PERFORMANCE OF BAMBOO STICKS AS STEEL REINFORCEMENT IN REINFORCED CONCRETE BEAM

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
B. ENG (HONS.) CIVIL ENGINEERING

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DEDICATION

This thesis is dedicated to all who involved directly or indirectly in the entire thesis production.

A special feeling of gratitude to my loving parents:

TAN KENG HOCK and ONG POH LEAN

As well as my sisters:

TAN KHYE LIH and TAN KHYE SIM

For their endless love, support and encouragement.

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ABSTRACT

This research deals with the experimental study on the behaviour of bamboo sticks as steel reinforcement in reinforced concrete beams. A small section of treated and untreated bamboo samples were prepared to study the microstructure of each samples using scanning electron microscope (SEM). There are two types of chemical used which include black oxide primer and sodium hydroxide solutions with concentration of 5%, 10% and 15%. The physical properties which include density, initial moisture content, water absorption, compression and tension of bamboo were also investigated. Based on the results obtained, the structural testing on concrete RC beams, including the load deflection, cracking patterns and mode of failure were performed. A total of three (3) samples of concrete beams with compressive strength of 30 MPa were tested under four-point bending test, which included one steel RC beam acted as a control beam (CB), one bamboo RC beam (BR) and one bamboo steel RC beam (BSR). The beam had a cross section of 120 mm in width and 300 mm in depth as well as a total length of 1600 mm. By comparing with untreated bamboo, treated samples with sodium hydroxide solution shows the elongation of pore structures with 10% concentration of sodium hydroxide. However, the concentration which is greater than 10% has caused the pore structure to be damaged. The pore structures of treated bamboo samples with oxide primer are fully protected by the coating of oxide primer. The resulting SEM images show that there are no visible pore structures after treatment. Coating of oxide primer also ensures bamboo is water resistant. In terms of physical properties, bamboo has remarkable results for tensile in which it was recorded to be 10% of steel tensile stress. The compressive strength of one node bamboo was recorded to be significant in which it is 59% higher than zero node bamboo. In structural aspect, experimental studies show that bamboo reinforcement with proper adaptations in beam BSR has managed to achieve 46% of the capacity in steel reinforcement in control beam (CB). However, beam BSR which is partially reinforced with bamboo did not show any significant effect in terms of beam strength.

ABSTRAK

Laporan kajian ini adalah mengenai kelakuan buluh sebagai tetulang keluli dalam rasuk konkrit bertetulang. Beberapa sampel buluh yang dirawat dan tidak dirawat telah disediakan untuk kajian dari segi mikrostruktur buluh dengan menggunakan imbasan elektron mikroskop (SEM). Terdapat dua jenis bahan kimia yang digunakan iaitu primer oksida dan larutan natrium hidroksida dengan kepekatan sebanyak 5%, 10% dan 15%. Selain itu, ciri-ciri fizikal buluh termasuk ketumpatan, kandungan kelembapan awal, penyerapan air, mampatan dan tegangan turut dikaji. Kajian terhadap struktur rasuk konkrit bertetulang juga dijalankan bagi mengkaji beberapa aspek struktur termasuk beban dan lenturan, corak retakan rasuk dan mod kegagalan. Sebanyak tiga (3) sampel rasuk konkrit dengan kekuatan mampatan 30 MPA telah diuji. Ketiga-tiga sample tersebut terdiri daripada rasuk konkrit bertetulang keluli sebagai rasuk kawalan (CB), rasuk konkrit bertetulang buluh (BR) dan rasuk konkrit bertetulang campuran keluli buluh (BSR). Rasuk dalam kajian ini mempunyai keratan rentas 120 mm lebar dan 300 mm tinggi serta panjang 1600 mm. Kepekatan larutan natrium hidroksida sebanyak 10% didapati telah menyebabkan pemanjangan liang-liang struktur buluh berbanding dengan buluh yang tidak dirawat dengan larutan natrium hidroksida. Walaupun demikian, kajian makmal telah menunjukkan kehancuran liang-liang struktur buluh sekiranya kepekatan larutan natrium hidroksida terlalu tinggi seperti 15%. Manakala liang-liang struktur sampel buluh yang dirawat dengan primer oksida didapati dilindungi sepenuhnya melalui lapisan primer oksida. Menerusi imej imbasan electron mikroskop, didapati tiada struktur liang dilihat selepas buluh dirawat. Lapisan primer oksida juga boleh memastikan buluh tidak menyerap air. Laporan kajian makmal menunjukkan buluh mencatatkan keputusan yang luar biasa untuk tegangan di mana ia direkodkan sebagai 10% daripada keluli. Manakala kekuatan mampatan buluh juga amat signifikan berbanding dengan keluli dimana kekuatan mampatan buluh yang beruas adalah 59% lebih tinggi daripada buluh yang tidak beruas . Dalam aspek struktur, kajian eksperimen menunjukkan bahawa tetulang buluh dengan penyesuaian yang betul telah berjaya mencapai 46% daripada kapasiti dalam tetulang keluli rasuk kawalan. Namun, rasuk konkrit bertetulang campuran keluli buluh (BSR) tidak menunjukkan apa-apa kesan yang ketara dari segi kekuatan rasuk.

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A_s	Area of tensile reinforcement
A_s’	Area of compression reinforcement
B	Breadth of section
F_{ck}	Characteristic strength of concrete
F_{yk}	Characteristic strength of steel
D	Effective depth
F_{cc}	Force of concrete in compression
F_{sc}	Force of steel in compression
F_{st}	Force of steel in tension
kg	Kilogram
Z	Lever arm
MPa	Mega Pascal
mm	Millimetre
mm^2	Millimetre square
N	Newton
N/mm^2	Newton per millimetre square
H	Overall depth of section

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Material
BS	British Standard
BR	Bamboo reinforcement
BSR	Bamboo steel reinforcement
CO_2	Carbon dioxide
CB	Control beam
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
SEM	Scanning Electron Microscope
RC	Reinforced Concrete

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Construction industry is considered as an industry which exploits the environment the most. Concrete is the most important building material due to its high compressive strength characteristic. It is incorporated with steel as reinforcement to cater on its weakness in tensile strength. The combination of both materials which formed reinforced concrete is able to sustain dead load as well as live load of building structures. Due to this large production of concrete and steel is needed to cater the demand. Indirectly, this has contributed to environmental deterioration. Malhotra (2000) stated that cement industry alone has generated for about 7% of carbon dioxide (CO_2) to the environment. Cement production is very energy extensive as it requires burning fossil fuel over 1400°C (Aziz, 1995). Besides that, rapid production of materials such as steel and iron releases over two tons of CO_2 to the atmosphere (Neville, 1995). Not only cement production, manufacturing of steel also requires extensive energy and normally the energy comes from coal, liquid oxygen as well as raw ingredients (Mahzuz and Alam, 2009). Besides that, steel is susceptible to corrosion in the presence of oxygen and water. The rate of steel corrosion is dependent on the concrete's electrical resistivity, moisture content and the rate at which oxygen migrates through the concrete and causing steel to corrode. Carbonation and chloride attack will accelerate corrosion due to the reduction of alkalinity in concrete. Therefore, there is a need to begin the search for materials that are eco-efficient which will be the substitute for steel as reinforcement in concrete.

Nowadays, many researchers have been done using available natural resources. Bamboo is an example of natural resources that has the potential to be substitute of steel reinforcement in reinforced concrete. Generally, bamboo is known as a giant grass which grows rapidly in tropical and subtropical regions. Its strength which is greater than timber and its tensile strength is approximately half as compared to steel making it suitable to be substitute to steel reinforcing bar in concrete (Khare, 2005). Furthermore, bamboo is light weight compared to steel. The utilization of bamboo as reinforcement will consequently reduce the cost of construction. This would be beneficial in which high strength of building can be achieved with lower cost. In short, bamboo has the potential to replace steel as reinforcement in reinforced concrete due to its characteristic to be cheap, easily available and most importantly strong in tension and compression.

Generally, Malaysia consists of 70 species of bamboo which includes 50 in Peninsular Malaysia, 30 in Sabah and 20 in Sarawak (Wong, 1989). In 1970, the area of bamboos in Peninsular Malaysia was approximately 20 000 ha (Mc Grath, 1970). Until now, the area has been increased to 329 000 ha (Abd. Razak and Abdul Latif, 1988). Azmy and Norini (1990) has stated that bamboo as the natural resources in Malaysia, has been identified as the second importance of non-timber source next to rattan. It has long been integrated with traditional, rural Malaysia lifestyle, but it has never been commercialize widely as the attention is only focused on handicrafts, timber and furniture industries or sometimes it is used as supplementary construction materials. Currently, bamboo resources in Malaysia are left as an unmanaged wild population.

This study is conducted with the intention to investigate the possibilities of exploiting bamboo, the natural resources in Malaysia which grow in abundance, as materials to be utilized in construction industry. Three major areas were considered in this study. Feasibility studies conducted in terms morphology behavior of bamboo with chemical treatments such as black oxide primer and sodium hydroxide solutions, physical properties of bamboo in terms of density, initial moisture content, water absorption, compression and tension strength that make it suitable to replace steel as reinforcement in concrete as well as the performance of bamboo sticks in terms of load deflection behavior, crack pattern and failure mode.

1.2 PROBLEM STATEMENT

The popularity of concrete as building material in construction industry is well known and it is produced more than 10 billion tons per year (Meyer, 2009). This is due to its relatively high compressive strength properties. However, it cannot be used alone without any reinforcement as it possesses low tensile strength. Usually, concrete will be reinforced with steel in order to provide strong tensile strength. However, steel is susceptible to corrosion when steel reinforced concrete expose to adverse conditions. Besides that, steel is made up from iron which is found abundant in earth crust. However, it will undergo depletion if continuous exploitation is carried out. In short, steel is not a renewable resource. Furthermore, rapid development and production of materials especially steel, iron and cement have given enormous impact to the environment. Steel industry has contributed to pollution which endangered to the humankind. Due to this, many researchers begun to search for materials that are renewable as well as have eco-efficient characteristic to be substitute for steel. Nowadays, many researchers have been done using one of the available natural resources which is the bamboo to be a potential material used as substitute for steel reinforcement. This is due to its characteristic to be cheap, easily available and most importantly strong in tension and compression. Malaysia has abundant bamboo resources which is not widely been utilized. Currently, bamboo resources in Malaysia are left unmanaged wild population. The usage of bamboo is mainly focused on manufacturing incense sticks, broomsticks and handicraft industries. Dato' Ghazi Sheikh Ramli, the founder and chairman of Global Innovation and Entrepreneurship Foundation (GIEF) quoted, "*Bamboo will be the new economic transformer of agriculture in Malaysia. It should not be seen as contributing to agriculture only but it has huge potential in many different industries as wel*l". Therefore, there is a need to study on the potential of bamboo to be used in other field especially in construction industry. In this study, feasibility study of using bamboo stick as replacement of reinforcing bar in concrete is conducted. The study of morphology behavior of bamboo sticks when treated with chemical using scanning electron microscope as well as its physical properties was performed. Four-point bending was conducted to investigate on the performance of bamboo reinforcement in concrete in terms of load-deflection behavior, crack pattern and failure mode.

1.3 OBJECTIVE

This study was conducted to achieve the following objectives:

i. To study the morphology behavior of chemical treated and untreated bamboo sticks using scanning electron microscope
ii. To evaluate the physical properties of bamboo sticks in terms of density, initial moisture content, water absorbability, compression and tensile strength
iii. To determine the performance of bamboo sticks as steel reinforcement in reinforced concrete beam under four-point bending in terms of load-deflection behavior, crack pattern and failure mode

1.4 SCOPE OF STUDY

In this study, the sources of bamboo used were taken from Pekan, Pahang. There were three main scopes included chemical treatment, physical properties and structural behavior in this study. Small section of bamboo samples were prepared and treated with chemicals such as black oxide primer and sodium hydroxide solutions of different concentration (5%, 10% and 15%). The morphology behavior of chemically treated and untreated samples was investigated. For physical properties of bamboo sticks, five tests were conducted such as density, initial moisture content, water absorption, compression and tensile tests. Based on the results obtained, proper adaptations were applied on bamboo reinforcement in reinforced concrete beams. Four-point bending test was conducted to investigate the behavior of beam in terms of load-deflection behavior, crack pattern and failure mode.

1.5 SIGNIFICATION OF STUDY

In most of the developing countries, there is a need of replacing traditional building construction materials such as steel to another economic and sustainable material which is in line with the current modernization in construction industry as well as the need of constructing more sustainable, modern structures. In this case, bamboo seems to be able to fulfill all the requirements and provide adequate substitute to steel in reinforced concrete structures. Besides that, the populations nowadays are ever increasing. Due to this, constructing multi storied building is a popular trend nowadays to accommodate with those increasing populations. However, those building are facing the risk of rapid deterioration such as corrosion in steel reinforcement. Therefore, there is a need to provide safe and economical place to live to mankind.

This study will provide knowledge on the feasibility of bamboo reinforced concrete to be used in construction industry. In this research, conventional steel reinforcement will be replaced by natural, cheap and readily available natural resources material which is the bamboo sticks. In ancient time, bamboo is already considered to be an excellent construction material due to its properties which are comparable to steel. However, in Malaysia, the utilization of bamboo in construction industry is still very rare. This is due to several uncertainties in which the feasibility of using bamboo sticks as substitute to steel reinforcement in concrete is still very limited despite of the abundance of resources in Malaysia. In this research, bamboo will be treated chemically using black oxide primer and sodium hydroxide solutions. From this, the morphology behavior of bamboo sticks when treated with chemical using scanning electron microscope will be investigated to determine the effects of chemical treatments. Furthermore, this research will enable us to identify the physical and mechanical properties of bamboo sticks as replacement of steel reinforcement in concrete. Therefore, the feasibility of bamboo reinforced concrete could be identified.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Concrete is a composite material which made up of cement, aggregates, water and some admixtures, if required. It is widely used in construction industry due to its high compressive strength property besides being readily available and economical. In order to cater the dead and live load of building structure, plain concrete is modified with the additional of steel reinforcements in it which is known as reinforced concrete. Therefore, reinforced concrete is able to handle load in compression as well as tension. However, the strength of concrete not only depends on the existence of constituent materials. There are many other factors that influenced the strength such as water/cement ratio, mix design, compaction and curing of concrete. Not only affecting the strength but concrete durability also will also be affected.

2.2 REINFORCED CONCRETE

Reinforced concrete is a composite material, consisting of steel reinforcing bars embedded in concrete. It is widely used in civil engineering applications such as construction of buildings, retaining wall, bridges, and foundations. Reinforcement is designed to carry tensile forces, which are transferred by bond between the interfaces of steel and concrete. If this bond is not adequate, the reinforcing bars will just slip within the concrete and there will not be a composite action.

2.2.1 Properties of Reinforced Concrete

As mentioned earlier, reinforced concrete is a composite which combines plain concrete with steels. This is due to plain concrete is unable to counteract tensile strength and ductility by itself. Steel reinforcement is commonly known as rebar which is fixed in the formwork before pouring and settling of concrete. The combination of both of these material, therefore, a strong building material has formed with high relative strength, improves bonding, and high tolerance to tensile strain which is identified as reinforced concrete.

2.3 STEEL IN CONSTRUCTION

There are much dependent of the usage of steels as building materials in construction industry is due to the positive characteristics such as prefabrication, strength and its speed of erection. Steels are used in many parts of the buildings for different purposes such as load-bearing frames, bridges and trusses. In order to prolong its lifespan, it should be protected against corrosion as well as fire- resistance. Steel is embedded in concrete to cater the tensile strength. Generally, bonding between steel and concrete is increased by using steel bars that have deformations on the surface to provide the “gripping” actions.

Steel properties can be described in terms of Young’s Modulus, yield strength, ultimate strength, steel grade designation as well as size or diameter of the bar. Of all these properties, yield stress, f_y of steel is the most useful property when calculating reinforced concrete design. Figure 2.1 shows the typical stress-strain curves for steel.

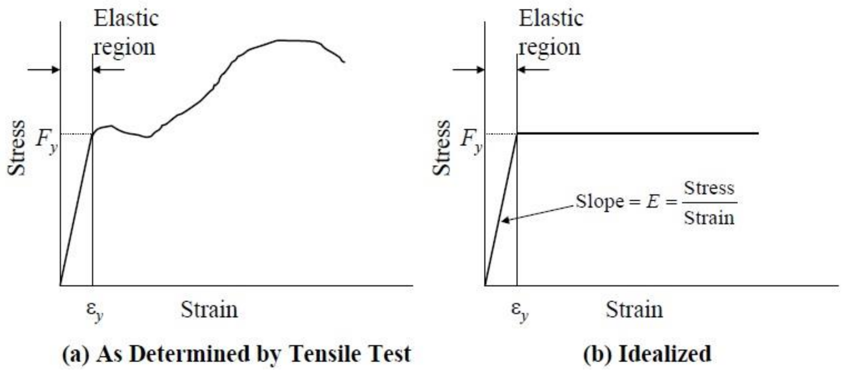


Figure 2.1: Typical stress-strain curves for steel

Source: Steiner (1990)

2.3.1 Sustainability of Steel

Figure 2.2 illustrates carbon footprint over life cycle for various common building materials. Steel industries have contributed to the global climate change. Coal is the raw material used to produce coke which will be converted to iron ore and finally to iron. In this case, almost 60% of energy derived from coal is needed to produce steel. Hence, the production is very energy extensive. Even though there are so many technologies have developed but all those technologies are still using coal-based principle. Furthermore, the coal-fired power plants also generating much of the electricity used by steel industry. Besides contributing to global climate change, the water discharges from steel industry contain hydrocarbons and suspended solids which will also affecting the water quality. In addition, the emissions of particulate materials including PM10s, as well as toxic gases like sulphur dioxide (SO_2) and oxides of nitrogen (NO_x) will pollute the air (Steiner,1990). Even though steel plays an important role as building material in construction industry for reinforced concrete, but its production has impacted the environment (Steiner,1990). Therefore, there is a need for researchers to study on other renewable materials to replace steel.

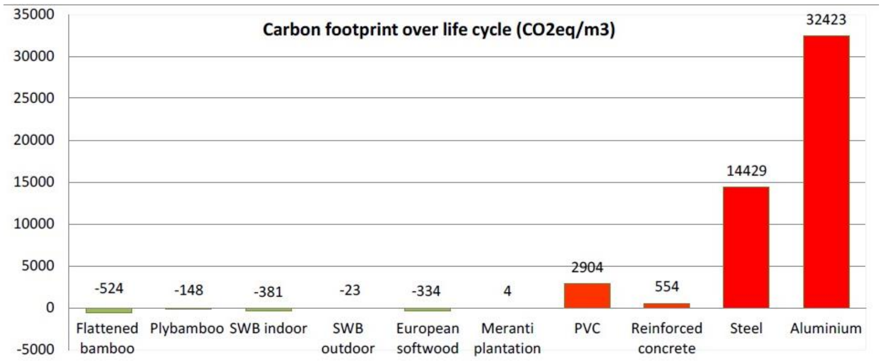


Figure 2.2: Carbon footprint over life cycle for various common building materials

Source: Lugt et al. (2015)

2.4 BACKGROUND OF VEGETABLE FIBERS

Brandt (2008) stated that sustainability of construction can be promoted with the usage of concrete reinforced with vegetable fibers. This is because vegetable fibers are renewable, natural composites which comprise of a cellular structure. Such combination with concrete is in line with environment sustainability as it will reduce the dependency of steel in construction industry. Concrete that integrate with vegetable fibers is able to increase concrete strength and durability which is comparable with steel reinforced concrete. However, the usage of natural fibers has disadvantage of having a high variation of properties which will contribute to unpredictable properties of concrete (Swamy, 1990). This shortcoming can be overcomed through pre-treatment of natural fibers (Savastano et al., 2000). Table 2.1 shows the properties of vegetable fibers. From the table, it can be concluded that most of the vegetable fibers have high tensile strength but low modulus elasticity. Table 2.2 presents the comparison between locally available natural fibers.

