EFFECT OF REINFORCEMENT TO THE SQUARE HOLLOW SECTION ON THE STRENGTH OF FOAMED CONCRETE BEAM

DOMINIC TIONG SIE HUO

B. ENG(HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

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Full Name : DOMINIC TIONG SIE HUO

ID Number : AA 15133

Date : 30 MAY 2019

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DOMINIC TIONG SIE HUO

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ABSTRAK

Konkrit bertetulang dengan ketumpatan 1600kg / m³ kini digunakan secara meluas sebagai komponen struktur seperti papak kerana ia lebih ringan daripada konkrit biasa. Sementara itu, ia membantu dalam menjimatkan kos dan mengurangkan penggunaan acuan. Seksyen berongga yang diterapkan ke rasuk juga merupakan usaha untuk menjadikan struktur lebih ringan. Processed Spent Bleaching Earth (PSBE) adalah sisa industri yang mempunyai sifat pozzolanic seperti simen. PSBE digunakan untuk sebahagian menggantikan kandungan simen untuk menjadikannya lebih mesra alam. PSBE sebahagiannya menggantikan simen sebanyak 30% daripada jumlah berat kandungan simen. Objektif kajian ini adalah untuk menganalisis kesan pengukuhan bahagian berongga pada kekuatan, pesongan dan mod kegagalan rasuk konkrit berbuih. Tiga spesimen disediakan untuk dianalisis dalam kajian ini. Spesimen 1 boleh dikenali sebagai balok kawalan yang bertindak seperti rasuk biasa tanpa bahagian berongga. Spesimen 2 adalah rasuk dengan bahagian berongga. Sementara itu, spesimen 3 ialah rasuk yang menambah bar keluli di sekeliling bahagian berongga untuk menguatkan bahagian berongga. Saiz rasuk dipasang pada semua spesimen dengan (150 x 200 x 1500) mm. Seksyen berongga yang melaksanakan kedua-dua spesimen adalah dalam saiz 50x50 mm ke tengah rasuk. Setiap spesimen disediakan sebanyak tiga sampel untuk ujian supaya mendapatkan kekuatan lenturan, pesongan dan mod kegagalan. Tiga Linear Variable Displacement Transducer (LVDT) digunakan untuk mengukur pesongan rasuk. Menurut hasilnya, spesimen 1 (pancaran kawalan) mempunyai kekuatan tinggi untuk menahan beban maksimum 31.003kN dan kekuatan lentur sebanyak 6.201 N / mm². Walau bagaimanapun, spesimen 3 dengan tetulang di sekitar pesongan boleh menahan lebih banyak pesongan berbanding dengan spesimen lain. Mod kegagalan untuk semua spesimen dianggap sebagai retak ricih kerana corak retak slaid ditemui. Singkatnya, bahagian berongga yang diterapkan ke rasuk telah memberi kesan kepada kekuatan dan pesongan rasuk walaupun dengan tambahan tetulang di sekitar bahagian berongga. Oleh itu, penting dalam balok menunjukkan kekuatan yang lebih besar dan mengurangkan pesongan dan retak.

ABSTRACT

Foamed concrete with a density of 1600kg/m³ is now widely used as a structural component like slab due to it lighter than the normal concrete. Meantime, it helps in saving cost and reduce the use of formwork. The hollow section that implemented to beam is also an effort to make the structural lighter. Processed Spent Bleaching Earth (PSBE) is an industrial waste which possesses pozzolanic properties like a cement. PSBE used for partially replacing the content of the cement to make it more environmentally friendly. PSBE partially replaced cement up to 30% of the total weight of the cement content. The objective of this study is to analyse the effect of the reinforcement of hollow section on the strength, deflection and mode of failure of the foamed concrete beam. Three specimens prepared to investigate in this study. Specimen 1 can be known as a control beam which acts like a normal beam without a hollow section. Specimen 2 is the beam with a hollow section. Meanwhile, specimen 3 is the beam that added a steel bar around the hollow section to reinforcement the hollow section. The size of the beam was fixed to all specimen with (150 x 200 x 1500) mm. The hollow section that implements to both specimens were in the size of 50x50 mm to the center of the beam. Each specimen was prepared up to 3 unit of samples for testing to get the flexural strength, deflection and mode of failure. Three units of Linear Variable Displacement Transducer (LVDT) were used to measure the deflection of the beam. According to the result, specimen 1 (control beam) had the high strength to resist maximum loading of 31.003kN and flexural strength up to 6.201 N/mm². However, specimen 3 with reinforcement around the deflection can resist more deflection compared to the other specimens. The mode of failure for all the specimens considered as a shear crack as slide cracking pattern found. In short, the hollow section implemented to the beam had affected the strength and deflection of the beam even with added reinforcement around the hollow section. Therefore, it is essential in beam exhibited greater strength and reduce the deflection and cracking.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

%	Percentage
σ	Flexural Strength
δ	Deflection

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
C-H	Calcium Hydroxide
C-S-H	Calcium Silica Hydrate
GHG	Greenhouse Gases
HB	Hollow Beam
IBS	Industrialized Building System
LVDT	Linear Variable Displacement Transducer
NGO	Non-Governmental Organizations
PSBE	Processed Spent Bleaching Earth
RHB	Reinforced Hollow Beam
SB	Solid Beam
SBE	Spent Bleaching Earth

CHAPTER 1

INTRODUCTION

1.1 Background Of Study

In a double storey house construction, there was lots of formwork being used to support the structural element on the upper floors where formwork constituent 60% of the total cost of the construction (Nemati, 2007). It will be the largest waste of the construction where the formwork like wooden formwork can only be used for one to two times. Even nowadays, there was another type of formwork being used in construction, but mostly construction still prefers the use of wooden as formwork in construction. Generally, formwork is used to support the wet concrete to dry out and form to the shape. The heavier the concrete, more material will be used in formwork to support the wet concrete as a mold. Thus, a lightweight structural element can be an excellent way to solve the problem by having a hollow section in the middle and using a light weight foamed concrete. A hollow foamed concrete was a duality way to reduce the weight of concrete elements. As a result, lightweight concrete needs less formwork to support the concrete. However, unreinforced hollow foamed concrete will primarily reduce the strength of the concrete. Thus, reinforcement was introduced to boost the strength of hollow foamed concrete to the original strength or even stronger.

