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Utilisation of Bamboo as Reinforcement Material in Concrete

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Abstract: The use of reinforced concrete is not a new feature in the construction industry in Malaysia. Nowadays, the problem of overuse of steel in the industry, cracks and low strength of concrete had been issued especially in the low cost residential area. On the other hand, bamboo is a natural resources which have a big population and potential to be used in construction due to the strength, durability and ability to replace steel in concrete. So, bamboo culm will be used as reinforcement material in concrete to improve the problems. The research objective of this study are to compare the compressive strength of the bamboo with various diameters and to compare the structural strength of reinforced concrete with standard concrete. The experimental work consists of casting and testing the 100x100x100 mm of reinforced concrete with concrete cover/diameter (0.781, 0.971 and 1.224) in various diameters Ø29, Ø34 andØ39) of bamboo culms. Then, the slump and compression test to determine workability and strength standard concrete and bamboo reinforced concrete were compared. The results of this study prove that bamboo culm are suitable to be used as reinforcement material and able to improve the strength and workability in reinforced concrete. Apart of reducing the usage of concrete and suitable to replace steel in reinforced concrete, this study is also to encourage the usage of natural renewable material as an alternative construction materials. It is also to educate society on the negative impact of carbon emission towards the environments and also to explore more on the potential of bamboo as an alternative material.

Keywords: Reinforced Concrete, Bamboo Culm, Compressive Strength

1. Introduction

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Bamboo is a plant with high potential for use as an engineering material. This is because bamboo has good physical and mechanical properties and is suitable for use, as well as readily available. From time immemorial, humans have applied the use of bamboo for various purposes and not only focused on food or handicrafts. In fact, bamboo has also been used in the construction sector as props, scaffolding, foundations, frames, frameworks, roofs, walls and even floors. Nowadays, bamboo has always attracted the attention of scientists and engineers because of its advantages which have some unique features such as high tensile strength, high strength to weight ratio and other factors such as, easy availability, low cost and harmless to the environment (Zhao *et al*,. 2012). This statement was also agreed by (Terai and Minami, 201) stating that the use of bamboo has its low construction cost in addition to rapid growth and wide growth spread. In addition, it is able to make a significant contribution to developing countries for seismic retrofit technology as well as earthquake-resistant construction. This is evidenced by the existence of the 'Masjid Buluh' at Kuala Kangsar, Perak, where the builder consists of bamboo and can accommodate up to 500 pilgrims at a time and even Sharma Springs in Bali, Indonesia also uses bamboo as the basis for its construction with a value of up to RM8 million because it is entirely made of bamboo (Berita Harian, 2019). In the meantime, many researchers have tried to study the use of bamboo as a substitute in concrete building structures. Kankam and Ewuakye (2006) and Elbasha (2012) have studied its application technology in reinforced concrete slabs and beams. Ghavami (2005) has used it for the reinforcement of lightweight concrete beams. Azmi and Azemi (2019) deals with the use of bamboo panels as reinforcement in concrete wall elements. Liao (2008) and Wu *et al* (2001) have studied the use of bamboo reinforced concrete floor slabs. This paper introduced the use of bamboo culms as the substitute in the concrete structure.

1.1 Research Background

In recent years, there have been discoveries of new materials using natural materials in the construction industry by several researchers including the United States Navel Civil Engineering Laboratory (1966-2000) initiated the use of bamboo as concrete reinforcement for prefabricated structural elements. This is because bamboo is one of the high potential natural materials as a replacement for steel in reinforced concrete. Khare (2005) states that bamboo has a greater strength than wood products and its tensile strength can reach up to 52 ksi (370 N / mm²) compared to 115 ksi (792 N / mm²) of steel that was making this natural material suitable for reinforcement in concrete. In general, bamboo has the advantage of growing faster, lighter than steel and has a low construction cost as there is no need to use heavy machinery to lift it. Due to its inexpensive, readily available and high tensile strength, it is a suitable substitute in this material for replacing steel as reinforcement in reinforced concrete. In short, this is a good achievement where high building strength can be achieved at a lower cost.