Table 2.1: Properties of vegetable fibers

Properties	**Specific gravity (kg/m3)**	**Water absorption (%)**	**Tensile strength (MPa)**	**Modulus of elasticity (GPa)**
Sisal	1370	110	347-378	15.2
Coconut	1177	93.8	95-118	2.8
Bamboo	1158	145	73-505	10-40
Hemp	1500	85-105	900	34
Caesarweed	1409	182	300-500	10-40
Banana	1031	407	384	20-51
Piassava palm	1054	34-108	143	5.6
Date palm	1300-1450	60-84	70-170	2.5-4

Source: Savastano et al. (2000)

Table 2.2: Comparison of locally available natural fibers

Type of Fibers	**Applications**
Sisal	Used for ropes, mats, carpets, cement reinforcement, etc
Bamboo	Reinforcement of concrete beam, circular columns and pillars, can be used for improvement of the concrete permanent bamboo shutter slabs, erosion control, watershed protection, soil remediation, medicinal application, bamboo pulp is used for paper making, etc
Coir	Production of yarn, rope, fishing nets, brushes, mattresses, act as a filler or reinforcement in different composite materials, etc
Jute	Packaging material (bags), carpet, ropes, yarns, wall decoration, etc

Source: Sen and Reddy (2011)

2.5 BAMBOO IN MALAYSIA

Malaysia consists of 70 species of bamboo which includes 50 in Peninsular Malaysia, 30 in Sabah and 20 in Sarawak (Wong, 1989). In 1970, the area of bamboos in Peninsular Malaysia was approximately 20 000 ha (Mc Grath, 1970). Until now, the area has been increased to 329 000 ha (Abd. Razak and Abdul Latif, 1988). Table 2.3 shows the density of bamboo in Peninsular Malaysia.

Table 2.3: Density of bamboo by forest districts, Peninsular Malaysia

State	Districts	Compartment areas		Species
		Hectares	**(%)**	
Johor	South	0.00	0.00	
	Center	0.00	0.00	
	East	4205.25	13.22	B. heterostachya
	North	27615.51	86.78	S. zollingeri
	Total	**31615.51**	**100.00**	
Kedah	South	13585.85	64.99	D. asper
	Center	4834.00	23.13	G. scortechinii, S. grande
	North	2482.70	11.88	
	Total	**20902.55**	**100.00**	
Kelantan	West	5788.00	6.38	G. scortechinii, S. grande
	South	58489.00	64.45	G. species, D. pendulus
	East	26470.00	29.17	
	Total	**90.747.00**	**100.00**	D. asper
Pahang	Bentong	2948.67	2.45	S. brachycladum,
	Jerantut	12112.12	10.06	S. brachycladum,
	Kuantan	9485.00	7.88	
	Kuala Lipis	88814.83	73.79	S. brachycladum,
	Rompin	5342.29	4.44	B. vulgaris
	Temerloh	1664.72	1.38	D. asper, B. ridleyi
	Total	**120367.63**	**100.00**	

Perak	Kinta/Manjung	5297.45	7.83	B. vulgaris, S. zollingeri
	Kuala Kangsar	10.676.90	15.78	B. vulgaris, G. wrayi
	Larut/Matang	5481.00	8.10	D. scandens
	South	6179.74	9.13	S. grande, G. scortechini
	Ulu Gerik	40045.40	59.16	B. vulgaris, S. grande
	Total	**67680.49**	**100.00**	
Selangor	Hulu Selangor	12193.36	30.76	G. scortechinii, D. asper
	Pantai Kelang	0.00	0.00	
	Center	27448.00	69.24	B. vulgaris
	Total	**39641.36**	**100.00**	
Terengganu	West	8060.00	35.08	G. scortechinii, D. asper
	South	13015.00	56.62	
	North	1901.00	8.27	D. sinuatus
	Total	**22976.00**	**100.00**	
P. Malaysia		421722.38	100.00	

Source: Lockman et al. (1992)

2.5.1 Current Uses of Bamboo in Malaysia

Bamboo is known as a useful natural material in rural, traditional lifestyle among Malaysians. Until now, bamboo is rarely used in construction industry. It is only associated with ornamental horticulture, traditional culinary practices as well as cooking delicacy. Table 2.4 shows the commercial bamboo species in Malaysia with their uses.

Table 2.4: Commercial bamboo species in Malaysia

Species	Local Name	Uses
Bambusa blumeana	Buluh duri	Chopstick, tooth picks, furniture, musical instrument, poles, shoots as food
Bambusa heterostachya	Buluh galah/tilan/pering/pengat	Poles, frames, tooth picks, blinds, skewer sticks
Bambusa vulgaris	Buluh minyak/aao/aro/gading/Tamalang	Ornamental, tooth picks, chopsticks
Bambusa vulgaris var. striata	Buluh gading	Ornamental
Dendrocalamus asper	Buluh beting/pering	Shoots as food, higo materials, chopstick
Gigantochloa levis	Buluh beting/bias	Shoots as food, higo materials, chopstick
Gigantochloa ligulata	Buluh tumpat/tikus belalai	Frames, shoots as food
Gigantochloa scortechinii	Buluh semantan/rayah/gala	Handicraft, smallscale industries, incense sticks
Gigantochloa wrayi	Buluh beti/raga	Handicraft, blinds, tooth picks
Schizostachyum brachyladum	Buluh nipis/lemang/padi/urat/rusa/pelang	Handicraft, rice vessels (lemang)
Schizostachyum grande	Buluh semeliang/semenyeh	Frames, leaves used for wrapping Chinese glutinous rice dumpling

Source: Azmy and Abd. Razak (1991)

2.5.2 The Potential of Bamboo for Future Use

Bamboo is a renewable resource due to its rapid growth rate. Thus, it has high potential to be a substitute for slow growing hardwood. Due to its high growth rate and extensive growth of root network, bamboo acts as a good erosion controller, water table preserver and carbon fixator. Furthermore, bamboo also gives positive effect on groundwater level besides gradually improve soil through the nutrients in plant debris (Lugt and Brezet, 2009).

Martin (1996) reported that bamboo stem grows 1.20 meters per day. In terms of annual yield, this has proven bamboo has the potential to substitute slower growing wood species. Due to the high speed of growing, an ongoing discussion related to larger carbon capture and storage capacity of bamboo compared to fast growing softwood trees is elaborated (Lugt and Brezet, 2009). In this case, bamboo materials are expected to be environmentally friendly. Figure 2.3 shows different types of bamboo products.

Figure 2.3: Bamboo products

Source: Larasati (1999)

2.5.3 Environmental Sustainability

Even though bamboo is perceived as environmental friendly material however, the sustainability of bamboo is often been questioned. There are arguments stating that the biomass bamboo production is not sustainable. This is because industrial production of bamboo materials is not only required to go through energy extensive production steps but also produce a lot of waste. Furthermore, bamboo composite products such as Bamboo Mat Board (BMB), Plybamboo, Strand Woxen Bamboo (SWB), and Bamboo Particle Board use many chemical substances like glue, lacquer, etc. (Lugt and Brezet, 2009)

Sustainability of bamboo has been evaluated based on Life Cycle Assessment (LCA). This assessment is a globally acceptable methodology which investigates the impact of materials especially bamboo in full life cycle. In other words, LCA investigates from the beginning stage which covers the resources extraction until the ending stage, demolition or recycling phase (Lugt et al., 2015).

From the findings of Lugt et al. (2015) related to environmental assessment of industrial bamboo products, the main components of carbon footprint from these products are energy consumption for processing, international and locally transportations as well as the use of resin. However, overall from their findings, they have concluded that all the industrial bamboo products produce CO_2 negative to the environment. In construction industry, bamboo has the highest potential to be the most eco-friendly building material available as it can be used in its natural form without any further processing. In terms of resources sustainability, bamboo is bio-based economy, renewable resource which has contributed to a promising solution to resources depletion problem or towards more sustainable living. Furthermore, due to its rapid growth rate as well as high yield, reforestation on degraded land is possible by harvesting bamboo to regain biodiversity loss due to deforestation in tropical and sub-tropical areas.

From all these positive effects of bamboo, the sustainability of bamboo should not be questioned. Reforestation and housing plans using bamboo can be further specified or financially supported by National Plans in order to achieve environmental sustainability objectives as agreed in Kyoto Protocol (Lugt et al., 2015).

2.6 DEGRADATION OF BAMBOO

The utilization of bamboo in Peninsular Malaysia is less even though bamboo has long been a part of traditional and rural life among Malaysians. In Malaysia, the majority of bamboo resources are left unmanaged, becoming wild populations. This is due to its limitation which is lack of durability, making it unsuitable to be construction materials.

Bamboo, being natural resources is susceptible to degradation due to biotic and abiotic agents. In this case, biotic agents represent living organisms such as insects and fungi. This happens due to the presence of starch and carbohydrates in bamboo. Bamboo is degraded by insects and fungi because these biotic agents obtain their food supply from the bamboo. Abiotic factors refer to weathering, cracks/splits as well as fire. Figure 2.4 shows the causes of degradation of bamboo. Table 2.5 summarizes the factors aiding degradation of bamboo

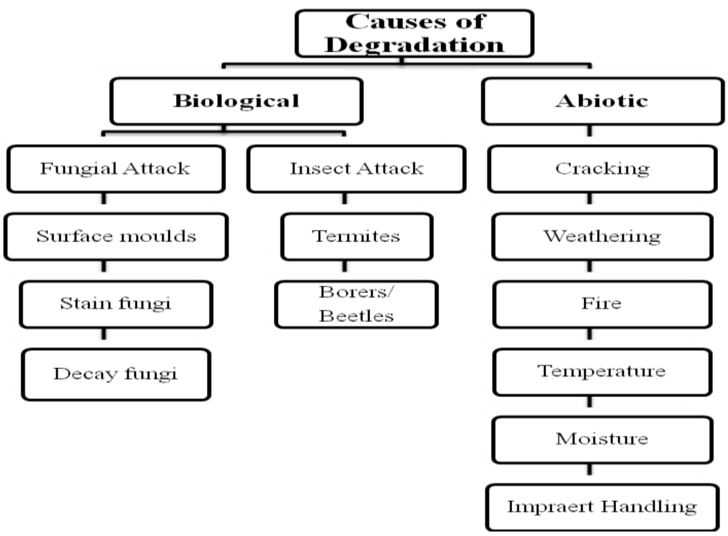


Figure 2.4: Agents causing degradation of bamboo

Source: Bhawan (2006)

Table 2.5: Factors aiding degradations of bamboo

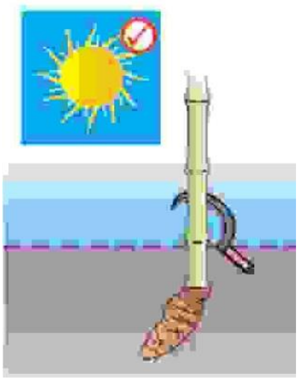
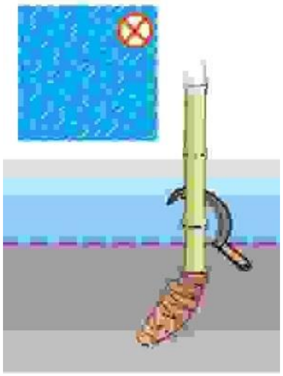
Types	Factors	Explanations
Biological	Food	The presence of starch makes bamboo susceptible to fungi and borers attacks.
	Oxygen	Limited oxygen retarded growth of fungal.
	Moisture content	Moisture level of 40 to 80 % is ideal for rapid growth of fungal. Dry bamboo with moisture level below 20% does not promote fungal growth.
	Temperature	Ideal temperature for fungal growth is between 25*C to 35*C
Abiotic	Sudden drying, direct expose to sun	Cracks and Splits Occurs due to stresses caused by sudden drying and direct exposure to sun. Cracks do not weaken the culm but create point of entry for decay organisms. End splitting can be prevented by coating ends with wax emulsion or coal tar.
	Fluctuations of temperature, relative humidity, solar radiation, repeated drying and wetting	Weathering Occurs due to interaction of different atmospheric conditions. Repeated drying and wetting of exposed bamboo results in widening of minute cracks. Solar radiations cause degradation of cellulose. The wind and dust particles have sand blasting effect on the culm surface giving a weathered look.
	-	Fire Treatment of bamboo to retard is ineffective and expensive.

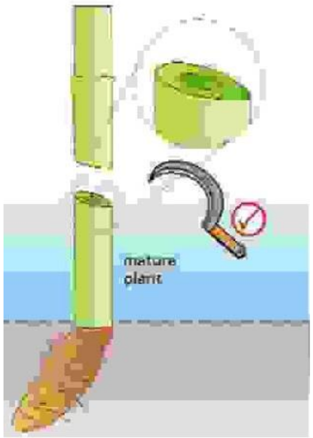
Source: Kumar and Dev (1994)

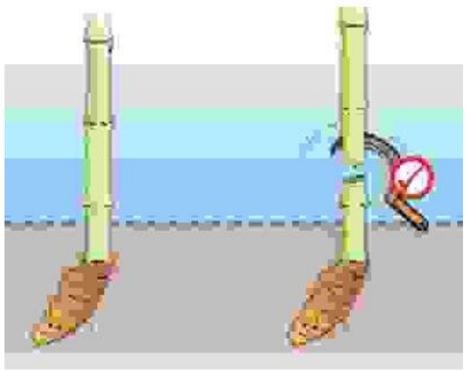
2.6.1 Bamboo Harvesting Practices

Bamboo harvesting practices are essential not only to ensure bamboo culms are resisted to any degrading factors but also to ensure their strengths, shapes, and form are fully retained as per original characteristics. Below are good harvesting practices recommended by National Mission on Bamboo Applications (NMBA) in India as shown in Table 2.6.

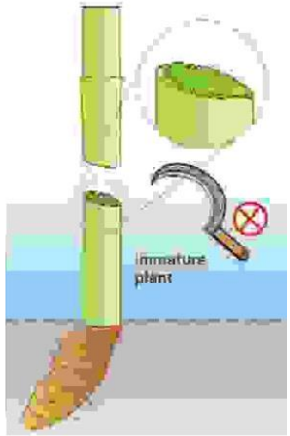
Table 2.6: Bamboo harvesting practices

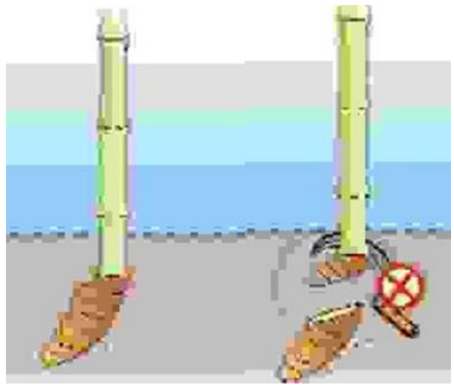
Do's	Avoid
• Harvest during the dry season due to lower starch content which will lower the chances of borer attack. The possibility of splitting and cracking also much lower as the moisture content in bamboo culm is reduced. 	• Harvest during winter season which is the dormancy period of bamboo plant. 
• Select only mature bamboo culms as the starch content is lower.	• Immature bamboo (< 3 years old) has incomplete lignifications which will be less strong and collapse on drying.





- Bamboo culm should be cut at the right height which is 10-15cm from the ground or just above the node.





- Cutting this way will weaken the plant system.

Source: National Mission on Bamboo Applications (NMBA, 2015)

2.6.2 Post Harvesting Practices

After harvesting, bamboo should be properly stored by keeping bamboo culms away from direct contact with soil as well as to ensure good ventilation is provided. It is suggested to place bamboo culms on tarpaulin sheet, thick plastic sheet or raised on a platform. This will protect bamboo from fungal and termite attack. Besides that, bamboo culms are required to be protected from rapid changes of moisture content. This can be done by covering with thin canvas sheet or storing in water tank to ensure leaching of starch from bamboo culms. Prophylactic treatment is needed for bamboo that needs to be transported over a distance which is highly favorable to insect attacks. Infected culms also needed to be removed from storage area. Figure 2.5 shows the different methods to store bamboo culms after harvest.

Bamboo culms can be stacked vertically against the wall as shown in Figure 2.6 which will ensure quick drying and reduce the chances for fungal attack. Besides that, bamboo can be stacked horizontally on raised platforms in Figure 2.7 to avoid direct contact with the ground as well as to allow uniform drying. This way of storage is suitable for large stacks of bamboo. However, this way might cause the culms at bottom to crack or bend due to the weight of stack.

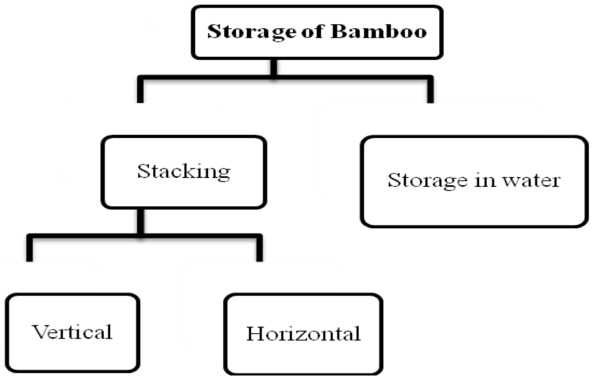


Figure 2.5: Method of bamboo storage

Source: Bhawan (2006)

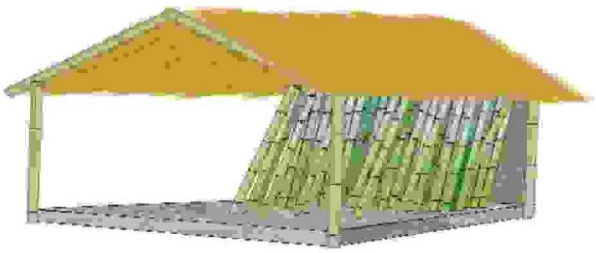


Figure 2.6: Vertical stacking

Source: Bhawan (2006)

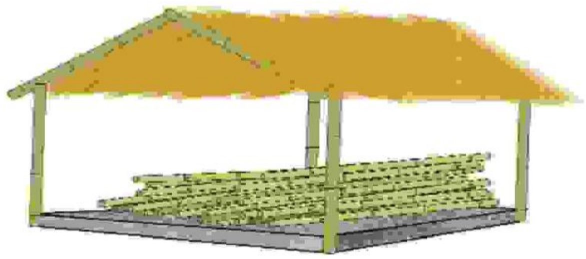


Figure 2.7: Horizontal stacking

Source: Bhawan (2006)

2.6.3 Treatment Methods

Bamboo treatment methods can be divided into two categories – chemical and traditional methods. Figure 2.8 shows the method of treatment for bamboo.

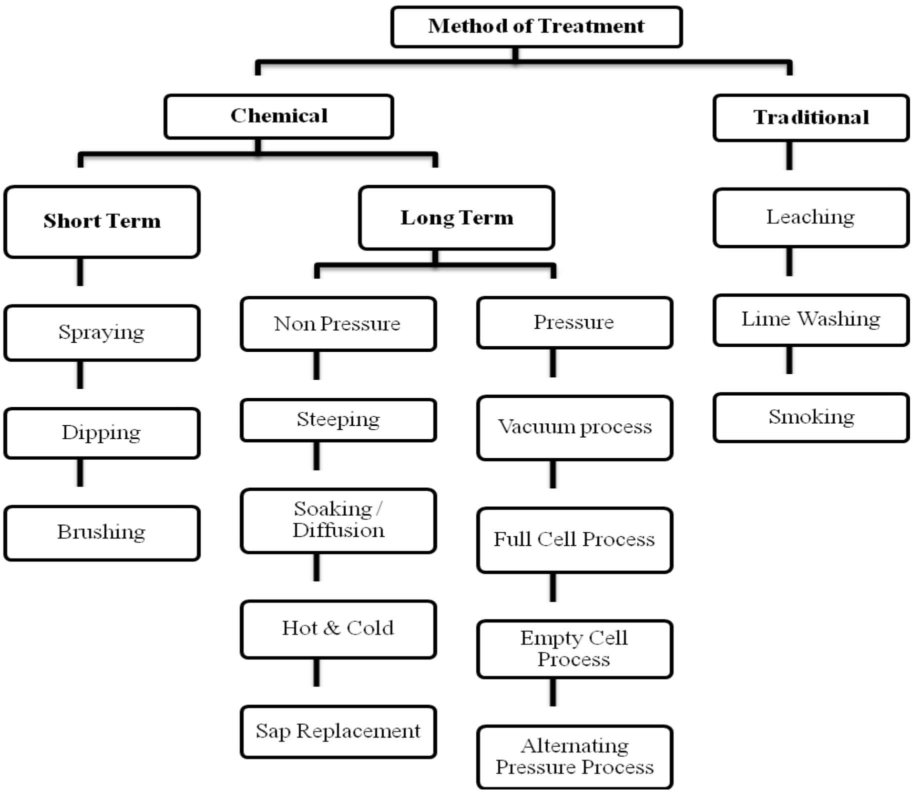


Figure 2.8: Bamboo treatment method

Source: Bhawan (2006)

2.6.4 Microscopy

Bamboo is a natural material. Therefore, it is susceptible to degradation if it is not properly treated. In this aspect, the choices of chemical treatment are essential as it must not be affecting the microstructure of bamboo.