Foamed concrete was a lightweight concrete used construction industry for a light loaded structure like slab and wall. Foamed concrete was a type of concrete with a large amount of foam or air void inside the concrete to reduce the volume of concrete and make the foamed concrete light. Foamed concrete is constituent from cement, foaming agent, sand and water. There was no aggregate used in foamed concrete to enhance its lightweight properties. Furthermore, the foaming agent was the key to produce foam in the concrete and make concrete light. An only a small amount of the foaming agent needed to mix with concrete to produce foam. The density of foamed concrete was around 400 kg/m³ to 1600 kg/m³ whereas foamed concrete with density of 400 kg/m^3 was used for non-loading structure and foamed concrete with density of 1600 kg/m^3 can be used for light loading structure. In this study, since the design based on the beam; thus, the density of foamed concrete chosen for 1600 kg/m^3.

Besides, concrete was indispensable in construction, especially for the high-rise building. However, concrete need cement as an ingredient to mix up with other materials like aggregate and sand. The production of cement contributes lots of Carbon Dioxide (CO_2), which will cause the greenhouse effect and global warming. To make the concrete more environmentally friendly, the use of cement can be partial replace by waste materials. In this study, the waste material used Processed Spent Bleaching Earth (PSBE). It is a refinery waste from the palm oil industry. PSBE was chosen as a replacement of cement due to its pozzolanic properties. Besides, it an excellent way to solve the landfill disposal problems cause by PSBE. By partially replacing cement with PSBE will surely make the concrete doubly friendlier to the environmental.

In short, this study is conducted to determine the effect of reinforcement to the hollow section on the strength of a foamed concrete beam with the flexural strength, deflection and the mode of failure.

1.2 Problem Statement

As mentioned above, heavy concrete needs lots of formwork to support the wet concrete before it dry. Thus, formwork is largely used in the construction to support and mold the wet concrete. According to Kamran (2007), formwork has constituent up to 60% of the total cost of a construction project. It is a way of destructive to our environment. Thus, the lightweight structure is being introduced nowadays to reduce the use of formwork and make the structure environmentally friendly. To achieve the lightweight structure, the hollow section can be implemented towards the structure. However, a hollow structure like a beam will have lower flexural strength compared to a solid beam. According to the previous study of Lee S. A. (2018), the unreinforced hollow beam has a lower flexural strength than the unreinforced solid beam where the crack pattern propagated under single cracking due to no reinforcement. In his study, Lee is using high density, but lightweight foamed concrete with a hollow section to make the structure lighter. On the other hand, replacing cement with waste materials is a method to make the structural more environmentally friendly as the production of cement will release greenhouses gases which is harmful to the environment. Cement industry contributes about 6% of the greenhouse gases like Carbon Dioxide (CO_2) that causes the world global warming (Ali et al., 2015).

1.3 Objectives

The purpose of this study is to analyze the effect of reinforcement of hollow foamed concrete to the strength of foamed concrete beam by partially replacing cement with Processed Spent Bleaching Earth (PSBE). Below are the objectives of the study.

i. To determine the maximum loading of the flexural beam.

ii. To determine the maximum deflection of the flexural beam.

iii. To determine the mode of failure of the flexural beam.

1.4 Scope Of Study

The scope of the study was to analyze the effect of reinforcement of foamed concrete beam which contains a hollow section in the middle. In this study, the cement of reinforced hollow foamed concrete was partially replaced by Processed Spent Bleaching Earth (PSBE) to make the concrete more environmentally friendly. The reinforced hollow foamed concrete was tested using 4 points bending test to analyze the maximum strength, deflection and identify the mode of failure of it. To make the result more accurate, American Society of Testing Materials (ASTM) used as a standard reference for the laboratory testing. The effect of adding rebar as a reinforcement to the hollow foamed concrete beam verified at the end of this study.

1.5 Significance Of Research

As pollution is getting dangerous to the earth, the human is aware of the importance of go green to save the earth. In the construction field, it is assuredly the practice of go green by having strategic like green building, eco-building and even some technology like Industrialized Building System (IBS). Through this study, the impact of reinforced hollow foamed concrete with partially replacing cement with Processed Spent Bleaching Earth (PSBE) will surely benefit the society by producing a more environmentally friendly beam in a building. Production of cement contributes about 6% of greenhouse gases that cause global warming. By partially replacing the cement with the PSBE, it helps to save the environment by using less cement in construction and at the same time, reduce the production of greenhouse gases. Besides, PSBE is a waste of industry. Replacing cement utilizing the waste of industry will help in reducing the landfill disposal problem also. Meanwhile, a beam with a hollow section in the middle is a way to reduce the self-weight of the beam and reduce the use of concrete. As the hollow beam will reduce the strength of the beam, reinforcement added to both the strength of the hollow beam back to the original strength or even stronger. On the other hand, foamed concrete has the same function as a hollow section which helps to reduce the self-weight and the use of concrete. With a lighter beam, less formwork is needed to support the lightweight concrete. It is duality saving the environment by reducing the use of formwork and cement. In short, this study will contribute an environmental lightweight eco-beam to the society in the future.

