EVALUATION OF OPTIMUM FIBER LENGTH OF BAMBOO FIBER REINFORCED CONCRETE

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EVALUATION OF OPTIMUM FIBER LENGTH OF BAMBOO FIBER REINFORED CONCRETE

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ABSTRACT

This research deals with the experimental study of the behavior of bamboo fiber with different fiber lengths and to study its effect as fiber reinforcing material. The species of bamboo that used throughout this experiment are the same species which is *Gigantochloa scortechinii* or commonly known as *buluh semantan*. The raw bamboo is delivered from the bamboo grove in Raub, Pahang which supplied by the local. The extractions of fiber are done based on the combined technique of chemical and mechanical using only 10% of w/v of sodium Hydroxide throughout the treatment process. In order to determine the bamboo physical and mechanical properties, a series of physical and mechanical test are done throughout this experiment and the composite samples are being mechanically tested in 3, 7, 14, and 28 days. The tests that has been conducted are bamboo water absorption test, compression and flexural tests. A total of 15 samples of concrete cubes and beams respectively are prepared including the control samples of 3 for each experiment groups for mechanical test. The cube sample and beam sample size used in this research are 100 mm x 100 mm x 100 mm and 100 mm x 100 mm x 500 mm respectively. Based on the results, it shows that the bamboo fiber in overall has only little contribution towards the improvement of concrete strength but significantly enhanced the concrete beam flexural strength which maximum up to 15%. The increase of fiber length leads to the increment of flexural strength but when it exceeds 38 mm, the performance decreased. Hence, it can be concluded that the optimum length for bamboo fiber reinforced concrete is 38mm.

ABSTRAK

Laporan kajian ini membincang tentang kelakuan serat buluh dengan panjang serat yang berlainan dan mengkaji kegunaannya sebagai bahan tetulang serat. Spesies buluh yang digunakan sepanjang eksperimen ini adalah spesies yang sama iaitu Gigantochloa scortechinii atau biasa dikenali sebagai buluh semantan. Buluh mentah didapati dari dusun buluh di Raub, Pahang yang dibekalkan oleh petani tempatan. Pengekstrakan serat dilakukan berdasarkan teknik gabungan kimia dan mekanikal dengan menggunakan hanya 10% w / v Natrium Hidroksida (NaOH) sepanjang proses rawatan. Untuk menentukan ciri fizikal dan mekanikal buluh, ujian fizikal dan mekanikal telah dilakukan sepanjang kajian ini dan sampel komposit telah diuji secara mekanikal dalam 3, 7, 14, dan 28 hari. Ujian yang dijalankan adalah ujian penyerapan air buluh, ujian mampatan dan ujian lenturan. Sejumlah 15 sampel kiub dan rasuk konkrit masing-masing disediakan termasuk 3 sampel kawalan bagi setiap kumpulan eksperimen untuk ujian mekanikal. Sampel kiub dan sampel rasuk yang digunakan dalam kajian ini adalah 100 mm x 100 mm x 100 mm dan 100 mm x 100 mm x 500 mm masing-masing. Berdasarkan hasilnya, ia menunjukkan bahawa serat buluh secara keseluruhannya hanya memberikan sedikit sumbangan terhadap penambahbaikan kekuatan konkrit tetapi peningkatan kekuatan lenturan rasuk konkrit boleh sampai sehingga 15%. Peningkatan dalam kepanjangan serat buluh membawa kepada kenaikan kekuatan lenturan konrit tetapi apabila ia melebihi 38mm, prestasi ia menurun. Oleh itu, dapat disimpulkan bahawa penemuan kami menunjukkan bahawa kepanjangan optimum untuk konkrit bertetulang serat buluh ialah 38 mm.

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LIST OF SYMBOLS

a	*Average distance between line of fracture and the nearest support measured on the tension surface of the beam*
A	*Average cross-sectional area of the specimen*
b	*Average width of specimen*
d	*Average depth of specimen*
D	*Diameter of specimen*
f_c	*Compressive strength of concrete specimen*
L	*Length of specimen*
P	*Maximum load applied*
R	*Flexure strength*
T	*Tensile strength*

LIST OF ABBREVIATIONS

ASTM	*American standard testing methods*
BFc	*Bamboo fibre cotton*
BS	*British standard*
CAN	*Chemical assisted natural*
CMT	*Compressive moulding technique*
FRC	*Fibre reinforced concrete*
N	*Normality*
OPC	*Ordinary Portland cement*
RMT	*Roller mill technique*
SFRC	*Steel fibre reinforced concrete*
TFA	*Trifluoroacetic acid*

CHAPTER 1

INTRODUCTION

1.1 Research Background

Concrete has the benefits such as low costs, high in availability, able to support for large compressive loads is now being the most common material used in construction. However, the normal concrete itself is low in tensile strength, ductility, and low resistance to cracking (Compendex, Elsevier and Services-usa, 2016). Micro cracks are always found in internal of concrete and because of the propagation of such micro cracks, the concrete experience in poor tensile strength as it making concrete become more brittle in fraction. In normal structural concrete and other similar brittle material, structural crack or called micro crack was already developed before any loading applied which is due to drying shrinkage or other causes of volume change happens to the concrete. Hence, to overcome these problems, the alternate ways such as fibre reinforced concreting method has been used. Fibre reinforced concrete is composite concrete that contained fibres, whether in orderly or randomly distributed manner in the cement matrix. Its efficiency of fibre to transfer the stress between the matrix is highly depended on the type of fibre, geometry of fibre, fibre volume and its distribution, mixing and compaction techniques of concrete as well and the size and shape of the aggregates used in the mix would define fibre reinforced concrete properties.

The used of fibres in the concrete mix as a reinforcing material was first recorded with Egyptians mixing straw and hairs of animal in the concrete as a reinforcing material for fixing of bricks in walls (Mahesh and Kavitha, 2016). After decades of research and improvement, steel fibre and synthetic fibre are now widely used as the fibre reinforced material in concrete. However, although high tensile strength of steel are used to complement the low tensile strength problem of concrete, but due to its high in cost and high energy consumption in manufacturing process making the use of steel to be limited

(C. Zhang et al., 2013). Thus, in response to the global warming issues and due to the global concern and emphasising on sustainable society especially for developing country, a more suitable material replacement with a lower cost, environmental friendly and also less energy consuming is needed. (Brindha et al., 2017).

While in current era of industrialization, as people are now tending to give more and more attention to the non-polluting materials and manufacturing process with less energy requirements (Zhang, Pan and Yang, 2012). A lot of research had made and found that there are many useable natural fibres which can work as reinforcement material such as sisal, jute, coir, kenaf, oil palm fibre, sugarcane and others (Ramaswamy, Ahuja and Krishnamoorthy, 1983). However, by addressing all these problems, bamboo was found by contained great potential to become one of the useful material as fibre reinforcement in concrete that can use in constructions with low cost implementation as bamboo is natural, cheap, widely available (Ahmad et al., 2014) and its having mechanical properties such as high tensile strength and high strength to weight ratio which had made bamboo a natural engineering material itself (Mehra et al., 2016).

In this research, mechanical performance of bamboo fibre reinforced concrete are studied through a series of compression and flexural tests. Comparative test was made to find out the impact of the bamboo fibre towards the concrete’s mechanical performance by acquiring the aspect ratio of bamboo fibre compare with plain concrete.

1.2 Problem Statement

Fibre reinforced concrete, which now is a common used construction material. Steel fibre are the most popular to be used in the concrete due to its ability to strengthen its concrete mechanical properties and control cracks development. Although addition of steel fibre in concrete can reduce micro cracks development but through a long period, various if action can corrode the steel causing it to lose of strength and bonding capability in concrete and this lead to the insight on the usage of organic and inorganic fibres which are eco-friendly and economic.

Main reason for people to start considering adding natural fibres in the concrete is due to the extremely high cost steel fibre. (Zhang, Huang and Chen, 2013). Other than high cost of raw material and the production itself, the production of steel fibre required a lot of energy consumption and the process itself contribute significant of greenhouse gases emission, eventually enhanced global warming process and leads to global concern on this issue (Mehra *et al.*, 2016).

Nowadays, people are more concern being in term of sustainability in various aspects. World Commission on Environment and Development (WCED) defined the meaning of sustainability as meeting the needs of the present without compromising the ability of future generations to meet their own needs (Onuaguluchi and Banthia, 2016). Increasing of world population and the pressure associated with the built environment has become one major problem that the mankind is facing. Significant waste generation, energy and material consumption were found as the aftereffect of high demands for building infrastructure by the industry. Therefore, the selection of materials used in construction became more important as it will directly affect to the environment issue raised. Therefore, the reasons for doing research on natural fibre has become a vital part to enhance the sustainability of material used in construction and reduce the impact to the environment.

According to the studies on natural fibres and steel fibres, natural plant fibres was found to be much more in term of renewable, eco-friendly, economical and very low in production cost (Phong *et al.*, 2011). For this research, bamboo fibre had been chosen to be studied as it has high strength to weight ratio and some of its engineering properties of material itself might able be able to use as alternative reinforcing material other than steel and synthetic fibre considering also the cost and availability issue. Hence, a study on bamboo fibres with different proportions of fibre-cement ratio and aspect ratio of are being compared with respect to plain concrete to understand its behaviour and mechanical effect in concrete.

1.3 Research Objective

The main objectives of this study is to determine the mechanical performance of bamboo fibre reinforced concrete with focusing on different fibre length. The other objectives of this study are stated as follow:

i. To determine the workability of the concrete added with bamboo fibre with 1.0% of mixture volume with fibre length of 25 mm, 38 mm, 51 mm and 63 mm respectively.
ii. To determine the mechanical properties of bamboo fibre reinforced concrete in terms of compression strength, flexural strength and tensile strength by adding bamboo fibre by 1.0% of mixture volume with fibre length of 25 mm, 38 mm, 51 mm and 63 mm respectively.
iii. To evaluate the performance of bamboo fibre reinforced concrete with normal concrete in terms of workability, compressive, tensile and flexural strength.

1.4 Scope of Work

There are several scopes covered in this study, as listed below-:

The grade 30 concrete are designed using bamboo fibre, crushed granite, river sand, Ordinary Portland cement, and tap water. The dimensions of cubes for compressive test used are 100 mm x 100 mm x 100 mm. While for flexural test, the size of beams used are 100 mm x 100 mm x 500 mm. The specimens are tested at the curing age of 3, 7, 14 and 28 days referencing the BS 1881: Part 116 (compressive strength), ASTM C78 / C78M – 15a (flexural strength). The bamboos from the same source are used in this study, which it means to be the same type of bamboo. Bamboo fibre with 1% of the cement weight and with fibre length of 25 mm, 38 mm, 51 mm and 63 mm are used in this study respectively.

1.5 Significance of Study

As normal structural concrete itself is generally low in tensile strength, low ductility, and low resistance to cracking, the application of fibre in concrete had been introduced to overcome the problems. In order to improve the sustainability of material used in construction, bamboo fibre as the natural addictive are being added into concrete mixture to enhance the compressive, tensile and flexural strength which would help to minimize the usage of steel fibre hence reducing the cost of the construction and also reduce the impact to the environment as the production or process of bamboo fibre require lesser energy compare to steel. In term of novelty, the success of this study will help in better understanding on the mechanical performance of bamboo fibre reinforced concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The most common material that are used in construction nowadays is concrete. Ordinary Portland Cement concrete, known for its compressive strength but weak in tension properties lead it to behave in brittle. Conventional steel bars as the reinforcement is the most common method used to overcome the weakness in tension and to some extend by introduce sufficient volume of fibres into the mix. Fibres are implemented and helps to recalibrate the fibre-matrix composite behaviour by improving its toughness after it was cracked (Rai and Joshi, 2014). This chapter aims to review information of the most commonly available fibres and its properties and its applications as well as the characteristics of bamboo as reinforced material.

2.2 Natural Fibre

At the present time, the public had a greater awareness on the issues that landfills are filling up, resources are being used up, the pollution issue around the planet and most importantly the non-renewable resources that will not last forever. Therefore, there is a need for more environmentally-friendly materials. This is also the reason that why there have been so many research on the potential application of natural fibres in construction done world widely in recent years. The eco-composite has been showing the important role of natural fibres in the modern industry (Hejazi et al., 2012). Natural fibres can be classified into three categories according to their origin as: mineral, vegetable and animal (Cheung et al., 2009; Nugroho & Ando, 2000; P Zakikhani et al., 2014). The classification of natural fibre is shown in Figure 2.1.

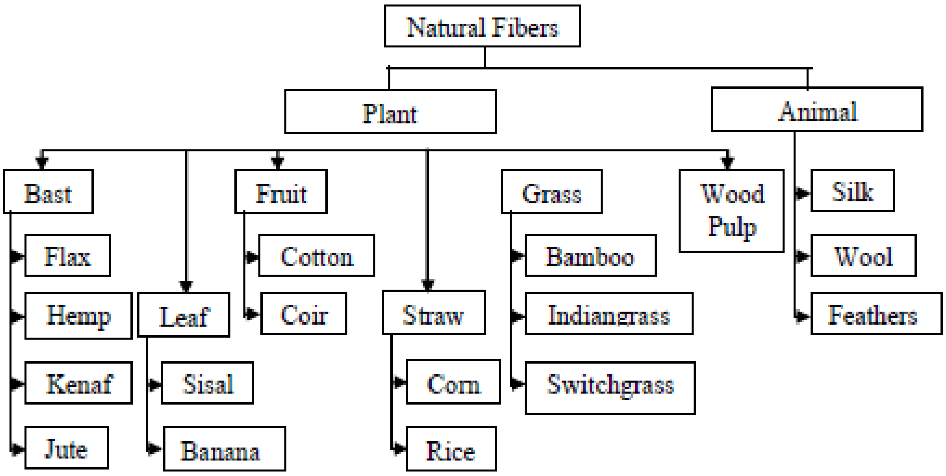
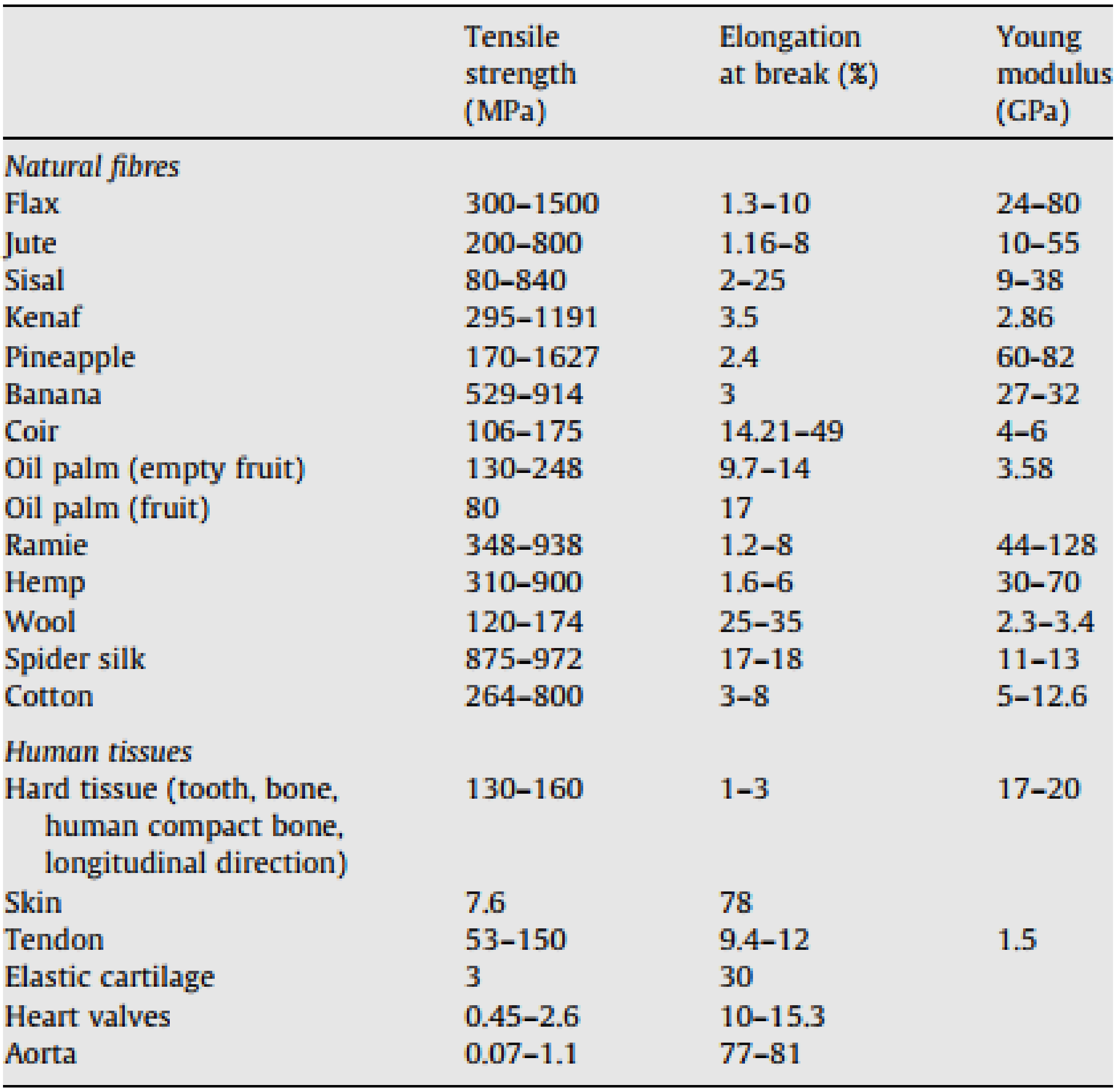