2.6.4.1 Black Oxide Primer

There are none of any research conducted to study the morphology behaviour of bamboo treated with black oxide primer. Generally, black oxide is known as the conversion coating formed by a chemical reaction with the iron in metal to form an integral protective surface. This is in contrast with other type of applied coating which bonds to the metal but does not react chemically. A black oxide conversion coating is applied to ferrous alloys when a blend of caustic, oxidizers and additives react with the iron to form magnetite (Fe_3O^4), the black oxide of iron. Therefore, it is used to treat bamboo and its morphology behaviour was observed.

2.6.4.2 Sodium Hydroxide Solution

Under scanning electron microscope (SEM), there are many uplifted filaments that packed together on the surface of bamboo fibers before and after treatment. The uplift materials are organic which have weak binding (Okubo et al, 2004). Therefore, it can be easily separated from the surface of fiber using external forces. Alkaline treatment will remove these filaments and therefore the surface will become clean with some joints and tiny fissures attachments. This explains that the inorganic impurities such as wax and hemicelluloses can be removed. The changes in terms of morphology is a good sign showing the increase in effective fiber surface for interlocking adhesion with resin besides leading to reduction of fiber diameter. In short, alkaline treatment plays an important role in terms of interfacial bonding when fibers are used as reinforcing agents (Zhang et al., 2015)

2.6.5 Physical Properties

The study of bamboo physical properties can be done in terms of density, initial moisture content, water absorbability, and compression as well as tension characteristics. These properties are essential to be studied as it will aid in the feasibility investigation of substituting steel reinforcement with bamboo in reinforced concrete.

Generally, bamboo has very low density. Therefore, it is suitable to become building materials especially for light construction. Based on the study than by Gupta and Ganguly (2015), it was found that the initial moisture content of bamboo increases along the bamboo culm from top to bottom. Furthermore, bamboo also possesses high water absorbability if it is untreated and also the nodes existence also increases the absorption of water. In terms of compression, bamboo failed either in cracking of fiber or crushing. From his findings, most of the bamboo failed in both modes. The additional cross sectional area in nodes has contributed to higher compressive strength compared to specimens without nodes. For tensile characteristic, bamboo has comparable value to yield strength of structural steels. Hence, bamboo is able to resist the tensile load in concrete.

Certain adaptations and modification shall be done on bamboo stick before it is be used as reinforcement in concrete. Studying on the properties of bamboo will ensure the most ideal bamboo reinforcement can be prepared.

2.7 ISSUES RELATED TO BAMBOO REINFORCEMENT IN CONCRETE

Bamboo sticks cannot be used naturally as reinforcement in reinforced concrete. Therefore, application of treatment or necessary adaptation should be applied on bamboo sticks. This is because there are several issues involved which are closely related to the strength of bamboo reinforced concrete.

2.7.1 Water Absorbability

Bamboo has high water absorbability. This is one of the factors that should be carefully considered when it is used as replacement if steel reinforcements in concrete. Concrete, as a composite material is made up of cement, aggregates and water. The utilization of bamboo as a substitute for steel reinforcement in concrete will expose bamboo to wet condition.

In wet environment, bamboo starts to swell as it absorbs water. The strength of concrete in fresh state is insufficient to prevent bamboo from swelling which will then cause expansion. Hence, crack will be induced in concrete. As soon as the water in cement has used up, the bamboo will shrink in volume by adjusting its moisture content in dry environment. Consequently, larger voids compared to volume of bamboo are present, causing little physical bonding between bamboo and concrete. This mechanism is explained in Figure 2.9. (Moroz et al., 2014)

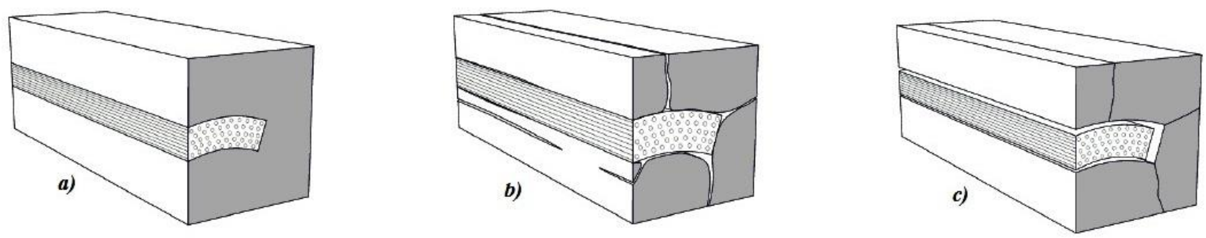


Figure 2.9: Behaviour of untreated bamboo reinforcement in concrete (a) Natural bamboo in fresh concrete, (b) Cracks caused by swelling of bamboo during curing of concrete, (c) After concrete has cured, dried bamboo in expanded voids de-bonded from concrete mix.

Source: Moroz et al. (2014)

Factors that influence the bonding between bamboo and concrete such as cement matrix adhesive properties, shear resistance of concrete due to surface form, roughness of reinforcing bars and the compression friction forces appearing on the surface of the reinforcement bar due to shrinkage of concrete (Sabnani et al., 2013). The swelling and shrinkage properties of bamboo when absorb water has become the limitation in replacing steel reinforcement. Therefore, an effective treatment using water repellent is essential in order to improve the bond between segments of bamboo and concrete. Sabnabi et al. (2013) stated the factors affecting the treatment such as properties of adhesive, water repellent property as well as the topography of bamboo and concrete interface. From the findings of Sabnani et al (2013), application of epoxy with fine sand coating is an effective treatment besides using asphalt paints, tar based paints and other bituminous materials. Those materials are highly recommended as they have good impermeability properties.

2.7.2 Bonding Strength

Pull out tests were conducted to investigate the bonding strength between bamboo and concrete. Sikadur 32-Gel, a product used to prevent corrosion of reinforcing bars has been applied on bamboo segments. From this investigation, treated bamboo with Sikadur 32-Gel had improved and increased bonding strength up to 5.29 times compared to untreated segments of bamboo and steel (Sabnani et al., 2013).

Calwell and Wolff (2015) suggested that only a thin coating of water resistant treatment shall be applied to bamboo before using it as reinforcement to concrete. This is because a thicker coating will create a weaker bond due to lubrication of the bamboo with concrete. In their findings, they had explained bituminous paint is the best option as a water proofing treatment for bamboo reinforced concrete. A dip coat or brush coat can be used to ensure a fine layer is applied. Besides bituminous paint, epoxy also has high water repellent ability according to their findings. However, even though epoxy gives a smooth finish when it is applied on bamboo but it may be possible causing the bamboo to slide due to its low adhesion bond between bamboo and concrete. Therefore, in order to increase the adhesiveness, fine sand should be added after applying thin epoxy coating. Paraffin wax is also one of the treatment alternatives that possesses completely impervious to water. It is suggested to use 1.5 mm diameter copper wire to wrap helically around the wax coated bamboo as paraffin wax has low level of adhesion. Thus, extra treatment is needed to be done in order to resist sliding of the reinforcement.

However, the pull out test results conducted by Calwell and Wolff (2015) showed that it failed and yieded the lowest bond strength. Table 2.7 summarized the bonding strength of bamboo segment subjected to pull out test.

Table 2.7: Bonding strength of bamboo segment subjected to pull out test

Treatment	**Bond strength of treated bamboo**	**Bond strength of untreated bamboo**
Without treatment	0.52	1.00
Negrolin + sand	0.73	1.40
Negrolin + sand + wire	0.97	1.87
Sikadur 32-Gel	2.75	5.29
Steel	3.25	6.25

Source: Calwell and Wolff (2015)

2.7.3 Adhesion Strength

Another issue of bamboo is the adhesion strength. Bamboo is a natural material which has smooth, waxy coating on the outer layer. This will prevent adhesion between segment of bamboo and concrete if it is used as reinforcement in concrete. Steel reinforcement provides strong adhesion when placed in concrete due to the existence of ribs. In order to provide surface modification on bamboo, Calwell and Wolff (2015) suggested to apply a thin layer of fine sand on the smooth outer coating before it is placed in concrete. Besides thats, this also can be done by cuttig edges of the bamboo or by wrapping it helically with thin wiring.

2.7.4 Bamboo Reinforced Concrete Beam

In the era with expanding world population and ever increasing demand on supply of materials, development of new materials that are cheaper and offer better quality is needed to cater the current demand. In Malaysia, there are various natural resources available such as coconuts, palm oil, and bamboo. The utilization of natural resources such as bamboo in construction industry for various applications has gotten the attention of researchers worldwide. This section provides the literature review of bamboo reinforced concrete beam which had been conducted by researchers.

Using bamboo reinforcement is an advantageous method to reuse existing beam that required strengthening. Bamboo sticks are suitable building material used to strengthen reinforced concrete beam that overloaded or under designed. Load carrying capacity increases as much as 84% with the utilization of bamboo sticks at bottom and both sides of beam (Nahar and Rahman, 2015).

Bamboo is unable to prevent concrete from cracking under ultimate loading. However, bamboo reinforcement increases the load carrying capacity of beam (Rahman et al., 2011)

For reinforced concrete having the same dimensions, it can be seen that the load bearing capacity increases about three times for bamboo reinforced concrete beam compared to plain concrete. Bamboo reinforced concrete beam has maximum deflection of 1.5 times compared to plain concrete (Sethia and Baradiya, 2014)

2.8 SUMMARY OF FINDINGS

This research is conducted to investigate on the viability of bamboo sticks as reinforcement in reinforced conrete beam. Therefore, there are three aspects were focused in this study which consisted of chemical treatment, physical properties and structural behaviour of reinforced concrete beam. Research gaps were identified based on the literature review.

For chemical treatment, this study focused on the microscopy structure of bamboo sources in Malaysia. The morphology behavior of bamboo treated with black oxide primer and alkaline solutions (NaOH) using scanning electron microscope (SEM) was studied in Malaysia perspective. Bamboo is natural material. Therefore, it should be treated before used. In this study, black oxide primer was introduced. Hence, the feasibility of black oxide primer to act as waterproofing agent in bamboo when it is left immersed in water for 30 days was investigated.

In the perspective of bamboo physical properties, this research focused on the bamboo resources in Malaysia. Proper adjustments were suggested based on the results to ensure it is suitable to be used as reinforcements. This study was aim to explore the possibility of bamboo resources in Malaysia to be building materials in construction industry.

Based on the results obtained from chemical treatment and physical properties of bamboo, proper adaptations were done to bamboo reinforcement. Four-point bending test was conducted and comparisons were made to investigate the performance of reinforced concrete beams with different types of reinforcement. Besides that, the effectiveness of bamboo splints as reinforcement in beam instead of using the bamboo culm was studied. Bamboo has smooth surface. In this study, bamboo reinforcements were coiled using wires and application of some sand were done to create bonding between concrete and bamboo. From this, the viability of this method can be investigated.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, all the conducted experimental works of research were presented. The experimental works conducted were designed mainly to identify the physical properties of bamboo sticks, the morphology behavior of chemical treated and untreated bamboo sticks using scanning electron microscope as well as to investigate on the feasibility of bamboo sticks to be reinforcement in concrete through four-point bending test.

Several samples of bamboo sticks were prepared to test the physical properties in the aspect of density, initial moisture content, water absorbability, compression and tensile strength. Next, bamboo samples were treated with chemical solutions such as black oxide primer and sodium hydroxide solution. The results from both of these aspects – physical properties and chemical treatment effect would become the reference to prepare the most suitable bamboo reinforcement in concrete. All the details were elaborated in this chapter. Figure 3.1 presents the flowchart of the overall experimental works in this research.

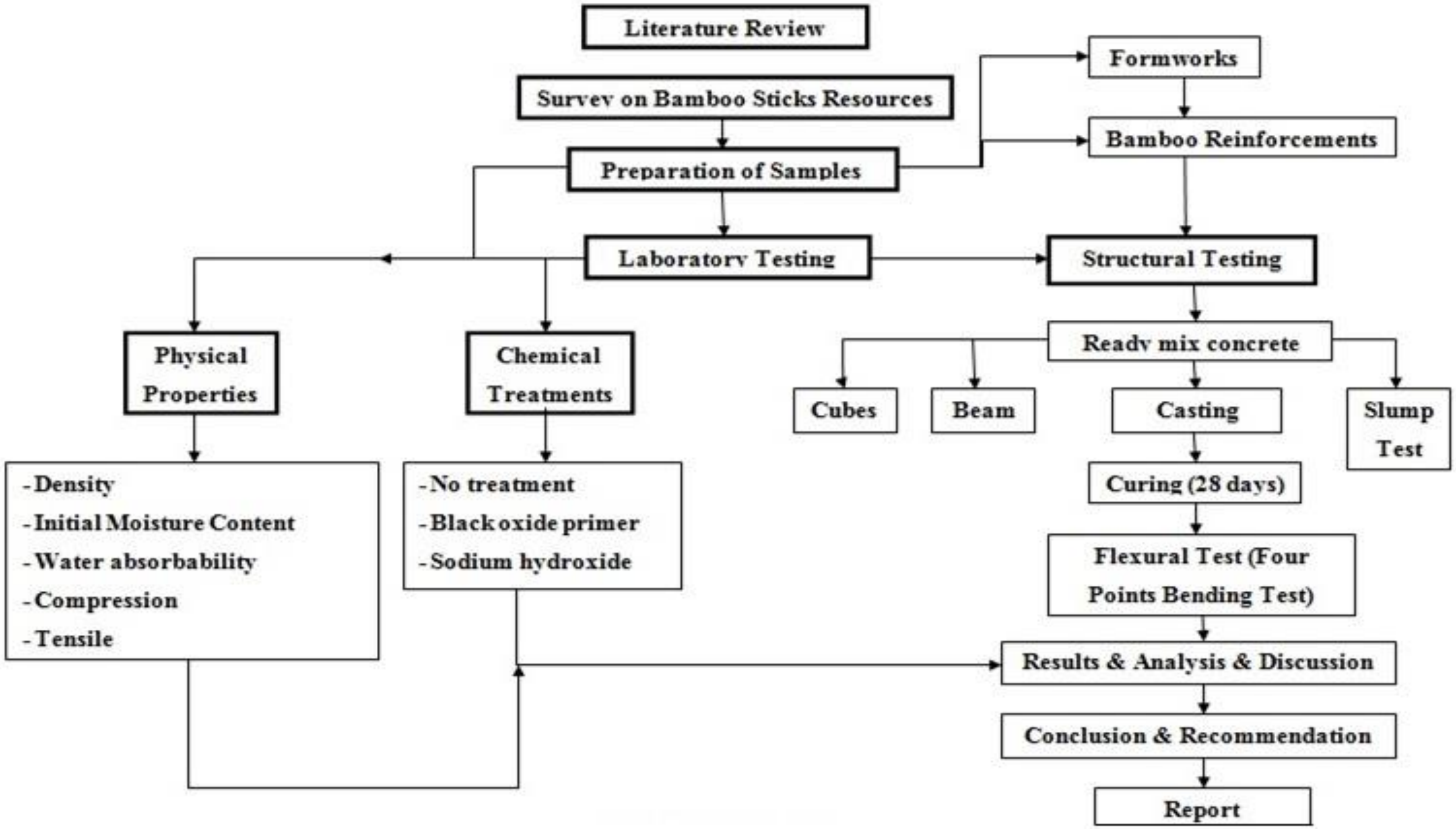


Figure 3.1: Flow chart

3.2 SOURCES OF BAMBOO

For the purpose of this research, sources of bamboo were taken from Pekan, Pahang as shown in Figure 3.2. The taxonomy name of the bamboo used in this study is unknown as it grows wild in the village in Pekan, Pahang. Therefore, several photographs of bamboo were taken and sent to Forest Research Institute Malaysia (FRIM) to identify the species. As a result, the scientific name of this bamboo species is known as *Bambusa Vulgaris*. The value of bamboo still remains unknown among community. Thus, most of the source of bamboo is left as unmanaged populations. Figure 3.3 shows felled bamboo culm is cut using "*parang*" into smaller sizes.

Figure 3.2: Sources of bamboo in Pekan, Pahang

Figure 3.3: Felled bamboo culm is cut into smaller size using "*parang*"

3.3 PREPARATION OF MATERIALS

Before execution of laboratory works, material preparation is essential in which it is begin with harvesting bamboo to treatment and finally cutting bamboo at the desired size for experimental samples. Further explanation is presented in this chapter.

3.3.1 Bamboo Harvesting

The bamboo culms must be treated to avoid decay or disintegration, splits or cracks as well as unseen stains or blotches. The technique of storage is very important. Post harvesting consists of several methods. For this research, the culms were stacked vertically and horizontally as shown in Figure 3.4 and Figure 3.5 respectively in a closed area which was under shed as well as keeping them away from direct contact with soil. This is done to avoid fungal and termite attack.

Figure 3.4: Vertical stacking

Figure 3.5: Horizontal stacking

3.3.2 Preparation of Laboratory Testing Samples

As soon as the harvesting stage of bamboo completed, long bamboo is cut according to the required dimension as preparation for laboratory testing. In this study, estimations of bamboo dimensions for each of the testing were conducted to prevent wastage of resources. Bamboo samples were prepared for physical properties tests, chemical treatment as well as reinforcements in reinforced concrete beams.

Figure 3.6 illustrates the dimensions of bamboo were measured whereas Figure 3.7 shows bamboo was cut using band saw. Figure 3.8 illustrate the prepared samples for laboratory testing and Figure 3.9 show the labelling of samples.

Figure 3.6: Dimensions of bamboo were measured

Figure 3.7: Bamboo was cut using band saw

Figure 3.8: Prepared samples for laboratory testing

Figure 3.9: Labelling of samples must be clear and permanent

3.3.3 Bamboo Reinforcement

There is no standard procedure to be referred for the design of bamboo reinforced concrete beams. Therefore, reinforced concrete design of the steel area of reinforcement for compression and tension were calculated according to EUROCODE. According to the calculation, four main reinforcement steel bars of 10 mm diameter were sufficient based on the size of beams to be cast. Bamboo reinforcements were prepared accordingly. Bamboo is a natural material. Therefore, it cannot be placed in concrete in its natural state.

The preparation of bamboo reinforcement was begin by cutting the bamboo into desired length and diameter using machineries available in laboratory. Then, it is coiled with wire in order to create bonding between bamboo splints and concrete. Bamboo is hygroscopic and will undergo degradation in long term. Therefore, the reinforcement samples were treated using black oxide primer. Besides act as water repellant agent, oxide primer can also protect bamboo against insect infestation. After coating with oxide primer, bamboo is left for drying process in ambient temperature for two days until it dries completely as shown in Figure 3.10. Figure 3.11 shows bamboo used as main reinforcement whereas Figure 3.12 illustrates bamboo reinforcement were placed in formwork.

Figure 3.10: Treated bamboo stick coiled with wire

Figure 3.11: Bamboo used as main reinforcement

Figure 3.12: Bamboo reinforcement were placed in formwork

3.3.4 Steel Reinforcement

In this study, three samples of reinforced concrete were prepared for comparison in terms of strength. As a control sample, steel reinforcing bars were used as the main reinforcement. Therefore, steel bars of diameter 10 mm were prepared as main reinforcement for this study as shown in Figure 3.13 and Figure 3.14.