1.6 Layout Of Thesis

This thesis consists of 4 chapters which mainly discuss the introduction of the reinforced hollow foamed beam with partially replace cement using Processed Spent Bleaching Earth (PSBE), literature review, methodology and expected outcome. Chapter 1 discussed the background of the study, problem statement, the objective of the study, the scope of study, the significance of the study and layout of the thesis. Meanwhile, chapter 2 was discussed the literature review on foamed concrete, the constituent material of foamed concrete, pozzolanic material, hollow beam, reinforcement, compressive strength, bending, and deflection. Chapter 3 was the methodology of study which included research planning, specimen preparation, mix design of foamed concrete, casting, mold and unmolding of the specimen, curing process, and testing method. Chapter 4 was discussed the expected outcome of the study according to the flexural strength, deflection and mode of failure. Lastly, chapter 5 discussed the research finding and issued through the experimental results.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussed on definition, history and application of foamed concrete, the constituent material of foamed concrete, pozzolanic material, hollow beam, reinforcement, compressive strength, bending, and deflection according to the studies that have been done by other research before.

2.2 Foamed Concrete

Foamed concrete is a lightweight concrete where it is a mix of foaming agent, water, sand and cement. There is no coarse aggregate in the foamed concrete as the course will sink at the bottom due to the light weight of foamed concrete. However, but it is replaced by the foaming agent to increase the void in the concrete. Foamed concrete is light in weight and low thermal conductivity, but it has low strength with increased shrinkage with age (Harith, 2018). The dry density of foamed concrete is around 400 – 1600 kg/m^3 and compressive strength at 1 – 25 MPa. Foamed concrete first made in 1923 as an insulating material. It was improved and widely used 20 years later with better superplasticizers of foam agents (Amran, Farzadnia, & Ali, 2015).

2.2.3 Application Of Foamed Concrete

Application of foamed concrete is now popular worldwide. For low density foamed concrete will be used for cavity filling and insulation meanwhile high-density foamed concrete used in a structural application. For example, road sub-base, shock absorber for traffic or airport and soil stabilization (Amran et al., 2015). Besides, low density foamed concrete will be used as an insulation brick and block to the flat roof, which is non-loading elements. For example, low density foamed concrete used as a non-loading wall and roof slab. Foamed concrete will also maintain the acoustical balance of concrete (Shaik Nasima, 2016).

2.3 Constituent Materials Of Foamed Concrete

2.3.1 Cement

Cement can consider a bonding material with cohesive and adhesive properties to stick all the construction materials like gum. It is the essential materials in the mix of concrete, including foamed concrete as well. For foamed concrete, the cement usually used is Ordinary Portland Cement (OPC). Ordinary Portland Cement (OPC) or Normal Portland Cement is a common type of cement used in the construction industry which does not exposure to sulphate in soil or groundwater. Its name, OPC, was given by Joseph Aspdin in the year of 1964 (Haseeb Jamal, 2017).

2.3.2 Sand

Aggregate is one of the essential materials used as in concrete mixture which take up to 70% of the total content of the concrete (Xu et al., 2018). This aggregate can be classified into coarse and fine aggregate. And sand is fine aggregate generally used in concrete mixing. There a various type of sands which can be either natural or man-made by crushing large rock. Different type of sand will have a different type of properties and hence affected the properties of concrete also. Sand will highly affect the compressive strength of the concrete (Binici & Aksogan, 2018).

2.3.3 Water

The use of water in construction of concrete is almost the same as the consumption of water in daily life. However, the water that is potable and can be used in construction is only 2% all around the world. Mostly, the water can be seen and found in oceans, but it cannot be used in construction. Water is the essential materials in concrete mixing as a mandatory of the curing process. It can help in improving the properties of concrete as well as worsening the properties of concrete. Water will affect the properties of concrete like the workability of concrete, strength, durability and setting time. Thus, choosing water with no deleterious chemical substances is very important to measure the concrete in good condition (Reddy Babu, Madhusudana Reddy, & Venkata Ramana, 2018).

2.3.4 Foaming Agent

The foaming agent is part of foamed concrete by increase the void or pore in the concrete. It mainly helps to reduce the density of concrete and a dead load of concrete. Type of foaming agent being selected or used as a concrete mixture; it will significantly affect the properties of foamed concrete as the foam formed by each foaming agents are different. However, foam in foamed concrete may be damaged by drainage, coalescence and disproportionation. Foaming agent that usually is being practiced is synthetic surfactants, plant surfactant and animal glue based surfactants (Sun, Zhu, Guo, Zhang, & Sun, 2018). Besides, the stability of foam will be affected by the concentration of the foaming agent. The optimum concentration is depending on the type of foaming agent used where they are various in particle size. As a result, the lower concentration of treated foaming agent shows an improvement in the properties of foamed concrete by lower the pore size and higher compressive strength achieved. Besides, the foaming agent with low concentration will increase the form stability also (Kuzielová, Pach, & Palou, 2016).

2.4 Effect Of Pozzolanic Material

Pozzolanic material or in another name Pozzolan is a very fine siliceous substance that reacts with Calcium Hydroxide, $Ca(OH)_2$ and water to form C-S-H gel which possesses cement properties. The reaction occurs at a normal temperature. C-S-H gel acts as binding glue-like cement in the concrete mixture. The pozzolanic reaction is shown in equation 2.1.

$$2Ca_3SiO_5 + 7H_2O = 3CaO \bullet 2SiO_2 \bullet 4H_2O + 3Ca(OH)_2 + 173.6kj \qquad (2.1)$$

In the hydration process, a by-product of Calcium Hydroxide, C-H can also be found about 25%. The percentage of by-product will counter the strength of concrete, weaken and shorten the concrete life. Partially replacing cement with pozzolan can help to transform C-H into supplementary C-S-H by allowing the pozzolanic reaction to occur within the hydrated paste. The C-S-H formed help to hold cement properties and make it denser and last longer. C-S-H even can be used to recover cracks and improve soil structures through injection into the healing zone (Saad, Nuruddin, Shafiq, & Ali, 2015).

From the previous research, adding pozzolan in concrete will help concrete to achieve higher performance with a low water-cement ratio (Shaikh & Supit, 2015). Generally, the pozzolanic reaction will have a higher output with large particles. The larger the particle size, the larger the surface area exploded to SiO_2. Large surface area of SiO_2 will reduces the inconsistency of constituents. Therefore, concrete will have higher strength and denser in the later ages (Jones, McCarthy, & Booth, 2006). Pozzolanic reaction is slower than the hydration reaction due to secondary C-S-H gel is produced from the by product of Calcium Hydroxide of hydratthe ion process.

