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The Durability of Concrete Wall Panel Containing Bamboo Mat as Reinforcement Material

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Abstract: Reinforced concrete wall panel has widely used in the commercial and residential building. However, there have some problems arise when the use of reinforcement steel bar in concrete wall panel contributes to carbon emission to environment, depletion of natural resource, the corrosion of steel bar and the increase in the cost of steel bar. On the other hand, bamboo is suitable to be use as reinforcement material in concrete wall panel because the maximum load-bearing capacity of treated bamboo reinforcement is closely equivalent to steel reinforcement. Besides, bamboo is abundant resources in Malaysia where there are about 421,722 hectare of bamboo area in peninsular Malaysia. In this research, bamboo was used as the reinforcement material due to its strength and availability in Malaysia. The research objective for this research are to compare the compressive strength between bamboo reinforced concrete wall panel and standard concrete wall panel, to determine the durability of bamboo reinforced concrete wall panel and to observe the feedback of bamboo mat as reinforcement material among construction stakeholders. The compressive strength of specimens with dimension of 300 mm x 300 mm x 150 mm is tested according to ASTM C805-97. Moreover, the durability test has carried out in accordance with ASTM C 267-01 which the specimen is soak in the 10% sulphuric acid solution for 7 days. Meanwhile, qualitative method has conducted through interview to achieve third objective. Experimental results of this research are there is a comparable compressive strength between two type of specimens which there is only 5.9 MPa (18%) different between the compressive strength of both type of specimens and the bamboo reinforced concrete wall panel are acceptable when exposed in normal environment. From qualitative analysis, all respondents are agreed with bamboo mat as reinforcement material must be tested and approve by legal expert before it is implemented. This study is aimed to reduce the use of steel bar in construction which can lead to the sustainable building construction and enhance the economy by using bamboo mat as reinforcement material in concrete.

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Keywords: Bamboo, Reinforcement, Wall Panel, Durability

1. Introduction

Reinforced concrete wall panel has widely used in the commercial and residential building as a building system, because reinforced concrete wall panel have several unique characteristics such as it can acting as a partition to divide the space whether vertically or horizontally in a building and it capable to resist the load from the building structure (Roy & Matsagar, 2020). On the other hand, concrete is a structure that have low tensile strength and it cannot be use as a building structure without the reinforce of other material. therefore, concrete has usually been reinforced by steel bar as the reinforcement. However, the use of steel bar is not effective on the aspect of the cost. The cost for the steel bar has increased since January 2016 by more than 50%. Hence, the bamboo has become one of the suitable materials to replace the steel bar as reinforcement in concrete because bamboo is a material that strong in tension and compression, especially it is widely available and cheap in cost (Ahmad *et al.*, 2014; S.A.Mansur, 2016). According to Siam *et al.* (2019), the bamboo species in peninsular Malaysia have at least 63 species and most of the bamboo are cultivation and only 25 species of the bamboo are indigenous. Bahari & Krause (2016) has stated that there are about 7% or 421,722 hectares of bamboo area has been previously estimated as the total forest land in peninsular Malaysia. Bamboo is as strength as steel reinforcement for concrete and it has been recognized as a high renewable and high strength alternative material to timber. Other than that, bamboo have higher compressive strength than other construction material and it is suitable to become the substitution of steel reinforcement bar (Chin *et al.*, 2017). Moreover, Kaware *et al.* (2013) has reported that the maximum load-bearing capacity of treated bamboo reinforcement is closely equivalent to steel reinforcement. Besides, the half of the tensile strength of the steel is the tensile strength of the bamboo (Prajwal & Prashanth, 2016).

The potential utilization of bamboo in construction industry has been proven by many researchers. According to Zea Escamilla & Habert (2014), a potential way of reducing the pressure of environment and natural resource has been identified which is with the use of bamboo-based construction material in the construction industry as well as the bamboo-based construction material have mechanical and environmental advantage over the conventional construction material. According to Mackechnie & Saevarsdottir (2007), the thermal conductivity of the precast concrete wall panel has a poor thermal performance on the building. Jusoh *et al.* (2013) has stated that the bamboo can flow the heat in the perpendicular direction with its grain, it provides lower thermal conductivity and good thermal insulation. Therefore, bamboo is suitable to use as the reinforcement material in concrete wall panel as it has a good thermal performance. From the research that have studied by Terai & Minami (2012), it has been stated that the bamboo have a higher bond strength in concrete compared to the plain steel bar in concrete.

There are some problems arise when the use of steel bar as reinforcement in concrete wall panel. There is a large amount of nonrenewable energy consumed by construction industry in construction activities and it has caused the large amount of carbon emission (CO2) to environment (Huang *et al.*, 2018). According to Mayer *et al.* (2019), the emission of greenhouse gas (GHG) for iron and steel sector are accounts approximately 25% out of total global industrial greenhouse gas emission which constitute about 7.5% of global greenhouse gas emission. On the other hand, abiotic natural resource in the world such as minerals and metals are gets less and less as time goes by (Yellishetty *et al.*, 2011). Abiotic resource has include the main resources for the production of steel which is include fossil resource metal and mineral (Burchart-Korol & Kruczek, 2016). Hence, the depletion of abiotic natural resource will affect and reduce the production and supply of the steel, while it will indirectly affect the construction activity because building structure are mostly dependent on the steel. Moreover, Steel bar was an essential construction material for the concrete structure member of a building, the increase of the price of steel bar will cause the increase of overall construction cost. The recent cost of steel bar in Malaysia has increased from RM 2800 per tonne to RM 4000 per tonne since October 2021 (Utusan, 2021). So, the increase of the price of steel bar will bring an effect toward the increase of the construction cost of

a project. Other than that, the problem of corrosion of reinforcement bar has also become a major factor that caused the deterioration of the durability of reinforced concrete structure (Lin *et al.*, 2017). Moreover, the corrosion of steel bar in concrete that cause the deterioration of concrete has decrease the durability of the concrete in the building structure. The corrosion of reinforcement steel that caused the deterioration of concrete may bring a safety hazard toward the building occupant and decrease the durability of the reinforced concrete structure in the building.

This research is focusing on the study of durability of concrete wall panel containing bamboo mat as reinforcement material. In this research, the bamboo as the reinforcement in the construction of building structures can reduce the dependence of the use of steel reinforcement which can contribute toward the sustainability in building construction. It can help to spread the awareness to contractor regarding the use unrenewable resources in construction industry and important of the use of natural resource in the construction industry. By conducting this study, it can help to enhance the economic by the providing of high strength performance in the building structure, contribute on academically which the other researchers can use this research as the reference to prove and improve the research on the performance and the effectiveness of the bamboo used as the reinforcement material and the use of bamboo as reinforcement material in wall panels will help to reduce the overall construction cost of a project. Therefore, this study is carried to compare the compressive strength of the bamboo reinforced concrete wall panel and standard concrete wall panel, determine the durability of bamboo reinforced concrete wall panel in normal environment and to observe feedback of bamboo mat as reinforcement material in concrete among construction stakeholders.