Figure 3.13: Steel reinforcement

Figure 3.14: Steel reinforcement was placed in formwork

3.3.5 Bamboo Shear Link

For bamboo shear link, bamboo branches were used. Bending of branches according to the required size was done carefully to avoid breaking the link. The bended links were tightened using steel wire. Next, the bamboo shear links were dipped coated with black oxide primer as shown in Figure 3.15 to provide water repellent effect when it is placed in concrete.

Figure 3.15: Untreated and treated bamboo shear link

3.3.6 Steel Shear Link

In this study, the diameter of shear links used were 6 mm. Steel shear links were bend manually as shown in Figure 3.16 because the bending machine available in laboratory was under maintenance. Through this method, there were higher possibilities of obtaining inaccuracy in terms of dimensions. In this case, cautions were taken to ensure that the links were bended according to the correct dimensions.

Figure 3.16: Steel shear link

3.3.7 Formworks

For this study, the size of beam required to be cast was 120 mm (width) x 300 mm (height) x 1600 mm (length). Therefore, formworks were fabricated using available machineries in Faculty of Civil Engineering and Earth Resources (FKASA) laboratory as shown in Figure 3.17. The fabricated formworks were made up of wooden planks and plywood. Wooden planks act as an outside shutter whereas plywood acts as concrete shuttering panels. Before starting fabrication works, plywood and wooden planks should be checked ensuring there were no rough surfaces that would possibly destroyed the surface of casted beams. The inner surface of formworks were coated by mould oil to ease formworks disassemble process as well as to avoid adhesion of concrete hardened. The fabricating work progress is shown in Figure 3.18. Figure 3.19 shows the completed formwork.

Figure 3.17: Machineries used to cut plywood and wooden planks

Figure 3.18: Formwork fabrication works in progress

Figure 3.19: Formworks completed

3.3.8 Casting Concrete

Casting of beams for this study was using ready mix concrete supplied by PAMIX SDN BHD. The composition of ready mix concrete can be referred in **APPENDIX B**. Inspection of formworks as well as prepared reinforcements should be done before pouring concrete. Formworks should be free from any impurities, defects or debris as shown in Figure 3.20. Besides that, the stability of formworks needed to be inspected in order to ensure they can withstand the weight of concrete. Furthermore, the reinforcements should be ensured tightens. Application of grease or oil should be done on every parts of the formwork before pouring concrete to enhance smooth surface of concrete after demould as depicted in Figure 3.21.

Figure 3.22 shows the reinforcements were placed in formworks. Figure 3.23 depicts the action of vibrating concrete using hand-held vibrator whereas Figure 3.24 illustrates the work of beam surfacing. Figure 3.25 represents the completion of casting concrete. Figure 3.26 shows the cube moulds and Figure 3.27 illustrates the vibrator used for concrete cubes.

Figure 3.20: Formwork must be free from impurities

Figure 3.21: Formwork must be applied with grease before pouring concrete

Figure 3.22: Reinforcements were placed in formworks

Figure 3.23: Vibrating concrete using hand-held vibrator

Figure 3.24: Surfacing the beam

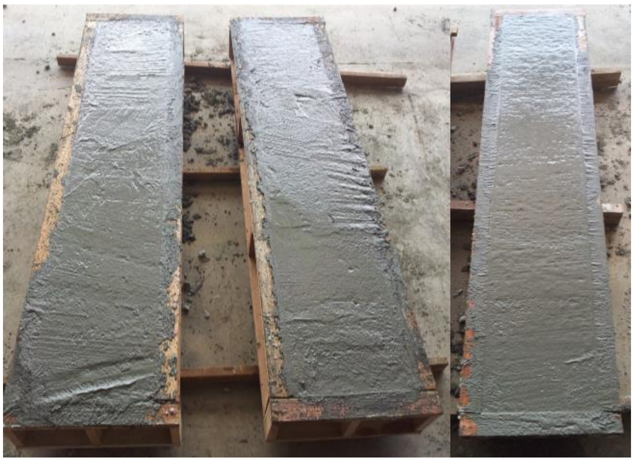


Figure 3.25: Casting concrete completed

Figure 3.26: Cube moulds

Figure 3.27: Vibrator for concrete cubes

3.4 CURING

In order to achieve better strength, concrete curing plays an important role. For this study, as soon as concrete has been poured into concrete cubes and beams formworks, were left to cure for 24 hours. After 24 hours, the cast beams were unmolded in Figure 3.28 and covered with gunny bags as shown in Figure 3.29. In order to provide continuous moisture to the casted beams, therefore, the gunny bags were wetted periodically in Figure 3.30. The wetting process was repeated until 28 days so that the casted beams can achieve the strength desired. For concrete cube, curing method was by placing cubes in water tank and the strengths were recorded for 3, 7 and 28 days as shown in Figure 3.31.

Figure 3.28: Demoulded beams

Figure 3.29: Gunny bags were used to cover beams for curing

Figure 3.30: Wetted gunny bags for concrete curing

Figure 3.31: Concrete cube curing

3.5 CHEMICAL TREATMENT

In the study of chemical treatment, small section of bamboo is cut and treated with black oxide primer and sodium hydroxide solutions. There is no standard procedure available for this testing. The testing procedure is presented.

3.5.1 Black Oxide Primer

Samples of bamboo are dip coat or brush coat with black oxide primer as shown in Figure 3.32. Coated samples were left to dry at room temperature for 24 hours.

Samples of treated and untreated bamboo sticks were tested using a scanning electron microscopy (SEM) to study on morphology of the bamboo sticks surface. The main purpose of carrying out this test is to investigate the effect surface modification of bamboo when samples are treated with black oxide primer.

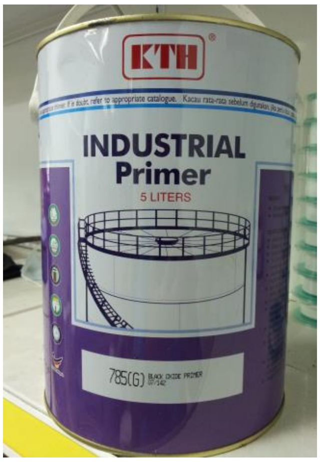


Figure 3.32: Black oxide primer

3.5.2 Alkaline Treatment

Bamboo samples were soaked in sodium hydroxide solution (NaOH) for 3 hours at room temperature with different concentrations (5%, 10%, 15%) as shown in Figure 3.33. Soaked samples were continuously washed under running water and dried for 2 days at room temperature. Samples of treated and untreated bamboo sticks in Figure 3.34 were tested using a scanning electron microscopy (SEM) to study on morphology of the bamboo sticks surface. The main purpose of carrying out this test is to investigate if there are any structural changes that occur after treatment.

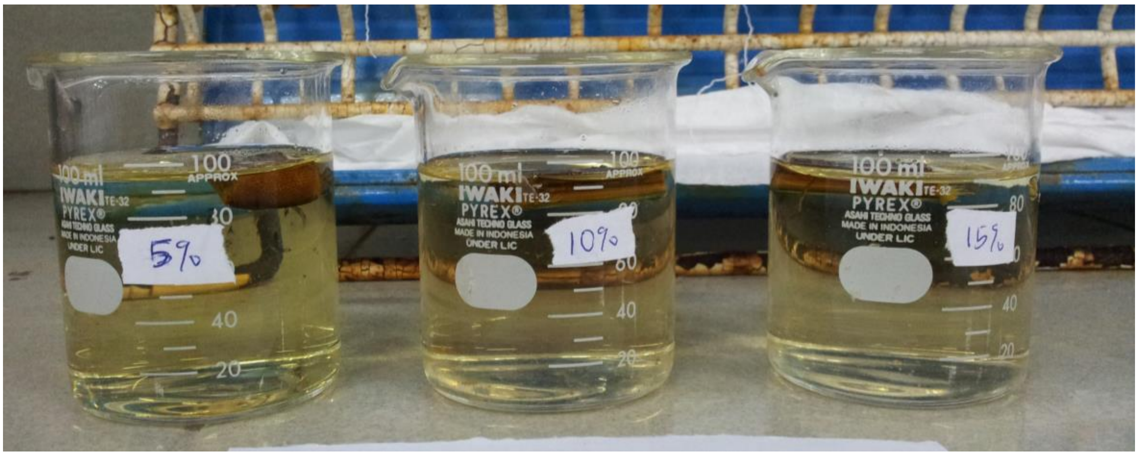


Figure 3.33: Samples immersed in sodium hydroxide solution

Figure 3.34: Samples are ready for scanning electron microscope (SEM)

3.6 PHYSICAL PROPERTIES

There are five testing involved for physical properties tests. There are density test, initial moisture content, water absorption, compression and tensile tests. In this study, the laboratory works to test the physical properties of bamboo were conducted in accordance to ISO standard 22157-1:2004.

3.6.1 Density Test

The basic principle of conducting bamboo density test is by weighing and taking dimensional measurements of samples to obtain mass and volume of bamboo respectively. Mass of unit volume of bamboo is calculated. Since this test is only dependent on oven dry mass and green volume of bamboo, therefore, density test can be used as an appropriate parameter to classify bamboo. In other words, density test can be considered as an indicator of purity of a material. Figure 3.35 illustrates the samples prepared for density test whereas Figure 3.36 shows the thickness of samples measured using vernier callipers. Volume of sample was measured using water displacement method as shown in Figure 3.37.

The following are laboratory testing procedures for density test:

i) Twelve samples of 25 mm in length x 25 mm in width x full wall thickness were prepared. The samples were taken from different position of bamboo sticks mainly from the base, middle and top.

ii) By using water displacement method, the volume of samples was measured.

iii) Samples were place in oven for 24 hours at 130°C in order to obtain the oven dried mass.

iv) The mass density (gm/cm3) for all samples was calculated by using the following formula:

$$\text{Mass Density}\left(\frac{\text{gm}}{\text{m3}}\right) = \frac{\text{Oven dry mass}}{\text{Volume of samples}} \tag{2.1}$$

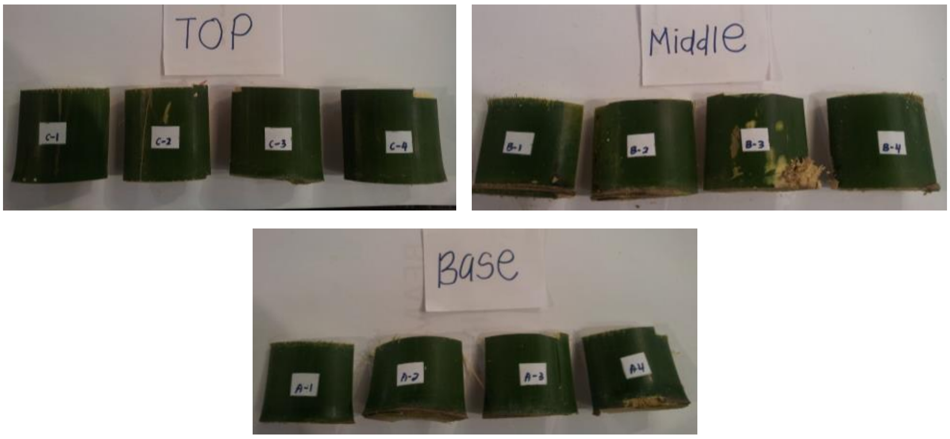


Figure 3.35: Samples prepared for density test

Figure 3.36: Thickness of samples measured using vernier callipers

Figure 3.37: Volume of sample is measured

3.6.2 Initial Moisture Content Test

With changes in surroundings temperature and relative humidity, bamboo, being hygroscopic material, its moisture content also changes. When bamboo starts to lose its moisture content, it starts to shrink. Bamboo shrinkage is directly proportional to amount of water lost. Therefore, this aspect needs to be considered when using bamboo sticks as reinforcement in concrete. If shrinkage of bamboo sticks which present in concrete as reinforcement happens, additional stresses and spaces will be created between bamboo and concrete. This will eventually contributed to decreasing in bonding between these two elements.

Figure 3.38 shows the prepared samples for this test. In this study, this aspect is tested by weighting the loss in mass of samples on drying to constant mass as shown in Figure 3.39. Laboratory testing procedures are as follows:

i) Twelve different types of bamboo sticks mainly zero, one and two internodes were taken from different portions of bamboo.
ii) All the samples were oven-dried for 24 hours at 130*C as soon as the initial weight of samples had been measured.
iii) Oven dried weight of samples were measured after 24 hours.
iv) Initial moisture content of samples were calculated using the following formula:

$$\text{Moisture Content } (\%) = \frac{\text{Initial Weight (gm)} - \text{ Oven dried Weight (gm)}}{\text{Initial Weight (gm)}} \text{ X } 100\% \quad (2.2)$$

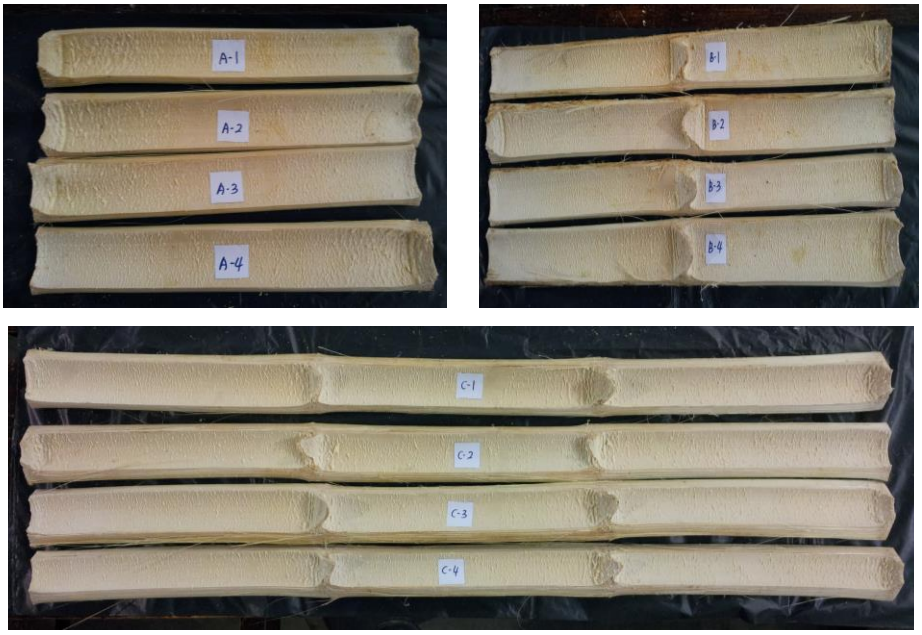


Figure 3.38: Prepared samples for initial moisture content test

Figure 3.39: Oven dried weight of sample is measured

3.6.3 Water Absorption Test

Bamboo is a hygroscopic material which absorbs moistures from its surroundings. When bamboo loses or gains moisture, its dimension changes. Due to its high water absorbability characteristic, bamboo reinforcement swells as it absorbs and reduces water in concrete mix. When concrete dry, bamboo stick reinforcement contracts as well as creating gaps between bamboo and concrete segments causing decreasing the bonding strength. In this case, the bonding between members fails. Table 3.1 summarized the samples prepared for water absorption test. Figure 3.40 shows the treated and untreated samples whereas Figure 3.41 illustrates the water curing tank.

Table 3.1: Samples prepared for water absorption test

Type A – Non Treated (No coating available)	**Type B – Treated (Coated with Black Oxide Primer)**
A-1 Zero node	B-1 Zero node
A-2 One node	B-2 One node
A-3 Two nodes	B-3 Two nodes

Water absorption test is conducted in laboratory according to the following:

i) Bamboo samples were cut and prepared based on Table 3.1.

ii) The prepared samples were kept in oven at 130°C for about 24 hours to remove all the moisture content present.

iii) Oven dried samples were prepared based on Type A and Type B requirements.

iv) The initial oven dry weight and thickness of samples were taken respectively before immersing in a water tank for 30 days at room temperature.

v) At 15th and 30th day of immersion, the final saturate weight and thickness of samples were measured respectively.

vi) The amount of water absorbed by Type A and Type B samples was calculated based on the following formulae:

$$\text{Water absorbed (gm)} = \text{Final Saturated Weight (gm)} - \text{Oven dried Weight (gm)} \qquad (2.3)$$

$$\text{\% by weight of water absorbed} = \frac{\text{Water absorbed (gm)}}{\text{Final Saturated Weight (gm)}} \text{ X } 100\,\% \qquad (2.4)$$

Figure 3.40: Treated and untreated samples

Figure 3.41: Water curing tank

3.6.4 Compression Test

Compressive strength test is important to investigate on the maximum allowable stresses in bamboo which will aid the upper fiber of doubly bamboo reinforced concrete beam. The basic principles of this test are to determine the nominal modulus elasticity and the ultimate compressive stress of specimens from culms. Table 3.2 summarizes the dimension of samples for compression test. Figure 3.42 shows the prepared samples for compression test and Figure 3.43 illustrates the compression test.

Table 3.2: Dimension of samples for compression test

Specimen	Nodes	Dimensions			Cross-Sectional Area, A (mm^2)
		Gauge Length, L (mm)	Outer diameter, D (mm)	Thickness, t (mm)	
A-1	0	290	71.82	17.49	2985.63
A-2	0	280	61.55	16.11	2300.07
A-3	0	298	62.82	8.96	1516.28
B-1	1	536	83.63	17.48	3633.10
B-2	1	502	77.21	18.57	3421.47
B-3	1	510	80.11	12,69	2688.17

The laboratory procedure as follows:

i) Zero and one node of bamboo samples are prepared based on Table 3.2. While preparing the samples, the ends must have a smooth surface in order to achieve uniform stress application.

ii) Compressive load was applied and the loading rate for all samples was kept constant to be 3.0 kN/sec.

iii) Ultimate compressive strength of the samples was obtained by the following formula:

$$\text{Ultimate compressive strength (MPa)} = \frac{\text{Force (N)}}{\text{Cross sectional area (mm2)}} \tag{2.5}$$

iv) Graph of stress and strain was plotted for each sample using the following formula:

$$\text{Stress (MPa)} = \frac{\text{Load (N)}}{\text{Cross Sectional Area (mm2)}} \tag{2.6}$$

$$\text{Strain} = \frac{\text{Displacement (mm)}}{\text{Gauge Length (mm)}} \tag{2.7}$$

Figure 3.42: Prepared samples for compression test

Figure 3.43: Compression test

3.6.5 Tensile Test

This test is carried out to identify the ultimate tensile strength of bamboo as it will be the fundamental data used to calculate the maximum allowable tensile stress in bamboo. Stress vs strain graph is plotted to study the characteristic property of a material such as creep, modulus of elasticity, toughness and ductility. Bamboo splints and bamboo rod were tested in this study. Table 3.3 summarizes the dimension of specimen for bamboo splints whereas Table 3.4 is for bamboo rod. Figure 3.44 and Figure 3.45 show the sample of bamboo splints and rod respectively. Figure 3.46 shows the tensile test conducted.

Table 3.3: Dimension of specimen for bamboo splints

Specimen	Nodes	Dimensions			Cross-Sectional Area, A (mm^2)
		Gauge Length, L (mm)	Width, B (mm)	Thickness, t (mm)	
A-1	1	300	30.70	22.91	703.34
A-2	1	300	26.74	21.40	572.24
A-3	1	300	31.95	22.06	704.82
A-4	1	300	31.17	25.26	787.35
A-5	1	300	26.12	19.85	518.48
A-6	1	300	25.55	17.43	445.34

Table 3.4: Dimension of specimen for bamboo rod

Specimen	Nodes	Dimension		Cross- sectional Area, A (mm^2)
		Gauge Length, L (mm)	Diameter, d (mm)	
A-1	1	150	10.70	89.92
A-2	1	150	8.08	51.28
A-3	1	150	8.36	68.19
A-4	1	150	9.18	66.19
A-5	1	150	11.51	99.23

Tensile test was conducted based on the following steps:

i) Samples were prepared according to Table 3.3.

ii) Tensile load was applied with strain rate of 3.0 kN/sec.

iii) Ultimate tensile strength of the samples was obtained by the following formula:

$$\text{Ultimate tensile strength (MPa)} = \frac{\text{Force (N)}}{\text{Cross sectional area (mm2)}} \quad (2.8)$$

iv) Graph of stress and strain was plotted for each sample using the following formula:

$$\text{Stress (MPa)} = \frac{\text{Load (N)}}{\text{Cross Sectional Area (mm2)}} \tag{2.9}$$

$$\text{Strain} = \frac{\text{Displacement (mm)}}{\text{Gauge Length (mm)}} \tag{2.10}$$

Figure 3.44: Samples of bamboo splints for tensile tests

Figure 3.45: Sample of bamboo rod for tensile test

Figure 3.46: Tensile test

3.7 Slump Test

In this research, concrete slump test as shown in Figure 3.47 was conducted before pouring the mix into formwork for concrete casting. It was done according to ASTM C 143-78. This test is important and must be performed to identify the property of fresh concrete in terms of its workability. This test required apparatus such as tamping rod, base plate and slump cone. Since the concrete used in this study is ready mix concrete, therefore complete mixing must be done before commencing slump test to avoid inaccuracy of the results.