2.5 Processed Spent Bleaching Earth

2.5.1 Spent Bleaching Earth (SBE)

Spent bleaching earth (SBE) is an industrial refining waste product of edible oil industry which is about 2 million tons of SBE is produced yearly all around the world. SBE can produce a high compressive strength monolithic sample by polymerization of the residual organic component in SBE under low-pressure compaction and heat treatment at 150°C. Therefore, SBE is widely used in construction by partially replacing the cement content in the concrete mix. Besides, SBE formed while the treated oil is separate from waste clay from the filter of oil or bleaching earth mix. (Beshara & Cheeseman, 2014). SBE produced from a bleaching process which causes a crucial environmental issue. The disposal of SBE is difficult due to it is expensive on the operating cost and the amount production of SBE is too large (Arpornpong, Charoensaeng, Khaodhiar, & Sabatini, 2018). However, the disposal of SBE can be resolved by removing the oil, filtrated, or coloring materials absorbed on clay. Reuse of SBE is one of the ways to solve the disposal problem and create a more environmentally friendly product at the same time (Eliche-Quesada & Corpas-Iglesias, 2014).

2.5.2 Processed Spent Bleaching Earth (PSBE)

Refining process of edible crude oil including of degumming, bleaching, neutralization and deodorization. In the bleaching process, activated clay or in other words, bleaching earth used. Generally, the bleaching process is the process they produce a large volume of solid waste, which is hard to be disposed into the landfill (Mana, Ouali, de Menorval, Zajac, & Charnay, 2011). The bleaching earth is bentonite-based natural clay of main montmorillonite, which can absorb coloring substances (Loh et al., 2013).

Pozzolan or pozzolanic material is a material which has pozzolanic properties. PSBE behavior pozzolanic properties. Thus, PSBE can be pozzolan used to partially replace the cement for concrete mix. In PSBE, there is 56.9% of Silica Oxide, SiO_2, which reacts with Calcium Hydroxide, $Ca(OH)_2$ and water to produce C-S-H gel through pozzolanic reaction. Meanwhile, cement will react with water and produce Calcium Hydroxide, $Ca(OH)_2$ during the hydration process.

Hydration Process

$$\text{Cement} + H_2O = C - S -H \text{ Gel} + Ca)OH)_2 \tag{2.2}$$

Pozzolanic Reaction

$$SiO_2 + Ca(OH)_2 + H_2) = C - S - H \text{ Gel} \tag{2.3}$$

Calcium Hydroxide, $Ca(OH)_2$ is defenseless to chemical attack and leaching, which may cause the concrete weaker. It is also the most soluble particles in the hydration process. However, Silica in PSBE is reactive which reach with Calcium Hydroxide, $Ca(OH)_2$ and reduce the content of Calcium Hydroxide, $Ca(OH)_2$ (Loh et al., 2013).

Table 0.1 Properties of SBE and PSBE

Characteristics	**SBE**	**PSBE**
Free moisture (%)	10.5	0 – 1.8
pH (20% suspension)	4.6	4.5 – 5.3
Chemical composition (%)		
SiO_2	60.4	56.9
Al_2O_3	11.55	9.24
Fe_2O_3	9.3	8.27
MgO	5.2	4.32
CaO	1.7	3.90
Na_2O	0.4	0.08

K_2O	1.2	0.96
MnO_2	N/A	0.10
TiO_2	N/A	0.90
P_2O_5	N/A	4.87

Source: (Loh et al., 2013)

2.6 Hollow Beam

The hollow beam is a beam with a hollow section which used to reduce the self-weight. Thus, the hollow beam considered as a lightweight beam compared to the normal traditional beam. Hollow beam usually used for a structure with long span like a bridge. Besides, the hollow beam used also for structure, which prior to low cost and lightweight (Namiq, 2012). In previous research, a solid beam resists more load than the hollow beam. Thus, solid beam cracks at higher loading than the hollow beam. Hollow beam failed near to the design load, but solid beam failed much more than the designed load. However, major cracks appear in the solid beam than the hollow beam. Both solid and hollow beam failed in a ductile manner with steel yielding before concrete crack. In short, the hollow beam is suitable when torsion is dominant while the solid beam is suitable when bending is dominant (Alnuaimi, Al-Jabri, & Hago, 2008).

2.7 Reinforcement

Reinforcement in a structural element of construction is the installation of rebar or steel to reinforce the concrete structure to achieve a higher strength of structural. In a construction project, the use of steel as a reinforcement to the concrete structure is in the large proportion which takes up to 26% of the total cost of a construction project (Zheng & Lu, 2016). Concrete structural is good in compression but weak in tension. However, the steel is strong in tension force. By implement the steel in the concrete structure, it will improve the weakness of concrete structure and cause the reinforced concrete structural stronger to withstand high load. In 1990, the yield strength of steel that used was about 300 MPa only. Until 2012, high strength concrete and steel reinforcement just introduced as high strength steel can help to reduce the use of steel in construction and hence largely reduce the cost of the total cost of construction. With high strength steel reinforcement, the cross-sectional area for reinforced concrete design can be reduced and reduce the number of steel to be also used (Yoo & Moon, 2018).

2.8 Compressive Strength

Compressive strength is a mechanical characteristic of a concrete structure. Generally, compressive strength determined from the compression test of concrete specimen (Nakamura, Nanri, Miura, & Roy, 2018). In a concrete building, the column will require higher compressive strength compared to the beam and slab (Choi et al., 2018). Besides, compressive strength will be affected by hydration and compaction also. Compressive strength of concrete can be increased by compacting the concrete well as the friction between the particles will increase after compaction of wet concrete (Chhorn, Hong, & Lee, 2018). The compressive strength of the foamed concrete beam is about 24MPa (Neenu Arjun, 2017).