2. Literature Review

This literature review will review the performance of bamboo as reinforcement material and gather the information that are related to this research from various source.

2.1 Bamboo

Bamboo is belonging to the family of Bambusoideae which is recognized as one of the subfamilies within the grass family of Poaceae and bamboo was the only lineage from grass family that adapted and diversified within the forest habitat (Clark *et al.*, 2015). According to Benton (2015), the world woody bamboo species is approximately around 75 genera and there are over 1250 species in the world and all of these species of bamboo are normally be native to Americas, Africa, Asia and Oceania. Bamboo have total of 1400 bamboo species are distributed over the world which it has been widely distributed over the world. In addition, there is 80 % of the bamboo coverage from the total of approximately 14 million hectares of bamboo on earth surface was in Asia and most of the bamboo species has been found in Asia-pacific and followed by South America and Africa which the bamboo species found in Africa was the least (Yeasmin *et al.*, 2015).

Bamboo in Malaysia has usually grow abundantly in certain specific area such as flat land, ex-logging area, riverbank and hill slopes. Besides, there is a large part of the forest in Malaysia has been cover by the grow of bamboo which the area of the bamboo has occupied approximately 6.9% or 421722 hectares of total forest land in Peninsular Malaysia (Mohamed *et al.*, 2007). On the other hand, bamboo is widely available and easily obtainable in Malaysia. Bamboo is generally growth in two different form which are sympodial and monopodial. However, all species of bamboo that grow in Malaysia are normally in sympodial form. There are approximately 59 species of bamboo are alive in Peninsular Malaysia that comprise of 7 genera which is Schizostachyum, Gigantochloa, Dendrocalamus, Thyrsostachys, Bambusa, Dinochioa and Recemobamboos in scientific name (Lias *et al.*, 2020).

Mechanical strength of the bamboo is different form species to species where different species of bamboo have a different mechanical strength. Awalluddin *et al.* (2020) has studied the mechanical

strength of four type of bamboo in Malaysia which is Dendrocalamus Asper, Bambusa Vulgaris, Gigantochloa Scortechinii and Shizotacyum Grande. The bamboo that has highest tensile strength among these four types of bamboo was Bambusa Vulgaris with the 212.38 N/mm2 of tensile strength on the middle part of bamboo where the bamboo that have lowest tensile strength is Shizotacyum Grande with only 107.83 N/mm2 of tensile strength on the middle part of bamboo. On the other hand, the compressive strength of Dendrocalamus Asper, Bambusa Vulgaris, Gigantochloa Scortechinii and Shizotacyum Grande has been studied by Dinie Awalluddin *et al.* (2017). The highest compressive strength and lowest compressive strength of the bamboo species are Bambusa Vulgaris and Shizotacyum Grande where the compressive strength of middle part for both bamboo species are 78.67 N/mm2 and 31.70 N/mm2 respectively. According to Sompoh *et al.* (2013), the compressive strength for the middle part of Gigantochloa Albociliata (Buluh Madu) is 53 N/mm2, the compressive strength of Gigantochloa Albociliata is in the middle range of the compressive strength between Bambusa Vulgaris and Shizotacyum Grande.

(a) Physical Appearance of bamboo

According to Bamboo Botanical (2019), the structure of bamboo has been divided into 4 main part which is bamboo root system at the lower part of bamboo, bamboo culm as the main part of the bamboo, bamboo node and bamboo internodes and followed by the another part of bamboo which is bamboo brunch. Bamboo root can knowns as the underground culm of the bamboo and it is as similar as Bamboo Rhizome, Bamboo Rhizome has been recognized as the underground culm which it is growth in the soil horizontally.

In addition, Bamboo Rhizome is growth under the ground surface and it also act as the part for the production of bamboo shoot and root through bamboo nodes. Bamboo culm was the segment of bamboo stem that is joint together that become a big segment of the bamboo while the joint between the ends and begins at the stem of the bamboo has called nodes which joint the stem of the bamboo to become a bamboo culm. Moreover, the stem that joint together to form the bamboo culm has known as internode for the bamboo and bamboo brunch has growth from the node on the bamboo culm which the structure of the brunch is similar with the bamboo culm and the leaf has growth through the node of brunch.

(b) Mechanical Properties of Bamboo

According to Jit Kaur (2018a), the load bearing capacity of bamboo is greater than steel, concrete and timber. When bamboo utilized as a building structure it can bring about 1 m3 per unit stress with 50 times less energy compared to concrete and steel. In addition, bamboo was a light weight material among the construction material. Moreover, the tensile strength for bamboo and steel is 28000 pounds per square inch and 23000 pounds per square inch respectively. Hence, bamboo is a suitable material to become an alternative to steel due to its comparable tensile strength with steel. On the other hand, bamboo have a good compressive strength and the compressive strength of bamboo will become higher when the age of bamboo increase which the compressive strength of five year age bamboo is greater than the one year age of bamboo (Gutu, 2013a).

Based on Gutu (2013b), the strength properties of bamboo is greater than many type of wood which the strength properties of bamboo is greater than most of the soft wood and several hard wood. Moreover, bamboo is a stable light weight and elastic construction material as bamboo cavities was elastic and light which the texture of bamboo is as similar as the texture of wood. Bamboo is more stable and dense than wood when utilized in the construction, texture of wood have a hard inner part and weak in outer part while the texture of bamboo have a cavities on its stem which distribute more densely in outer part. In addition, the shear strength of structural wood is relatively lower than bamboo can withstand a longer period to reach ultimate failure than structural wood.

(c) Utilization of Bamboo

Bamboo was a suitable alternative material for various production purpose such as the production of handicraft and construction material, it also has been utilize in the paper and pulp industry. Besides, bamboo has also been utilized in the production of food in food industry due to its nutritional value as food. Different part of the bamboo have different purpose such as the bamboo shoot can be process to become the food for human and bamboo leaf can be utilize as the fodder for panda (Jit Kaur, 2018b). On the other hand, bamboo has been utilized in more than 2500 different traditional way and the company that is related to the production of bamboo-based product in the world are approximately at the total of 3000 companies (Chongtham *et al.*, 2011).

Bamboo shoot is usually utilise for the purpose of food production while bamboo culm is generally utilize for various production. Based on van Dam *et al.* (2018), in Asian countries bamboo shoot has been used for the purpose of the production of beverage and medicine. On the other hand, bamboo culm has been used to produce many different products such as chopstick, mat, basket and round poles for scaffolding in construction. On the other hand, bamboo culm has also been used in the production of food which bamboo culm was processed to become the pickles. In some rural area, bamboo culm has utilized as the cooking equipment because fresh bamboo culm has a special flavour which is good for the purpose of cooking (Liese *et al.*, 2015).