Figure 2.1: Classification of natural fiber
Source: P Zakikhani et al., (2014)

A lot of different fibres are found in nature. Each of them are distinguished and classified by its structure, mechanical, physical, chemical and geometric properties which affected by many factors such as hydrophilic nature, morphology of the plant, cell dimensions and defects. One of the disadvantages of natural fibres is that the mechanical properties are highly variable and was found to be a lot higher compared to inorganic fibres (Rosamaria et al., 2013). Table 2.1 shows the mechanical properties of different types of potential natural fibres for composite applications.

Table 2.1: Mechanical properties of natural fiber



	Tensile strength (MPa)	Elongation at break (%)	Young modulus (GPa)
Natural fibres			
Flax	300–1500	1.3–10	24–80
Jute	200–800	1.16–8	10–55
Sisal	80–840	2–25	9–38
Kenaf	295–1191	3.5	2.86
Pineapple	170–1627	2.4	60-82
Banana	529–914	3	27–32
Coir	106–175	14.21–49	4–6
Oil palm (empty fruit)	130–248	9.7–14	3.58
Oil palm (fruit)	80	17	
Ramie	348–938	1.2–8	44–128
Hemp	310–900	1.6–6	30–70
Wool	120–174	25–35	2.3–3.4
Spider silk	875–972	17–18	11–13
Cotton	264–800	3–8	5–12.6
Human tissues			
Hard tissue (tooth, bone, human compact bone, longitudinal direction)	130–160	1–3	17–20
Skin	7.6	78	
Tendon	53–150	9.4–12	1.5
Elastic cartilage	3	30	
Heart valves	0.45–2.6	10–15.3	
Aorta	0.07–1.1	77–81	

Source: Cheung et al., (2009)

Natural organic fibres are fibres that can be obtained easily from the natural resources around us, such as bamboo, jute, coil, coconut, pineapple leaf, wood, flax and animals fur. While natural inorganic fibres are produced from materials that are present in the Earth’s crust and that are inorganic rather than polymeric. Currently the most popular inorganic fibres that are being used is basalt and asbestos. The advantages of natural fibres such as low cost, environment friendly, inexhaustible supply and naturally abundant, makes natural fibres compatible with synthetic fibres (Shen et al., 1998).

Rai & Joshi, (2014) studied the application and properties of fibre reinforced concrete and findings suggest that concrete with additional of natural fibre improved in term of performance such as compressive strength, tensile strength, flexural strength and split strength compared to plain concrete. It also shows better resistance to wear and tear, better resistance to atmospheric effect and improved permeability. Ramaswamy, Ahuja, & Krishnamoorthy, (1983) conducted research on the application of jute, coir and bamboo fibres as concrete reinforcing material. The results of various experiments concluded that natural plant fibres such as jute, coir and bamboo is applicable in concrete and having advantages which likely the same to other fibres. Long term testing are still required to be conducted although it exhibited well stability in cement concrete in order to evaluate their durability.

2.3 Bamboo

Bamboo as shown in Figure 2.2 is one among agriculture crops fully grown in varied continents of the globe. Bamboo has 7-10 subfamilies of genres and there a 1575 distinction species starting from the kind of wood to bamboo herb. In Malaysia, there are just about seventy species of bamboo during which 50% in Peninsular Malaysia, 30% in Sabah and 20% in Sarawak (Tan et al., 2017). Bamboo in general dominated in Six Asian Countries viz. India, China, Indonesia, Philippines, Myanmar, Vietnam (Lobovikov et al., 2007). Bamboos being the fastest developing woody vegetation in the world. The excessive increase rate of bamboo and therefore the undeniable fact that bamboo can grow in such various climates makes the bamboo plant a sustainable and versatile resource.

Figure 2.2: Bamboo

Source: Tan et al., (1989)

Bamboo is a strong, cheap, biodegradable and environmental-friendly material. It belongs to the grass family, Poaceae and being one of the fastest growing woody plants on earth.

Some species of bamboo can grow up to 1 meter in a day (Mehra *et al.*, 2016). Ultimate strength is being reached in only three (3) to four (4) years and attains the maturity in five (5) years. Bamboo is having incredibly high tensile strength and the ultimate tensile strength can be similar to the mild steel yield strength with 6 times higher of strength to weight ratio than steel which can be found in some of its bamboo species. Bamboo can withstand both compression and tension just like steel bars did whereas most of the vegetable reinforcing materials are not even able to carry on compressive loading. While on the other hands, the production of bamboo for one cubic meter per unit stress is approximately 50 times less energy required than of steel. (Agarwal et al., 2014).

Being the fastest growing plan on earth, due to the unique rhizome-dependent systems. Bamboo is now being identify as both economic and cultural significance in Asia pacific region. Bamboo has been proven to have greater strength, if not comparable, to that of time. Various of products were made by the bamboo culm or stem which ranging from domestic household products to industrial application. Besides that, bamboo was found extensively used as construction material for bridge, scaffolding and housing in Asia but usually for temporary exterior construction material only. (Ahmad, Raza and Gupta, 2014).

Because of its excellent engineering properties, bamboo seems to be a prominent engineering material for the future and sparks the interest of researches. In the last few decades, bamboo segments have started to reinforce several structural elements for example concrete beams, circular columns and pillars. Ghavami (1995) conducted a study on the mechanical properties of bamboo fibre reinforced in concrete beam. The ultimate load of bamboo reinforced concrete was found to be 4 times higher than plain concrete. Anurag et al. (2013) states U.K Department of International Development had done a study in response to a devastating earthquake that happened in Iran that cause death of forty thousand people. The local were trying to replace the use of conventional mud brick with a low cost earthquake-proof material. A prototype bamboo reinforced concrete house was constructed and being tested with an earthquake simulator with Richter scales of 7.8 earthquake. Bamboo being highly resilient to earthquakes and cracking were found none in the concrete, and it was 50% cheaper than conventional mud brick construction. Bamboo fibres were also added into concrete, so called bamboo fibre reinforced concrete which aim to improve the concrete properties and retard the crack (Vajje and Krishna, 2013). These fibres were distributed homogenously in the mix, which result in enhancement of strength and reduced the plastic and drying shrinkage by controlling the propagation of cracks. Adding of bamboo fibre in concrete has significantly increase concrete splitting tensile property by 17% to 40%. The group of 1% volume ratio of 45 mm bamboo fibre was found the be the best in concrete enhancement. (Zhang, Huang and Chen, 2013).

2.4 Anatomical Structure and Morphology of Bamboo

Bamboo is a monocotyledon plant in the grass family Poaceae. Layers of sheaths covered the young shoot of bamboo and when it turns into a mature culm the sheaths begin to fall off. The inner part of the bamboo is hollow and having horizontal partitions called ‘Diaphragms’. While at the outer part, ring around the culm denote these layer of partitions. ‘Node’ is formed on the outside of bamboo by a diaphragm together with the ring and these nodes is the place where branches start to grow. ‘Internode’ is the term they used for the part between two nodes. Bamboo are structured by these three basic tissues, namely epidermal, vascular, and ground. The shell of the bamboo is known as the thick epidermis tissue whilst the longitudinal fibre that used to supported the bamboo is known as vascular tissue. Lastly, the tissue that fill the rest of the organ is ground tissue or matrix. (Low et al., 2006).

Nodes will define the characteristic of the culm. Cells are strongly oriented in axially manner within the internodes. The lateral movement of the nutrients or fluid is highly restrained and therefore no radial cell elements are found in culm. Diaphragm, the solid layer wall is being provided in transversal interconnection by the nodes. When bamboo grow, the sheath leaving scar at the node marks due to the insertion of culm sheath and branches and when they occur, originate just above this scar.

Lacuna, is a large cavity fluid that surrounded the culm wall or shell which ranging of thickness found from the internode of most bamboo species. Male bamboo, sometimes referred as the solid bamboo that do not have lacuna in it. A transversal section of a culm internode with the lacuna shows the ground tissue in which collateral vascular bundles are embedded. The longitudinal fibre that supporting the bamboo are also known as the vascular tissues or bundles. The transverse appearance of the solid crass wall is determined by their shape, size and arrangement. The vascular bundle in inner zone bamboo is found to be larger and fewer but vascular bundle is found smaller and more numerous at the peripheral zone (node). The walls of the internodes become smaller when the height is increasing as the bamboo are generally being tapers from the base to the tip. An increase in their density is highly proportional to the decrease in the total number of vascular bundles. (Walter, 2002).

Bamboo is a typical natural fibre composite material, being longitudinally reinforced by strong fibres. The outer surface region was found to have denser distribution of fibre while in the inner surface region it only sparely with their volume fraction being a function of radius. The reinforcement unit, hollow, multi-layered and spirally-wound bast fibre, has been found to play a vital role in its physical and mechanical behaviour (Low et al., 2006). The structure of a bamboo culm is depicting in Figure 2.3.

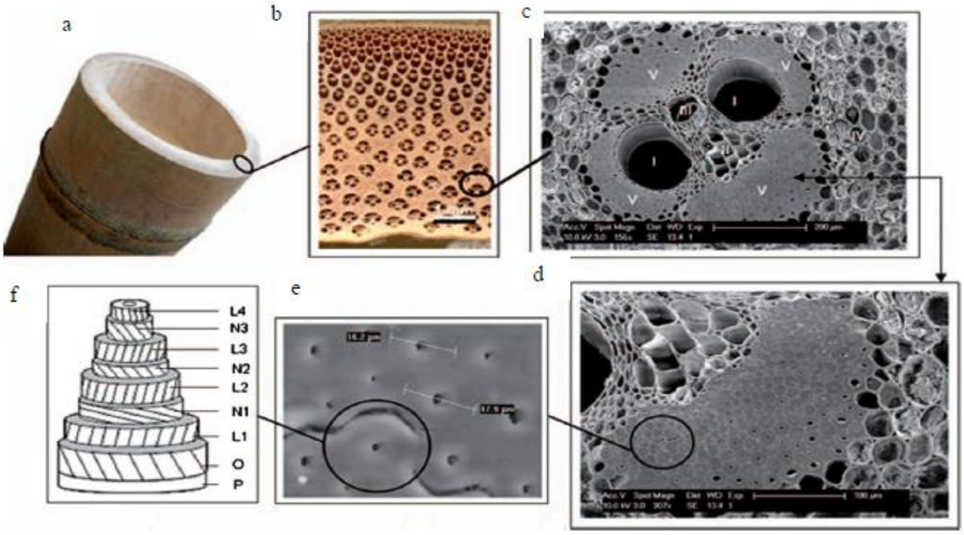
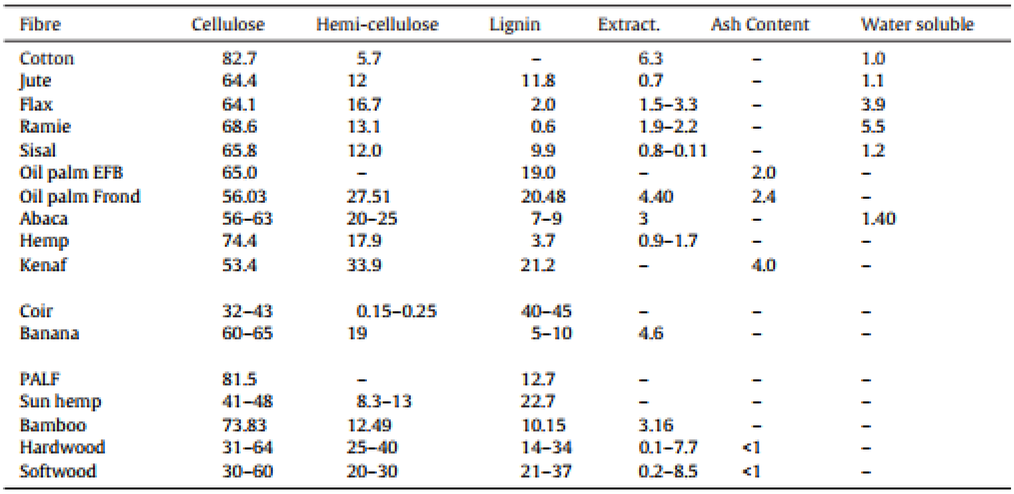


Figure 2.3: a) bamboo culm, b) cross-section of bamboo culm, c) vascular bundle, d) fibre strand, e) elementary fibres, f) model of polylamellae structure of bamboo

Source: Parnia Zakikhani et al., (2014)

Bamboo fibres are mainly constituted by cellulose, hemicellulose and lignin as the main chemical composition (Jawaid and Abdul Khalil, 2011). Only 10% of the total weight of bamboo fibre are not made up by these high-glycan components (Abdul Khalil *et al.*, 2012). Table 2.2 depicts the chemical composition of common lignocellulose fibres.