2.9 Bending

Bending of a beam causes the deflection and change of the shape. While a beam bend, tension stress, compressive stress and shear stress will occur at the same time. Normal stress and shear stress that applied on the cross-section of a beam is the main reason for a beam deformation (Babiak, Gaff, Sikora, & Hysek, 2018).

2.10 Deflection

The flexible beam will generally face a large deflection (Jeong & Yoo, 2017). Long-term deflection can be predicted from the study of creep and shrinkage of concrete. It is essential for the serviceability of concrete structures. Reinforced concrete beam contains ground granulated blast-furnace slag (GGBFS) will have higher deflection (Un, Sanjayan, San Nicolas, & Van Deventer, 2015). Deflection is a slight bending of a beam which subjected to vertical stress and bending moment. Bending of the beam will cause a small vertical displacement in the beam which so-called deflection. Deflection is mainly depending on the depth of a beam. The bigger the depth of a beam, the lesser the deflection occur. However, the maximum deflection occurs at the mid-span of the beam where the bending moment is maximum also (Al-Azzawi, Mahdy, & Farhan, 2010). The deflection of the solid beam is higher than the hollow beam (Aik & Othman, 2018).

2.11 Mode Of Failure

Structural would undergo failure if the design were inadequate. Mode of failure can be observed through the crack pattern of structural failure. There is a different type of failure of the beam that has been found nowadays, which are the flexural failure and shear failure. Flexural failure is the failure of beam due to overloading of stress to the beam. Flexural failure normally occurs at the mid-span of the beam. Flexural failure can be prevented by increasing the concrete strength and main reinforcement. On the other hand, shear failure or sliding failure is due to overloading of shear stress. However, the shear stress is maximum at 45 degrees. Shear failure usually occurs at the end of the beam, where it connects to the column as shear stress is higher at the support. Shear failure can be prevented by adding more shear reinforcement (Al-kamyani, Guadagnini, & Pilakoutas, 2019).

Mode of failure of a structure will be affected by the stain of rebar, the ultimate strength of structure, cracking pattern and strain distribution in the main reinforcement — the failure type determined from the cracking pattern. Meanwhile, the crack pattern observed by the yielding of the reinforcement. On the other hand, the humidity will affect the fracture mode of concrete also as concrete will become brittle in a dry condition. In research of concrete behavior, concrete is transformed from ductile to brittle if humidity during curing is low (Mi, Hu, Li, & An, 2018).

The crack pattern of a beam easily observed while the beam failed due to overloading. The type of failure determined through the criteria of the location of cracking, the orientation of cracking and crushing of concrete. Cracking of beam at the edge will affect the deformation of the beam and the beam cannot back to its original state after deformations. This is due to shear stress near the crack tip (Behzad, Ebrahimi, & Meghdari, 2008). Solid beam and hollow beam shared the same crack pattern (Aik & Othman, 2018).

2.12 Bending Test

Four points bending test is flexural testing used to find the parameter like modulus elasticity, stress and strain of the materials. 4 points bending test produces peak stresses along an extended region of material hence exposing a larger length of the materials. The testing is sensitive to specimen and loading geometry and strain rate. A flexural test produces compression stress in the concave side and tensile stress in the convex side of the material. This creates an area of shear along the midline. Thus, to prevent the primary failure of the material to come from the shear stresses but rather from the tensile or compressions stresses, the distance between the two supporting pins to a height of the sample ratio must be controlled to minimized shear stresses (Sim & Quenneville, 2016).

CHAPTER 3

METHODOLOGY

3.1 Introduction

Chapter 3 discuss the methodology of the study. In this research, various reinforced hollow foamed concrete beam with PSBE as a partial replacement of cement was tested using 4 points bending test to obtain the maximum strength and maximum deflection of the flexural beam. The step of testing from the beginning of the preparation of material, then continuous with specimen preparation, casting, curing process, painting and finally testing of the flexural beam deeply discussed. The testing of the flexural beam by using 4 points bending test was according to the standard of ASTM D6272. The testing was carried out after 28 days of the curing process of the beams. Meanwhile, the materials used in preparing foamed concrete were Ordinary Portland Cement, Processed Spent Bleaching Earth (PSBE), protein foaming agent, silica sand and water.

