properties of natural and alkali-treated bamboo are summarized in Table 4.3 and 4.4. It can be seen that, all the tested samples failed. The tensile strength of all alkali treated bamboo increased as compare to natural bamboo as shown in Figure 4.9 and 4.10. The top part of this species shows the highest tensile strength reading as compared to its middle, bottom parts' readings. This is due to the tensile strength is inversely proportional to moisture content as the moisture content decrease from bottom to top section of bamboo. The highest tensile strength for alkali-treated bamboo *Gigantochloa Ligulata* was 115.70 N/mm2 in contrast to the natural bamboo of 80.24 N/mm2 while for alkali-treated bamboo *Gigantochloa Scortechinii* was 150.58 N/mm2 in contrast to the natural bamboo of 97.68 N/mm^2. A maximum enhancement of tensile strength was obtained approximately 35.46 N/mm^2 or 44.2 % is accomplished by NaOH treatment for bamboo *Gigantochloa Ligulata* and 52.9 N/mm^2 or 54.2 % for bamboo *Gigantochloa Scortechinii*. The improvements of the tensile properties had agreed with (Sheng Tong et al., 2018), due to the cementing materials like lignin and hemicellulose were eliminated during the alkaline treatment, which leads to an increment of the effective fibre surface area and roughness.

Figure 4.9: Sample for tensile strength test

Figure 4.10: Failure after test

Figure 4.11: Machine for tensile strength test

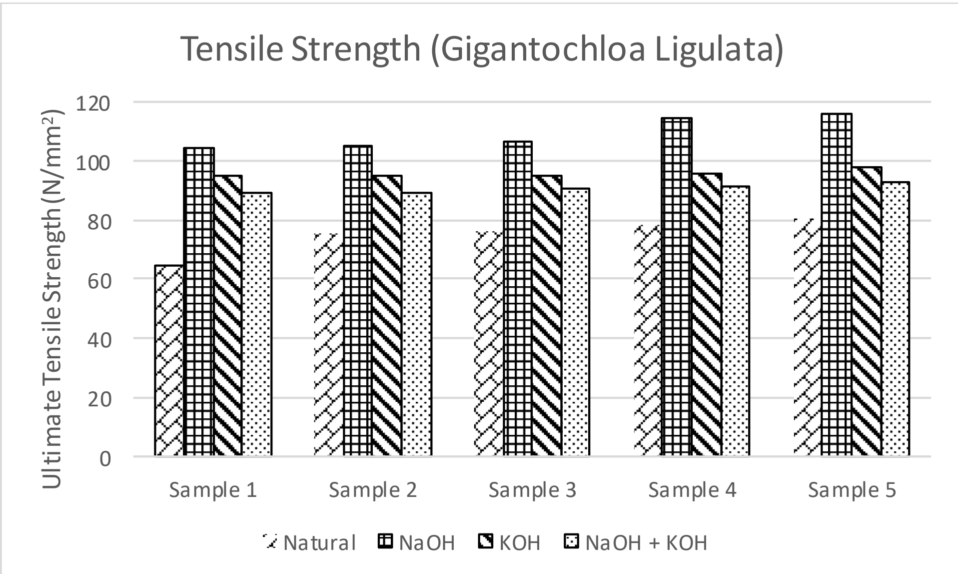

Figure 4.12: Tensile Strength Test for bamboo Gigantochloa Ligulata