Other than that, Figure 1 shows a rectangular stress block depicting the distribution of stresses on sections by Yassin and Abdullah (2012). The stresses at the top and bottom areas are maximum while the minimum stresses are on the neutral axis. Therefore, the stresses applied to the concrete is near the neutral axis. The neutral axis does not contribute much to the structure. There is no stress and strain on the neutral axis. Alternative methods for replacing a neutral axis with an inert material will not greatly affect the strength and properties of the concrete and will not affect the geometry and shape of the concrete. This theory is applied to bamboo reinforced concrete where the neutral axis can be replaced with a bamboo culm. The neutral axis will be nullified to produce minimum pressure. Thus, this study will focus on the use of bamboo culms that can increase the strength of the structure, reduce cracks and use bamboo to replace the concrete in the middle of the neutral axis.

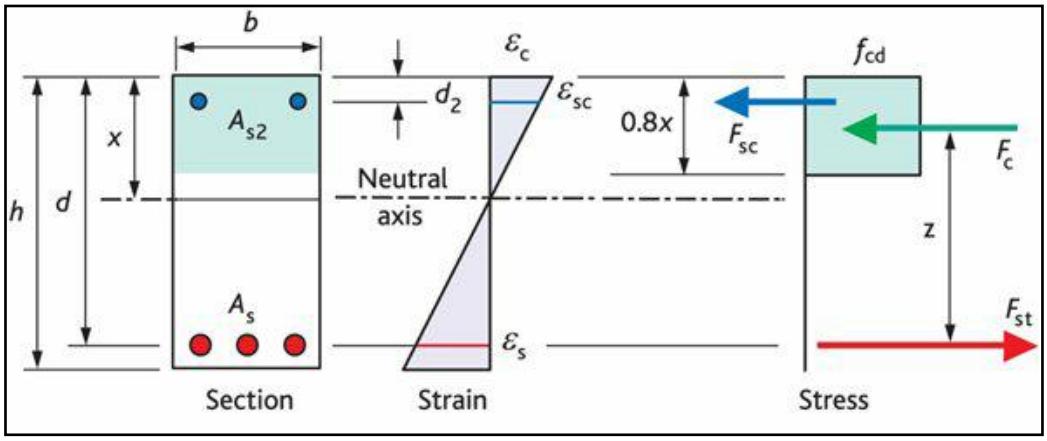


Figure 1: Rectangular stress block, Yassin and Abdullah (2012)

1.2 Problem Statements

One of the most important and most widely used materials in the construction industry is concrete. However, concrete is usually reinforced by using steel to bear the load and add a strong tensile strength to the concrete. As a result of excessive use of materials (steel, cement, sand and stone) in concrete, this will cause the price of a concrete to increase and increase construction costs. (Rayadu *et al*., 2017). In addition, there are still many raw materials on the market but in the future it can not be guaranteed due to the availability of non-renewable raw materials. In addition, the price of raw materials is getting higher as it shows an increase in early 2016 ready-made concrete RM220 / m3 and in mid-2017 increased to RM240 / m3 (CIDB, 2017). Furthermore, the rapid production and production of raw materials especially steel and cement will have a significant impact on environmental degradation in terms of pollution. Clearly, this is agreed by many researchers including Mali and Datta (2018a); Sutharsan (2020); Wibowo *et al* (2017); Yong *et al* (2019) and Ghavami (2005).

At the same time, Moroz *et al* (2014) stated that this is still a problem for municipalities and government organizations, especially in developing countries where the provision of safe and affordable housing facilities. In addition, the problem of cracking and low structural strength of buildings, especially in low cost housing areas. This unpleasant situation reduces the comfort of life and at the same time forces stakeholders to find options to solve the problem. However, many researchers began to look for one of the natural resources that can be renewed and able to overcome the problem of cracks and strength of building structures as well as being able to replace steel.

In this study, bamboo was selected to be an alternative material to replace steel reinforcement. According, Sutharsan (2020) states that bamboo is a very good natural source for strengthening in concrete because it has an incredible ratio of strength and weight and its workmanship is very simple by using ordinary tools. This statement is also supported by Archila *et al* (2018) who also stated that bamboo is a strong material in its tension and compression as well as its nature is low cost and readily available. This study, bamboo will be used as a substitute for increasing the strength and durability of concrete. Bamboo will be placed in the middle of the middle layer of concrete. The bending strength of bamboo can overcome the burden of life or death and bamboo can also reduce deforestation and can overcome the availability of non-renewable raw materials.

1.3 Research Questions

The research questions in this study are as follows:

I. What are the compressive strength of bamboo as reinforced material with various diameters of bamboo rod?
II. What are the comparison of structural strength performance between bamboo reinforced concrete with standard concrete?