2.2 Bamboo as Construction Material

Bamboo has widely used for the purpose of human daily life from the production of handcraft, raw material for production of paper basket and even as a vegetable for people. Moreover, bamboo was a strong material when treated and it is used as the material for building construction in some countries (Correal *et al.*, 2010a). Other than that, bamboo as construction material has bring some advantage and disadvantage toward the construction which the advantage was it is low energy consumption and it has a competitive mechanical properties, social and economical value and ecological value while the disadvantage was bamboo are required for the fire safety and preservation when used as construction material (Kumar & Ashish, 2015).

Recently, there is an increase in use of bamboo construction material in construction industry. Based on Sharma *et al.* (2015), bamboo product has show an increasing interest internationally as the bamboo product is ecologically responsible alternative construction material and it is cost effective and sustainable. Besides, bamboo was also a sustainable resource that is rapidly renewable and it has a similar mechanical properties with the timber. Moreover, bamboo has been used in many aspects of the construction work such as scaffolding, substitution for reinforcement bar in concrete and even become a formwork for concrete. Other than that, bamboo has become a potential raw material for sustainable and eco-friendly construction due to its high strength, short rotation age and fast growth rate (Correal *et al.*, 2010b).

Bamboo is versatility and it is flexibility and high strength on its culms. Hence, it has been widely used in the construction activities and it has been produced to become bamboo-based construction material such as bamboo mat panel and bamboo pole (Zea Escamilla & Habert, 2014). The used of bamboo as main construction material for residential building was due to several reason which is it was economy and convenient and it have low carbon environmental protection characteristic (Hong *et al.*, 2019). In addition, the rapid urbanization process has caused the depletion of tropical resource by deforestation, it has bring the consequence of the rising demand in the sustainable construction material. Hence, bamboo has gaining more interest to be develop and used in modern construction because it is rapidly renewable compared to the timber (Gatóo *et al.*, 2014).

2.3 Natural Material as Reinforcement in concrete

(a) Hemp Fiber

Bast fiber has been recognized as a waste product that is usually disposed as landfill. The availability of the bast fiber has make the fiber used for hemp fiber reinforced concrete become extremely cheap (Zhou *et al.*, 2017). Ziane *et al.* (2020) has studied the utilization of hemp fiber as the reinforcement in the concrete by the placement of various percentage of hemp fiber in the concrete. The study has used the hemp fiber concrete with the placement of 0.25%, 0.5% and 1% of hemp fiber in concrete. The result of compressive strength test for the hemp fiber concrete has suggest that the increase of the hemp fiber content in the concrete has caused the compressive strength of concrete to decrease. Besides, the compressive strength of hemp fiber concrete has been estimated to reduce at the rate of 11.93% for 0.25%, 35.73% for 0.5% and 37.26% for 1% of hemp fiber in concrete. However, the tensile strength of the hemp fiber concrete has increase when the content of hemp fiber was increase from 0.25% and 0.5% as well as 1%.

(b) Coir Fiber

The price of the coir fiber is relatively inexpensive and widely available and the tenacity of the coir fiber was the highest among the natural fiber. Hence, the coir fiber has become one of the natural resources that utilized as the reinforcement in concrete (Ali *et al.*, 2012). A research of the use of coir fiber as concrete reinforcement has been conducted by Babafemi *et al.* (2019). The research has been conducted by the placement of different of proportion of coir fiber in the concrete of 0.5% and 1% of coir fiber in the concrete. The result of the research has showed that the utilization of coir fiber in concrete as reinforcement has improved the compressive strength of the concrete which 0.5% and 1% of the proportion of coir fiber in the concrete has indicate an increasing of compressive strength during curing process. Moreover, the result of tensile stress strength of the coir fiber reinforced concrete has suggest that the tensile strength has increase when curing age increased and the result for the durability test has showed the loss of compressive strength and mass in coir fiber reinforced concrete.

(c) Oil Palm Trunk Fiber

Oil palm trunk fiber has been recognized as a fiber that have a good characteristic in mechanical properties which the oil palm trunk fiber is high in density and it have a great tensile strength on it. Due to the good mechanical properties of oil palm trunk fiber, it has become a suitable material for the reinforcement in concrete (Abdullah *et al.*, 2013). Based on Z. Ahmad *et al.* (2010), the researcher has studied the utilization of oil palm trunk fiber for concrete reinforcement. The research has been conducted with the use of different volume of oil palm trunk fiber in the concrete as reinforcement which is 0%, 1%, 2% and 3%. The result has suggested that the compressive strength test and tensile strength test for oil palm trunk fiber reinforced concrete has deceased when the content of the oil palm trunk fiber in the concrete has increase. Moreover, the flexure strength for the oil palm trunk fiber reinforced concrete has showed that the increased of oil palm trunk fiber content in the concrete has caused the flexure strength of the concrete increase.

2.4 Bamboo as Reinforcement in Concrete

(a) Bamboo Reinforced Concrete Beam

Mali & Datta (2020) has studied on the experimental evaluation of bamboo reinforced concrete beam. The research has been conducted by tested on three different types of concrete beam which is bamboo reinforced concrete beam, conventional steel reinforced concrete beam and concrete beam without reinforcement. The bamboo reinforced concrete beam that has been tested in the study are divided into two types which is 2.8% and 3.8% longitudinal bamboo reinforcement content in the concrete beam. The result for the load and deflection test for the bamboo reinforced concrete has showed that both 2.8% and 3.8% of inclusion of bamboo reinforcement in concrete beam has improved the ultimate load, ductility and energy absorption capacity for concrete beam when compared to the concrete beam without reinforcement. In addition, the flexure strength test for the bamboo reinforced concrete beam in this research has suggest that both bamboo reinforced concrete beam of 2.8% and

3.8% bamboo inclusion has higher than theoretical predicted value. Other than that, the shear strength test in the research has showed that the bamboo reinforced concrete beam with 3.8% bamboo reinforcement has a greater shear strength compared to the bamboo reinforced concrete with 2.8% of bamboo reinforcement.

(b) Bamboo Reinforced Concrete Slab Panels

The utilization of bamboo as reinforcement in the concrete slab panels has been studied by the researcher. Mali & Datta (2018) has conducted the research through the experimental evaluation of bamboo reinforced concrete slab panels. The research has study on the flexure behaviour of bamboo reinforced concrete slab panels compared with plain cement concrete slab panels and conventional steel reinforced cement concrete slab panels. Based on the result, ultimate load carrying capacity for the bamboo reinforced concrete slab panels has been identified greater than the steel reinforced cement concrete slab panels and followed by plain cement concrete slab panels. On the other hand, the result of the study has indicated that the increasing of the bamboo content in plain cement concrete can increase the flexure strength of bamboo reinforced cement concrete slab panel by 1.5 to 2 times higher. Moreover, the research has shown that the energy absorption capacity of bamboo reinforced cement concrete slab panels under deflection can be greater than plain concrete cement slab panels for 48%.