Table 2.2: Chemical composition of common lignocellulose fibres



Fibre	Cellulose	Hemi-cellulose	Lignin	Extract.	Ash Content	Water soluble
Cotton	82.7	5.7	–	6.3	–	1.0
Jute	64.4	12	11.8	0.7	–	1.1
Flax	64.1	16.7	2.0	1.5–3.3	–	3.9
Ramie	68.6	13.1	0.6	1.9–2.2	–	5.5
Sisal	65.8	12.0	9.9	0.8–0.11	–	1.2
Oil palm EFB	65.0	–	19.0	–	2.0	–
Oil palm Frond	56.03	27.51	20.48	4.40	2.4	–
Abaca	56–63	20–25	7–9	3	–	1.40
Hemp	74.4	17.9	3.7	0.9–1.7	–	–
Kenaf	53.4	33.9	21.2	–	4.0	–
Coir	32–43	0.15–0.25	40–45	–	–	–
Banana	60–65	19	5–10	4.6	–	–
PALF	81.5	–	12.7	–	–	–
Sun hemp	41–48	8.3–13	22.7	–	–	–
Bamboo	73.83	12.49	10.15	3.16	–	–
Hardwood	31–64	25–40	14–34	0.1–7.7	<1	–
Softwood	30–60	20–30	21–37	0.2–8.5	<1	–

Source: Jawaid & Abdul Khalil, (2011)

Among the type lignocellulose fibres, the lignin content of bamboo was found as high as up to 32% and this microfiber angle is relatively small ranging from 20 -100 (Liu et al., 2012). These factors lead to extremely high tensile strength, flexural strength, and rigidity of the fibres poly-lamellate wall structure (Liu *et al.*, 2012). Based on its anatomical properties, ultra-structure and plant fracture mechanism bamboo establishes itself a superior natural fibre (Abdul Khalil *et al.*, 2012)

2.5 Physical Properties of Bamboo

Li (2004) investigated the chemical, physical, and mechanical properties of the bamboo. It was recorded that the bending properties and specific gravity of bamboo are varied with the vertical height of bamboo culm and age. The mechanical properties of bamboo were found to be increase with age up to five years. Specific gravity and bending properties was found much higher in the outer layer than the inner layer but specific gravity is varying along the culm. Specific gravity was found to be higher in top portions compare to base. The specific gravity has direct relation with the bending strength of bamboo. Compressive strength along the longitudinal direction was found to be higher than that across it (Oscar Ontario, 1993).

Found that the bamboo physical as well as mechanical properties are differ in term of species, height, diameter, year, position along the culm, moisture content of bamboo. Structural properties of bamboo nodes are investigated. It states that the nodes are actually strengthening the bamboo culm as a column. It is recommended that cautions are needed to be taken when designing beams as shear and crushing failures are common place. Also, it also reported that advantages of bamboo having incredible fast in growth rate is better than other natural construction materials, up to 25m over 6 months. The report underlined the ability of bamboo to resist seismic forces due its lightness as well as high strength to weight ratio (Li, 2004).

Another research team examined abrasive wear tear effect of the cross section of bamboo culm. Mixture of quartz sand is used as the abrasive material for testing. It was reported that the increase of vascular fibre content is bringing increase in wear resistance of bamboo. Discussion on the impact strength and tensile strength of bamboo effects on its abrasive wear are being progressed (Tong et al., 2005).

It has been noted that the volume fraction of longitudinal fibres is proportional to radius. The percentage of fibres was found to be maximum at outer periphery while it is minimum at the inner side unlike to steel. Another study was found in contradict with others, it suggests that bamboo fibres are having tensile strength that can be corresponds to that of steel. The origin of fracture and the volume of fraction of longitudinal fibres will determine the fracture properties of bamboo based on their main finding (Amada and Untao, 2001). The fibres in the nodes was found not contributing any fracture resistance as lower average fracture toughness was found in the nodes compared to the minimum value of the entire culm (Lo et al., 2004).

Ghavami et al., (2003) studied the bamboo structure as a functionally graded composite material constituted by long and aligned cellulose fibres embedded in a lignin matrix. The fibre distribution was found to be vary throughout its thickness through the analysis of the bamboo culm transversal section. Digital imaging analysis was used to analyse the meso-structure of bamboo culm. The fibre distribution across the thickness of the bamboo culm cross section can be present by developed equations. Composite material's approach was implemented to establish the basic equations to study, how this variation occurs. Modification of equation will be done in order to model the mechanical behaviour of bamboo and establish the variations of the volume fraction of the cellulose fibres across the transversal section for any bamboo. New study is successfully being conducted on the variation of fibre volume fraction in different samples of bamboo species through this developed methodology (Ghavami et al., 2003).

2.6 Mechanical Properties of Bamboo

Different in type, height, diameter, moisture content, position along the culm and also age was found the be the main variable to affect the mechanical properties of bamboo causing to be considerably vary in much (Alves et al., 2013). The strength of bamboo was found to be increased with age but as it reached its optimum at 2.5-4 years then the strength decrease following on maturity. Findings indicates that the density and diameter of fibre, thickness of fibre cells wall and the moisture content was the main factor affecting the strength (Low et al., 2006).

High mechanical strength, low specific weight ratio, high tensile strength and high modulus of elasticity are what distinguish bamboo from others (Sen and Reddy, 2011). Amada et al. (1997) have conducted study on mechanical properties of particular variety of bamboo. The geometry of bamboo’s longitudinal profile has a macroscopically functionally graded structure which able to withstand wind loads from the environment. The fibre distribution and orientation inside bamboo culm’s wall is denser in outer region and sparsely in inner region which makes outer surface to be stronger or higher strength than inner surface. According to Yu et al., (2014), it states that the bamboo fibres called ‘natural glass fibre’ have a specific strength of 610MPa, while the ground tissues (matrix), which are in the honeycomb foams shape have a much more lower strength of 50MPa. The fibre strength was found to be around 600MPa which is 12 times higher than the ground tissue strength and the Young’s modulus of fibre is much higher (46 GPa) compare to the ground tissues (2 GPa). Whereas the density of the fibre was found to be 1.16 and the ground density is 0.67 gm/cm^3 and the average density of the bamboo is 0.8 gm/cm^3 (Amada *et al.*, 1997) . Bamboo can be now distinguished as a composite materials of cellulosic fibres with 700MPa of tensile resistance based on results (Sen and Reddy, 2011).

According to S.C. Lakkad and J.M.Patel (1980), bamboo is found to have higher specific strength than that of mild steel. The specific modulus of bamboo and mild steel are similar and compete-able. The specific properties provided an enlightenment into comparative strength and stiffness on a weight basis which would under unidirectional loads.

However, the presences of humidity, light, temperature and bacteriological effect can deteriorate the mechanical properties of bamboo but this can be reducing or avoid by implementing suitable treatments on the sample.

2.7 Fibre Aspect Ratio

Fibre volume fraction and the interfacial adhesion between the fibre and matrix had been favourite effect study in most of the researcher as its ensure on the effectiveness of stress transfer. However, the fibre orientation and the fibre aspect ratio (*l/d)* was being understand that it also plays a very important role in mechanical properties of composites. (Tian et al., 2014).

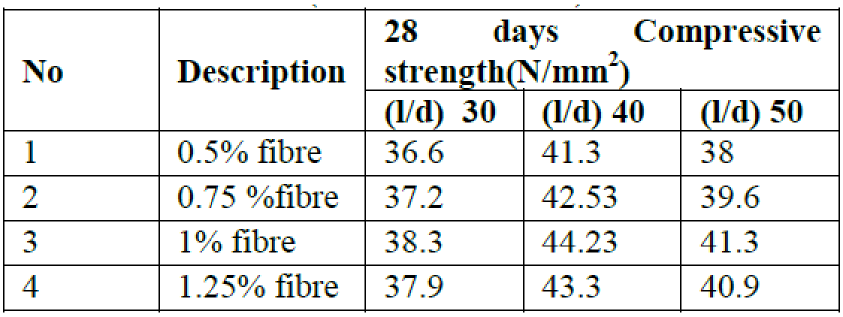
Aspect ratio is also known as one the of parameter that define the properties of fibre. Aspect ratio is the ratio of fibre length to the fibre diameter. Aspect ratio is used to multiply with the fibre diameter to decide its length. Strength of fibre are strongly being influenced by the length of fibre which may affect in flexural, compression and even in tension.

Wang et al., (2010) conducted a study on the effect of fibre aspect ratio on mechanical properties of steel fibre reinforced concrete (SFRC) and reported that the fibre aspect ratio is being a very important parameter than going to affect the mechanical properties of steel fibre reinforced concrete. Based on the findings, optimum aspect ratio is existing for the SFRC in view of mechanical performance. Toughness was found to be enhanced rather than the strength as the volume of steel fibres added in the concrete are increasing. However, higher fibre aspect ratio was also found to be high energy absorption and better in restraining crack propagation due the enhancement of toughness and maximum strain of SFRC are being increased but it may cause the compressive strength and the modulus of elastic to be lower in overall.

While according to Gao et al., (1997), it states that the fibre aspect ratio (*l/d*) is directly proportional increment with the deflection limit corresponding to the ultimate load which can say the effect of steel fibre on the flexural behaviour is highly prominent. The shape of the descending branch of load-deflection curves tended towards gently, and flexural fracture toughness was largely improved because the fibre pull-out and debond increased the value of the fracture energy required.

Mahesh and Kavitha (2016) conducted a study on bamboo fibre and to determine the effect of its aspect ratio use as reinforcement material in concrete. They found that aspect ratio *(l/d)* of 40 with 1% of fibre volume produced a greater strength in compression, greater flexural strength and greater split tensile strength when compared to others aspect ratio. Based on the finding, the aspect ratio *(l/d)* of 40 was found to exhibit the maximum in mechanical performance with 1% of fibre content. Table 2.3 shows the result of 28 days' compressive strength of bamboo fibre reinforced concrete with diameter of 1.244mm.

Table 2.3: 28 days compressive strength result of bamboo fibre reinforced concrete



No	**Description**	**28 days Compressive strength(N/mm^2)**		
		(l/d) 30	**(l/d) 40**	**(l/d) 50**
1	0.5% fibre	36.6	41.3	38
2	0.75 %fibre	37.2	42.53	39.6
3	1% fibre	38.3	44.23	41.3
4	1.25% fibre	37.9	43.3	40.9

Source: Mahesh & Kavitha, (2016)

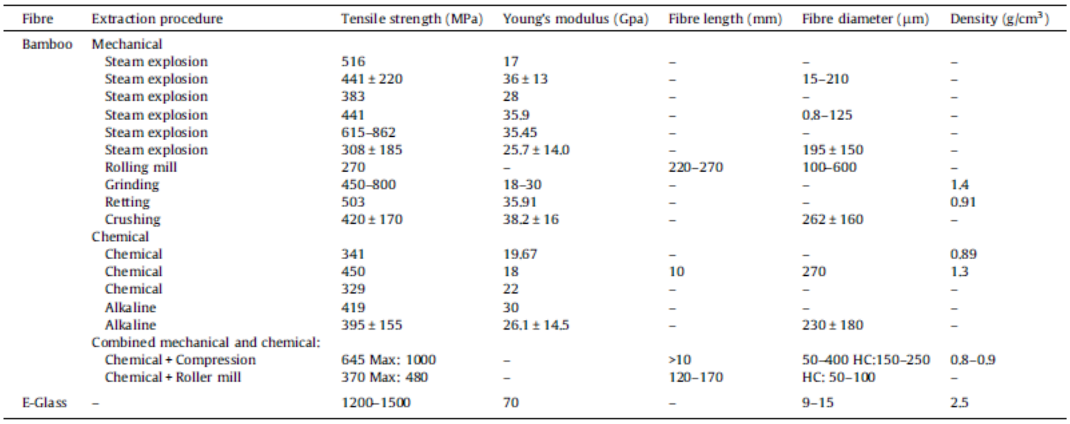
Other than affecting the concrete mechanical strength, the workability of the fresh concrete mixture was found to be lowered when there is increment of fibre in term of selected aspect ratio (*l/d*) and fibre content volume. Yazici et al., (2007) reported that the workability of fibre reinforced concrete mixture had been drastically decreased when they used fibres with *(l/d)* ratio of 80 and fibre volume of 1.0% and 1.5%. By using fibres what vary in aspect ratio and content volume induced, the overall density of the concrete is increasing as well. Study indicates that dosage of 4-19% of steel fibre are contributing in compressive strength increment. It also significantly increased the split tensile strength (11-54%) and flexural strength (3-81%) of concrete compare to the control specimen. SFRC was found to have incredible higher flexural strength increment compared to the split tensile and compressive strength regarding on the same fibre aspect ratio and content volume induced.

2.8 Extraction of Bamboo Fibre

In order to extract the bamboo fibres from its culm, the diaphragm and node are need to be removed and then the hollow portion will be used for processing.

Based on current findings, there have been many methods found to be effective in extracting bamboo fibres which these extraction methods can be classified in mechanical. Chemical or combination of both (Phong et al., 2011); (Kim et al., 2013). However, it is difficult to extract the fibre in a form that we desired under controlled manner in term of uniform diameter, length and superior mechanical properties (Parnia Zakikhani *et al.*, 2014). Up to date, there is not much information regarding the bamboo fibre extraction methods exposed by industries, but it was believed that the selection of the appropriate technique would highly depends on the application requirements of the fibres such as mechanical properties, chemical properties, costing and environmental impact. Besides that, different extraction methods will yield different results in term of mechanical properties and physical properties of bamboo fibre as shown in Table 2.4.

Table 2.4: Mechanical and physical properties of bamboo fibre



Fibre	Extraction procedure	Tensile strength (MPa)	Young's modulus (Gpa)	Fibre length (mm)	Fibre diameter (μm)	Density (g/cm^3)
Bamboo	Mechanical					
	Steam explosion	516	17	–	–	–
	Steam explosion	441 ± 220	36 ± 13	–	15–210	–
	Steam explosion	383	28	–	–	–
	Steam explosion	441	35.9	–	0.8–125	–
	Steam explosion	615–862	35.45	–	–	–
	Steam explosion	308 ± 185	25.7 ± 14.0	–	195 ± 150	–
	Rolling mill	270	–	220–270	100–600	–
	Grinding	450–800	18–30	–	–	1.4
	Retting	503	35.91	–	–	0.91
	Crushing	420 ± 170	38.2 ± 16	–	262 ± 160	–
	Chemical					
	Chemical	341	19.67	–	–	0.89
	Chemical	450	18	10	270	1.3
	Chemical	329	22	–	–	–
	Alkaline	419	30	–	–	–
	Alkaline	395 ± 155	26.1 ± 14.5	–	230 ± 180	–
	Combined mechanical and chemical:					
	Chemical + Compression	645 Max: 1000	–	>10	50–400 HC:150–250	0.8–0.9
	Chemical + Roller mill	370 Max: 480	–	120–170	HC: 50–100	–
E-Glass	–	1200–1500	70	–	9–15	2.5

Source: P Zakikhani et al., (2014)

2.8.1 Chemical Extraction Method

Kaur et al., (2013) studied on different retting technique to extract bamboo fibres. There methods, Chemical Assisted Natural (CAN), acid and alkaline retting were used to extract bamboo fibre bundles with different concentration of sodium carbonate to separate the vague regions and diminish the lignin content of the fibres. Retting is a technique that combined the effect of temperature, moisture, bacteria or fungi, resulting in the fibrillation of the fibre bundle from gummy and cementing non-cellulosic substances like hemicellulose, lignin and pectin which enclose the cellulose.

2.8.1.1 Degumming

Rao & Rao, (2007) and Kim et al., (2013) have conducted a study using that extract bamboo fibres through degumming technique through removing of pectin along with gummy fill from the decorticated bamboo strips. The level of this process is needed to be controlled in order to producing long single fibre from the bundles. It was shown that this method successfully yielded about 33% of fibres on weight basis.