1.4 Research Objectives

The objectives of this research are as follows:

I. To investigate the compressive strength of bamboo as reinforcement concrete material with various diameters of bamboo rod.
II. To compare the structural strength performance between bamboo reinforced concrete with standard concrete.

1.5 Scope of the Study

The scope of the research involving the testing in the laboratories, there were some scope of the research:

This study only focuses on the use of bamboo rods only.

I. The tests involved in this research are slump test and compressive strength test.
II. The specimens will be used in this research are bamboo reinforced concrete and standard concrete.
III. This study only focuses on the use of bamboo rods as reinforcement material only.
IV. The size of concrete is 100mm (Length) x 100mm (Height) x100mm (Weight).
V. The grade of concrete is M20 with ratio 1 : 1.5 : 3 (cement : fine aggregate : course aggregate) and concrete curing process is performed.

1.6 Significance of the Study

I. This study will attract contractors, construction companies and product manufacturers to incorporate these innovations into their construction industry.
II. The production of bamboo can reduce pollution because of this reinforcement concrete using natural material as reinforcement material.
III. To explore more about structures and environmentally friendly chemical reactions of bamboo.
IV. To ensure the country's economic factors are stable but at the same time promise good strength performance.
V. As a cross reference that will provide background or overview of bamboo to further researchers.

2. Literature Review

2.1 Introduction of Bamboo

Bamboo is a tribe of evergreen flowering perennial plants in the subfamily Bambusoideae of the grass family Poaceae. The bamboo tree structure is hollow in the middle and the cross section of the vascular bundle is scattered throughout the trunk. It also has no xylem. Bamboo is one of the fastest growing plants in the world due to its unique rhizome-dependent system. It can grow up to 91–122 centimetres/day (3.8-5.0 centimetres/hr) (Armstrong 2014).

(a) Anatomical Properties

Facts clearly prove that to know the physical and mechanical properties and uses of bamboo, the anatomy of bamboo needs to be studied first as it is the basis of knowledge about bamboo. Figure 2 shows the anatomy of a bamboo. According to Awalluddin *et al* (2017) says that all bamboo species have the same anatomy in terms of nodes, internodes and diaphragm.

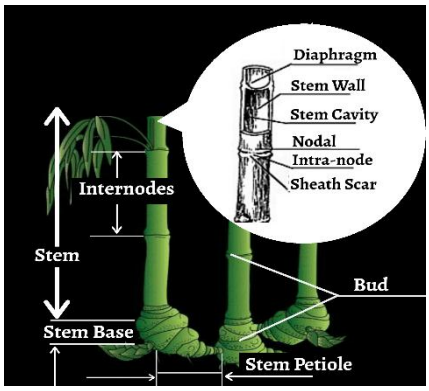


Figure 2 : Anatomy Bamboo

Meanwhile, the study of Siam *et al* (2019) showed four basic types of vascular bundles, which are vascular bundle types I, II, III, and IV. Figure 3 shows anatomical structures of the 13 species. There four type of vascular bundle in Malaysia : Type I : Monopodial species; Type II: Have enlarged fibre sheath at the phloem side; Type III: Have one isolated fibre bundle; Type IV: Have a central vascular strand that has small sclerenchyma sheaths, and two isolated fibre strands located at the phloem and protoxylem sides.