2.5 Bamboo Reinforced Concrete Wall Panel

(a) Bamboo Reinforced Concrete Wall Panel Under Two Way in Plane Action

Ganesan *et al.* (2019) has studied on the strength and behaviour of bamboo reinforced concrete wall panel under two way in-plane action. There is three different size of bamboo concrete wall panel specimen has been constructed to conduct the research which the size of the specimen has been differentiate by the ratio of height to length (Aspect Ratio) and length to thinness (Thinness Ratio) of bamboo reinforced concrete wall panel which is 1.667. 1.818, 2 and 12.5, 13.75, 15 respectively. The result of load deflection behaviour for the wall panel under two-way in plane action has showed that the increase in the aspect ratio of wall panel has caused the increase in the deflection of wall panel while the increase in the thinness ratio of wall panel will caused the deflection of wall panel to reduce. On the other hand, the study has showed that the ultimate load of wall panel has decrease when the aspect ratio of the wall panel has increase while the ultimate load for wall panel has increase as the thinness ratio of wall panel increase.

(b) Bamboo Reinforced Concrete Wall Panel Under One Way in Plane Action

Ganesan *et al.* (2020) has studied on the behaviour and strength of bamboo reinforced concrete wall panel under one way in plane action. There are three specimens with different aspect ratio and thinness ratio has been casted which the aspect ratio and thinness ratio for the bamboo reinforced concrete wall panel specimen for the study are 1, 1.204, 1.515 and 16.5, 20.75, 25 respectively. The result has showed that when the aspect ratio of wall panel increased the deflection of wall panel will also increase, while the increase of thinness ratio of wall panel will cause the deflection of wall panel decrease. Moreover, the result for ultimate load of wall panel has indicated that the increase in aspect ratio of wall panel will cause the ultimate load of wall panel to decrease while when the increase of thinness ratio has increased the ultimate load of the wall panel.

3. Research Methodology

3.1 Research Framework

Flowchart in *Appendix* A has showed the overall laboratory work process of this research. The laboratory process has start with material preparation and followed by the preparation of standard

concrete wall panel specimen, concrete mix design, formwork design and casting, process of mixing concrete, Slump test, curing process, compressive strength test as well as durability test. The final process of this research was the collecting and analyzing of data.

3.2 Experimental Setup

(a) Specimen Detail

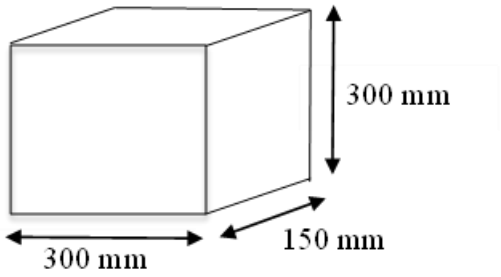


Figure 1: Sample of Wall Panel

This research was focused on the production of concrete wall panel specimen to conducting the experiment. There are 6 specimens of concrete wall panel are produced before the laboratory test start which is 3 specimens of bamboo concrete wall panel and 3 specimens for standard concrete wall panel. The bamboo concrete wall panel specimen is produced to test on the compressive strength and durability. Based on the Figure 3.1, the figure shows the size of concrete wall panel specimen used in this study for a dimension of concrete wall panel specimen is 300 mm x 300 mm x 150 mm. The design of the size and dimension of the concrete wall specimen in this research is based on the standard of the specimen to test the compressive strength of concrete which the standard specimen to test on the compressive strength is cylinder shape of concrete with dimension of 150 mm diameter and 300 mm height (Hamad, 2017).

(b) Material Preparation

The material used is “Gigantochloa Albociliata” which also known as “Buluh Madu”, R6 steel bar, fine and coarse aggregate, cement and water and the concrete mixture in this experiment are mix with the ratio of 1:2:4 of concrete grade M15.

i. Treatment of Bamboo

The preparation and treatment of the bamboo is start with; a) Collecting the bamboo. “Gigantochloa Albociliata” at Batu Pahat, Johor. b) Clean the bamboo by the water to remove the impurities and debris on the surface of bamboo and expose bamboo under sunlight to dry. c) Cut bamboo into suitable size and treat the bamboo in the borax solution and wait until the water in tank turn into dark. d) Take bamboo out from borax solution and dry the bamboo by using oven e) Design and produce bamboo mat by treated bamboo.

				
(a)	(b)	(c)	(d)	(e)

(c) Preparation of Standard Concrete Wall Panel

Process of the preparation of steel reinforcement is start with the cutting of R6 steel bar which the steel bar is cutting into 240 mm length with according to the size of the concrete wall panel specimen with 30mm of concrete cover. Then, the steel bar is arranged according to the standard way of arrangement which is 100mm spacing between steel bar and the steel bar are tie with the steel wire to form the reinforcement for the standard concrete wall panel.

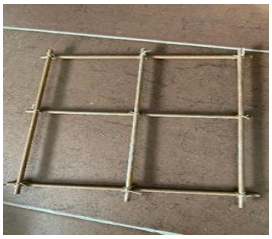


Figure 2: R6 steel bar has cut into suitable size and tie with the use of steel wire to produce reinforcement

(d) Concrete Mix Design

In this research, the concrete mix design has used the normal concrete to make the specimen with concrete grade M15 which the ratio is 1: 2: 4 and the composition that include in this study is consists of bamboo, steel bar, coarse and fine aggregate, cement, and water. The bamboo mat reinforcement in the wall panel specimen is design with 100 mm spacing between each bamboo and 6mm diameter for each bamboo. The measurement of each concrete wall panel specimen is 300 mm x 300 mm x 150 mm (length x height x weight), all specimens are gone through the curing process.

(e) Formwork Design/Casting

The mould of for the concrete wall panel specimen in this research is prepared with the measurement of 300 mm x 300 mm x 150 mm and there will have 6 mould to be prepare and casting to conducting the experiment which 3 mould are produced to casting for bamboo concrete wall panel while 3 mould are produced to casting for standard concrete wall panel. Furthermore, 2 specimens for both bamboos reinforced concrete wall panel and standard concrete wall panel are used to conduct the compressive strength test while 1 specimens for both bamboo reinforced concrete wall panel and standard concrete wall panel are used to conduct the durability test. The casting of the specimen for this research is start with; a) the process of mixing and weigh concrete and cement, sand and aggregate on scale along with the water and put into a pan for mixing and the concrete was mix at the ratio of 1: 2: 4. b) Do slump test for the concrete mixture. c) Setup the mould and casting for bamboo reinforced concrete wall panel specimen and standard concrete wall panel specimen. d) Left all specimen in room temperature for 28 days for harden.