2.8.1.2 Acid or Alkali Retting

For Alkali retting method, bamboo strips were heated with 1.5N NaOH solution in a stainless steel container at 70 ℃ for 5 hours. Subsequently, the alkali treated fibre strips were pressed by the press machine and being isolated by a steel bar or nail. The extracted treated fibre was then needed to be wash with water followed by the oven drying process. (Kim *et al.*, 2013) concluded that this extraction method cause the least damage to the fibre. In other study conducted by (Kumar et al., 2010), bamboo are chopped into small size and was boiled with NaOH for 120 minutes at 4% mass per volume to affect the cellulosic and non-cellulosic parts. This technique was being done few times repeatedly under designed pressure on the bamboo pulp to extract the bamboo fibre. However, problem is that this technique or extraction methods was found to produce large bundles of fibre. While research team Deshpande et al., (2000) have conducted studies on bamboo fibre extraction method by soaking small bamboo strips into 1N NaOH solution for 72 Hours in order to smoothen the fibre extraction. Due to lignin is soluble in both acid and alkali solution, Trifluoroacetic acid (TFA) and alkaline solution were used to separate the bamboo fibres form the bundles. In this process, the large portion of lignin was removed but the lignin content in the middle of lamellae was remained.

For CAN technique, He et al., (2007) use various percentage of sodium sulphite, sodium silicate and sodium polyphosphate solution to extract the fibre from bamboo culm. The bamboo sample are first dry in oven with 150 ℃ for 30 minutes and then soaked in water at 60 ℃ for 24 hours. Then the bamboo chips are air-dried and to further remove the impurities by repeating rolling. Hot water was then use to wash the fibres before treated with Xylanase. Subsequently, bamboo fibres are cooked again at 60 ℃ for 100 minutes and sulphuric acid solution are used to treat these bleached fibres. The fibres size that processed was around 2.5mm in average and it was found that in order to produce long fibre, pectin and lignin are needed to be connected. In overall, alkali treatment was found to improve the interlocking adhesion or bonding reaction of composites as compare with other methods (Takagi and Ichihara, 2004). While according to F. S. Tong et al., (2015), bamboo fibres that undergoes alkaline treatment provide better thermal stability than untreated fibres. The surface was found to be smoother than untreated fibre which makes the interlocking surface adhesion of composite stronger. Besides that, the tensile strength and modulus of fibre were found to be improved about 45.6 to 72%.

2.8.2 Mechanical Extraction Method

Various different form of procedures can be used as mechanical extraction methods such as steam explosion, crushing, grinding and rolling in a mill. All these methods were found to be effective and being used by industries to obtain fibres for the implementation of bamboo fibres reinforced composites (Parnia Zakikhani *et al.*, 2014). The mechanical extracted fibres (except steam explosion) were found to have better mechanical properties, higher yield, convenience and environmental friendly (Phong *et al.*, 2011).

2.8.2.1 Steam Explosion

This method is a low energy consumption method used to separate the cell walls of a plant to produce pulp. Steam Explosion method consume very low amount of energy to produce pulp by separating the cell walls of a plant. Okubo et al., (2004) have conducted a study using this methods to extract bamboo fibres and found that single fibre are unable to be effectively separated from bamboo fibre bundle. A bigger machine with mesh filtering is used to produce fibre bundles that ranging from 125-210 μm diameter. Next, the fibres were dried at 120 ℃ for 2 hours. As a conclusion from their research, it was found that lignin content is not able to remove completely from the fibres using this method. Therefore, mixing machine are needed to use in order to remove the excessive lignin content from the fibres and process to bamboo fibre cotton (BFc). Another same method have been conducted by (Phong *et al.*, 2011), the raw bamboo was chopped into culm with 70-80cm length and being placed into an autoclave with over-heated steam at 175 ℃ with a pressure of 0.7- 0.8 N/mm^2 for 60 minutes long. Next, hot steam was immediately released for 5 minutes and this cycle is being continuously repeated for 9 times in order to ensure the fully breaking of cell walls. Lastly, hot water is used to wash the ash on the fibres with additional of soap at 90-95 ℃ for 15 minutes and then drying in oven at 105 ℃ for 24 hours.

2.8.2.2 Crushing

Raw bamboo was first cut into small pieces and then place into a roller crusher to extract the bamboo fibres. Subsequently, coarse fibre is extracted from those small pieces by a pin roller. Excessive fat of these coarse fibres were boiled for 10 hours at 90 ℃ and move to rotary dryer to dry it before put into dehydrator. However, problem was found as the result of this process which is it will produce short fibres that will makes the fibre become powder if over-pressing of mechanical happens (Parnia Zakikhani *et al.*, 2014).

2.8.2.3 Grinding

The internode of bamboo culm was chop into strips and immersed in water for 24 hours. The drenched strips were then being chop with a knife into smaller pieces. The wider strips passed through an extruder while the small chips were obtained by cutting the longer strips. Later, a blender was used to grind the bamboo chips in a very high speed for 30 minutes to produce short bamboo fibres. Several size of sieves with various apertures were used to separate the bamboo fibres. Finally, the extracted fibres are then oven-dried at 105 ℃ for 72 hours (Thwe and Liao, 2002).

2.8.2.4 Roller Mill

Jindal, (1986) initially soaked the 1mm thick of bamboo strips in the water for 60 minutes to smoothen the detachment of the fibres. The bamboo strips are then going through the mill rolling machine at low speed and under low pressure. The soled bamboo was then immersed with water for 30 minutes and detach into fibres using a razor blade followed by drying under the sun for 2 weeks. The length of the fibres was ranging from 200 to 270mm. In another research, 2 pairs of steel cylinders are used to extract the fibres by pressing on the shortened bamboo strips without soaking it in water (Shin et al., 1989). Yao and Zhang, (2011) conducted the rolling technique to extract the bamboo fibres. This technology generally sliced the bamboo into strips and then steam to soften so that the solid part of the lignin content in the middle of lamellae isolates. This eventually weaken the bonding strength between the fibre and the external force experience on the bamboo by the mechanical friction that will eventually lead to fibre decomposition through action of rolling.

2.8.3 Combined Mechanical and Chemical Extraction

Combined technique is usually selected by the pulp industries or when is required to pulping in paper. The Roller Mill technique (RMT) and the compression moulding technique (CMT) are usually being apply after the chemical process in treatment. Both techniques are required the bamboo strips to be first treated with alkali. Next, they using two plates of 10 tons of load to pressurised the bamboo strips in compression moulding technique. The quality of fibre to be extracted are directly affected by two important parameters which is the time and the starting bed thickness of the mould. For RMT, the bamboo strips that already treated with alkali were rolled in the roller machine and it was repeated continuously until the fibres are being well separated from the bundles. These combination of methods was found to be effectively and easily to separate fibres (Deshpande, Bhaskar Rao and Lakshmana Rao, 2000). Other than the two important factors mention earlier, the ability to extract the desired fibre are being highly affected by the diameter of the rollers and the size of the compression mould in both techniques. Phong et al., (2011) used extract fibres with only one roller in their research. Only the internodes of bamboo culm are used and been sliced into smaller strips follow its original longitudinal direction. The bamboo trips are then treated with different concentration of sodium hydroxide solution at 70 ℃ for 10 hours. Fibres are then extracted by rolling the alkali treated bamboo strips with a roller and these small fibres that extracted will required to neutralise with water and drying at 105 ℃ for 24 hours with oven.

2.9 Durability of Bamboo

Bamboo which is natural plants like timber is susceptible to the environmental degradation and is highly prone to insects and fungi attack. Different in species, age, conservation methods, treatment and curing are the main factors that affects the durability of bamboo. Bamboo are needed to be cure immediately one it was cut at the bamboo grove. Findings suggest that the insects’ attack are strongly related between the level of starch and the moisture content of bamboo culm. Bamboo is required to undergoes various treatment including curing on the spot, soaking, heating and smoke which aim to reduce the starch content (Ghavami & Hombeeck, 1981; Janssen, 1981; Dunkelberg et al., 1985 and Ghavami, 1988).

David Farrelly (1984) conducted study on the method to minimize the content of starch in bamboo. Reducing the starch is done by leaching, an expensive and simple treatment. Since still water decolours bamboo, culms are kept submerged in moving water for several weeks before use. By this method, starch, sugar, and water soluble minerals are removed. In a variation of this method, the bamboo is first soaked for five days in water and the shiny gelatinous substance which is extruded is wiped off. This increases oil absorption in the next step, which is to soak the bamboo in Rangoon oil for 48 hours. Though stored in a beetle-infested area 15,000 bamboos so treated were reported perfectly sound five years later

Another method of removing starch is by "shed curing". The culms are placed in a covered shed so that air can circulate around them freely for a period of eight weeks. According to David Farrelly (1984), the most effective treatment is a combination of clump-shed-water curing. The exposure to heat and smoke can also, afford effective protection. Farrelly also, reported that baskets and other small bamboo items are often stored in rural China in lofts above the kitchen where they can be exposed to the heat and smoke of the cooking fire.

Lima et al., (2008) studied the mechanism of natural bamboo fibre degradation in an alkaline environment which can not only reduce the fibre tensile strength, but also cause the fibre flexibility to decrease. Despite this, the bamboo fibres are difficult to be penetrated by the cement hydration as higher area to perimeter ratio are occurred when we used bamboo splints as reinforcement in concrete. From the results of the tests it was observed that the Young’s modulus of the node is half that of the culm which was believe it was because of its more complex microstructure in the node.

Oscar Ontario (1993) concluded that, the shrinkage in bamboo begins right at beginning of seasoning; it affects both size and shape of the cross section. The shrinkage is 4 to 14% in wall and 3 to 12% in diameter depending upon the species. Thick walled mature bamboo is more liable to crack; this is due to the fact that during drying, outer fibre bundles get pressed together while inner ones are stretched.

For conservation purpose, drying of bamboo is extremely important. Dunkelberg et al. (1985) states that when the moisture content of bamboo is less than 15% or when it is low, it has lesser chance prone to the insect attacks.

Ghavami (1998) and Dunkelberg et al. (1985) findings indicates that the decrease of bamboo moistures content can increase its physical and mechanical properties. Drying of bamboo is important in order to ensure penetration when the bamboo is treated with preservative and also to ensure desired result together with transportation costs reduces. Drying can be done in various method such as are drying, green house drying, oven or even heating with fire.

Treatment methods that is compile with the designed requirement are the main factor to decide the durability of treated bamboo. Chemical that used in the treatment must not affect the bamboo fibre and easily to be washed out due to rain or humidity factor once the chemical or preservative is injected (Janssen, 1981; Dunkelberg et al., 1985; and Ghavami, 1988).

2.10 Fibre Reinforced Concrete

Normal structural concrete were originally low in tensile strength, low ductility, and low in resistance towards cracking (Compendex et al., 2016). Internal micro cracks were developed even before loading particularly due to drying shrinkage or others causes of volume change. Therefore, to overcome all these problems, Fibre Reinforced Concrete (FRC) was introduced. Induction of fibres in hardened state of concrete brings advantages such as post racking control due to the fibre bridging ability at the cracks region and improvement in mechanical strength, concrete maximum strain and its toughness.

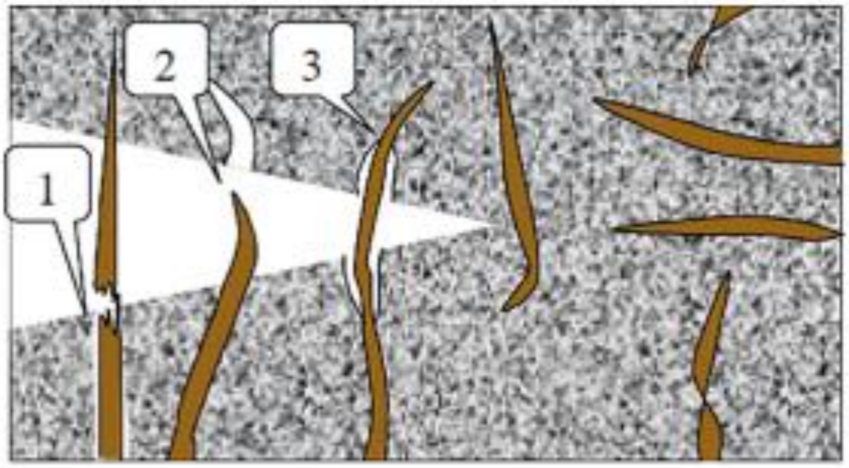


Figure 2.4: Mechanical behaviour of fiber in concrete
Source: (Regina *et al.*, 2017)

According to schematic diagram in Figure 2.4 shows the mechanical behaviours of fibre in concrete. This diagram illustrating on how the fibres act to absorb energy and restrain the propagation of cracks. The cracking and fibre working schematics can have been seen from the left towards the right along the crack where as these fibres are representing the rupture, pull out, bridging by tension and also fibre matrix debonding at the interface respectively. Matrix are showing that these fibres are controlling the crack propagation within the concrete by effectively absorb and release the stress from the loading. Water and others form of contaminants are prevented to penetrate the concrete matrix due to the bridging of crack width by the fibre in the matrix hence it enhances the concrete properties and on the same time corrosion of reinforcing steel bar and degradation of concrete can be minimized. But on the other hands, the matrix will distribute the minor cracks to other locations. According to Regina et al., (2017), the overall reinforcement effect by the individual fibre is in cumulative although single fibre only able to contribute in small.

Rai and Joshi (2014) have conducted a research on the applications and the behaviour of fibre reinforced concrete along with its properties. Findings indicates that the concrete toughness, wear and tear resistance and shrinkage cracking resistance of the composite are being effectively enhanced by FRC. Flexural toughness of the composite is the main reason to be enhance through the use of fibre reinforced composite but not the composite strength. On the other hand, concrete ductility was also found to be enhanced together with its capacity to resist post-cracking load. In FRC, the density of crack was reported to be increased but the crack size is decreased. However, large quantities of fibre is required to improve the FRC concrete performance in term of the resistance but it will subsequently cause the concrete workability to be decreased with additional of fibre induced.

2.11 Fibre Length

Other than the fibre aspect ratio, fibre length are also an important parameter than will effect on the overall fibre tensile strength and its capability to resistance. Takagi & Ichihara, (2004) indicates that the fibre length and fibre content are strongly affecting the mechanical properties of the composite. The trend is the increase of fibre length leads to the increase of flexural strength. However, findings also indicate that the 15mm long bamboo fibre are experiencing surface fracture as shown in Figure 2.6 which is also indicating that it has exceeded its critical length required for the composite as the frequency of fracture in pull-out of fibre action is increased with the increasing of fibre length. While for the 8mm fibre that shown in Figure 2.5 do not have any surface fracture found when pull out.