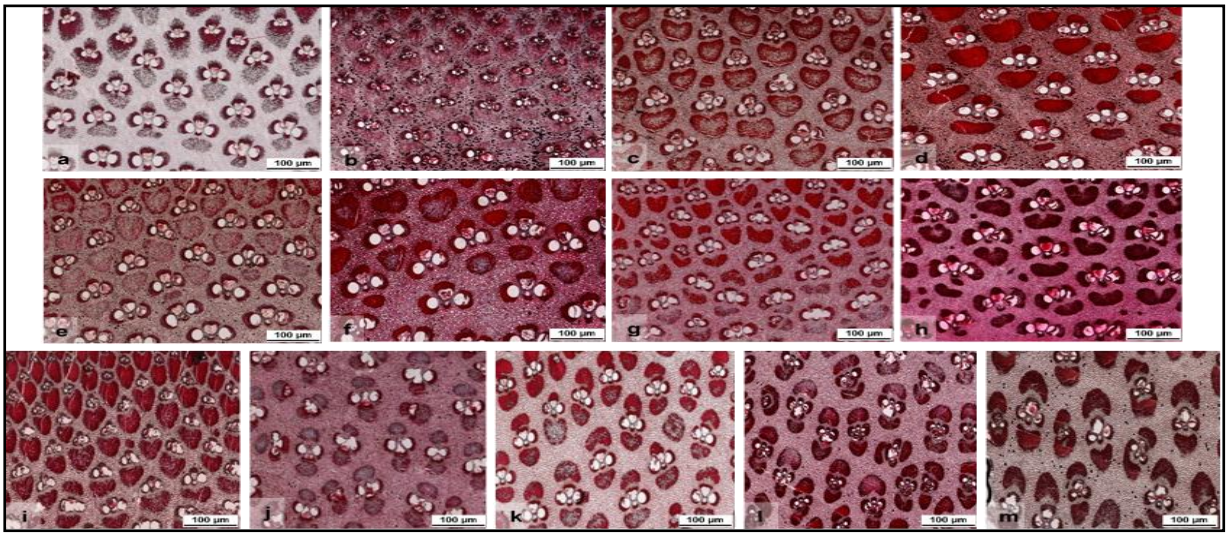


Figure 3: Type II (a and b) : S.brachycladum and S. zollingeri, respectively; type III (c - j): G. thoii, G. scortechinii, G. ligulata, G. wrayii, G. brang, S. grande, B. heterostachya, and B. vulgaris cv. vittata, respectively; type IV (k - m) : B. vulgaris, B. blumeana, and D. asper, respectively (Siam *et al* 2019)

(b) Physical Properties of Bamboo

Researchers have found that bamboo strength properties are best used as a supplement in the industry and that their strength is higher than most wood but bamboo technology is not widely applied and bamboo is only used for handicraft industries such as weaving baskets, chairs, mats where some rural residents have the benefit of it (Gutu 2013). The physical characteristics of the 13 respective bamboo species in this study are presented in Appendix 1.

(c) Mechanical Properties of Bamboo

Mechanical properties closely related to density and shrinkage are considered to be important factors in determining the suitability of bamboo for various applications (Anwar *et al*. 2005; Abdullah *et al*. 2017). The mechanical properties of bamboo are also important in structural design and industrial use (Shahril and Mansur 2009; Correal and Arbelaez 2010; Gutu 2013).

2.2 Bamboo as Construction Materials

Studies on bamboo as a basic ingredient in construction or structural are increasingly needed as the use of bamboo in construction is beginning to be of concern. Bamboo can also be used as an engineering material due to its good physical and mechanical properties, and is ideal for use as reinforcement material in ready-made concrete to overcome the problem of running out of steel in the market. (Khare, 2005)

In addition, its properties are flexible due to the presence of split or horizontal walls and that maintain the strength of the resistance factor in the face of superior construction quake. (Vengala *et al*, 2015) There have been studies that show that the ratio of tensile strength to specific weight of bamboo is six times greater than that of steel (Xiao, 2009). Kaminski *et al* (2016) found that, the strength-to-weight ratio of bamboo is similar to wood, and its strength is generally similar to that of soft wood or hardwood.

Bamboo has been applied in various construction such as recreation, defense, housing and large scale construction. Bamboo can also be used as a building material for scaffolding, bridges, houses and buildings. (Sharma *et al*, 2014). Specifically bamboo can be made into a concrete reinforcement by making bamboo reinforcements in concrete, possibly used as one of the following building components: columns, beams, slabs and walls.

The results of many studies show that bamboo can replace steel satisfactorily and the structural elements of bamboo reinforced concrete can be used in many building projects. (Kankam and Ewuakye, 2006); (Elbasha, 2012); (Ghavami, 2005); (Azmi and Azemi, 2019); (Liao, 2008) and (Wu *et al*, 2001).Therefore, it is hoped that cheap bamboo reinforced concrete materials will have a broad market in the future of building structures.

2.2 Previous Research of Bamboo Reinforced Concrete

(a) Slab

From previous research, Mali *et al* (2018) has studied about bamboo reinforced concrete slab. In his study he used bamboo strips as the main reinforcement on concrete slab panels. A total of 15 concrete slab panels were tested with compressive strength tests using EN 12390-4 (2000) . In this study also, shows that the researcher compared the test on concrete block panels with PPC (Palin Cement Concrete) and RCC (Reinforced Cement Concrete) sheets. Test results show that the increased fit and ubha shape of the bamboo strip is used as reinforcement on the concrete slab panel. In fact, the results of using bamboo reinforcement show a very significant bending performance when compared to RC slabs which have a bar as the main reinforcement. In conclusion, this study shows evidence that bamboo can be used as a replacement for steel and can overcome the problem of expensive materials, non-renewable, not environmentally friendly and heavy.