Figure 3.47: Slump test

3.8 Compressive Strength

Compressive strength of hardened concrete was performed according to BS 1881: Part 124:1988. In this study, the compressive strength of cubes was taken based on different days of curing which are 3, 7 and 28 days. Compression machine was used to determine the quality of concrete based on the characteristic compressive strength and ultimate strength of concrete mix supplied.

3.9 Structural Test

Structural testing was carried out to test on the reinforced concrete beams casted. The test conducted is known as four point bending test which is in accordance to the standard procedure of BS EN 12390-5:2000.

3.9.1 Four-point Bending Test

Three beams of dimensions 120 x 300 x 1600 mm with spacing of shear links to be 300 mm each were fabricated in prepared formworks. Those three beams differ with each other in terms of reinforcements. The reinforcement category is summarized in Table 3.5.

Table 3.5: Reinforcement category

Beam	Reinforcements
A	Main Reinforcement : Steel Shear Link : Steel
B	Main Reinforcement : Treated Bamboo Shear Link : Treated Bamboo
C	Main Reinforcement : Treated Bamboo Shear Link : Steel

The beams were tested with four point bending test after a curing period of 28 days. This test was conducted in accordance to the reference standard, BS EN 12390-5:2000. Figure 3.48 shows the loading system of the prepared concrete beams.

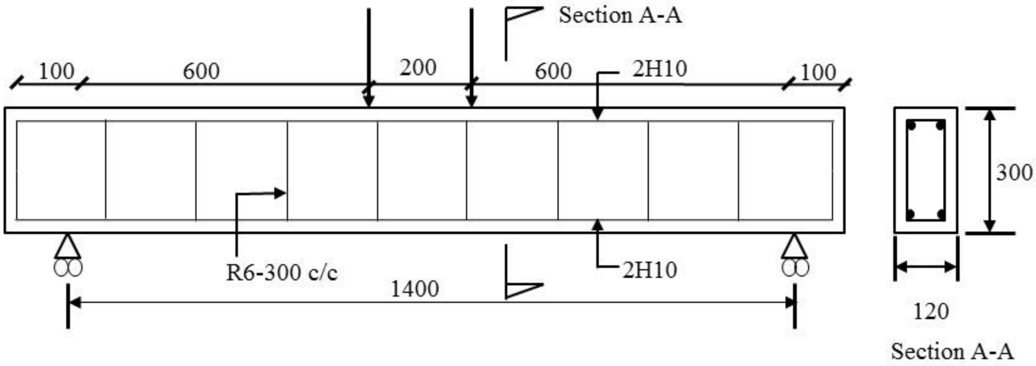


Figure 3.48: Loading system of reinforced concrete beams

The four-point bending test was conducted using Magnus Frame available in the laboratory. Generally, the Magnus Frame consists of two support noses and two loading noses. For this study, the loading points are 200 mm apart in which the points were equally distant to the centre line. Loading was delivered to the beam specimens by using a spreader beam. The loads were applied in a direction vertically downward until the beam specimens failed. In order to ensure the accuracy of deflection, one linear variable displacement transducer (LVDT) was mounted at the bottom soffit of the midspan of beam whereas another two LVDT were placed 100 mm apart from the midspan of beam. Other than that, electric resistance strain gauges were also used to predict propagation of cracks. During the commencement of testing, the strain gauges and LVDT pasted on beams were connected to data logger in order to obtain concrete strains and deflection respectively during the testing period.

Figure 3.49 and Figure 3.50 show the prepared beam specimens whereas Figure 3.51 illustrates the 60 mm strain gauge in which the installation of strain gauge is at the mid-span of beam as shown in Figure 3.52. For four-point bending test, the Magnus frame and the setting up is referred to Figure 3.53 and Figure 3.54.

Figure 3.49: Beam specimens were painted

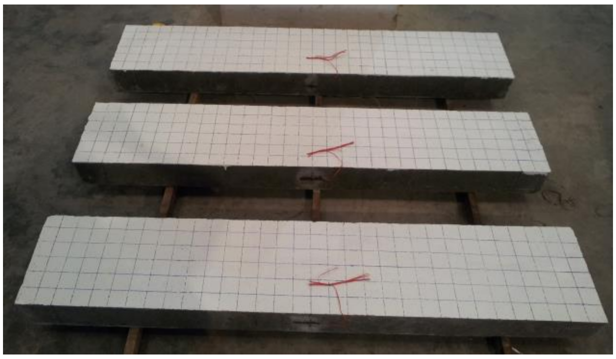


Figure 3.50: Gridlines for crack identification

Figure 3.51: 60 mm strain gauge

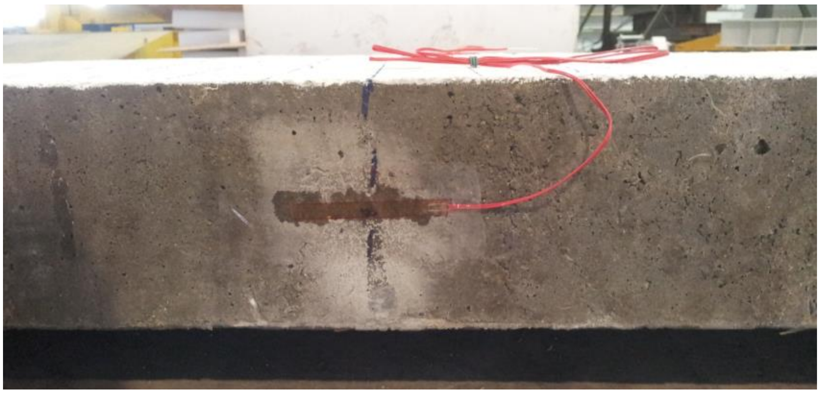


Figure 3.52: Installation of strain gauge at the mid-span of beam

Figure 3.53: Magnus frame for four point bending test

Figure 3.54: Setting of four point bending

3.10 SUMMARY OF EXPERIMENTAL WORKS

The experimental works in this study is summarized in Table 3.6.

Table 3.6: Laboratory testing

Scope of study	**Type of tests**
Chemical treatment	Coating bamboo with black oxide primer
	Immersing bamboo in sodium hydroxide solution
Physical properties of bamboo	Density test
	Initial moisture content test
	Water absorption test
	Compression test
	Tensile test
Performance of bamboo sticks in terms of load deflection behavior, crack pattern and failure mode	Four point bending test

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the results of all the conducted experimental works were presented. In order to conduct this research, experimental works were divided into three categories which were designed to achieve the objectives of this study. The first part consisted of studying the morphology behavior of chemically treated and untreated bamboo samples using scanning electron microscope (SEM). The SEM images were presented in this chapter. Next, physical properties of bamboo were investigated by carrying out several experimental works. The results were analyzed showing the properties of bamboo. From this, several adaptations were applied to bamboo sticks to be used as reinforcement and four-point bending test was conducted on concrete RC beams which have different type of reinforcements. The performance of all samples were analyzed in terms of load-deflection behavior, crack pattern and failure mode. Besides presenting results of experimental works, this chapter also provided the results interpretation.

4.2 MICROSTRUCTURE OF BAMBOO

In this study, a small section of bamboo was taken from the bamboo culms as shown in Figure 4.1. Treatment of bamboo using oxide primer as well as different concentration of sodium hydroxide solutions as shown in Figure 4.2 to 4.4 were carried out before examined using scanning electron microscope (SEM).

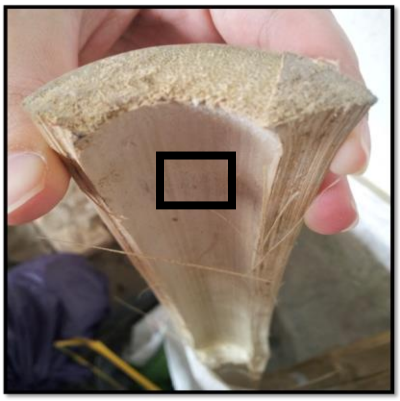


Figure 4.1: Section of samples taken

Figure 4.2: Untreated sample

Figure 4.3: Treated – oxide primer

Figure 4.4: Treated – 5%, 10%, 15% sodium hydroxide solution

4.2.1 Untreated Bamboo Samples

In the perspective of biology study, bamboo belongs to the member of *Poaceae* plant family which is considered as grass. Generally, all green plants consist of tissues which are known as epidermal, hypodermis and vascular. It is clearly seen from Figure 4.5 that the microstructure of bamboo comprised of numerous pore structures which are fibrous and stiff. The resulting SEM images show that these pore structures are densely packed along the length of bamboo. The density gradient of these pore structures increases radially outward which seems to be the densest near its outer walls. Due to this variation, the mechanical properties of bamboo will also be increased from the inner to the outer edge of bamboo species. This characteristic shows that bamboo is strong. Figure 4.5 shows the resulting SEM images for untreated bamboo samples with magnification of x200 and x500.

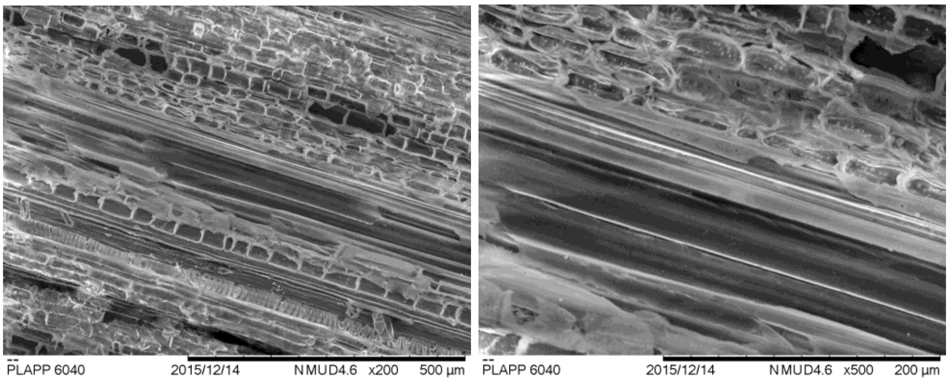


Figure 4.5: SEM images for untreated bamboo samples

4.2.2 Treatment Using Sodium Hydroxide Solutions

The resulting SEM images of bamboo samples treated with different concentration of sodium hydroxide mainly 5%, 10% and 15% are presented in Figure 4.6 to 4.8 with magnification of x200 and x500. By comparing the images of samples with different concentrations, it is observed that the variation concentration of sodium hydroxide solution (NaOH) provided different level of treatment on the samples.

When bamboo sample is treated with 5% concentration of sodium hydroxide solution, it is observed that the existing pore structures have enlarged compared to the untreated sample. In terms of roughness of bamboo, the pore structures of treated sample have roughened with the treatment of sodium hydroxide solution. The densely packed pore structures are seen to be arranged in an orderly manner compared to untreated sample.

For the sample treated with 10% of sodium hydroxide solution, elongation of pore structures is observed. The resulting SEM images show that the pore structures are unusually widen and becoming longer compared to untreated sample and sample with 5% treatment of sodium hydroxide. Besides that, there are sign of damages of bamboo pore structures occurring with 10% concentration of sodium hydroxide solution. This is because the “rectangle-like shape” pore structures begin to show distortion in which the arrangement of pore structures are no longer in orderly manner. The pore structures begin to rupture.

The pore structures of bamboo sample with 15% concentration of sodium hydroxide shows massive damage in which the “rectangle-like shape” pore structures are no longer visible. This shows that high concentration of sodium hydroxide will damaged the pore structures of bamboo causing it to rupture.

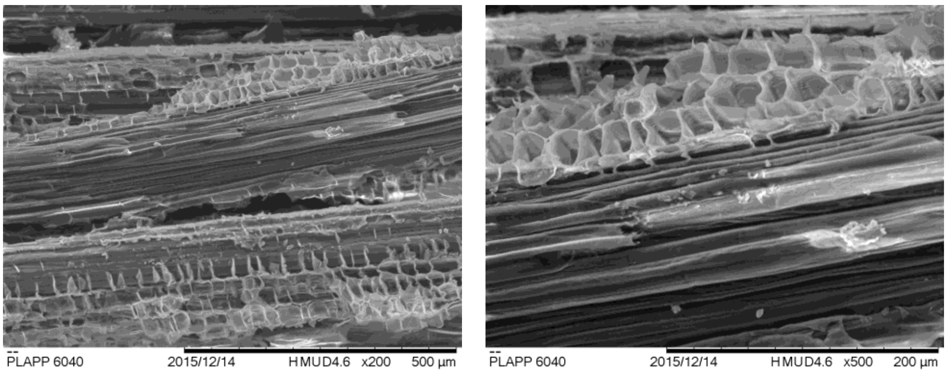


Figure 4.6: SEM images for 5% sodium hydroxide solution treated bamboo samples

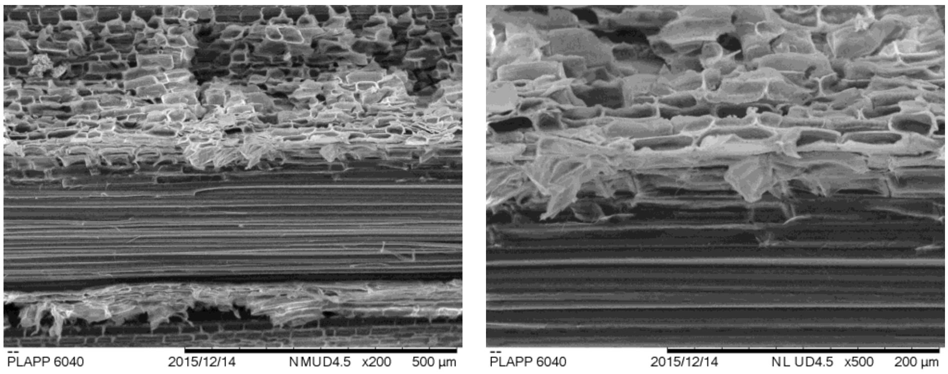


Figure 4.7: SEM images for 10% sodium hydroxide solution treated bamboo samples

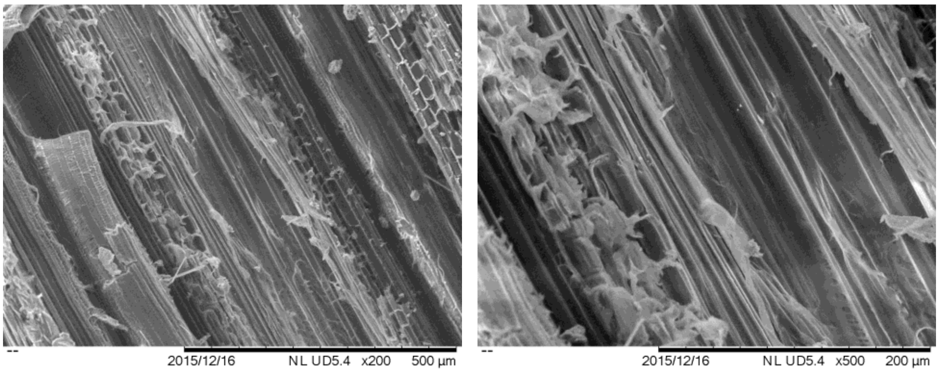


Figure 4.8: SEM images for 15% sodium hydroxide solution treated bamboo samples

4.2.3 Treatment Using Black Oxide Primer

Black oxide primer is used to treat bamboo stick to prevent insect attack as well as to create a thin of water resistance layer on the surface of bamboo. Generally, oxide primer is widely used in the industry to provide surface coating on the metal to prevent corrosion. Figure 4.9 illustrates the resulting images of SEM for bamboo samples treated with black oxide primer. The resulting images show no pore structures are visible after the application of black oxide primer in which all the pore structures are fully covered up by black oxide primer.

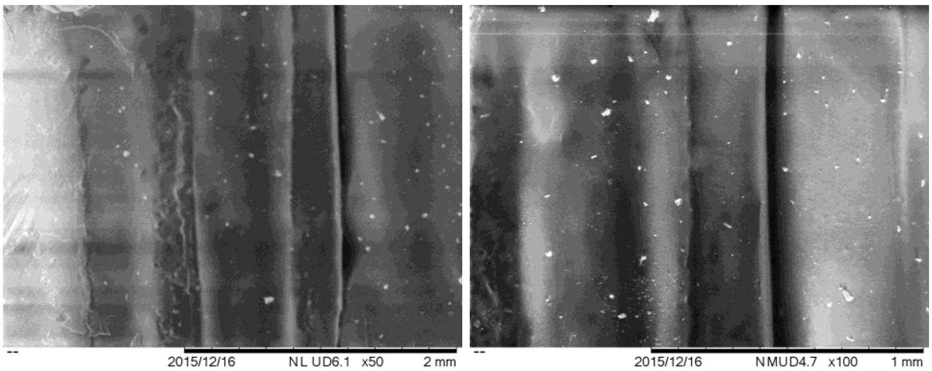


Figure 4.9: SEM images for bamboo samples treated with black oxide primer

4.3 PHYSICAL PROPERTIES OF BAMBOO

In this study, samples of bamboo were prepared in accordance to the physical properties tests which were carried out. There are five tests conducted such as density, initial moisture content, water absorption, compression and tension. Figure 4.10 illustrates the samples prepared for laboratory testing.

Figure 4.10: Prepared samples for physical properties testing

4.3.1 Density Test

Figure 4.11 shows the oven dried bamboo samples from different positions of culm. Based on the results, the density of bamboo samples is between 0.4 – 0.49 gm/cm^3 as listed in Table 4.1. This shows that bamboo is light weight and it has low density. With these characteristics, bamboo is suitable to be used as building material in construction industry. As it is very light, therefore it can be worked and transported easily which in turn reduce the utilization of machineries unnecessary in construction industry. Other than that, construction in remote area can be made easy with utilization of bamboo as this material does not required any skilled labors or heavy machineries in handling. Graph of average mass density against position of bamboo culm is plotted in Figure 4.12.