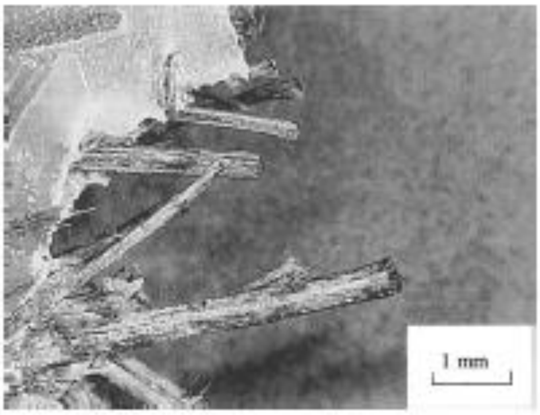


Figure 2.5: Surface image of 8mm fibre pull out from reinforced composites
Source: (Takagi and Ichihara, 2004)

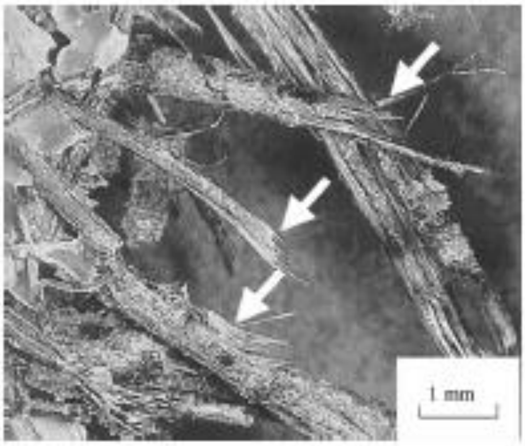


Figure 2.6: Surface image of 15mm fibre pull out from reinforced composites
Source: (Takagi and Ichihara, 2004)

While for team C. Zhang et al., (2013), they used 3 different kind of fibre length which is 22.5mm, 45mm and 67.5mm respectively in their research. Research finding shows that the compression strength of the concrete in overall have no contribution form the fibres but the split tensile property of the concrete had been significantly enhanced with the fibre induction and the optimum length they found is 45mm. While X. Zhang et al., (2012) found that the concrete cube compression strength are actually decreasing with the increasing length of bamboo fibre used regarding the fibre content remain constant in the experiment. However, the trend is follow the increasing of length leads to increasing of strength in flexural and it starts to drop as it reached its optimum length.

2.12 Summary

By reviewing the details of the past researches, the research gaps have been identified. Bamboo have been found to be a suitable engineering material due to its physical and mechanical properties such as high strength to weight ratio, high flexural and tensile properties. However, most of the investigation on fibre reinforced concrete that had been done are mainly confined to kenaf, jute, steel fibre and synthetic fibre. Although there was already some investigation that had been conducted on bamboo fibre as reinforcing material in concrete, but mostly their focus is mainly on fibre to cement volume only and extraction of fibre with different methods. Therefore, focuses in this research will be on the improvement by different of bamboo fibre length on the performances of fresh and hardened concrete through combine extraction method of alkaline retting and roller mill method.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter reviews the details of methodology used to examine the performance of concrete added with bamboo fibre through experiments and tests. Most of the methodology and findings from this field are mainly profound from the journals and thesis, and they serve the purpose of improving the upcoming studies. The aim of this research is to collect date through slump test, compressive and flexural strength test. The British, ASTM, European and Malaysian standards are used to support the properties of material and physical tests. The research methodology flow chart is shown in Figure 3.1.

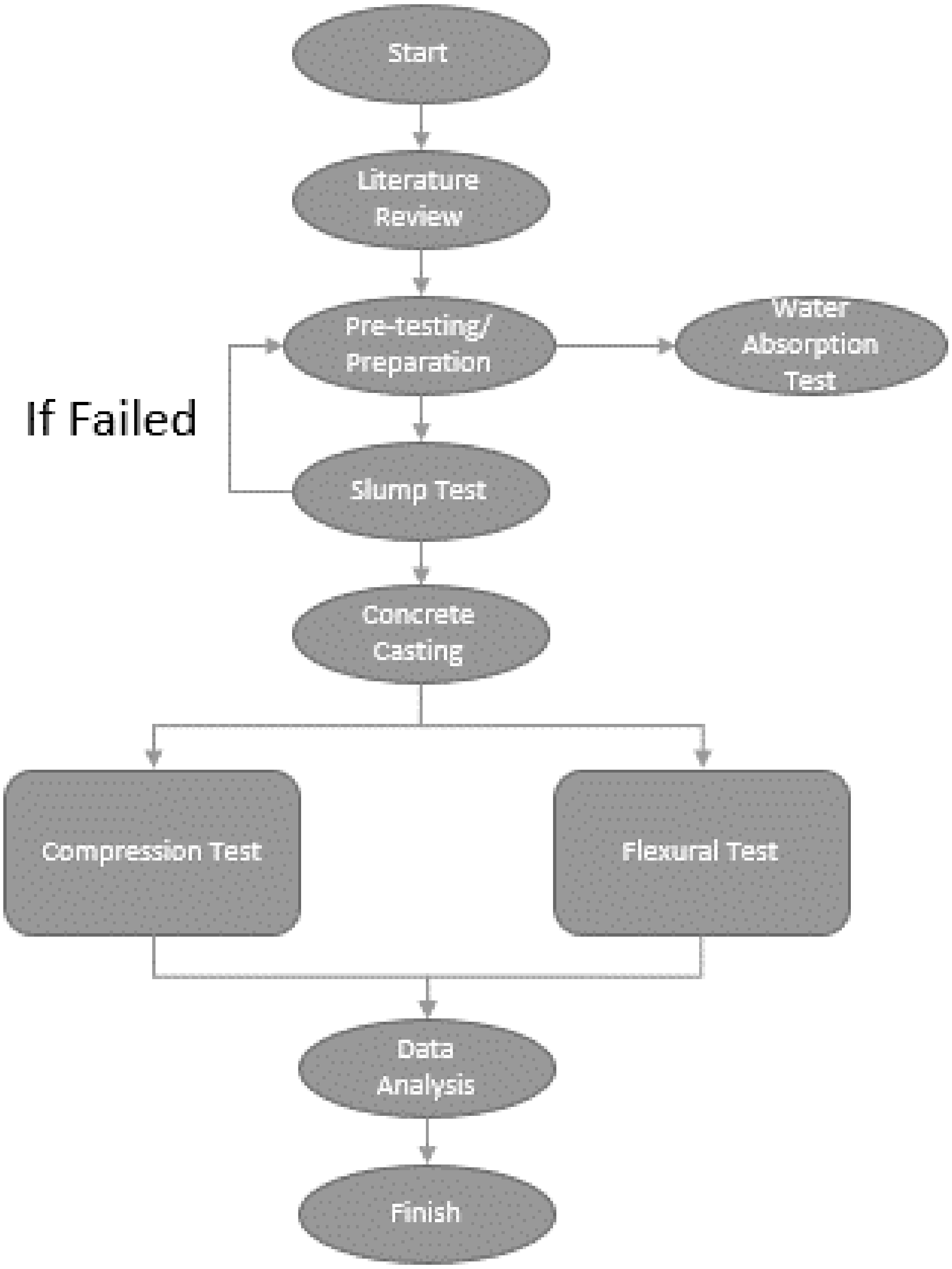


Figure 3.1: Research methodology flow chart

3.2 Materials

3.2.1 Ordinary Portland Cement

Ordinary Portland Cement (OPC) produced by YTL as certified to MS 522-1:2007 (EN 197-1:2000), CEM I 42.5N/ 52.5N and MS 522: Part 1:2003 has been selected as the main material for this study. This cement in one of the most common type of cement that is used in Malaysia construction work and it has been proved effectively for concreting work, plastering, screeding and tilling. The packing of the cement is shown in Figure 3.2.

Figure 3.2: Orang Kuat brand ordinary portland cement

3.2.2 Coarse Aggregates

The size of aggregate greater than 4.75mm is recognized as coarse aggregate. Crushed aggregates are better in improving the strength due to its interlocking properties by the angular particles, while rounded aggregates are more likely to improve the flow due to its internal friction is lower regarding on the characteristic of different type of aggregates.

In this study, crushed granite was selected as coarse aggregate and is displayed in Figure 3.3. The crushed granite was sieved to acquire the desired size wherein the granite must pass 20mm sieve size while retained in 5mm. In other words, the maximum size of the crushed granite used in this was 20mm while the minimum size was 5mm.

Figure 3.3: Crushed granite

3.2.3 Fine Aggregates

The size of aggregate lesser than 4.75mm is recognized as fine aggregate. Both crushed and rounded sands can be used in concrete. The volume of fine aggregate should be around in the range of 1/4th to 1/3rd of the total volume of the mixture. River sand which is locally available in Malaysia and passed through 4.75mm was used for all of the mixes of concrete in this study. The river sand was left to be air-dried as shown in Figure 3.4 before it was used.

Figure 3.4: Air dried sand

3.2.4 Water

The water used in this study was the tap water supplied in the laboratory. The water used was clean and free from impurities. The amount of water was added to the mix is according to the designed water to cement ratio of 0.50.

3.3 Bamboo Fibre

3.3.1 Preparation of Bamboo Fibre

The extraction of fibres involved cutting, retting, milling and drying. A total of thirty-two (32) bamboo culms with the approximate length of 3000mm were harvested by the labours at the tropical forest in Raub, Pahang. The bamboo culms were delivered, stored properly and dried in shade under atmospheric conditions in Non-Wood Product Workshop at FRIM which is situated at Kepong, Selangor Darul Ehsan. The age of bamboo culms was in the range between 3 to 5 years old and shortened to the range of 1300 to 1500mm in longitudinal length using saw machine. The hollow cylindrical portion of bamboo culm is used for processing of the fibre. The cylindrical portion of bamboo culms were cleaved into 10 strips in longitudinal direction with varying width and thickness using heavy-duty bamboo splitters 10 way as depicted in Figure 3.5. The diaphragms were broken up during the splitting process, therefore the remaining nodal parts were removed using a knife.

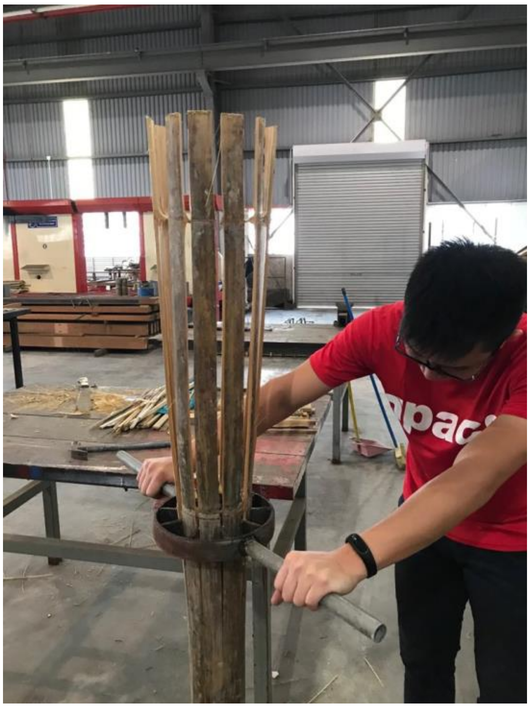


Figure 3.5: Spliting of bamboo culm

Figure 3.6: Bamboo culm cleaved into splits

In the present study, combination of chemical and mechanical techniques was used to extract the fibres from the raw bamboo. The bamboo alkaline retting using aqueous NaOH solution as the chemical technique whereas mechanical method was Roller Mill Technique (RMT) method. The Bamboo strips were treated by soaking in an aqueous NaOH solution of 10% in mass over volume (w/v) for a duration of 48 hours at ambient temperature which was found to be the optimum soaking duration and concentration of aqueous solution for this treatment (Tong *et al.*, 2015). The colour of the solution was changed from white to yellow and finally to dark brown after 24 hours as shown in Figure 3.7.

Figure 3.7: Alkaline retting process

This phenomenon indicates that the non-cellulose components such as lignin, hemicellulose, wax and other surface impurities has been dissolved in the solution. The softened bamboo strips were taken out and washed with the tap and distilled water to remove the alkaline content. Later, the bamboo strips were air dried under the sun to remove excess moisture contents after immersed in the water for 12 hours. The treated bamboo strips were mechanically defibrated using mill roller machine to extract the fibres and further remove impurities as shown in Figure 3.8. The bamboo strips were flattening and fibres emerged during repeated milling process between two rollers.

Figure 3.8: Roll milling process

Next, the bamboo fibres were rinsed with distilled water for several times to eliminate the alkaline content and until individual fibres were obtained. In order to ensure the pH of fibre is neutral (pH 6), the fibres were wash with distilled water several times and examined by Universal Indicator Paper as shown in Figure 3.10. The fibre samples which exhibiting a pH of 6 are proceeded to dry in an electrical oven at 60 ℃ for 24 hours. The heat treated fibre has higher strength than those untreated (Sen and Raddy, 2013b).

Figure 3.9: Neutralization of bamboo fibers

Figure 3.10: Measuring the PH value of bamboo fibre

3.3.2 Characterization of Bamboo fibre

The diameter of each fibres specimens are then taken and measured directly using an electronic Vernier Calliper as shown in Figure 3.11. The shape of fibres was assuming to be in cylindrical shape. A total of three (3) measuring points were recorded at different locations along the gauge length of each fibres specimen in order to obtain a valid and reliable average. The variation in the diameter along the fibre length was insignificant ranging from 0.2mm to 0.6mm. However, due to the diameter of fibres extracted are too small, the fibre length to be cut according the aspect ratio will be too small for concrete application and it will not be practical. Therefore, bamboo fibre was cut into length of 25mm, 38mm, 51mm and 64mm respectively according to sub chapter 2.11. All these fibre specimens are then packed according to different aspect ratios which will be used together with concrete mix later.

Figure 3.11: Vernier calliper

3.4 Formwork

A total of twelve (12) rectangular beam and twelve (12) cube are cast at once. Therefore, steel moulds are used during this research and its specifications were compiled according to standard of codes. Steel moulds of size 100 mm x 100 mm x 500 mm are used to cast concrete beam while steel moulds of size 100 mm x 100 mm x 100 mm are used to cast on concrete cube as shown in Figure 3.12 and Figure 3.13 respectively. The releasing agent (mould oil) will be applied on the inner surface of the formwork to ease the formwork to be disassembled and reduce the adhesion of concrete with formwork or mould surface.

Figure 3.12: Beam formwork

Figure 3.13: Cube formwork

3.5 Concrete Mix Design

Concrete mix design is aim to ensure the proportions of constituent materials to achieve the desired workability in the plastic stage and produce concrete with desirable strength to be the most optimized. The concrete characteristic strength of 30 N/mm^2 at 28 days is designed with the mix proportion of 1:1.85:3.02 and free water to cement ratio of 0.50 are chosen as per designed. Table 3.1 tabulated the mix proportion that is used in this study.

Table 3.1: Design mix proportion

Quantities (m^3)	Cement (kg)	Water (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
1	380	190	703	1147

In this study, 1% of fibre content according to the weight of cement with different fibre lengths are mixed together with cement, sand, aggregate and water. Mixing is done by concrete mixer as shown in Figure 3.14 to ensure homogenization of constituent material.

Figure 3.14: Concrete mixer

3.6 Concrete Mixing, Casting and Curing

Before the commencement of beam and cube concreting, all the necessary checking of the moulds was conducted. The constituent materials are weighted and mixed dry in concrete mixer for two (2) minutes and next the fibres are spread into the mixer while mixing as shown in Figure 3.15 and after 2 more minutes, the required amount of water is added and mixed thoroughly for 3 minutes. Slump test is conducted once the mixing are done to ensure that the obtained slump value is accordance to the mix design requirement before sampling of the cubes and beam. All the cubes and beams are casted simultaneously and concrete vibrating are conducted using vibrating table for 10-15 seconds until the mould is fully filled. A total of three (3) layers of concrete are filled into the mould whereas every layer was blows 25 times by using a tamping rod.