(b) Beam

Dewi at al (2017), there is a study on the use of bamboo in beam reinforced concrete. This study was carried out using beam concrete measuring 10cm x 20 cm x 160 cm. This study also compared bamboo beam reinforced concrete with aggregate buoyancy. Bamboo fiber is coated with paint and covered with sand. The purpose of this method is done to avoid hygroscopic properties and increase

the weight of bamboo to avoid the float of bamboo fibers during casting. Researchers found that bamboo fibers experienced a reduction in cracks and deflections of concrete as well as an increase in post-crack load capacity. The conclusion that can be obtained is that the use of bamboo can prove that the cracking of concrete can be reduced. Apart from that, bamboo is able to maintain the workability and quality of a concrete object.

(c) Column

Bamboo From a previous study, Sonar (2014) has studies about precast concrete columns. By using hollow circular columns have different types which are I, II, III, IV and V having internal diameters of 100 mm, 125 mm, 150mm, 175 mm and 150 mm respectively are considered for analysis. The result on this study showed that saving 59% and 69% on the cost of reinforcing columns for columns I and III and IV to V respectively. This type is compared to the cost between the hollow precast column and the conventional column. There is also 10% to 7% concrete savings for columns I to V. The ultimate load capacities of all hollow columns are nearly equal to those of conventional columns. This study shows that hollow column is a good idea in cost savings and can reduce raw material consumption in the construction industry.

3. Research Methodology

3.1 Research Framework

Based on Figure 4 was focussed about the framework of experimental methodology throughout this research to make sure a guide to achieve the objectives and scopes of the study.

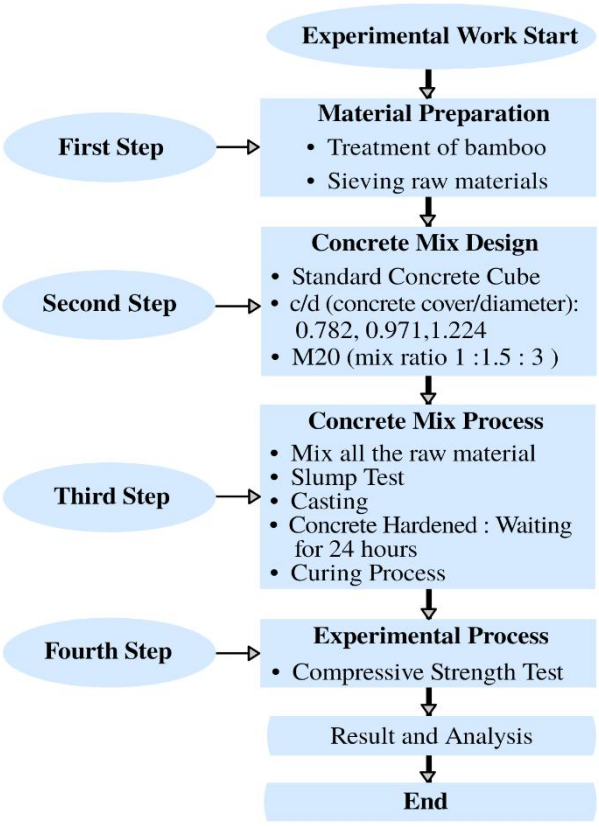


Figure 4: Flow Chart of Detail Experimental Work Process

3.2 Data Collection

(a) Specimens Detail

The experiment consisted of casting and testing sixteen (16) cubes with 100mm(L) x 100mm(H) x 100mm(W) of which is four (4) was an ordinary cubes and twelve (12) cubes with different c/d (concrete cover/diameter) such as 0.782, 0.971 and 1.224. Table 1 shows the detailed properties of concrete and Figure 5 shows the size of the concrete cube is 100mm (Length) x 100mm (Height) x 100mm (Weight).