			
(a)	(b)	(c)	(d)

3.3 Slump Test

The slump test carry out in this research is to access and measure the consistency, workability as well as checking the correct amount of water of fresh concrete before it is harden. The slump test is carry out in accordance with BS EN 12350-2: 2009. The apparatus and equipment that used to conducting the slump test is show at Figure 4 below. The apparatus and equipment require to conducting the slump test are the cone shape mould, base plate, measuring scale and tamping rod. The mould that used in the slump test is a metallic mould with the frustum of cone in shape which having 20 cm bottom diameter, 10 cm for top diameter and 30 cm height.

Figure 3: Slump Test

3.4 Curing Process

Proper curing process for the concrete will improve the strength and reduce the permeability of the harden concrete. In this experiment, the curing process is conducted after the harden of concrete wall panel specimen and curing process is conducted according to BS 8110-1:1997 standard. The concrete wall panel specimen will harden 28 days after the casting process, all concrete wall panel specimens is cover by the wet towel to go through the curing process. Then, the concrete wall panel specimens that cover by the wet towel are placed in shaded place for 7 days for the curing process.

3.5 Experimental Test

(a) Compressive Strength test

Compressive strength test is a mechanical test that measures the maximum compressive load that a material can withstand before the material is cracking or fracturing. In this study, the compressive strength test is conducted to test on the maximum compressive strength of the bamboo concrete wall panel and standard concrete wall panel. There are 4 specimens which 2 specimens for bamboo reinforced concrete wall panel and 2 specimens for standard concrete wall panel are test on the compressive strength test after the 28 days curing process of specimen is done. The compressive strength test in this study is carry out according to the standard from ASTM C805-97 by using the digital rebound hammer. The process of compressive strength test is start with; a) clean the surface of the specimen and make sure there is no water or free moisture on the surface of concrete b) put the plunger rebound hammer perpendicular to the surface of the concrete and start to impact and push the rebound hammer on the surface of concrete c) 9 reading of impact point are taken from the test area d) the result will show on the rebound hammer and the result will be record.

Figure 4: Rebound Hammer Test for Specimens

3.6 Durability Test

The durability test is the test that test to evaluate the durability and the resistance of the specimen against the acid attack. In this research, the concrete wall panel specimen is tested on the durability according to ASTM C 267-01 by the used of the sodium sulphuric acid (Anagnostopoulos *et al.*, 2016). There are 2 specimens which is 1 specimen for both bamboo and standard concrete wall panel specimens are being weigh and soak in the 10% sodium sulphuric acid solution for 7 days. After 7 days, all specimens are taken out from the sodium sulphuric acid solution and wash with the water as well as dried by oven. Then, all specimens have been weighted and recorded the result of the percentage loss of all specimens as well as making the comparison of the durability between the bamboo concrete wall panel specimen and standard concrete wall panel. After that, the specimen is gone through the compressive strength test to test for the strength performance of the bamboo reinforced concrete wall panel specimen and standard concrete wall panel specimen after the durability test.

Figure 5: Durability Test

3.7 Qualitative Method

In order to achieve the third objective of this research, the qualitative method is used to obtain the feedback of construction stakeholders about the bamboo as reinforcement material in concrete which the phone call interview has conducted to the target respondent.

3.8 Research Instrument

This research has used the interview method to collect and obtain the data to achieve the third objective for this research which the researcher will conduct a phone call interview to the targeted respondent. In this research, the semi-structured interview method will be used to conduct the research, all of the respondent will receive a same question by the researcher and the question will be ask by the researcher during interview session.

4. Results and Discussion

Data obtained are discussed and described the finding on the experimental test conducted on bamboo reinforced concrete wall panel and standard concrete wall panel specimen. The discussion of the finding are also included the finding of interview to construction key player on the feedback of bamboo mat as reinforcement material. Moreover, the compressive strength and durability of bamboo reinforced concrete wall panel and all data obtained are presented in graphs to see the comparison.

4.1 Result

4.1.1 Compressive Strength Test

Table 2, Figure 6 and Figure 7 below shows the compressive strength of bamboo reinforced concrete wall panel and standard concrete wall panel specimen after 28 days of the curing process.

Table 2: Compressive Strength of Wall Panel Specimen

Specimen Name	Specimen Mass (kg)	Point Reading			Position	Specimen Strength (MPa)	Average Specimen Strength (MPa)
Bamboo Reinforced Concrete Wall Panel Specimen 1	30.56 kg	29	26	25	Horizontal	21.91	27.81
		30	26	27			
		31	34	28			
Bamboo Reinforced Concrete Wall Panel Specimen 2	29.88 kg	30	52	36	Horizontal	33.70	
		33	41	33			
		38	40	32			
Standard Concrete Wall Panel Specimen 1	30.40 kg	38	37	36	Horizontal	35.09	33.71
		34	33	35			
		52	41	37			
Standard Concrete Wall Panel Specimen 2	30.16kg	37	32	59	Horizontal	32.32	
		30	33	36			
		31	40	29			

Based on the result in table 2, both specimen of bamboo reinforced concrete wall panel have a significant different in compressive strength which recorded 21.91 MPa and 35.09 MPa respectively. However, this result can be accepted due to the proper procedure of conducting the experimental process of this research. Moreover, there are a similarity between both specimen of standard concrete wall panel which the compressive strength of both specimens are around 30 MPa.

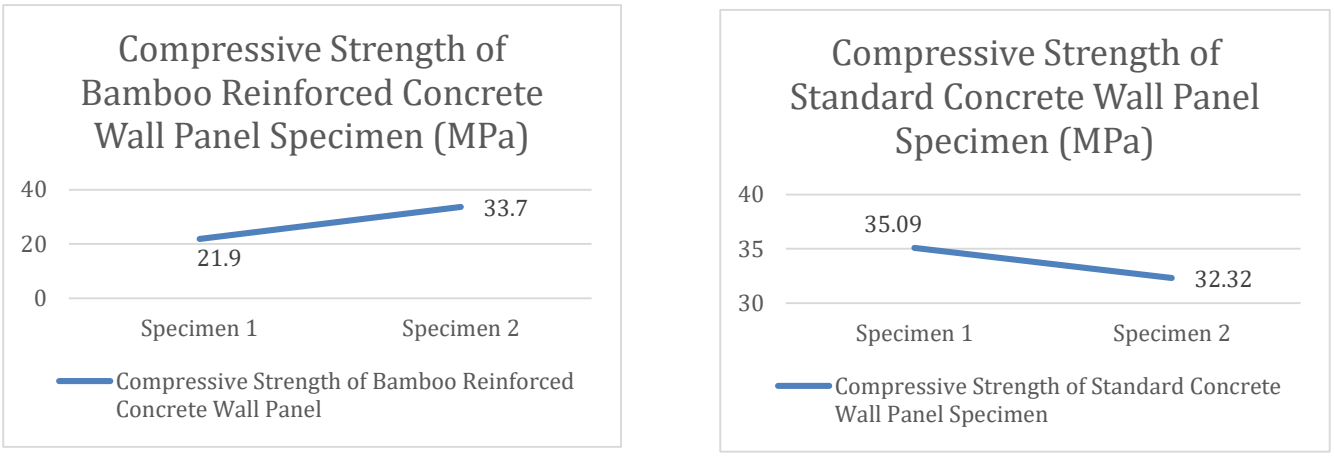


Figure 6: Compressive Strength of Concrete Wall Panel Specimen After 28 Days Curing