Figure 3.15: Fibre disperse in concrete mixer

Twelve (12) concrete cubes and twelve (12) concrete beams are unmoulded after 24 hours of pouring and are labelled before placing into water tank for 3, 7, 14 and 28 days testing.

3.7 Water Absorption Test

Bamboo is a hygroscopic material which absorbs moisture 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 reduce water in the concrete mix. When concrete dry, bamboo fibre reinforcement contracts as well creating micro gaps between bamboo and concrete segments which might cause in decreasing of bonding strength. Table 3.2 summarized the samples prepared for water absorption test. Figure 3.16 shows the bamboo sample immersing in the water curing tank.

Table 3.2: Samples prepared for water absorption test

Non Treated Sample
A-1 Zero internode (1)
A-1 Zero Internode (2)
A-2 One internode (1)
A-2 One internode (2)
A-2 One internode (3)
A-3 Two internode (1)
A-3 Two internode (2)
A-3 Two internode (3)

Bamboo samples was cut and prepared based on Table 3.2. The prepared samples were kept in oven at 130 ℃ for about 24 hours to remove all the moisture content present. Oven dried samples were prepared based on non-treated raw bamboo. Next, the initial oven dry weight and thickness of samples were taken respectively before immersing in a water tank for 30 days at room temperature. At 15^{th} and 30^{th} day of immersion, the final saturate weight and thickness of samples were measured respectively. The amount of water absorbed by these samples was calculated based on the equation 2.1 and equation 2.2.

$$\text{Water absorbed (gm)} = \text{Final Saturated Weight (gm)} - \text{Oven Dried Weight (gm)} \quad (2.1)$$

$$\text{\% by weight of water absorbed} = \frac{Water\ absorbed\ (gm)}{Final\ Saturated\ Weight\ (gm)}\ x\ 100\% \quad (2.2)$$

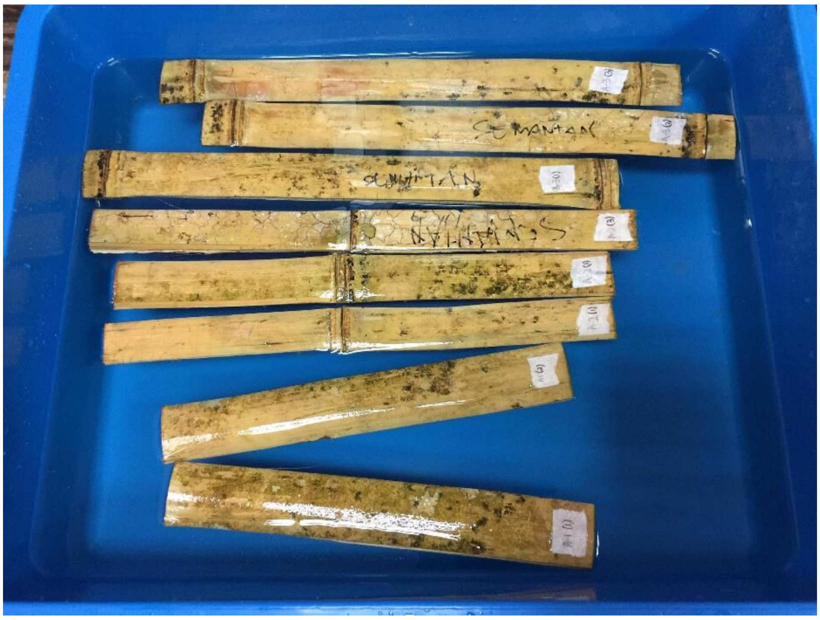


Figure 3.16: Bamboo samples immersed in water curing tank

3.8 Laboratory Testing

3.8.1 Slump Test

The slump test is conducted and observed during concrete pouring in accordance to reference standards, BS 1881: Part 102 (1983). The workability and consistency of the fresh concrete are determined and measured during laboratory testing. Slump cone, based plate, tamping road and measuring tape are used during slump test. The methods to measure the slump value is shown in Figure 3.18.

Figure 3.17: Blowing tamping rod for compaction

Figure 3.18: Slump test

3.8.2 Compression Test

Compression Test is carried out to determine the compressive strength of the hardened concrete specimen (cubes) referring to BS 1881: Part 116: 1983. Test was conducted at different ages of concrete at 3,7, 14 and 28 days. The compressive strength test machine as shown in Figure 3.19 are used to determine the quality, specified design characteristics compressive strength and ultimate strength of concrete mix supplied. The maximum strength of each specimen was recorded and the average of three (3) samples was considered the compressive strength at the specific day. The maximum loads were computed and the compressive strength of the concrete can be calculated manually using the formula as stated below:

$$f_c = \frac{P}{A} \tag{2.3}$$

Where, f_c= Compressive strength of concrete specimen (N/mm^2 or MPa)
P= maximum load applied (N)
A= average cross sectional area of the specimen (mm^2)

Figure 3.19: Universal testing machine

3.8.3 Flexural Test

Flexural test is carried out to determine the flexural strength of concrete specimens (beam) accordance to the ASTM C 78-02. Test was conducted using flexural four-point loading machine as shown in Figure 3.20. The weight and dimension of the concrete specimens were measured before commencing the test. Location of the supports and loading point were indicated on the specimen surface. The beam was placed carefully under the testing machine and supports were placed at the measure location of 100 mm inside from each end. After placing the beam, two-point loading spanning out from the centre of the beam was applied gradually by controlled pumping unit. The flexural strength of concrete can be manually calculated using formula as stated below if the fracture initiates in the tension surface within the middle third of the span length:

$$R = \frac{PL}{bd^2} \tag{2.4}$$

where, R= Flexure strength (N/mm^2 or MPa)
P= maximum load applied (N)
L= span length (mm)
b= average width of specimen (mm)
d= average depth of specimen (mm)

If the fracture occurs in tension surface outside of the middle third of the span length by not more than 5% of the span length. Flexural strength can be calculated using formula as stated below:

$$R = \frac{3Pa}{bd^2} \tag{2.5}$$

Where, a= average distance between line of fracture and the nearest support measured on the tension surface of the beam (mm)

Figure 3.20: Flexural test machine

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The results obtained from experimental work are discussed in this chapter. Experimental work was carried out and discussed based on the research methodology and literature review adopted in the previous chapter. This includes slump test, concrete compression and flexural test. Comparison was made in each test with their respective control specimens.

4.2 Physical Testing

4.2.1 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 term of water absorb ability is studied. Bamboo, being natural material has the ability to absorb water in its surrounding environment. Therefore, before bamboo fibre is placed in concrete, understanding on water absorbing rate are needed so that it would not affect the water cement ratio of the concrete which will reduce the concrete strength due to shrinkage. In this study, bamboo samples are immersed in water to study its changes of before-after effect on weight and thickness.

4.2.1.1 Changed in Weight of Bamboo

The result of percentage weight water absorbed of bamboo after 15 and 30 days is tabulated in Table 4.1 and Table 4.2 respectively. Graph of percentage of water absorbed of bamboo by weight after 15 and 30days against nodes are plotted respectively in Figure 4.1 and Figure 4.2. The bamboo was weight initially before immersed in water curing tank.

Table 4.1: Percentage by weight of water absorbed by bamboo after 15 days

Samples	***Initial Weight (gm)***	***Final Saturated Weight (gm)***	***% by weight of water absorbed***	***Average % of water absorbed***
A-1 Zero internode (1)	***74.51***	***112.20***	***33.59***	***33.77***
A-1 Zero internode (2)	*74.70*	*113.10*	*33.95*	
A-2 One internode (1)	*77.50*	*116.40*	*33.42*	*34.83*
A-2 One internode (2)	*85.75*	*132.20*	*35.14*	
A-2 One internode (3)	*80.73*	*126.00*	*35.93*	
A-3 Two internode (1)	*112.96*	*177.80*	*36.47*	*34.20*
A-3 Two internode (2)	*114.45*	*175.10*	*34.64*	
A-3 Two internode (3)	*114.90*	*167.70*	*31.48*	

Table 4.2: Percentage by weight of water absorbed by bamboo after 30 days

Samples	***Initial Weight (gm)***	***Final Saturated Weight (gm)***	***% by weight of water absorbed***	***Average % of water absorbed***
A-1 Zero internode (1)	***74.51***	***115.00***	***35.21***	***35.44***
A-1 Zero internode (2)	*74.70*	*116.10*	*35.66*	
A-2 One internode (1)	*77.50*	*119.30*	*35.04*	*35.69*
A-2 One internode (2)	*85.75*	*134.50*	*35.25*	
A-2 One internode (3)	*80.73*	*127.70*	*36.78*	
A-3 Two internode (1)	*112.96*	*180.30*	*37.35*	*35.04*
A-3 Two internode (2)	*114.45*	*177.60*	*35.56*	
A-3 Two internode (3)	*114.90*	*169.50*	*32.21*	

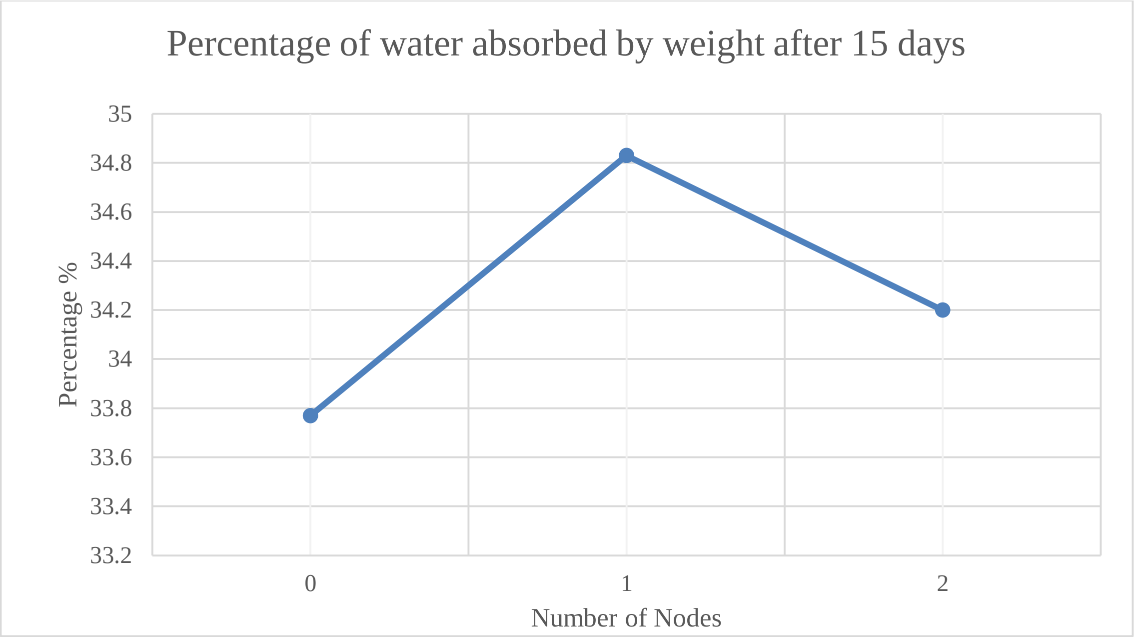


Figure 4.1: Weight changed after 15 days

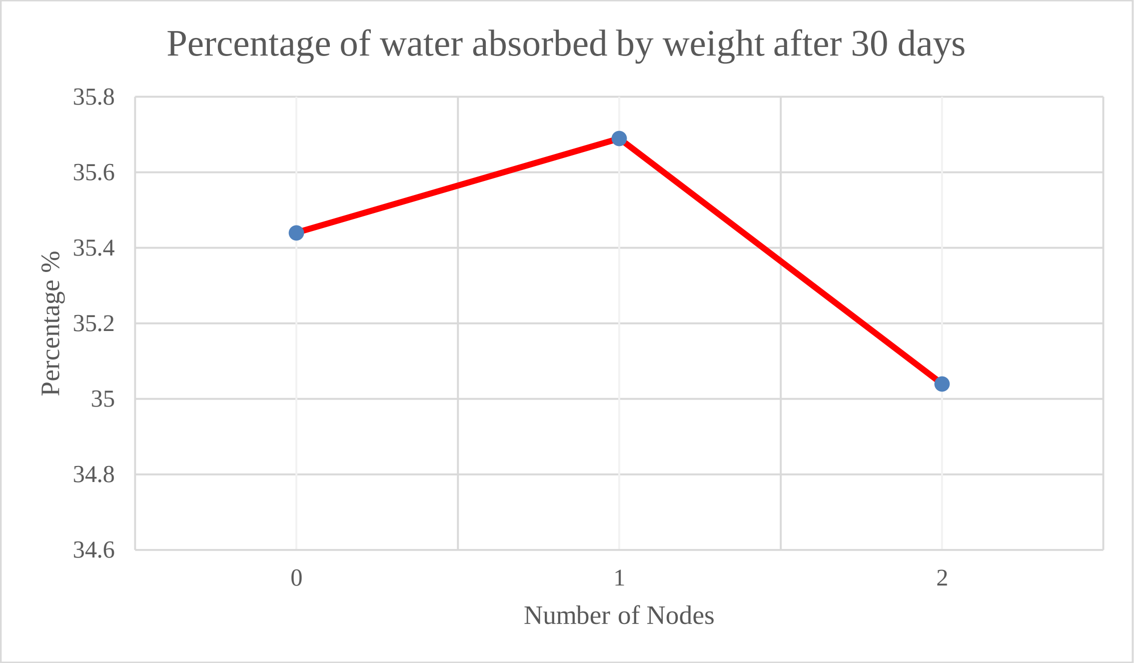


Figure 4.2: Weight changed after 30 days

Based on the results shown in Figure 4.2, the percentage of weight changed in the last 30 days is 35.44%, 35.69% and 35.04% for zero, one and two nodes respectively. The water absorbing rate of bamboo was 35.39% in average. Bamboo is a natural material. Therefore, the ability to absorb water for each samples is dependent on the cross sectional area, thickness and positions of the bamboo samples taken. In this study, the variable such as cross sectional area, thickness and positions of bamboo samples taken are not controlled. Therefore, inconsistency in the results was obtained.

4.2.1.2 Changed in Thickness of Bamboo

The results of thickness changed of bamboo after 15 and 30 days is tabulated in Table 4.3 and Table 4.4 respectively. Graphs of thickness changed of bamboo after 15 and 30 days against nodes are plotted in Figure 4.3 and Figure 4.4 respectively.

The results after 30 days show the percentage of thickness changed is 10.08%, 15.47% and 9.50% respectively for zero, one and two nodes bamboo. The results obtained from Gupta & Ganguly (2015) showed when the number of nodes increased, the percentage change of thickness also increased. However, the result obtained in this study is not consistent which might due to uncontrolled sampling method of bamboo parts for testing.