Figure 4.11: Oven dried bamboo samples from different positions of culm

Table 4.1: Density of bamboo

Position of bamboo culm	Samples	Thickness (cm)	Oven dry mass (gm)	Volume of samples (cm^3)	Mass density (gm/cm^3)	Average mass density (gm/cm^3)
	A-1	1.09	8.1	20.4	0.40	
Base	A-2	1.24	8.9	23.1	0.39	
	A-3	1.25	8.5	20.7	0.41	0.40
	A-4	1.40	8.9	21.9	0.41	
	B-1	1.68	17.3	38.0	0.46	
Middle	B-2	1.66	17.3	37.4	0.46	
	B-3	1.57	18.8	40.3	0.47	0.46
	B-4	1.49	16.4	37.3	0.44	
	C-1	1.63	19.8	39.5	0.50	
Top	C-2	1.75	19.2	39.3	0.49	
	C-3	2.02	22.6	45.5	0.50	0.49
	C-4	1.94	24.6	50.2	0.49	

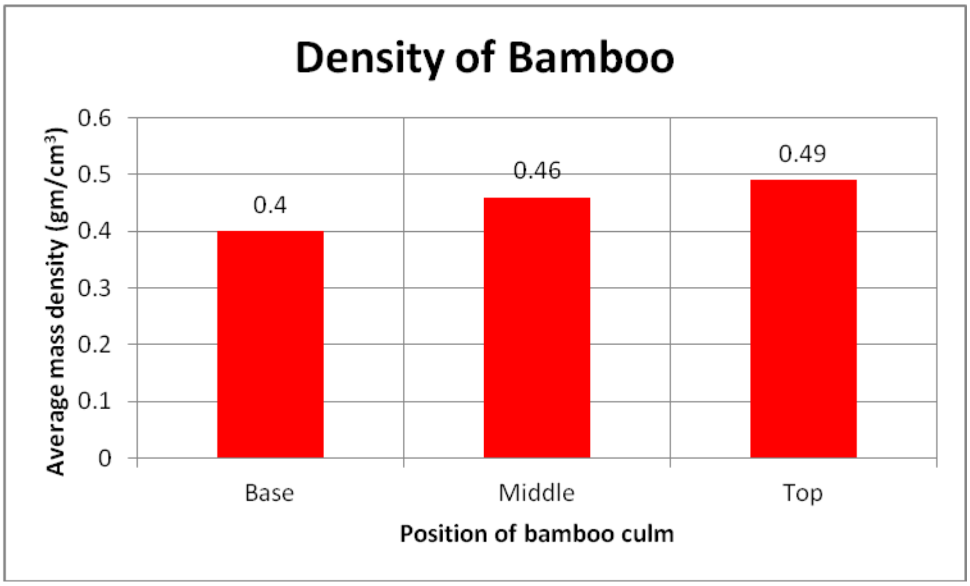


Figure 4.12: Graph of bamboo density

4.3.2 Initial Moisture Content Test

Bamboo is natural, hygroscopic material. Therefore, it is essential to investigate on its moisture content as it has significant role in causing degradation of bamboo stiffness as well as the strength. When bamboo loses water, it will begin to shrink which is directly proportional to the amount of water content lost. If this happen when bamboo reinforcement is placed in any structural elements, it will cause creation of additional stresses which will decrease the bonding between bamboo and concrete. This will cause failure in the structure. Hence, bamboo samples with variety of nodes mainly zero, one and two nodes were weight before sent to oven-dry in order to obtain the initial moisture content.

Based on the results obtained, there is a linear relationship between the initial moisture content with number of nodes. The average initial moisture content of bamboo samples lies between the ranges of 48% to 52% with the variation of number of nodes. The average moisture content of bamboo samples decreases with the increasing number of nodes existed. Due to this, proper adaptation should be done in preparing bamboo reinforcement. Since the bottom portion has the maximum initial moisture content, therefore, it is suggested that bamboo sticks at this part should be avoided to be used as reinforcement in concrete if proper seasoning is not done. Another alternative besides avoiding the utilization of that portion is ensuring the bamboo sticks are properly harvested and seasoned before use.

From the perspective of bamboo anatomy, the thickness of bamboo varies along its length which means the thickness is the maximum at the bottom portion and it decreases to the top. As a result, the graph between average moisture content and thickness of bamboo shows that there is no possible correlation which can be drawn from the plot. This happen because the bamboo samples for this test were prepared randomly, neglecting its position of the culms.

Figure 4.13 illustrates the oven dried bamboo samples. The result of initial moisture content of bamboo is summarized in Table 4.2. Graph of average moisture content against number of nodes is plotted in Figure 4.14. Besides that, graph of average moisture against thickness is also plotted in Figure 4.15.

Figure 4.13: Oven dried bamboo samples

Table 4.2: Initial moisture content of bamboo

Samples	Nodes	Thickness (cm)	Initial Weight (gm)	Oven dry Weight (gm)	Moisture Content (%)	Average Moisture Content (%)
A-1	0	1.935	80	36	55.000	
A-2	0	1.664	71	34	52.113	
A-3	0	1.556	80	38	52.500	51.570
A-4	0	1.978	75	40	46.667	
B-1	1	1.311	140	77	45.000	
B-2	1	1.093	150	74	50.667	
B-3	1	1.280	140	69	50.714	49.761
B-4	1	0.858	169	80	52.663	
C-1	2	2.856	520	277	46.731	
C-2	2	1.432	495	249	49.697	
C-3	2	2.747	515	266	48.350	47.861
C-4	2	2.885	450	240	46.667	

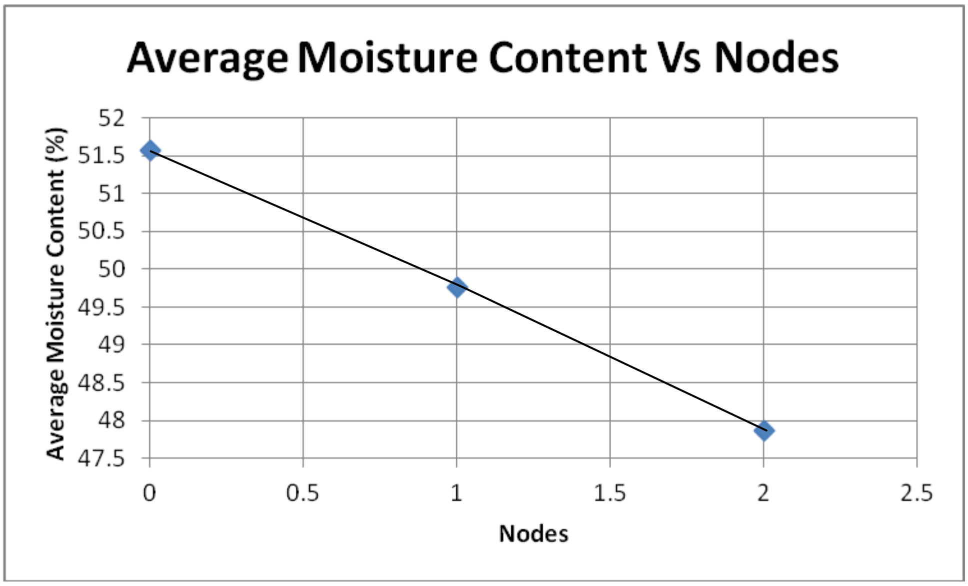


Figure 4.14: Graph of average moisture content against number of nodes

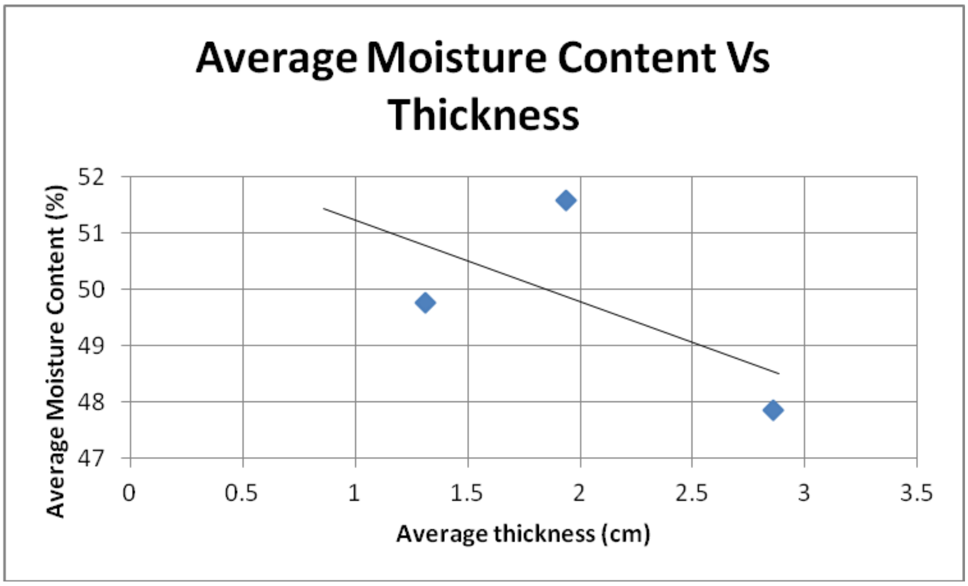


Figure 4.15: Graph of average moisture content against thickness

4.3.3 Water Absorption Test

Concrete requires sufficient water for it to gain ultimate strength. Shrinkage will occur when concrete loses water either when it is in plastic or hardened state. Therefore, the property of bamboo in terms of water absorb ability is studied. Bamboo, being natural material has the ability to absorb water in its surrounding environment. Therefore, before bamboo reinforcement is placed in concrete, it must be treated first so that it can resist water. Or else, water from concrete will be absorbed continuously until it dries by the bamboo. As a result, the strength of concrete will be reduced due to shrinkage. In this study, water resistant layer was created by treating bamboo sticks with black oxide primer. Figure 4.16 illustrates the samples of bamboo after immersing in water curing tank.

Figure 4.16: Samples after immersing in water curing tank

4.3.3.1 Changed in Weight of Bamboo

The results of percentage weight water absorbed of bamboo after 15 and 30 days is tabulated in Table 4.3. Graphs of percentage of water absorbed of bamboo by weight after 15 and 30 days against nodes are plotted respectively in Figure 4.17 and Figure 4.18. Based on the results obtained, black oxide primer is proven to be able to act as water proofing agents for bamboo in which its application can resist bamboo to absorb water.

The experimental results for first 15 days of immersing in water show that, there is reduction of 18% of water absorbed by the treated zero node bamboo, 15% for one node bamboo whereas two node bamboo recorded to be reduced 35%. The results after 30 days show the percentage weight of water absorbed is 8%, 5%, and 18% for zero, one and two nodes bamboo respectively. Bamboo is a natural material. Therefore, the ability to absorb water for each sample is dependent to the cross sectional area, thickness and positions of bamboo samples taken. In this study, the variables such as cross sectional area, thickness and positions of bamboo samples taken are not controlled. As a result, there are inconsistency in the results between untreated and treated samples after 15 and 30 days.

Table 4.3: Weight of water absorption

	Samples	Nodes	% by weight of water absorbed after 15 days	% by weight of water absorbed after 30 days
Non-treated	A-1	0	60.42	57.92
	A-2	1	59.44	57.23
	A-3	2	48.78	45.29
Treated	B-1	0	42.22	50.40
	B-2	1	44.93	51.95
	B-3	2	13.72	27.47

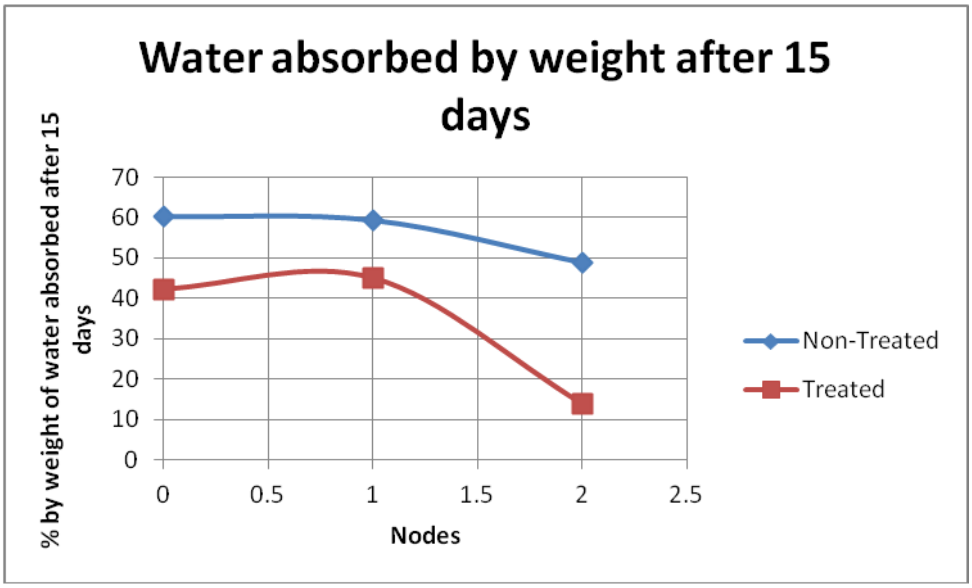


Figure 4.17: Weight changed after 15 days

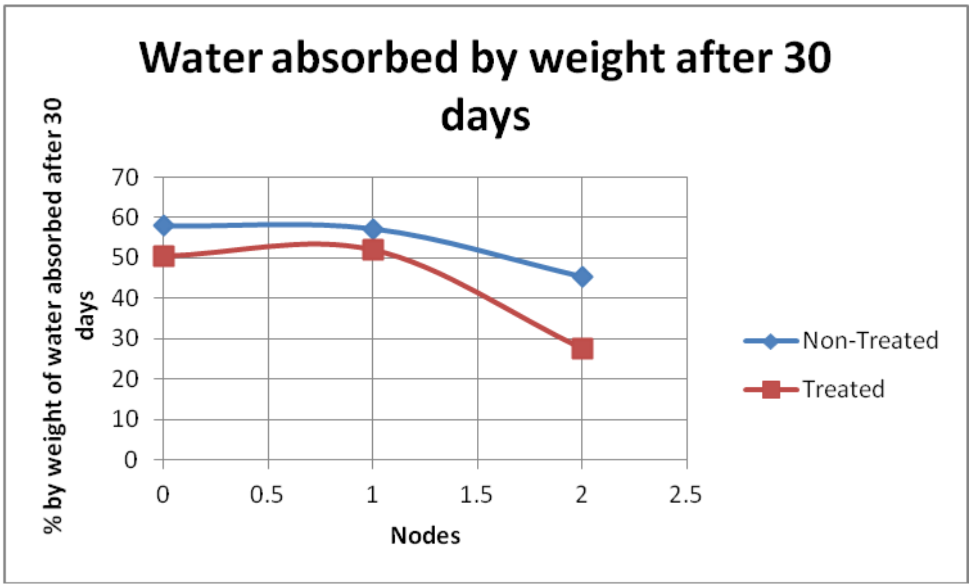


Figure 4.18: Weight changed in 30 days

4.3.3.2 Changed in Thickness of Bamboo

The results of thickness changed of bamboo after 15 and 30 days is tabulated in Table 4.4. Graphs of thickness changed of bamboo after 15 and 30 days against nodes are plotted in Figure 4.19 and Figure 4.20 respectively. Similar to the preceding experiment, the results obtained based on changed in thickness of bamboo, black oxide primer has the ability to resist bamboo from absorbing water from its surrounding environment.

The experimental results for first 15 days of immersing in water show that, there is a reduction of 13% of increment in thickness by the treated zero node bamboo, 19% for one node bamboo whereas two node bamboo recorded to be reduced by 7%. The results after 30 days show the percentage of thickness changed is 25%, 2%, and 48% respectively for zero, one and two nodes bamboo. The results obtained from Gupta & Ganguly (2015) showed when the number of nodes increased, the percentage changed of thickness also increased. However, the results obtained in this study showed inconsistency between untreated and treated samples after 15 and 30 days. The possible reasons maybe because of the bamboo cross sectional area, initial thickness and position of sample taken.

Table 4.4: Increment of thickness for bamboo samples

	Samples	Nodes	% Increase in thickness after 15 days	% Increase in thickness after 30 days
Non-treated	A-1	0	18.17	36.84
	A-2	1	24.85	9.209
	A-3	2	12.33	50.390
Treated	B-1	0	5.56	12.05
	B-2	1	5.92	7.631
	B-3	2	5.60	1.907

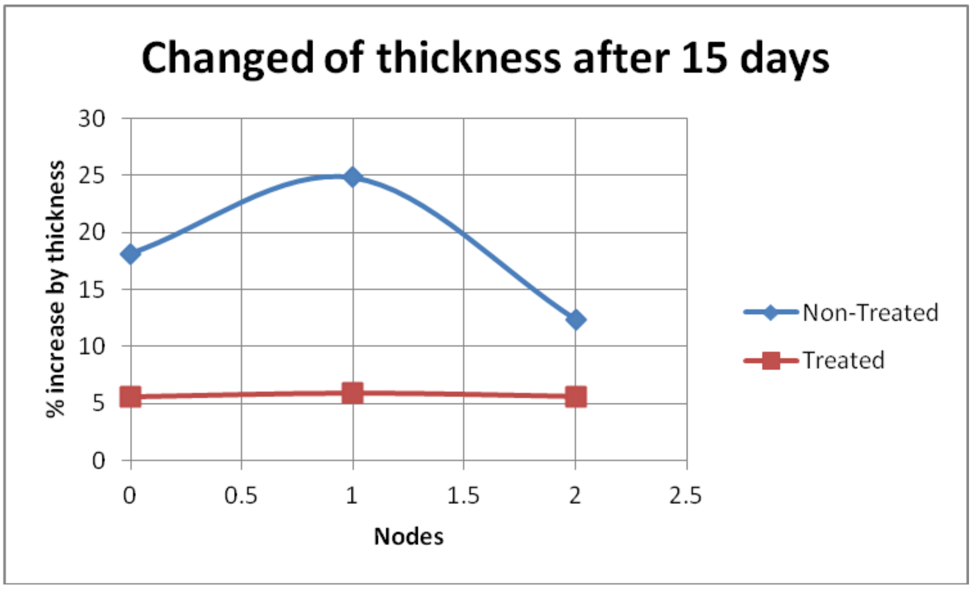


Figure 4.19: Graph of thickness changes in 15 days

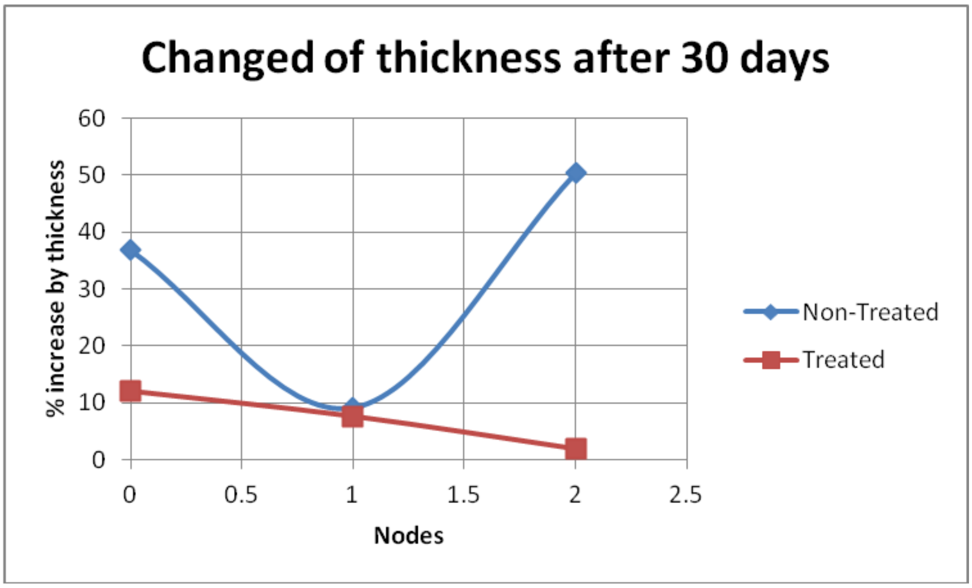


Figure 4.20: Graph of thickness changes in 30 days

4.3.4 Compression Test

It is observed that the bamboo samples failed in the way of crushing, cracking of fibres or combination of both when exerted with compression loading. From the results, bamboo samples with one node have greater value of ultimate compressive strength compared to samples without node. The existing nodes in bamboo provide additional cross-sectional area making the wall thicker and thus providing stiff behaviour to the bamboo. Therefore, bamboo with nodes has higher capability to be able to resist compressive loading compared to bamboo without node.

Figure 4.21 illustrates the failure mode of zero and one node bamboo under compression test. The ultimate compressive strength of bamboo samples with zero and one node is summarized in Table 4.5. Graph of stress against strain for zero and one node bamboo is plotted in Figure 4.22 as well as Figure 4.23 respectively.