3.2 Research Planning

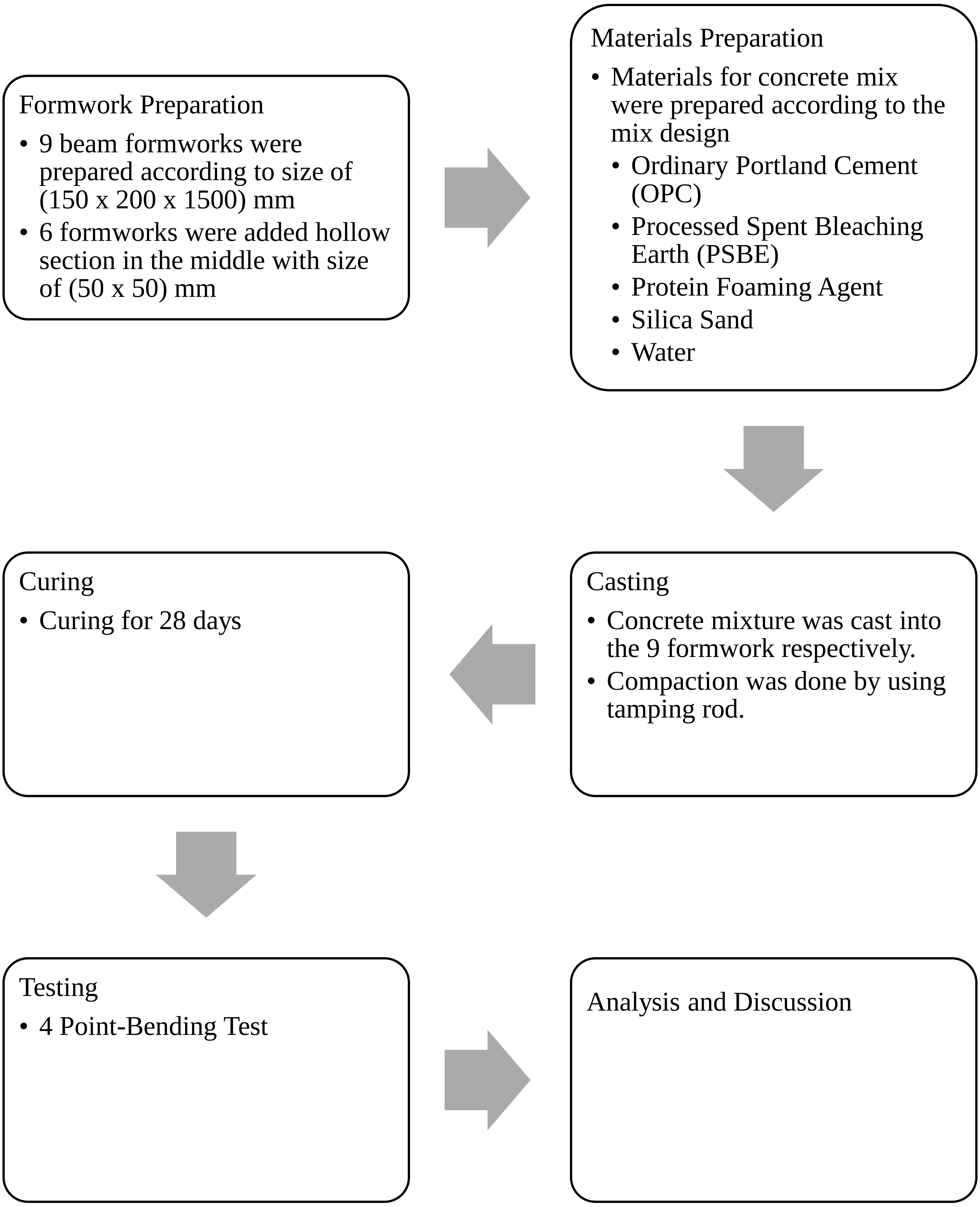

Figure 3.1: Research planning flow.

3.3 Specimen Preparation

The materials used to produce foamed concrete in this study were Ordinary Portland Cement (OPC), Processed Spent Bleaching Earth (PSBE), protein foaming agent, silica sand and water. Processed Spent Bleaching Earth (PSBE) used for partial cement replacement, which up to 30% of the total weight of the cement used. Specimen preparation included formwork preparation, materials preparation, casting, curing, and the painting discussed.

3.3.1 Formwork Preparation

Formwork is the temporary mold used to form the shape of the beam specimen and support the fresh foamed concrete before it hardened. In this study, formworks prepared in the early stage. There were nine beam formworks prepared with a size of 150 x 200 x 1500 mm for the casting of foamed concrete. Among nine beam formworks, there were six formworks added a hollow section in the middle with the size of 50 x 50 mm. All of the formworks made from steel formwork. The making of beam formwork separated into three main parts, which were the base, wall and faces of the beam. Base of the formwork must be strong enough to withstand the weight of foamed concrete, reinforcement and its self-weight. Wall of the formwork act as a wall to hold concrete from flow out and mold the specimen into the designed shape we wanted. Faces or back of the formwork was act like a wall to hold and mold concrete, but it also holds the hollow section in the middle.

Figure 3.2: Formwork of the beams.

3.3.2 Ordinary Portland Cement

In this study, Ordinary Portland Cement (OPC) branded "*Orang Kuat,*" which manufactured by YTL Cement Berhad. "*Orang Kuat*" OPC was certified with MS EN 197-1 and CEM I 42.5N / 52.5N, used for high strength product to achieve greater productivity. Before weight the cement according to the mix proportion designed, the cement was sieve in 300 µm pan to prevent lump during casting.

Figure 3.3: Ordinary Portland Cement (OPC)

3.3.3 Silica Sand

Silica sand act as a fine aggregate for the foamed concrete mixture. It was a common type of fine aggregate used in the construction industry. Silica sand resisted to heat and chemical attack. Thus, it suitable to be used to achieve higher flexural strength and packing density without adversely affecting the chemical properties of the binding system. Silica sand contains silica oxide where the content should more than 98% to suit the condition of fine aggregate used in construction. Meanwhile, the size of the silica sand used in the study was in between 0.001 mm and 0.6 mm.

Figure 3.4: Silica Sand

3.3.4 Protein Foaming Agent

In this study, protein type of foaming agent used in producing foamed concrete. The foam formed, and air trapped by the foaming agent into concrete had no fumes and toxic. Besides, the foaming agent used in this study had no chemical reaction with the cement and hence maintained the properties of foamed concrete. The foam produced with the dosage of 1 liter of a foaming agent to 25 liters of water through dilution.

3.3.5 Processed Spent Bleaching Earth (PSBE)

In this study, Processed Spent Bleaching Earth (PSBE) used as a partial cement replacement in the foamed concrete mix with a portion up to 30% of the total weight of the cement used. PSBE was a pozzolanic material or pozzolan which had a pozzolanic property. It contains 56.9% of silica oxide, SiO_2.

Figure 3.5: Processed Spent Bleaching Earth (PSBE)

3.3.6 Water

In this study, the sources of water used for the foamed concrete mix was from tap water supplied by concrete laboratory University Malaysia Pahang (UMP), Gambang. The tap water was clean, clear and free of impurities, which were suitable for concrete mix. The amount of water needed for the concrete mix was according to the water-cement ratio stated in the design mix table. The water-cement ratio for 1600 kg/m³ density of foamed concrete with 30% of PSEB as partial cement replacement was 0.5.