Table 4.3: Percentage of thickness increased after 15 days

Samples	***Initial Thickness (mm)***	***Final Thickness (mm)***	***% of increase in thickness***	***Average % of increased thickness***
A-1 Zero internode (1)	***7.69***	***8.28***	***7.67***	***7.67***
A-1 Zero internode (2)	*8.00*	*8.03*	*0.38*	
A-2 One internode (1)	*7.34*	*8.04*	*9.54*	*11.8*
A-2 One internode (2)	*6.97*	*7.95*	*14.06*	
A-2 One internode (3)	*7.29*	*7.35*	*0.82*	
A-3 Two internode (1)	*7.94*	*8.30*	*4.53*	*4.78*
A-3 Two internode (2)	*7.96*	*8.48*	*6.53*	
A-3 Two internode (3)	*7.94*	*8.20*	*3.27*	

Table 4.4: Percentage of thickness increased after 30 days

Samples	***Initial Thickness (mm)***	***Final Thickness (mm)***	***% of increase in thickness***	***Average % of increased thickness***
A-1 Zero internode (1)	***7.69***	***8.49***	***10.40***	***10.08***
A-1 Zero internode (2)	*8.00*	*8.78*	*9.75*	
A-2 One internode (1)	*7.34*	*8.63*	*17.57*	*15.47*
A-2 One internode (2)	*6.97*	*8.76*	*25.68*	
A-2 One internode (3)	*7.29*	*7.52*	*3.16*	
A-3 Two internode (1)	*7.94*	*8.67*	*9.19*	*9.50*
A-3 Two internode (2)	*7.96*	*8.74*	*9.80*	
A-3 Two internode (3)	*7.94*	*8.49*	*6.93*	

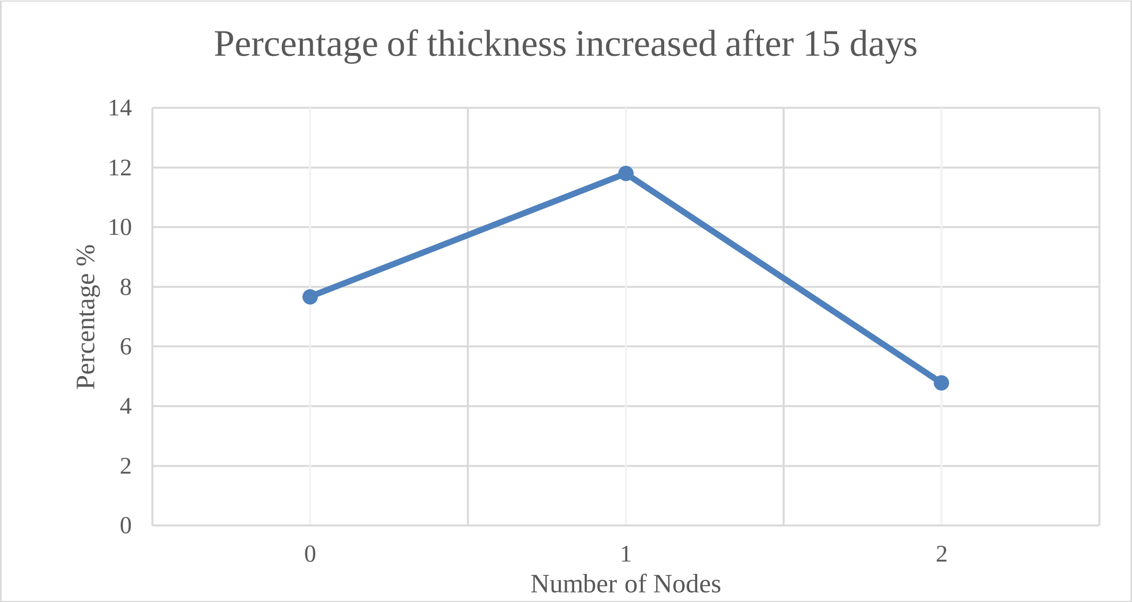


Figure 4.3: Changed in thickness after 15 days

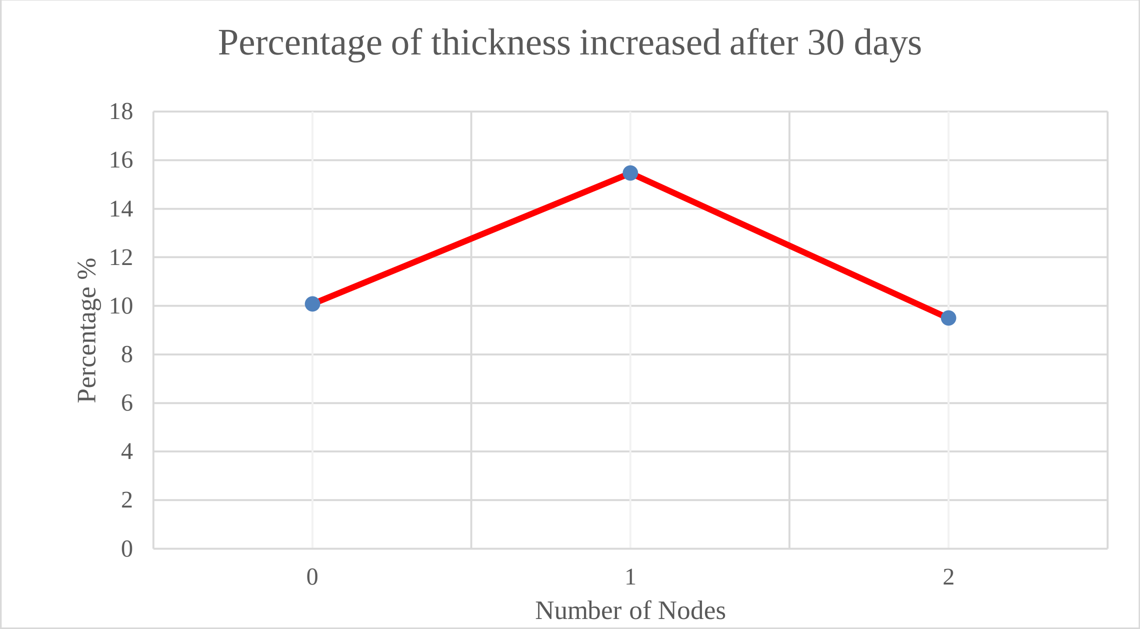


Figure 4.4: Changed in thickness after 30 days

4.2.2 Slump Test

Slump Test were carried out for each concrete specimen mixes to determine the concrete workability according to the concrete design mix. Comparison between plain concrete and fibre concrete mixes are being discussed and the slump value with the corresponding fibre length are tabulated in Table 4.5.

Table 4.5: Slump value for each concrete mix

No	***Description***	***Slump Value***	***Type of Slump***
1	***Control***	***45***	***True Slump***
2	*25mm Fibre*	*11*	*True Slump*
3	*38mm Fibre*	*0*	*True Slump*
4	*51mm Fibre*	*0*	*True Slump*
5	*63mm Fibre*	*0*	*True Slump*

Figure 4.5: Slump Test for Control Mix

Figure 4.6: Slump Test for Fibre Concrete Mix

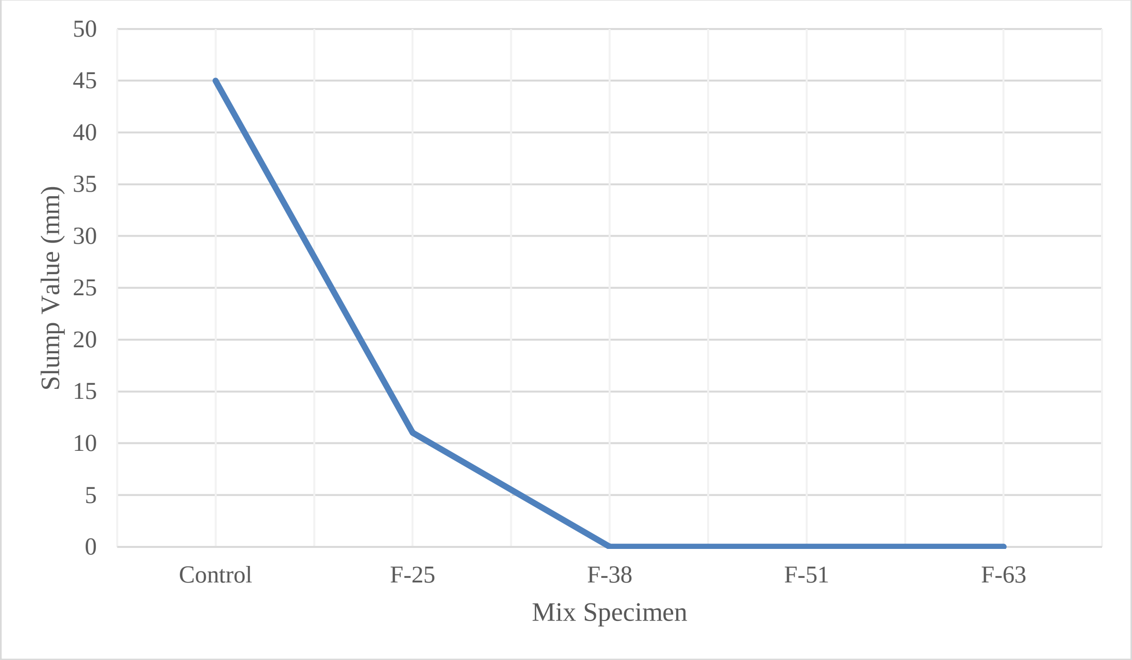


Figure 4.7: Comparison of Slump Value for each mix

Figure 4.7 indicates that the slump value of concrete mix decrease with the increase of fibre length introduced into the mix. The slump value is more likely to be the measure of concrete workability. Slump value was decreased from 45 mm to 11mm for specimen F-25 concrete mix and to 0mm for the other longer fibre length specimens. The reason of decreasing workability can be explained by the greater the length of fibre, it greater the difficulty to the aggregate particle movement, restricting the mobility of the mixture and this eventually lead to the loss of workability causing the compaction process to be more difficult. However, based on the observation, slump test was no longer able to measure the impact of fibre length towards the mobility of material in this mix design as the slump value for concrete mix 1%-1.5 to 1%-2.5 gives 0 slump value unless the mixing ingredient contained workability enhancer admixture.

4.3 Mechanical Testing

4.3.1 Compression Test

The concrete cube compression test was conducted using a compression testing machine to determine its targeted compressive strength. A total of sixty (60) hardened cubes with dimensions of 100mm x 100mm x 100mm were tested at age of 3,7,14,28 days, respectively. The maximum load is obtained when concrete cube specimens are compressed until it failed. The cubic compressive strength of the samples, f_{cu} is listed for each types of specimen in Table 4.6 and a summary of concrete cube compressive strength in Table 4.7.

Table 4.6: Compressive Strenght of cube samples with 3, 7, 14 and 28 days

Concrete Age	Compressive Strength, f_{cu} (KN)				
	control	25mm	38mm	51mm	63mm
3rd	26.209	30.45	26.62	22.34	21.45
	26.186	22.58	24.74	24.26	23.53
	28	21.38	25.75	25.79	20.52
Average	26.2	21.98	25.7	24.13	22.49
7th	43.07	27.45	30.28	30.8	30.36
	36.52	26.65	29.07	30.69	29.49
	41.04	36.52	31.38	28.94	31.45
Average	38.78	27.05	30.24	30.14	30.43
14th	37.93	38.84	36.39	34.51	35.12
	39.44	45.55	35.18	36.96	32.93
	41.1	37.26	35.61	34.42	34.45
Average	39.49	37.85	35.73	35.3	34.79
28th	44.02	52.21	40.06	39.6	40.95
	34.11	50.83	33.23	36.49	36.13
	46.43	41.52	32.95	39.52	37.42
Average	45.23	41.52	40.06	39.56	36.78

Table 4.7: Summary of concrete cube compressive strength, f_{cu}

No	***Description***	***Compressive Strength, f_{cu} (KN)***			
		3^{rd} day	***7^{th} day***	***14^{th} day***	***28^{th} day***
1	*Control*	*26.2*	*29.6*	*35.17*	*39.07*
2	*25mm Fibre*	*21.98*	*27.05*	*37.85*	*41.52*
3	*38mm Fibre*	*25.7*	*30.24*	*35.73*	*40.06*
4	*51mm Fibre*	*24.13*	*30.14*	*35.3*	*39.56*
5	*63mm Fibre*	*22.49*	*30.43*	*34.79*	*36.78*

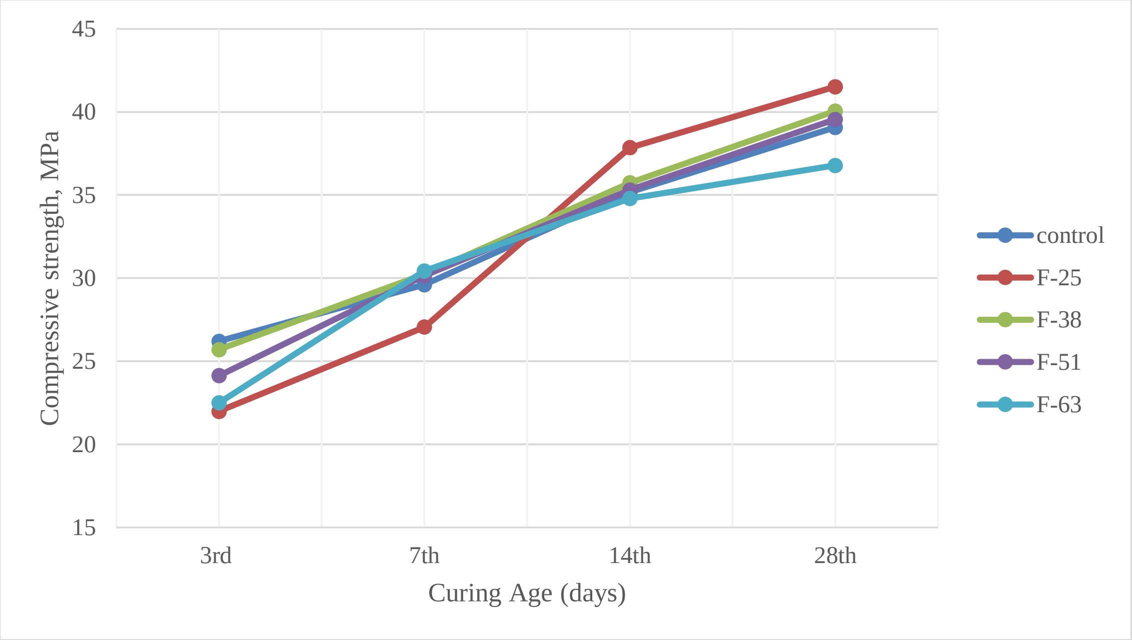


Figure 4.8: Graph of average compressive strength against fibre length

Figure 4.8 indicates the changes occur in compressive strength with fibre inclusion of various length into the concrete. It can be observed that the concrete with the additional of fibre generally exhibited higher resistance value compared to normal structural concrete cube. The highest value achieved is in the concrete with specimen mix with 1% and 25mm length of bamboo fibre. The mechanical behaviour of all concretes with inclusion of fibre was generally higher than the standard structural concrete. Based on 28th days result, the enhancement of fibre towards the flexural strength compared with normal concrete were 6.27%, 2.53%, 1.25% and -5.86% respectively. The increase of fibre length resulted in the increase of compressive strength but when the length exceeded 25mm, the compressive strength decreased as the fibre length increase. Hence, it can be concluded that specimen mix of 1% with 25mm are the optimum length for bamboo fibre reinforced concrete in term of compressive strength. However, the findings suggested that bamboo fibre reinforced concrete does not have significant effect on the improvement to the compressive strength. However, the improvement can be observed by the failure pattern of the cube discussed in subchapter 4.3.1.1.