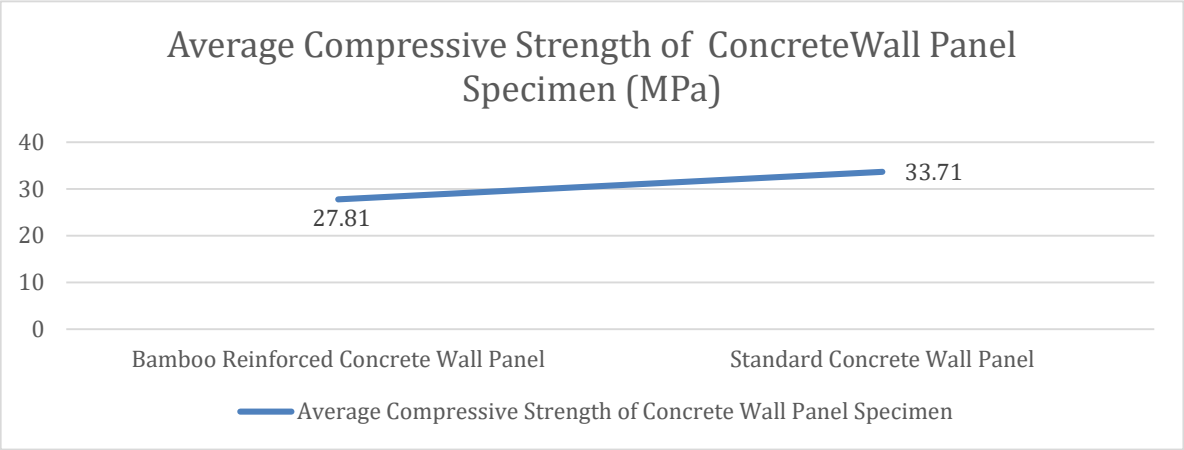


Figure 7: Average Compressive Strength of Concrete Wall Panel Specimen After 28 Days Curing

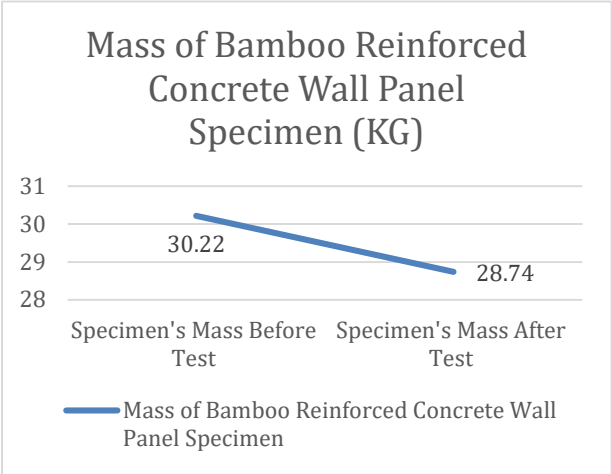
Based on figure 7, the average compressive strength of the bamboo reinforced concrete wall panel are closely equal to the standard concrete wall panel which the different between the average compressive strength of both specimens are 18% which similar as 5.9 MPa. As the result, the average compressive strength of bamboo reinforced concrete wall panel is around 30 MPa which it is similarly to the compressive strength of standard concrete wall panel. This results are similar to the result reported by Mali & Datta (2020) which the bamboo reinforced concrete have a comparable strength with steel reinforced concrete.

4.1.2 Durability Test

4.1.2.1 Percentage loss of weight for specimen

Table 3: Percentage loss of weight for specimen

Specimen Name	Specimen's Mass Before Test (kg)	Specimen's Mass After Test (kg)	Percentage Loss
Bamboo Reinforced Concrete Wall Panel Specimen	30.22 kg	28.74 kg	4.89%
Standard Concrete Wall Panel Specimen	30.32 kg	28.91 kg	4.65%



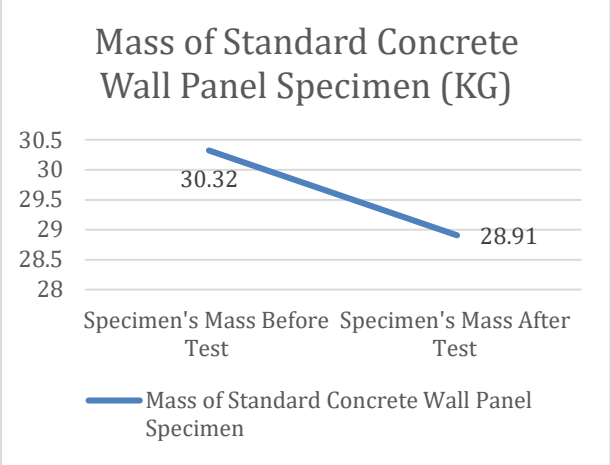


Figure 8: Loss of Weight for Specimen

Based on figure 8, it shows that the loss of weight for the bamboo reinforced concrete wall panel specimen and standard concrete wall panel after the specimen has been soak in the sulphuric acid solution for 7 days. From table 3 above, the weight for bamboo reinforced concrete wall panel and standard concrete wall panel are almost the same before and after the test which the weight for both specimen before the test and after the test are around 30 Kg.

Meanwhile, the result of the percentage loss for both specimens are illustrated in the table 3. the percentage loss of weight for the specimen are recorded 4.89% and 4.65% for bamboo reinforced concrete wall panel and standard concrete wall panel respectively. There is a small difference between the percentage loss of weight for two type of specimens which the different of weight between two types of specimens after the test is only 0.24%. Hence, it can be concluded that the bamboo reinforced concrete wall panel are comparable to the standard concrete wall panel which there is no distinct different between the percentage loss of weight for both specimens after the test.