Figure 4.21: Failed bamboo samples with zero and one node

Table 4.5: Ultimate compressive strength of bamboo samples

Samples	Nodes	Thickness, t (mm)	Width, B (mm)	Ultimate compressive strength, (MPa)
A-1	0	17.49	71.82	10.380
A-2	0	16.11	61.55	5.217
A-3	0	8.96	62.82	7.440
B-1	1	17.48	83.63	10.717
B-2	1	18.57	77.21	25.464
B-3	1	12.69	88.11	18.734

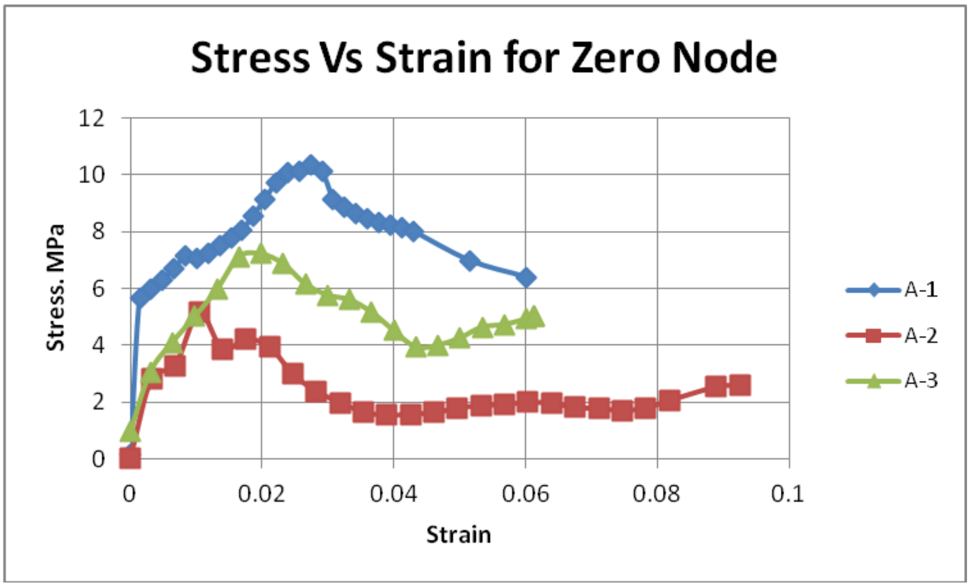


Figure 4.22: Graph of stress against strain for bamboo samples with zero nodes

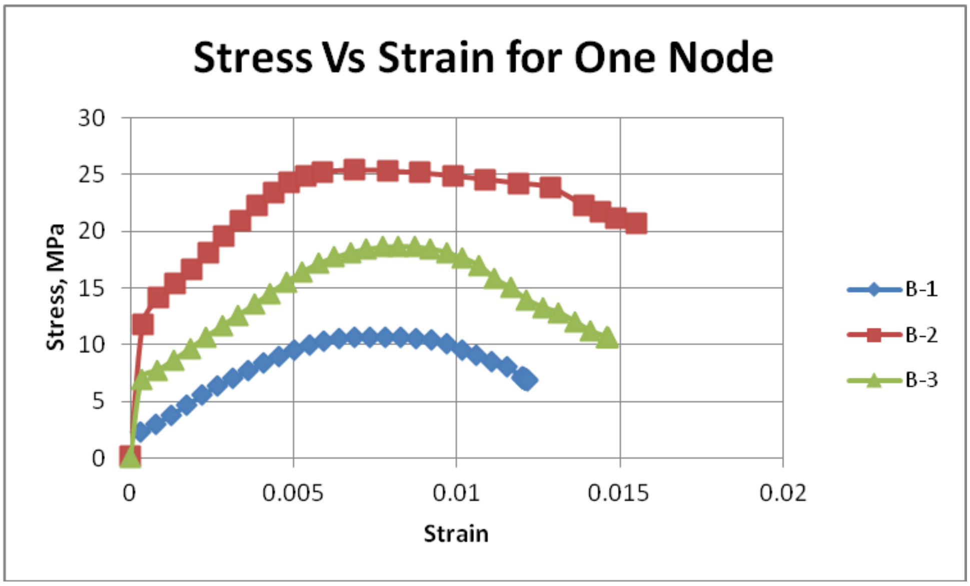


Figure 4.23: Graph of stress against strain for bamboo samples with one node

4.3.5 Tensile Test

Tensile tests for bamboo and steel bars of 10 mm and 6 mm shear links were conducted using the available Universal Testing Machine (UTM) in laboratory. In this study, bamboo samples consisted of bamboo splints which is the cut section from bamboo culm and bamboo in the form of rod were tested to identify the tensile results for both types of samples as shown in Figure 4.24. Results obtained and recorded were plotted for analysis. Comparison results between bamboo and steel bars as well as shear links were performed for the analysis.

Figure 4.24: Sample of bamboo (a) Bamboo splint (b) Bamboo rod

4.3.5.1 Bamboo Reinforcement

In this study, tensile test was conducted on six bamboo samples with one node. Bamboo is a natural material. Therefore, all samples prepared were not of the same thickness and width. The resulting failure mode of bamboo splints under tensile stress is illustrated in Figure 4.25. The tensile test results for six samples are summarized in Table 4.6.

Graph of stress against strain for bamboo splints is plotted in Figure 4.26. Based on the graph, it increases linearly until reaching the maximum value before it begins to decrease. With uniform elongation, bamboo splints take load linearly until reaching the point which is the maximum value. This point is known as the ultimate load. In this test, the ultimate load is 97.3 MPa. Overall, the average tensile strength is 79.65 MPa. As soon as the ultimate load has reached, the graph decreases even with the increase in elongation which indicates that bamboo tissue has ruptured causing the size of splints to be reduced at failure section. The graph continues to decrease until the material showing completion of ruptures. This indicates that the material fails completely.

According to Bhonde et al. (2013), the structure of bamboo splints comprised of fibres which are longitudinal along the length of bamboo. This explained that the strength of bamboo is good along its length. However, bamboo splints pose weak bonding between the longitudinal fibres. Thus, the bamboo splint samples used for tensile test were observed to split at failure longitudinally. Failure such as breaking in nodes and splitting of fibres from nodes were observed in all the samples of bamboo splints tested in tensile load. Therefore, it can be concluded that the weakest point of bamboo splints is at the node.

Figure 4.25: Failure mode of one node bamboo samples under tensile stress

Table 4.6: Ultimate tensile strength of bamboo samples

Samples	Nodes	Thickness, t (mm)	Width, B (mm)	Ultimate tensile strength, (MPa)
A-1	1	22.91	30.70	83.4
A-2	1	21.40	26.74	88.8
A-3	1	22.06	31.95	52.2
A-4	1	25.26	31.17	65.2
A-5	1	19.85	26.12	91.0
A-6	1	17.43	25.55	97.3

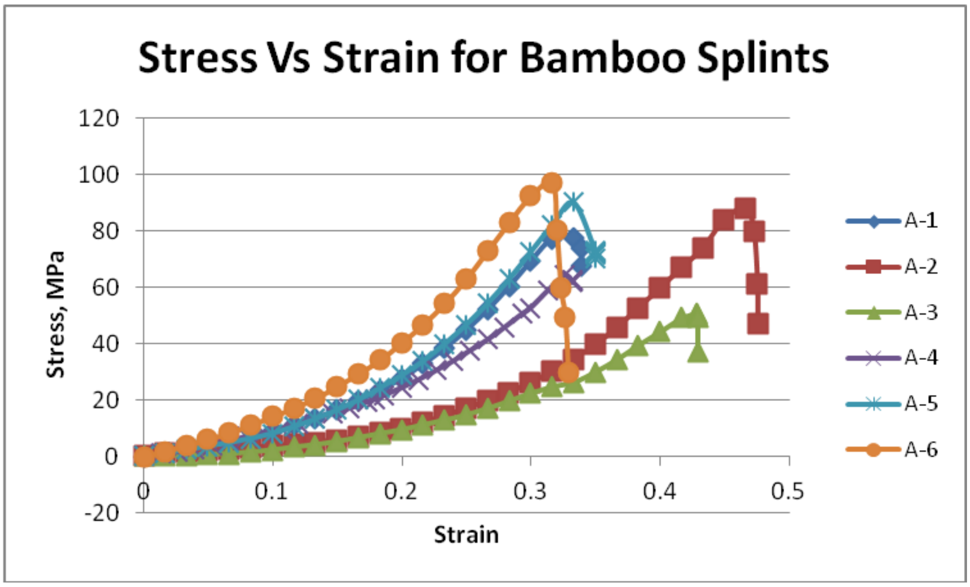


Figure 4.26: Graph of stress against strain for bamboo splints

Graph of comparison between bamboo splints and steel bars with diameter of 10 mm is plotted in Figure 4.27. By comparing with steel of 10 mm in diameter, the tensile stress of bamboo is 10% of steel strength in which the tensile stress for steel is 798 MPa. Even so, bamboo still possesses the ability to resist tensile stress which is suitable to be an alternative as reinforcement in concrete RC beams for smaller structures.

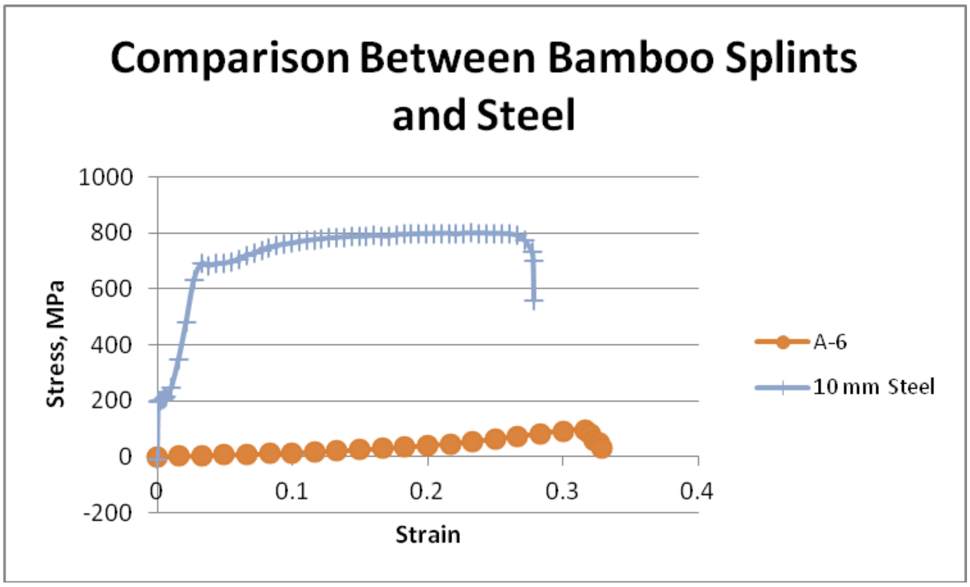


Figure 4.27: Comparison between bamboo splints and Y10 steel

4.3.5.2 Bamboo Shear Links

In this study, tensile test was conducted on five bamboo samples with one node in the form of rod. This experiment is to investigate the tensile stress of bamboo shear links. Similar to bamboo splints, all samples of bamboo in the form of rod prepared were not of the same thickness and width.

The tensile test results for five samples are tabulated in Table 4.7. Graph of stress against strain for bamboo rod is plotted in Figure 4.28. In the aspect of tensile strength, the behaviour of bamboo sample in the form of rod is similar to the bamboo splint in which on the graph, the tensile stress will increases linearly until reaching the maximum value before it decreases. In this test, the ultimate load is 37.82 MPa. Overall, the average tensile strength is 26.69 MPa.

Table 4.7: Ultimate tensile strength for bamboo shear link

Samples	Nodes	Diameter, d (mm)	Ultimate tensile strength, (MPa)
A-1	1	10.70	26.52
A-2	1	8.08	37.82
A-3	1	8.36	28.10
A-4	1	9.18	18.05
A-5	1	11.51	22.94

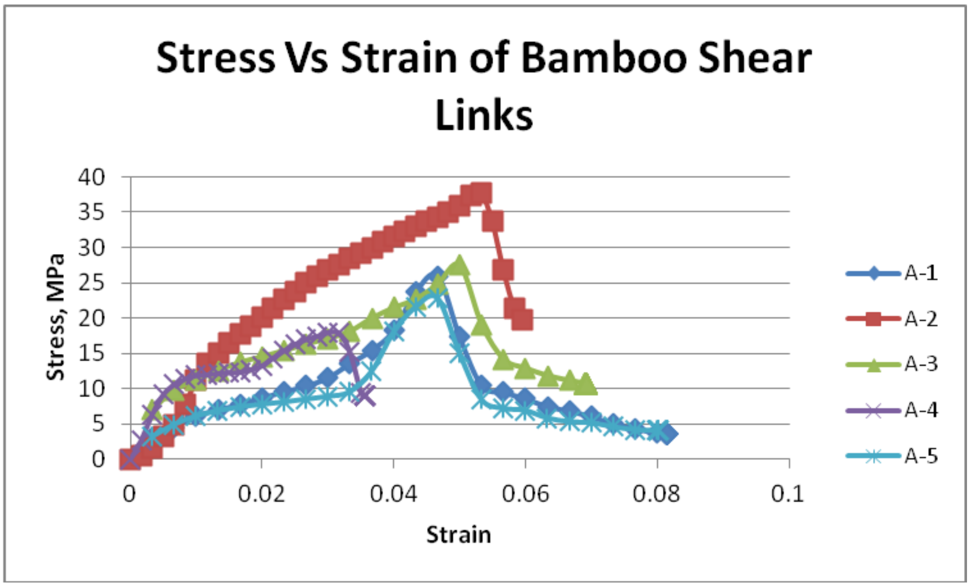


Figure 4.28: Graph of stress against strain for bamboo rod

Graph of comparisons between bamboo and steel shear links is plotted in Figure 4.29. By comparisons, the average tensile strength for bamboo rod is 26.68 MPa which is 8% of tensile strength in steel shear link of 6 mm in diameter.

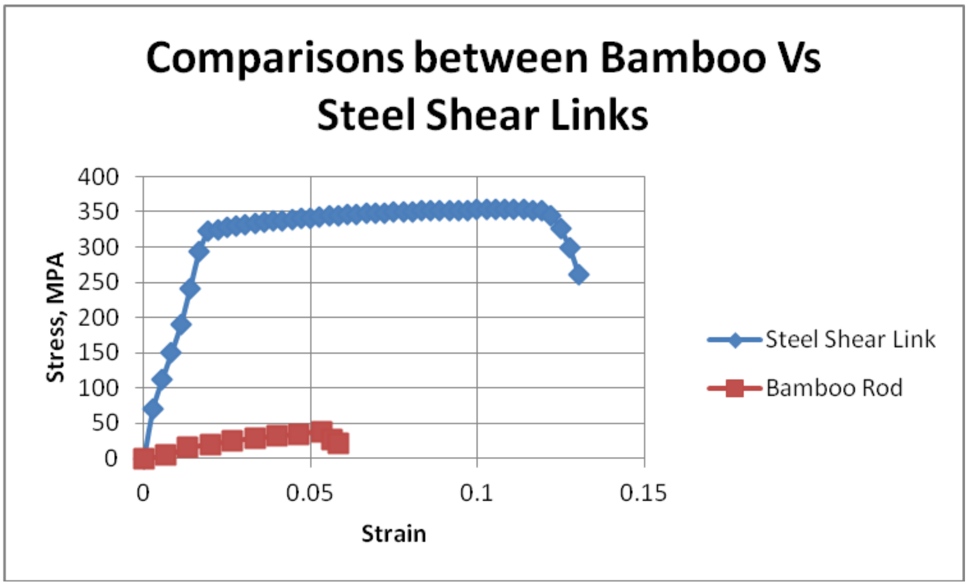


Figure 4.29: Comparisons between bamboo and steel shear links

4.4 CONCRETE QUALITY TESTING

There are two tests were conducted to test the concrete quality. The test consists of slump test and compressive strength test.

4.4.1 Slump Test

The height of slump obtained from ready mixed concrete was 75 mm. This value showed similarity to the value specified from the batching plant. Based on the result, the obtained slump is categorized as true slump. A true slump indicates that the ready mixed concrete has high workability mixes. Therefore, ready mixed concrete quality is acceptable. Figure 4.30 shows method of measuring slump height.

Figure 4.30: Measuring slump height

4.4.2 Compressive Strength

Other than conducting slump test, concrete quality can also be determined by carrying out the compression test on cast concrete cubes as shown in Figure 4.31. In this study, compression test was carried out to identify the compressive strength of concrete cubes in 3, 7, and 28 days after casting.

Table 4.8 shows the compressive strength of cast concrete cubes cured in 3, 7 and 28 days. The targeted strength of ready-mixed concrete is 25 MPa as indicated by the manufacturer in batching plant. Based on the result, the average compressive strength obtained in 3 days were 17.94 MPa whereas the 7 days strength is 24.05 MPa. At 28 days, the average compressive strength of the mix showed 31.74 MPa which is satisfactory. Figure 4.32 shows graph of average compressive strength against sample age.

Figure 4.31: Compression test

Table 4.8: Compressive strength of cube samples with 3, 7 and 28 days

Sample	**Weight (kg)**	**Sample Age (days)**	**Load (kN)**	**Compressive Strength (MPa)**	**Average Compressive Strength (MPa)**
A1	7.78	3	412.00	18.31	
A2	7.85	3	423.78	18.84	
A3	7.70	3	392.74	17.46	17.94
A4	7.55	3	391.24	17.39	
A5	7.70	3	397.89	17.68	
A6	7.55	7	506.98	22.53	
A7	7.70	7	513.57	22.83	
A8	7.85	7	524.88	23.33	24.05
A9	7.85	7	552.68	24.57	
A10	7.85	7	606.99	26.98	
A11	7.70	28	722.28	32.10	
A12	7.75	28	694.80	30.88	
A13	7.75	28	748.63	33.27	31.74
A14	7.61	28	705.27	31.35	
A15	7.73	28	699.21	31.08	

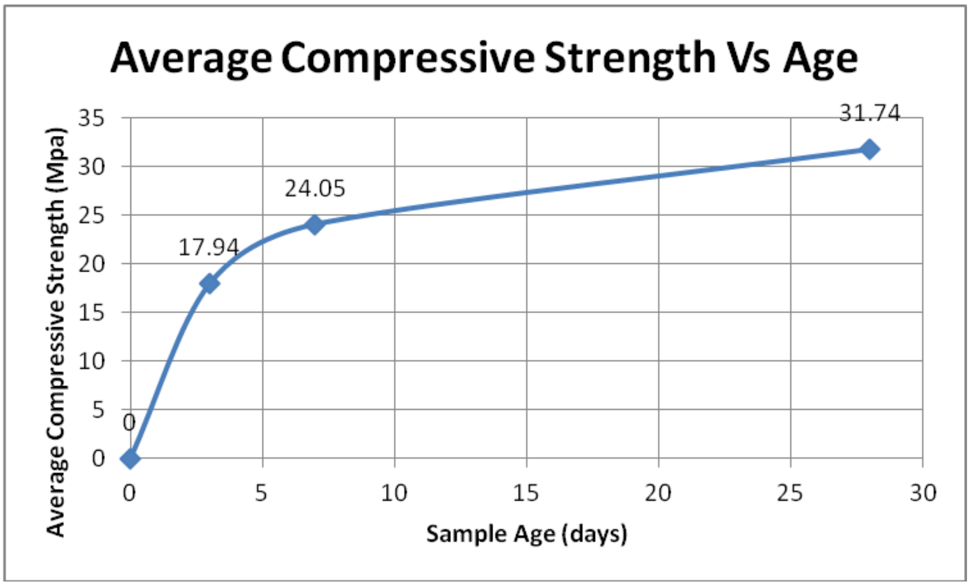


Figure 4.32: Graph of average compressive strength against sample age

4.5 Flexural Strength Test

In this study, three RC beams with the dimension of 120 x 300 mm and length 1600 mm were prepared. One reinforced concrete beam which act as the control beam (CB) consists of the reinforcement is in steel. The remaining two RC beams were fully incorporated with bamboo reinforcement (BR) as well as partially bamboo and steel reinforcement (BSR). Four-point bending test was conducted on all the beam specimens. In this structural testing, the parameters used to analyze the performance of bamboo sticks were in terms of ultimate load, deflection, mode of failure and cracking behavior.

4.5.1 Ultimate Load

Based on the experimental results, all three samples of beams show remarkable results. From the result, the control beam (CB) with steel reinforcement can support the maximum load without failure compared to other samples. The ultimate load for control beam is 63.31 kN. The ultimate load of bamboo reinforcement (BR) is 34.06 kN which is 46% of the load of CB whereas the sample of bamboo steel reinforcement (BSR) obtained a load of 11.32 kN which is about 65% lower than beam (BR). From the results of ultimate load, it shows neither bamboo reinforcement nor bamboo steel reinforcement is stronger than steel. There is no sign of improvement when bamboo reinforcement or bamboo steel reinforcement is used.