3.4 Mix Design

In this study, the foamed concrete beam was designed to use as a structural part of a building. Thus, the density of foamed concrete designed to 1600kg/m³. The foamed concrete was constituent of Ordinary Portland Cement (OPC), Processed Spent Bleaching Earth (PSBE), foaming agent, silica sand and water. The cement-sand ratio and water-cement ratio were set to 1.5 and 0.5, respectively. PSBE used for partial cement replacement which constitutes up to 30% of the total weight of the cement. Table 3.1 shows the mix proportion of foamed concrete. FCB represents the standard foamed concrete beam while PFC (30%) represents the foamed concrete beam with added 30% of PSBE as partial cement replacement.

Table 3.1: Mix Proportion of Foamed Concrete.

Mixture	kg/m³	s/c	w/c	Cement	PSBE	Sand	Foam
FCB	1600	1.5	0.5	288.0	-	432	12.96
PFCB (30%)	1600	1.5	0.5	201.6	86.4	432	12.96

3.5 Casting, Moulding & Unmoulding Of Specimens

In this study, the properties of foamed concrete were the same for all the specimens. Only the arrangement of the reinforcement will be the difference. The amount of materials was accordingly to the mix proportion design. Before mixing the materials, the materials were weighted. After that, the materials were mixed into a concrete mixer and poured into formworks. Before casting, the formworks were cleaned and greased to ease the dismantling of formwork. Foamed concrete was cast into three formworks for each type of specimens. The formwork filled with foamed concrete was then compacted using the tamping road. After that, all the specimens were covered with wetted gunny sack to prevent the evaporation of water and maintain the quality of foamed concrete. The formworks were dismantled after 24 hours and continue for the curing process.

Figure 3.6: Mixing foamed concrete materials.

Figure 3.7: Fresh foamed concrete right after mix.

Figure 3.8: Foamed concrete beam.

3.6 Curing Process

In this study, specimens covered with wet wooden gunny bag for seven days of the water curing process and 21 days of the air curing process. This curing help to cure concrete by preventing water evaporating from concrete and prevent shrinkage. It was a process to help concrete gain strength as designed. Curing process of this study was started right after dismantled the formwork of specimens to ensure the quality of concrete. As any delay of the curing process of concrete may cause water to evaporate faster where shrinkage will be had a high possibility to occur and thus affected the desired strength of concrete. The specimens have undergone a total of 28 days of curing process before testing (Zou, Long, Ma, & Xie, 2018).

Figure 3.9: Curing process.

3.7 Painting

In this study, all the specimens were painted into white color to ease the observation of crack pattern.

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Figure 3.10: Beams with white paint.

3.8 Testing Method

All the specimens were undergone four points bending test to obtain the maximum strength, maximum deflection and cracking pattern.

3.8.1 Four-Point Bending Test

In this study, the beams were tested using four points bending test to obtain the data of maximum loading, deflection and crack pattern. Four points bending test was testing that used two points loading applied to the top of the flexural beam and two base supports. Two base supports were placed 150 mm from both ends of the beam. Meanwhile, the loading points set at 200mm from the center of the beam to both sides. During the testing, the beams were being loaded constantly until the beam failed or cracked. The testing was conducted according to the standard of ASTM D6272 which mentioned the standard test method for flexural properties of unreinforced and reinforced plastics and electrical insulating materials by four points bending test. The data was collected and process to analysis. Meanwhile, deflection data of the beam was collected by using Linear Variable Differential Transformer (LVDT). Figure 3.11 shows the setting of four points bending test. Figure 3.12 shows the setup of four points bending test.

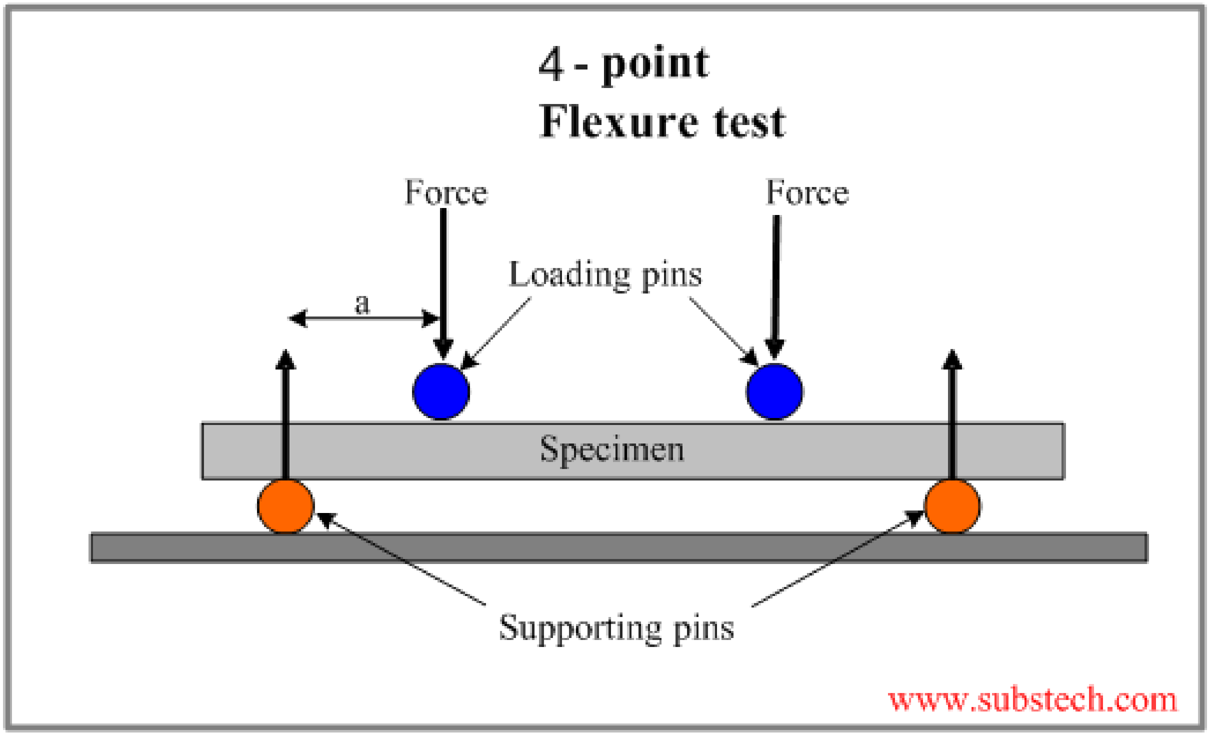


Figure 3.11: Setting of four points bending test.