4.1.2.2 Strength Performance of Specimen After 7 Days of Soak

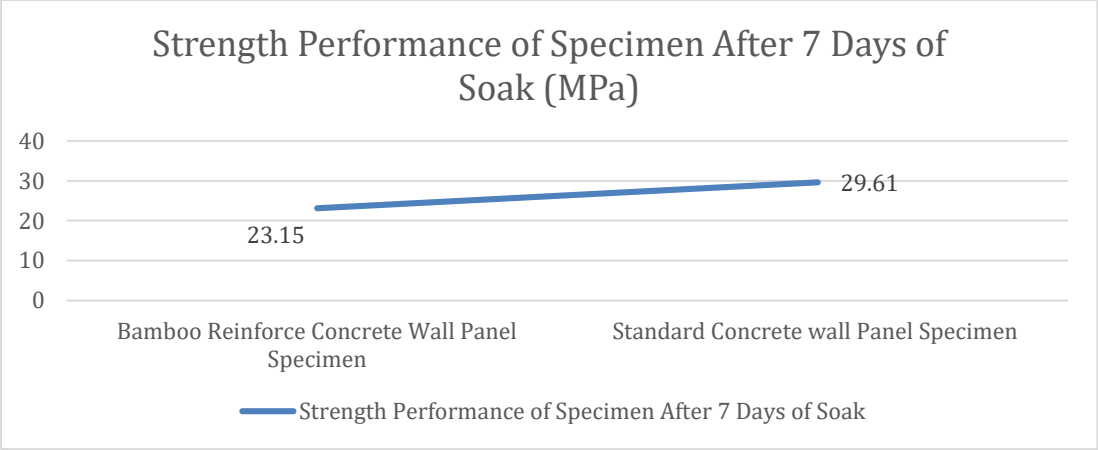


Figure 9: Strength Performance of Specimen After 7 Days of Soak

The result of the strength performance for both bamboo reinforced and standard concrete wall panel specimen after 7 days of soak in 10% sulphuric acid solution was illustrated in figure 9 above. From the table, the result of strength performance for both type of specimen has shared a number of key features which the strength for both type of specimen is around 25 MPa. In the same way, the graph has showed there is no significant different between the strength of bamboo reinforced and standard concrete wall panel specimen.

In addition, there is only 6.46 MPa of difference between both specimen which the result has recorded 23.15 MPa for the strength of bamboo reinforced concrete wall panel and 29.61 MPa strength for standard concrete wall panel. According to Uri (2013), the moderate strength for the concrete is between the range of 3000 to 6000 psi which it is similar to the range of 20 to 40 MPa. Hence, the strength of bamboo reinforced concrete wall panel can be accepted because it is within the range of 20 to 40 MPa.

As a conclusion, the bamboo reinforced concrete wall panel have a comparable strength with the standard concrete wall panel in normal environment and bamboo can be suggested as the replacement for the steel in the concrete wall panel after the 28 days curing process of concrete.

4.3 Respondent Background

The respondent in this research is was the construction stakeholders in the Malaysia's construction industry which is including of civil engineer and project manager from different company. The table 4 below show the background of the respondent.

Table 4: Background of Respondent

Respondent	Organisation	Position	Working Experience
Respondent 1	Company A	Project Manager	Above 3 Years
Respondent 2	Company B	Civil Engineer	Above 3 Years

4.4 Views on the Replacement of Steel Bars by Other Materials

The concept of the replacing steel bar reinforcement with other material in concrete is a new concept to the targeted respondent which this is the first time for all respondent to be aware of the concept of replacing steel bar with other material in concrete structure.

R1	R2
"In my opinion, it is not yet had other material that can replace steel bar in concrete. Since this research topic are focus about the use of bamboo mat as reinforcement replacement. So, it can be use as a method to test run for the steel bar reinforcement replacement because it is a good plan, if the data sheet can support, I think this is a good choice."	*"Based on my opinion, this concept is new to me, and I never heard it before. In the market, all the concrete are using steel bar as reinforcement, and this is first time for me to hear about the using of bamboo as reinforcement material in the concrete"*

4.5 Opinion on the Acceptance of Using a Bamboo Mat as a Steel Bar Reinforcement Replacement

All respondents have an opinion of the bamboo mat as reinforcement replacement is acceptable but in overall the concept of bamboo as reinforcement replacement must be gone through the testing before it can be applied in the construction building.

R1	R2
"Bamboo mat can be accepted to become a reinforcement replacement for the steel bar because it is cost saving, it is environmentally friendly and from the aspect of unloading it will be more easily to unload. In the aspect of biology, steel bar or mesh is replaceable."	*"The replacement of bamboo mat as reinforcement material must gone through the testing to proof it strength when compared to standard reinforced concrete. The replacement of bamboo mat as reinforcement material is acceptable but it must be involve a lot of parties to proof for the strength and certain criteria needed to be fulfil before it apply for all building, even though the researcher has been gone through the testing."*

4.6 Comment on the Suitability of the Implementation of Bamboo Mat as Reinforcement Replacement in Malaysian Construction Industry

Bamboo mat as reinforcement replacement material has only been suggested to implement in small and low-rise buildings and it is not suggestible by all the respondents to implement in heavy structure and high-rise buildings in Malaysia.

R1	R2
"More tests needed to be conducted on the bamboo mat as reinforcement replacement before it is implemented and provided as a real product and it can start to implement it in the small building before it implements in heavy and high-rise building. on the other hand, it requires a professional and an authoritative expert of engineer's supervision to implement it. So, it can start to implement in Malaysia."	*"In Malaysia, the bamboo mat must be proofed for its strength before it is implemented but not all buildings can apply and implement the bamboo mat as reinforcement replacement. Meanwhile, the type of bamboo used as the replacement for steel bar reinforcement also needed to consider. However, a bamboo mat as a replacement for steel bar can be implemented in non-structure concrete such as drainage or other concrete structure without carrying a heavy load if the strength is achievable against the standard reinforced concrete. Bamboo as reinforcement replacement is not suitable to implement on a high-rise building in Malaysia."*

4.7 Suggestion and Comment on This Research or Product

Bamboo mat as reinforcement replacement is a good concept for the opinion of all respondents which the implementation of this technology may bring a lot of benefit to the construction industry, but it needed to be observed and testing properly before it is implemented in construction industry.

R1	R2
"If the strength of bamboo as reinforcement can achieve the require strength, it can be accepted to implement in construction industry, but it will need a long period to test on it before it is accepted to be implement. The current situation is the price of steel bar has increased dramatically after the MCO. So, if there is a material that suitable to replace the steel bar reinforcement it will bring a good impact to the construction industry and in the aspect of economy it is a good idea to help to stable the	*"Researcher can go through some research and get the proven by the parties such as IEM. IEM is one of the engineering institutes in Malaysia, if IEM can accept this concept as well as it is depending on the type of building that is wanted to implement. Not all type of building is suitable to use bamboo as reinforcement replacement, it is not suitable to implement in a high-rise building and heavy structure, but it may be implemented in the substructure. To prove the bamboo as reinforcement replacement, it must be gone through certain criteria and fulfil the*

market in current situation. The overall concept of this research is a very good concept."	*requirement by the expert engineer. There is a lot of new technology is implemented in the construction industry overseas, but Malaysia still has not yet implemented the new technology in the construction industry. So, the use of bamboo as reinforcement replacement is no harm to try and it can try to implement in the future construction industry in Malaysia."*

5. Conclusion

This section will present the summary of the research finding as well as present the overall achievement of the objective in this research. Moreover, this section will also discuss on the recommendation for this research.