Table 4.9 summarized the comparison in terms of ultimate load. From the result, control beam has the highest ultimate load which is 63.31 kN. While for beam BR and beam BSR, the maximum load that it can support is only 34.06 kN and 11.83 kN respectively. In terms of strength ratio, beam BR only achieved 0.54 compared to beam CB.

Based on the results obtained, steel is the strongest material and most dominant building material in construction. In this context, bamboo could be only the potential material in building industry for smaller structures in which its utilization will reduce the consumption of steel.

Table 4.9: Comparison in terms of ultimate load

Specimens	Ultimate Load (kN)	Strength Ratio (compared to control beam)
CB	63.31	1.00
BR	34.06	0.54
BSR	11.83	0.18

4.5.2 Load-Deflection Behaviour

For all RC beams, the deflections were measured at the mid-span of the bottom soffit of the beams. Table 4.10 presents the deflection corresponding to the ultimate load whereas the experimental results are summarized in Table 4.11. Figure 4.33 illustrates the load-deflection curves of three beam samples.

According to the trend of load deflection curve, the control beam (CB) experienced strain hardening after first cracked at load 42.1 kN. With deflection, the load increased gradually until a constant load was achieved before failure. The beam experienced plastic deformation indicating control beam has ductile behavior.

Next, beam BR shows a different trend for the load-deflection curve compared to CB. As soon as the beam undergo first visual cracking load at 13.63 kN, a decrease in load was observed before an increase in load. This indicates strain hardening. The beam shows brittle failure as it experienced a sharp reduction in load at a deflection of 10 mm. This explained that bamboo reinforcement was weak to resist tensile forces, thus, most of the loading was resisted by the concrete in compression strength.

The load deflection curve for beam BSR exhibited a sudden decrease in load after the first cracking load at 11.83 kN and failed at the same load. Similar failure mode of beam BR was found in beam BSR. The beam experienced strain hardening before a brittle failure. In this case, there is no significant difference in load was traced when steel shear link was incorporated to replace bamboo shear link in beam BSR.

Table 4.10: Comparison in terms of deflection at mid-span

Specimens	**Deflection at mid span at ultimate load (mm)**	**Deflection Ratio (compared to control beam)**
CB	42	1.00
BR	10	0.24
BSR	9	0.21

Table 4.11: Summary of experimental results

Specimens	**First Visual Cracking Load (kN)**	**Failure Load (kN)**
CB	42.10	63.31
BR	13.63	34.06
BSR	11.83	11.83

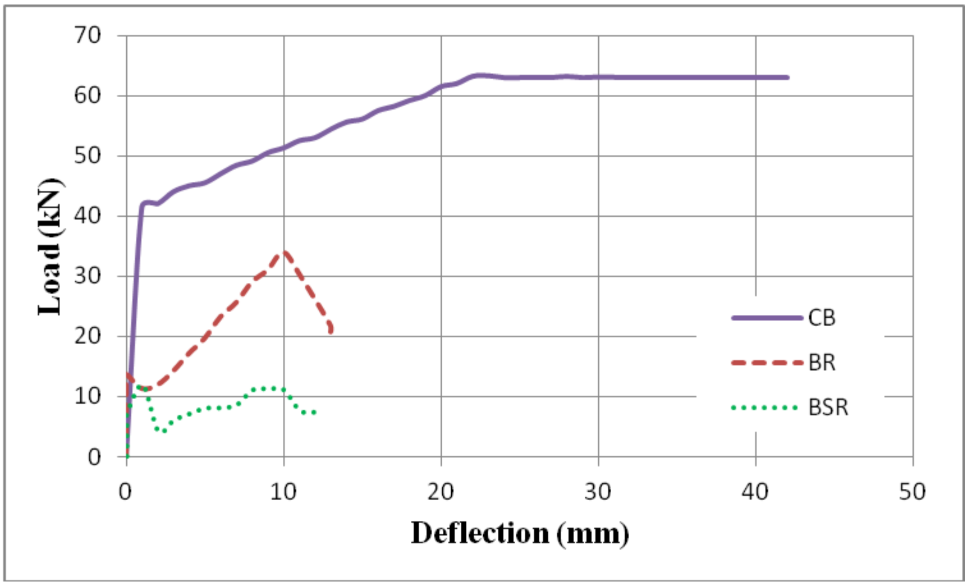


Figure 4.33: Load deflection of different beam samples

4.5.3 Mode of Failure

The experimental results indicate that all three samples undergo flexural failure as design to fail in bending. As the application of load increased, the length of the cracks increased. Besides that, the crack widths were widened as the load increased. Table 4.12 summarizes the failure mode of beam samples.

Table 4.12: Failure mode of beam samples

Specimens	Failure Mode	Sequence of Failure Mode
CB	Flexural	i. Vertical cracking ii. Vertical crack widen iii. Beam failed gradually iv. Ductile failure
BR	Flexural	i. Vertical cracking ii. Beam failed with vertical crack iii. Brittle failure
BSR	Flexural	i. Vertical cracking ii. Beam failed with vertical crack

4.5.4 Cracking Behaviour

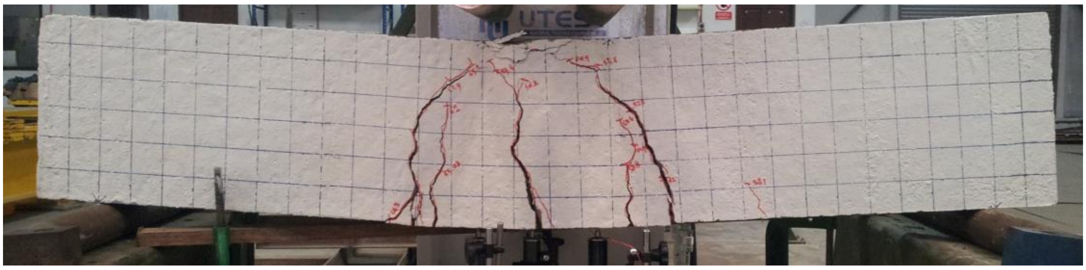


Figure 4.34: Crack pattern for control beam (CB)

Based on Figure 4.34, the first vertical cracks were observed in the middle of tension zone. Eventually, these vertical cracks were turned into flexural cracks in the mid-span of the beam. These flexural cracks propagated to the neutral axis of the beam near to the loading points when the load application continues. Before the beam was failed in a ductile manner, the crack width was found visible and enlarged. This signified a bending failure.

Figure 4.35: Crack pattern for bamboo reinforcement (BR)

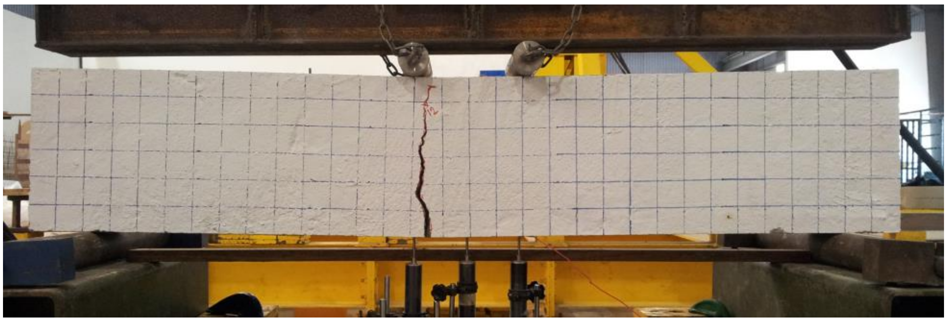


Figure 4.36: Crack pattern for bamboo steel reinforcement (BSR)

The crack pattern for beams BR and BSR are illustrated in Figure 4.35 and Figure 4.36. The crack pattern for beams BR and BSR were found to be dissimilar as compared to CB. Only a vertical crack was found in the mid-span of the beam. Before failure, the vertical crack penetrated to the neutral axis besides enlargement of crack was observed. Upon failure, a sudden crack sound was heard. The beams were failed in a brittle manner in bending.

The cracking behavior indicates that longitudinal bamboo reinforcement placed along the tension zone was unable to resist the tensile stresses and thus, a vertical crack appeared in the middle of the tension zone of the beam. There are no significant difference in terms of crack pattern recorded when steel shear link was used in beam BSR. The experimental result is presented in Table 4.13. Figure 4.37 shows measuring crack width using vernier caliper.

Table 4.13: Characteristic of the cracks

Specimens	Load at first crack (kN)	Max. crack width (mm)
CB	42.40	9.35
BR	13.63	10.66
BSR	11.80	11.18

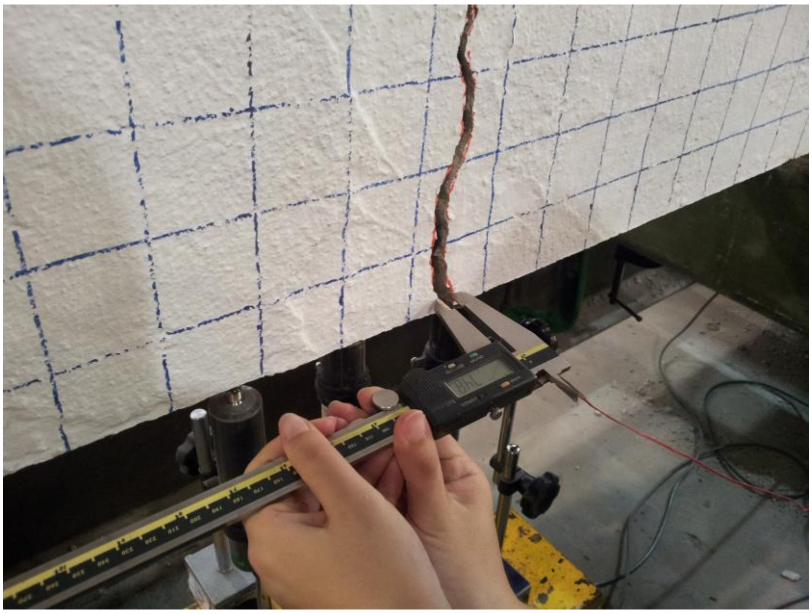


Figure 4.37: Crack width measurement using vernier caliper

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

In this chapter, the evaluation of utilizing bamboo as reinforcement material in concrete structural element was carried out through series of laboratory experimental works. In order to identify the viability of bamboo as reinforcement in concrete RC beam, experiments were conducted in three aspects which included the microstructure of treated and untreated bamboo, physical properties as well as structural behavior. Therefore, this chapter presents the conclusion and future work recommendations.

5.2 CONCLUSION

Based on the experimental results obtained, several conclusions can be drawn. The following conclusions are made based on the objectives stated in Chapter 1.

(i) In terms of bamboo morphology behavior, pore structures which are densely packed can be seen in untreated bamboo under scanning electron microscope. Those structures have become enlarged and roughen when treated with 5% of sodium hydroxide. When treated with higher concentration which is 10%, the pores elongated. However, 15% of sodium hydroxide had damaged the pore structures. Coating of oxide primer on the surface of bamboo has caused the pore structures to be invisible under scanning electron microscope.

(ii) Bamboo has very low density and its initial moisture content property deceased with the increase of number of node. In compression test, the compressive strength of bamboo samples with internode has been found to be 59% higher than specimen without internode. The tensile stress of bamboo is 10% of steel strength in which the tensile stress for steel is 798 MPa. Even so, bamboo still possesses the ability to resist tensile stress which is suitable to be an alternative as reinforcement in RC beams for smaller structures. Besides that, the average of tensile strength for bamboo rod is 26.7 MPa which is 8% of tensile strength in steel shear link of 6 mm in diameter.

(iii) According to the results, beam BR in which it is fully reinforced with bamboo managed to achieve 46% of the capacity of control beam (CB). For both beams which reinforced with bamboo, brittle failure in bending was observed whereas the vertical cracks in the midspan were found propagated to the neutral axis of the beams. On the other hand, beam BSR which is partially reinforced with bamboo did not show any significant effect in terms of beam strength.

5.3 RECOMMENDATIONS

Overall, it can be concluded that bamboo is a potential building material to be used other than steel as reinforcement in concrete. The utilization of bamboo reinforcement reduces the steel consumption in building industry. The motivation of this research is towards in creating sustainable, green building in construction industry. However, the feasibility study in this research is only conducted in laboratory scale. Certain method or technique of production might not be very practical if massive production is required for future needs. Hence, future research is required to be conducted. The following are several suggestions on the future study that should be carried out:

(i) According to the bamboo species identification by the Forest Research Institute Malaysia (FRIM), it was identified that the species used for this research is known as *Bambusa Vulgaris*. Further research can be carried out to identify the effectiveness of utilizing other species of bamboo. It was suggested by FRIM that the bamboo species *Gigantochloa* *scortechinii* or commonly known as "*buluh semantan*" is the strongest species of bamboo which is suitable to be used in construction.

(ii) A model of house made by bamboo reinforcement can be designed and constructed in reality to ensure the viability of the application of this research in real building industry.

(iii) Finite element analysis can be done by using software to provide a simulation of failure of the bamboo house model.

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APPENDIX A

DELIVERY ORDER (D.O.) FOR READY MIXED CONCRETE GRADE 25

PAMIX SDN BHD (Company No. 261694-H)

OFFICE ADDRESS : A-9, 2nd & 3rd Floor, Pusat Komersial Kuantan Perdana, Jalan Tun Ismail, 25000 Kuantan, Pahang Darul Makmur.
TEL. NO : 09-5172810, 5172813, 5172819, 5172820 FAX NO : 09-5172821
GST NO. : 001201274880

SERIAL NO: C 464692

PLEASE PLACE ALL ORDER TO :
TEL : 09-5172820
FAX : 09-5172821

Customer :
PAMIX S/B

Delivery Order No. : RMC

Date : 23.02.2016

Deliver To :
UMP GAMBANG

Account No :

Delivery From Plant No : BT 12 JLN GAMBANG

Grade	Max. Aggregate Size (mm)	Specified Slump (mm)	Total Order (Cu. Metre)	This Load (Cu. Metre)	Progress Total (Cu. Metre)
P254A	20MM	75+/-25	1.20	1.20	1.20
	Cement Type O.P.C		Admixture Type 40RA	Water Added At Site (Litres)	0
Truck No.	Driver's Name	Batchers Name	Batching Time	Arrival Time	Time Left
CDK 458	HALIM	ZUL C.A	11:40		

Remarks,

Goods received in accordance with the standard conditions of sale and delivery

Batcher's Signature

Company's stamp and signature

Name : Tan Khye Fang

IC No: 920117-07-5172

1. Interest of 1.5% per month shall be charged on any overdue invoices.
2. All cheques must be crossed and drawn to order of Pamix Sdn Bhd.
3. No receipt is valid unless issued on the Company's official receipt.
4. Any discrepancies in this delivery order must be notified to us upon receipt of goods otherwise this delivery order deemed to be in order and accepted as correct.

APPENDIX B

MIX DESIGN FOR CONCRETE GRADE 25

PAMIX SDN. BHD. (Company No. 261694-H)
, A-9,2nd & 3rd Floor, Pusat Komersial Kuantan perdana,
Jalan Tun Ismail, 25500 Kuantan, Pahang Darul Makmur,
Tel : 09-5172810/2813/2819/2820 Fax : 09 - 5172821/2806

CONCRETE MIX DESIGN COMPUTATION & SUMMARY

Reference Standard : For Specifying Production And Compliance Creteria
(MS523: 1993 / BS 5328 / JKR 20800 - 132 - 23 (Sec D :2005)

1	1.1	Characteristic Strength (**OPC**)	Specified **25 N/mm2 at 28 days** below which 5 % of test results may be expected to fall	
	1.3	Designed Standard Deviation	4.0 N/mm2	
	1.4	Designed Margin	1.64 * = 7.0 N/mm2	
	1.5	Target Mean Strength	**32.0 N / mm2**	
	1.6	Cement Type	OPC	
	1.7	Cement Source	PAHANG CEMENT	
	1.8	Aggregate Type : Coarse	Graded Granite	
		: Fine	Natural / Manufacturing Sand	
	1.9	Free Water / Cement Ratio Specified	0.53	
2	2.1	Specified Slump (**NORMAL**)	**75 +/- 25 mm**	
	2.2	Maximum Aggregate Size	20 mm	
	2.3	Type of Concrete	Ordinary	
	2.4	Free Water Content	160	Kg/m3
3	3.1	Cement Content (**OPC**)	300	Kg/m3
	3.2	Cement Content ( )	-	Kg/m3
	3.3	Maximum Cement Content	-	Kg/m3
	3.4	Minimum Cement Content	-	Kg/m3
4	4.1	Relative Density of Aggregate	2.6	
	4.2	Concrete Density	2306	Kg/m3 (Average)
	4.3	Total Aggregate Content	1846	Kg/m3
5	5.1	Grading of Fine Aggregate	BS 882 C or M Limit	
	5.2	Proportion of Fine Aggregate	44.0%	
	5.3	Fine Aggregate Content	813	Kg/m3
	5.4	Coarse Aggregate Content	1033	Kg/m3

6 6.1 **SUMMARY – NORMAL MIX PER CUBIC METRE**

Mix (Mpa)	**Slump** (mm)	**Cement (OPC)** (Kg/m3)	**20mm granite** (Kg/m3)	**Sand** (Kg/m3)	**Water** (Kg/m3)	**A/C** Ratio	**W/C** Ratio
25	**75 ± 25**	**300**	**1033**	**813**	**160**	**6.15**	**0.53**

7 **ADMIXTURES**

Mighty 40RA (RETARDAR) at	500	ml / 100 kg of OPC @	**1.5**	lit / m3
Mighty 150M (PLASTICIZER) at	0	ml / 100 kg of OPC @	**0.0**	lit / m3

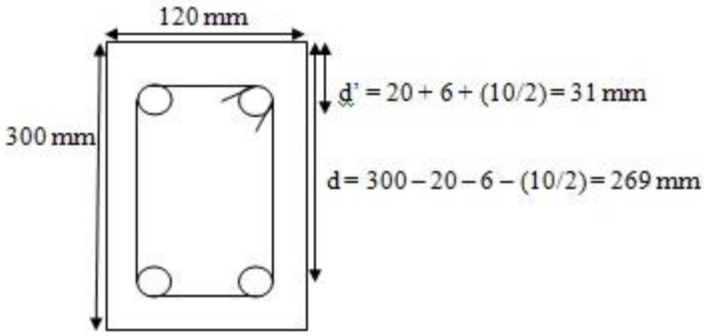
8 REMARKS : **MIX CODE P254**

Mohd Faisal Bin Ali
Sr. QA/QC Executive

Date : ***07/01/2016***

APPENDIX C

CALCULATION OF STEEL AREA OF REINFORCEMENT USING EUROCODE 2



Specification:

Size, b X h	= 120 X 300 mm
Concrete cover, C	= 20 mm
fck	= 25 N/mm^2
fyk	= 500 N/mm^2
Diameter of bar	= 10 mm
Diameter of link	= 6 mm
Reinforcement (Compression)	= 2H10 (As' = 157 mm^2)
Reinforcement (Tension)	= 2H10 (As = 157 mm^2)

Calculation:

Forces

Fcc = 0.454 X fck X b X x	= 0.454 X 25 X 120 X x	= 1362x
Fsc = 0.87 X fyk X A's	= 0.87 X 500 X 157	= 68 295 N
Fst = 0.87 X fyk X As		= 68 295 N

Equilibrium of Forces

Fst = Fcc + Fsc

68 295 = 1362x + 68 295

x = 0 (< 0.617d = 170 mm)

d’ / x = 0

Lever arm

z = d – 0.4x = 269 – 0.4 (0) = 269 mm

z_1 = d – d’ = 269 -31 = 238 mm

Moment of Resistance

M = [Fcc X z] + [Fsc X z_1]

M = [0 X 269] + [68295 X 238] X 10^-6

M = 16.25 kNm

Check

Minimum Reinforcement Area

Asmin = 0.26 X [fctm/fyk] X b X d

Asmin = 0.26 X [2.6/500] X 120 X 269

Asmin = 43.64 mm2

0.0013bd = 41.96 mm2

Asmin > 0.0013 bd OK!

Maximum Reinforcement Area

Asmax = 0.04 X b X h

Asmax = 0.04 X 120 X 300

Asmax = 1440 mm2

Overall.

Asmin < As < As max OK!

Asmin < As’ < As max OK!