4.3.1.1 Failure Mode

Under the leading of uniaxial compression, extensive cracks were formed in the concrete during pre-peak stage and then failed suddenly at the peak load. Figure 4.9, shows the failure mechanism of normal plain concrete and indicates concrete too be more brittle, fails violently and suddenly. It is observed from Figure 4.10, that when fibres in discrete form are introduce in the concrete, the bonding of fibres into the concrete restrained the propagation of crack, making the concrete to become more ductile one instead of usual brittle behaviour. Therefore, this signifies that bamboo fibre reinforced concrete improves the post cracking load and energy absorption capacity

Figure 4.9: Failure pattern of normal concrete cube

Figure 4.10: Failure pattern of bamboo fibre reinforced concrete cube

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4.3.2 Flexural Test

Four-point bending flexural test was carried out to determine the beam flexural strength, the modulus of rupture when is internally being reinforced with bamboo fibre. A total of sixty (60) concrete beam with dimensions of 100 mm x 100 mm x 500 mm in width, depth and length respectively were tested at age of 3,7,14 and 28 days respectively. The ultimate load is obtained when concrete beam specimens are completely failed. The flexural strength of the samples, *R* is listed for each kind of specimen in Table 4.8 and a summary on the concrete flexural strength is shown in Table 4.9.

Table 4.8: Flexural Strength of beam samples with 3, 7, 14 and 28 days

Concrete Age	Flexural Strength (MPa)				
	Control	1%-1	1%-1.5	1%-2	1%-2.5
3rd day	4.77	4.854	3.393	5.010	2.934
	4.542	5.022	3.564	5.679	4.440
	4.476	4.911	3.735	4.680	4.269
Average	4.596	4.938	3.564	4.850	4.350
7th day	5.427	4.881	5.310	5.175	5.196
	5.415	5.409	2.535	5.490	4.839
	6.246	5.460	5.748	5.230	4.758
Average	5.421	5.250	5.529	5.330	4.930
14th day	6.501	5.316	4.800	5.685	7.293
	4.290	5.310	5.286	6.258	7.359
	6.081	5.259	5.700	5.124	6.867
Average	6.291	5.300	5.700	5.690	6.880
28th day	7.254	8.670	2.640	2.358	6.875
	7.692	7.455	7.521	6.825	5.910
	5.844	7.443	7.653	6.663	8.256
Average	6.549	7.450	7.59	6.740	7.010

Table 4.9: Summary of concrete beam flexural strength

No	***Description***	***Flexural Strength***			
		3rd day	***7th day***	***14th day***	***28th day***
1	*Control*	*4.596*	*5.421*	*6.291*	*6.549*
2	*25mm Fibre*	*4.938*	*5.250*	*5.300*	*7.450*
3	*38mm Fibre*	*3.564*	*5.529*	*5.700*	*7.590*
4	*51mm Fibre*	*4.850*	*5.330*	*5.690*	*6.740*
5	*63mm Fibre*	*4.*	*4.930*	*6.880*	*7.010*

Figure 4.11 indicates the change occur in flexural strength with different inclusion of fibre length into the concrete. It can be observed that, also in this experiment, the concrete without the additional of fibre presented in the lowest resistance value and the highest value occurred in the concrete with specimen mix with 1% and 38mm length of bamboo fibre. The mechanical behaviour of all concretes with inclusion of fibre was higher than the standard structural concrete. As we see in 28th days result, the enhancement of fibre towards the flexural strength compared with normal concrete were 13.75%, 15.85%, 2.92% and 7% respectively. The increase of fibre length resulted in the increase of flexural strength but when the length exceeded 38mm, the flexural strength decreased as the fibre length increase. Therefore, results are actually showed that the bamboo fibre can enhance the flexural strength of concrete significantly up to 15%. Hence based on the result, it can be summarized that the specimen mix of 1% with 38mm are the optimum length for bamboo fibre reinforced concrete in term of flexural strength.

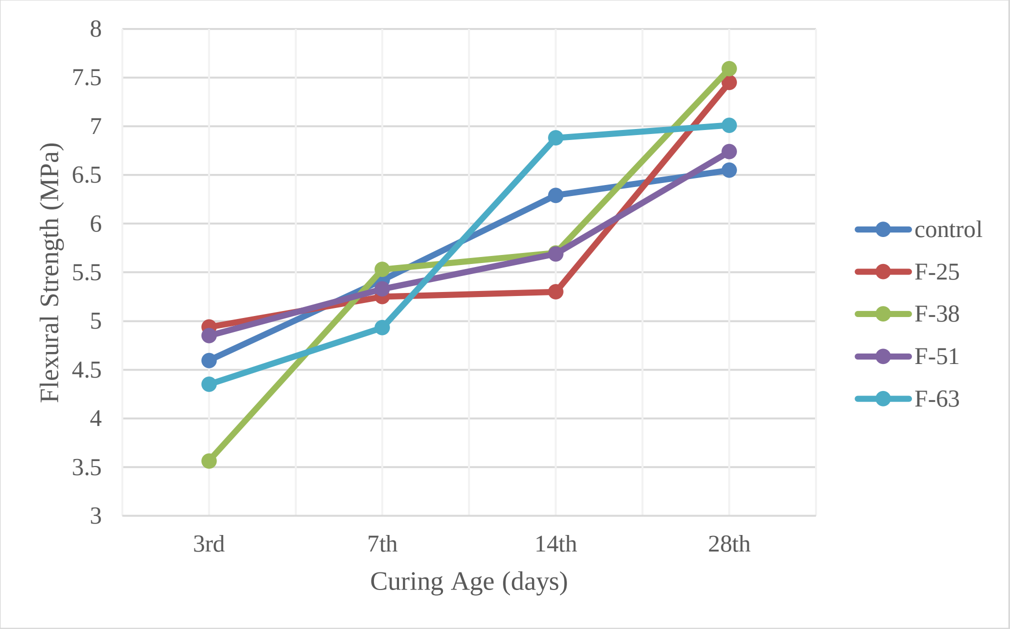

Figure 4.11: Graph of average flexural strength against fibre length

4.3.2.1 Failure mode

Concrete beam were tested under four-point loading on a simply supported beam with a span of 300 mm through a close loop hydraulically operated Universal testing machine. The load was applied at the rate of 0.8 KN/s. Concrete beam failed when it reached the ultimate load that it can sustained. Figure 4.12 depicts the failure mechanism of normal structural beam. Failure of the normal concrete did not always occur at the mid-point of the beam. During testing, all the normal structural concrete beams experienced sudden failure with large crack. While for most of the bamboo fibre reinforced concrete as shown in Figure 4.13, sudden failure occurring was lesser and the width of the crack is smaller compared to the plain concrete as fibre are in functioning to bridge micro cracks from expanding and oppose the crack formation in step with the stress increment. The fibre was bearing the tensile stress that was transferred from the rupture section at the crack zone. Subsequently, more gradual failure after the initial crack of all the fibre reinforced matrices, bamboo fibre can to be attributed for the improvement of concrete ductility performance.

Figure 4.12: Failure pattern of normal structural beam

Figure 4.13: Fibre bridging inside the concrete

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

In this chapter, the evaluation of utilizing bamboo fibre as reinforcement material in concrete structural element was carried out through series of laboratory works. In order to identify the viability of bamboo as reinforcement in concrete RC beam, experiments were conducted in two aspects which included the physical properties of fresh concrete as well as structural behaviour of hardened concrete. Hence, this chapter presents the conclusion and recommendations for future works.

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. The workability of fresh concrete was found to be decrease with increase of fibre length as it restrains more movement within the mix.

ii. The maximum enhancement in 28 days' strength was observed in 25mm long fibre mix specimens with total enhancement of 6.27% only. However, findings suggest that overall of bamboo fibre mix are actually not contributing significant result in compressive strength of concrete. No actual optimum length can be specified as the overall contribution was roughly the same.

iii. In term of flexural, significant enhancement up to 15.85% was found in 38mm long fibre mix specimens. The flexural strength of concrete increased with increase of fibre length but when it exceeded 38mm, the strength decrease. Therefore, 38mm is the optimum length from both compressive and flexural strength view.

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. However, the feasibility study in this research is only conducted in laboratory scale and there is need to further study on industry practices. Hence, future research is required to be conducted. The following are several suggestions on the future study that should be carried out:

i. A more efficient fibre extracting methods are required in order to produce in massive quantity. Although current alkaline retting and mill rolling technique is simple and convenient to be conducted without the need of skilled operator, but high amount of water is needed in order to neutralise the alkalinity of bamboo which was resulting in massive waste.

ii. Water reducing agent, superplasticiser should be added in the bamboo fibre concrete mix as the fibre restrained the movement of aggregates and reduce the fresh mix workability. Besides that, the mix resulted in drier state as the bamboo fibre absorbed portion of the water from the mix causing some part of the cement did not bond well and which might eventually effect the concrete strength as there is most pores inside the concrete.

iii. Fibre dispersion method for the industry application should be further improved as it is needed in large scale. In our research scale, although the fibre volume is only used in small quantity but it has consumed a lot of time to disperse the fibre.

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APPENDIX A

MIX DESIGN FOR CONCRETE GRADE 30

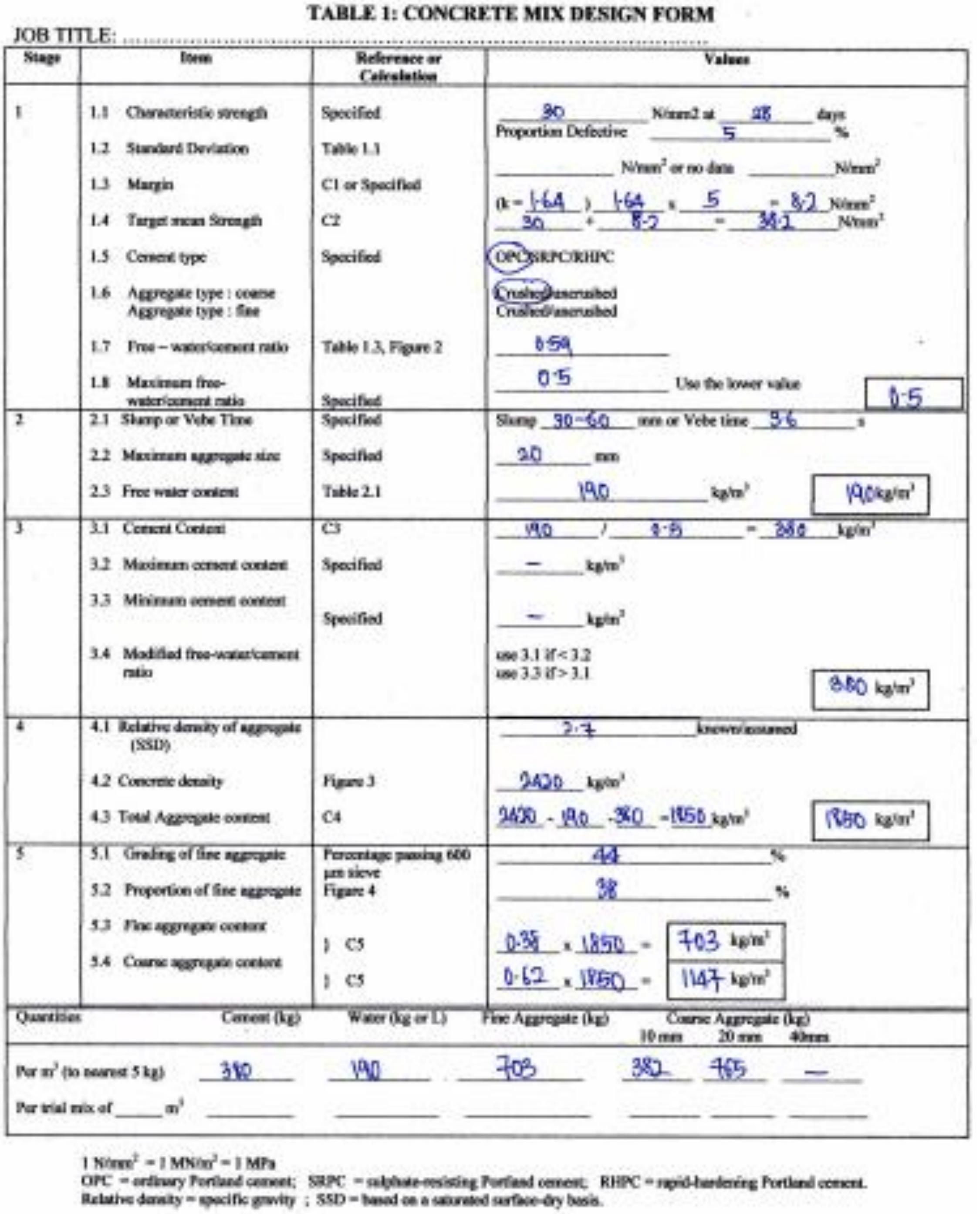

TABLE 1: CONCRETE MIX DESIGN FORM

JOB TITLE: ……………………………………………………………

Stage	Item	Reference or Calculation	Values
1	1.1 Characteristic strength	Specified	30 N/mm2 at 28 days Proportion Defective 5 %
	1.2 Standard Deviation	Table 1.1	______ N/mm² or no data ______ N/mm²
	1.3 Margin	C1 or Specified	(k = 1.64) 1.64 x 5 = 8.2 N/mm²
	1.4 Target mean Strength	C2	30 + 8.2 = 38.2 N/mm²
	1.5 Cement type	Specified	[✓ OPC]/SRPC/RHPC
	1.6 Aggregate type : coarse Aggregate type : fine		[✓ Crushed]/uncrushed Crushed/uncrushed
	1.7 Free – water/cement ratio	Table 1.3, Figure 2	0.59
	1.8 Maximum free-water/cement ratio	Specified	0.5 Use the lower value 0.5
2	2.1 Slump or Vebe Time	Specified	Slump 30-60 mm or Vebe time 3-6 s
	2.2 Maximum aggregate size	Specified	20 mm
	2.3 Free water content	Table 2.1	190 kg/m³ 190kg/m³
3	3.1 Cement Content	C3	190 / 0.5 = 380 kg/m³
	3.2 Maximum cement content	Specified	– kg/m³
	3.3 Minimum cement content	Specified	– kg/m³
	3.4 Modified free-water/cement ratio		use 3.1 if < 3.2 use 3.3 if > 3.1 380 kg/m³
4	4.1 Relative density of aggregate (SSD)		2.7 known/assumed
	4.2 Concrete density	Figure 3	2420 kg/m³
	4.3 Total Aggregate content	C4	2420 - 190 - 380 = 1850 kg/m³ 1850 kg/m³
5	5.1 Grading of fine aggregate	Percentage passing 600 µm sieve	44 %
	5.2 Proportion of fine aggregate	Figure 4	38 %
	5.3 Fine aggregate content	} C5	0.38 x 1850 = 703 kg/m³
	5.4 Coarse aggregate content	} C5	0.62 x 1850 = 1147 kg/m³

Quantities	Cement (kg)	Water (kg or L)	Fine Aggregate (kg)	Coarse Aggregate (kg) 10 mm	Coarse Aggregate (kg) 20 mm	Coarse Aggregate (kg) 40mm
Per m³ (to nearest 5 kg)	380	190	703	382	765	—
Per trial mix of ____ m³						

1 N/mm² = 1 MN/m² = 1 MPa
OPC = ordinary Portland cement; SRPC = sulphate-resisting Portland cement; RHPC = rapid-hardening Portland cement.
Relative density = specific gravity ; SSD = based on a saturated surface-dry basis.