5.1 Research Conclusion

a) Objective 1: To compare the compressive strength of the bamboo reinforced concrete wall panel and standard concrete wall panel.

The result of this research objective has obtained and analyzed. According to the graph in the result for compressive strength test, there is no significant difference for result of average compressive strength between bamboo reinforced concrete wall panel and standard concrete wall panel which the average compressive strength for both specimens are around 30 MPa which it is recorded 27.81 MPa and 33.71 MPa for bamboo reinforced concrete wall panel and standard concrete wall panel respectively. This has indicated that there is a comparable compressive strength between two type of concrete wall panel specimens. Hence, bamboo reinforced concrete wall panel is acceptable for the implementation.

b) Objective 2: To determine the durability of bamboo reinforced concrete wall panel in normal environment.

Based on the result for the percentage loss of weight of specimen in previous chapter, there is an inessential different between the bamboo reinforced concrete wall panel specimen and standard concrete wall panel which there is only 0.24 percentage of different of the weight loss after the specimen taken out from sulphuric acid solution. The strength performance for both specimens after taken out from sulphuric acid solution are comparable which there is only 6.46 MPa different in strength. Hence, it can be concluded that the bamboo reinforced concrete wall panel are acceptable when exposed in normal environment after compared to standard concrete wall panel.

c) Objective 3: To observe the feedback of bamboo as reinforcement material among key players in construction industry

Data that has been collected in this research objective has throughout the interview to two respondent that have many years of working experience in construction industry which the data are obtained from a project manager and a civil engineer from different company. Based on the interview data, all respondents are agreed with the bamboo mat as reinforcement material is acceptable. However, both respondents also have an opinion on the implementation of the bamboo mat as reinforcement material must be tested and approve by certain expert and parties in construction industry before it is implemented in construction industry.

5.2 Recommendation

I. The durability test of concrete specimen against acid attack in this research were tested by the soak of concrete specimen in 10% H2SO4 solution for 7 days only, it is recommended that the future research test in 2, 7, 14, 28 days to soak the specimen in the 5% H2SO4 solution to gain a better understanding of the long-term durability performance of the concrete specimen.

II. More specimens need to be test for the durability test, the specimen that tested with the durability test in this research are only one specimen for both bamboo reinforced concrete wall panel and standard concrete wall pane. Hence, it is suggested to prepare two specimens for each type of specimen to conduct the durability test to obtain a more accurate experimental test result.

III. Make a proper schedule planning for the overall research work to make sure the overall research process can be going smoothly and complete the research work on time.

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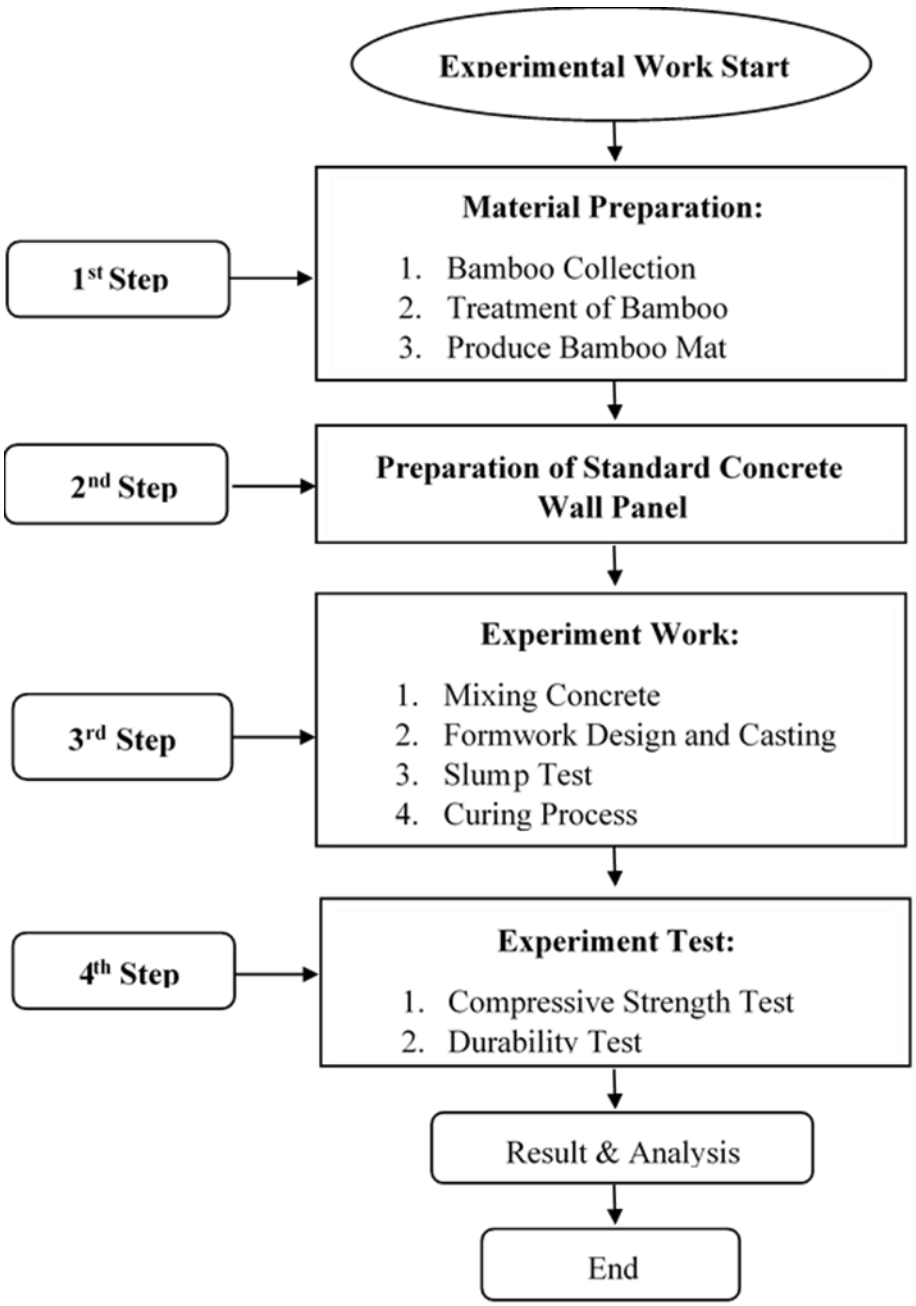
Appendix A



Flow Chart of Experimental Work Process