Table 1 : Quantity of Specimens

Days	Standard Concrete Cube (control)	Bamboo Reinforced Concrete		
		0.782	0.971	1.224
7	-	-	-	-
28	4	4	4	4

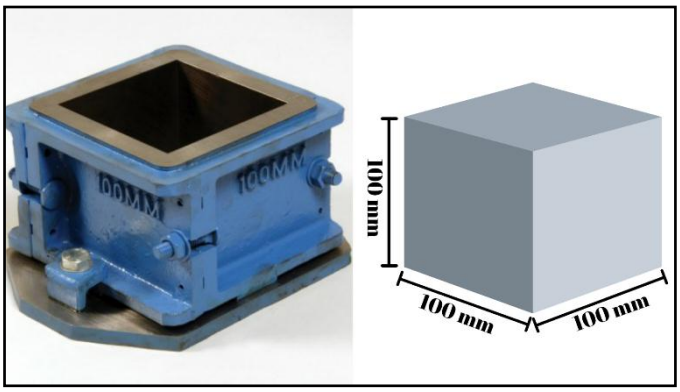


Figure 5 : Sample of Cube

(b) Concrete Mix Design

Concrete mix design that used for Bamboo Reinforcement Concrete is standard concrete with ratio of 1: 1.5 : 3 (M20) using Ordinary Portland cement to comply with BS 12: 1996, fine aggregate (≤5mm), course aggregate (≤ 10mm), and water. The detailed properties of concrete are shown in Table 2.

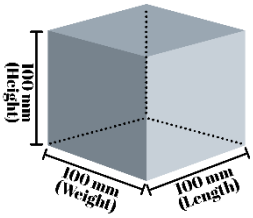
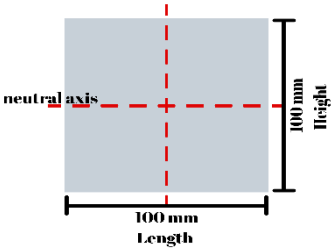
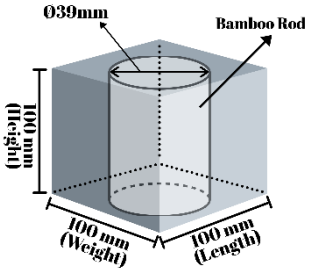
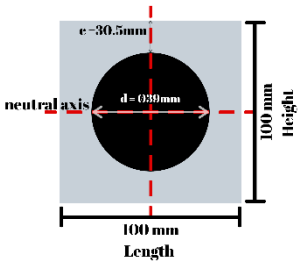
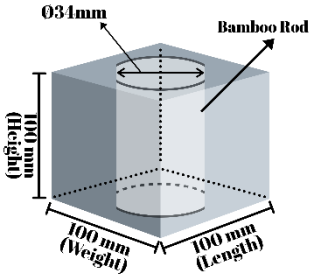
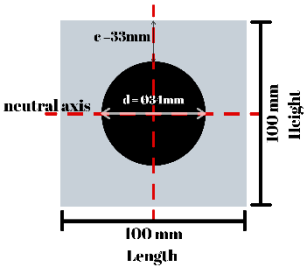
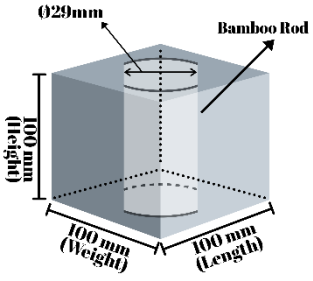
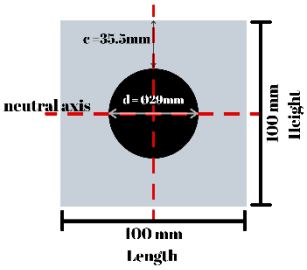
Table 2 : Mix Design

Sample (c/d)	Diameter of Bamboo (mm)	Coarse Aggregate (kg) / (≤ 10mm)	Fine Aggregate (kg) / (≤ 5mm)	Cement (kg)	W/c Ratio
Ordinary	0	4.710	2.355	1.570	0.60
0.782	Ø39				
0.971	Ø34				
1.224	Ø29				

(c) Reinforcement Material

The reinforcement material used in this research is bamboo rod. The bamboo rods were used to make bamboo reinforcement concrete slab with various diameters such as Ø39 mm, Ø34 mm and Ø29 mm in four specimens for each diameter. Table 3 showed that bamboo rods are inserted on a neutral axis inside the cubes, then inserted into the mould and finally concrete mix is poured into the mould.

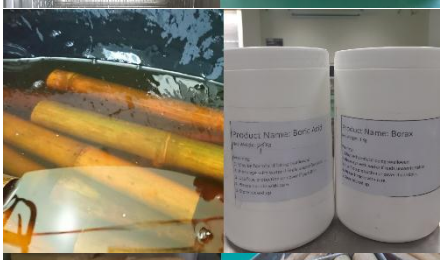
Table 3 : The Detail of Reinforcement

Sample (c/d)	Diameter of Bamboo (mm)	Concrete Cover (mm)	Diagram	Cross-sectional
Ordinary	-	-		
0.782	Ø39	30.5		
0.971	Ø34	33		
1.224	Ø29	35.5		

(d) Treatment of Bamboo

The process of preparing the bamboo culms for the treatment can be referred in Table 4:

Table 4: Process of Bamboo Treatment

No.	Work	Description
1.		The scientific name for this type of bamboo is *Gigantochloa Albociliata*, while the commercial name is known as "Buluh Madu". Bamboo was collected in Parit Raja, Johor.
2.		Clean the bamboo to ensure it is free of soil and impurities.
3.		The bamboo was dried in the sun and then the bamboo was cut according to the size of the specimen.
4.		When bamboo dried, dried bamboo is boiled in an Ultrasonic Water Bath machine at 40 ° C for 1 hours.
5.		After that , the bamboo was treated into Borax and Boric solution until the water turned into dark.
6.		After the water turned into darker, the bamboo is dried into the oven. The bamboo rod was heated in the oven at 250 ℃ for one hours to allow excess water in the rod to evaporate.

3.2 Data Analysis

(a) Slump-test

This test is carried out according British Standard EN 12350-2: 2009 to test the fresh concrete for slump-test. The test should be carried out by filling the slump cone in three equal layers with the mixture being tamped down 25 times for each layer. Table 5 shows the results of slump-test.

Table 5: Result of Slump Test

Sample (c/d)	Slump Test (mm)	Description
0	90	Acceptance
0.782	90	Acceptance
0.971	94	Acceptance
1.224	94	Acceptance

(b) Curing Process

Curing plays an important role in the development of strength and durability of concrete and to control the rate of moisture lost from concrete during cement hydration. After leaving the concrete in the formwork for 24 hours until it is dried in moisture air, the concrete is removed from the formwork and completely submerged in water. The curing process was performed for 7 and 28 days in accordance with British Standard EN 12390-2: 2009 that tested fresh concrete.

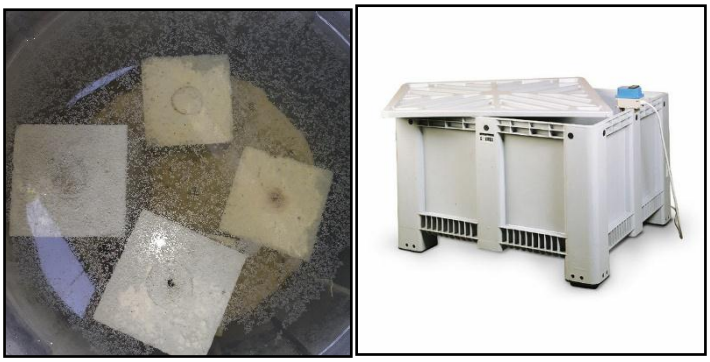


Figure 6 : Curing Process

(c) Compressive Strength Test

This test was accordance to British Standard EN 12390-3: 2009 to determine 7 and 28 days compressive strength test. Hydraulic compressive strength test machines are used with British Standard EN 12390-4: 2000 for specification for testing machines.

Table 6 : Conditions Cube Before and After Compressive Strength Test

Before	After
	

4. Results and Discussion

4.1 Introduction

In this chapter, test results from experimental laboratories are analyzed and data results are discussed.

4.2 Compressive Strength Test Results

(a) Results from Standard Concrete

Table 7 below shows that the results of the standard concrete compressive strength test for 28 days were conducted at the Faculty of Technology and Business Management (FPTP) UTHM.

Table 7 : Results of Compressive Strength Test of Standard Concrete

Sample (c/d)	Cube No.	Days	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
0	1	28	29.452	31.773
	2	28	27.771	
	3	28	37.792	
	4	28	32.076	

Table 7 above shows the results of the compression strength test for the four standard cubes for 28 days. The average compressive strength of the four standard cubes was 31.77 MPa.

(b) Results from Bamboo Reinforced Concrete for 28 days

Table 8 : Results of Compressive Strength Test of Bamboo Reinforced Concrete

Cube		Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
Sample (c/d)	Cube No.		
0.782	1	17.42	20.41
	2	16.68	
	3	24.03	
	4	23.49	
0.971	1	19.42	18.64
	2	15.12	
	3	22.03	
	4	17.97	
1.224	1	18.27	16.02
	2	12.53	
	3	17.29	
	4	15.97	

Table 8 shows the compressive strength of bamboo reinforced concrete cube. Based on the table, the relationship between average compressive strength and sample. There are three sample are tested which are 0.782, 0.971 and 1.224 of bamboo reinforced concrete. From the table shown that there are decrement. The result of compressive strength shown in table 8, the highest compressive strength is 20.41 N/mm² (0.782) decrease 18.64 N/mm² (0.971) and continuous decline to 16.02 N/mm² (1.224). This is because, bamboo culms it responsible for proves that the strength of bamboo over steel. As a conclusion, replacement of 0.782 achieved the highest strength with 20.41 N/mm² and can be suggested as the optimum sample of bamboo reinforced concrete.

4.3 Strength Comparison Between Standard Concrete with Bamboo Reinforced Concrete.

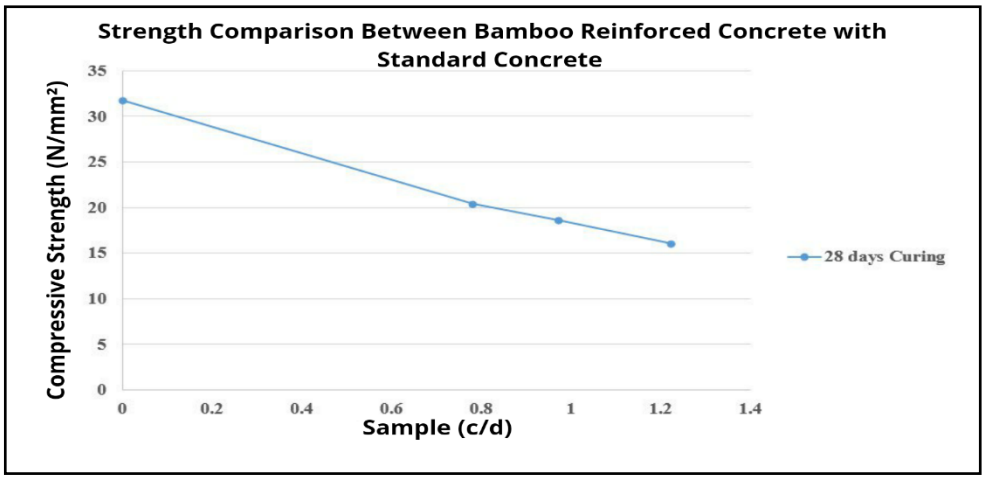


Figure 7: Strength Comparison Between Bamboo Reinforced Concrete with Standard Concrete

Figure 7 shows the difference in compressive strength between bamboo reinforced concrete and standard concrete. Based on the picture, the relationship between compressive strength and sample has been sketched. In figure 7, the graph shows that there is a slidely decline from sample 0 to sample 1.224 and the highest average compressive strength for bamboo reinforced concrete test results is 0.841 with 20.41 MPa. The trend continued to decline at 0.971 with a value of 18.64 MPa. Significant change where the highest compressive strength is collected from 0.841 with 20.41 MPa of bamboo reinforced concrete as a substitute for concrete reinforcement, while the lowest compressive strength is 1.224 which is 16.02. However, the highest compressive strength of bamboo reinforced concrete samples of 0.841 with 20.41MPa decreases 22% from standard concrete which is sample 0 with 31.77MPa. This shows that the strength of bamboo successfully proves that it is stronger than wood products and about more than half the strength of bamboo than steel (Khare, 2005).

5. Conclusion

As a conclusion, based on the data that has been recorded, this study succeeded in finding objective 1 to find a suitable compression strength to replace steel with bamboo in addition to reducing the use of concrete. The results show that sample 0.781 succeeded an about that half of bamboo strength over steel. Although, the bamboo reinforced concrete cube at sample 1.224 has the lowest results but in terms of strength it is still able to show that it is about half the strength with steel and also can reduce the use of raw materials. As for objective 2, the comparison of bamboo reinforced concrete and standard concrete, bamboo reinforced concrete shows that the structural strength of bamboo reinforced concrete is more than half than that of ordinary concrete. These factors indicate that the effect of the use of bamboo is able to give the effect of structural strength in concrete.

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