Figure 3.12: Setup of 4 points bending test.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discussed the result and analysis collected throughout this research. The results obtained and analysis to show the effect of reinforcement to the square hollow section on the strength, deflection and mode of failure of the foamed concrete beam. Three main parameters collected from the experiment, which is the maximum loading, deflection and cracking pattern of the foamed concrete beam. Maximum loading of the foamed concrete beam was obtained from the 4 points bending test. The deflection collected from the linear variable displacement transducer (LVDT) which placed under the beam during the 4 points bending test. Cracking pattern was obtained by analyses the crack pattern while the beam failed to resist more loading. The results and the relationship between the objectives were evaluated and analyzed.

4.2 Flexural Strength

In this research, the flexural strength obtained from the maximum loading of the beam which can get from the 4 points bending test. All the specimens were undergoing the 4 points bending test to get the maximum loading of the foamed concrete beam. The maximum loading data then converted to the flexural strength of the beam through the formula of flexural strength. Relationship between all the specimens analyzed. Specimen 1 was the controlled beam, which also known as a solid beam (SB). Specimen 2 was hollow beam (HB) which had a square hollow section of 50 mm x 50 mm at the middle part of the beam. Specimen 3 was reinforced hollow beam (RHB) with added reinforcement around the hollow part of 50 mm x 50 mm at the middle section of the beam. From the results obtained, the maximum loading for SB, HB and RHB were 31.003 kN, 18.519 kN, and 20.031 kN respectively. The calculations of the flexural strength for all the specimens were shown in the Appendix A. The flexural strength of the SB, HB, and RHB was 6.201 N/mm^2, 3.704 N/mm^2, and 4.006 N/mm^2 respectively. Table 4.1 shows the maximum loading and flexural strength for all the specimens.

Table 4.1: Maximum loading and flexural strength of beams.

Specimen	Maximum Loading (kN)	Flexural Strength (N/mm^2)
SB	31.003	6.201
HB	18.519	3.704
RHB	20.031	4.006

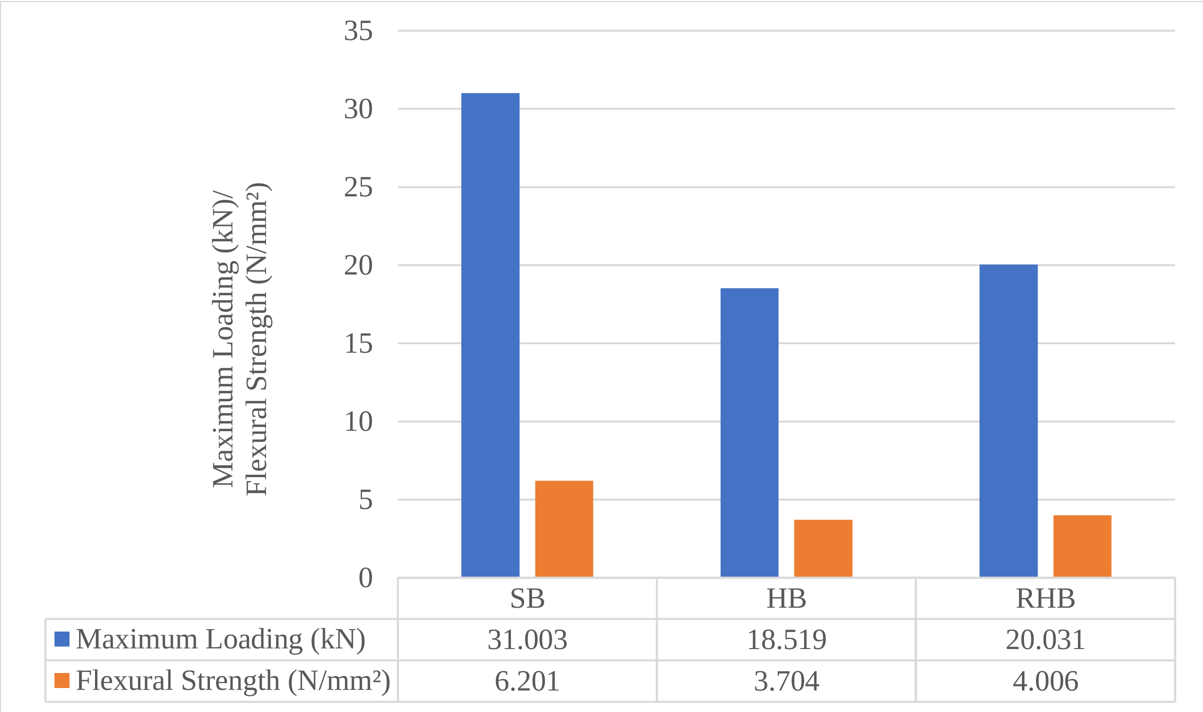


Figure 4.1: Maximum loading and flexural strength of the beams.

Figure 4.1 shows the bar chart used to compare the maximum loading and flexural strength of the beams between each specimen. From the analysis of the result, the percentage of loading and strength lost for HB and RHB were 40.27% and 35.40% respectively. The hollow section in the beams has affected the strength of the beam with lost of 40.27%. Meanwhile, with added reinforcement around the hollow section, it helps the beams to gain back 7.54% of strength. Thus, for RHB with added reinforcement around the hollow section, it only helps to gain a small amount of strength.

The discussion was that the hollow section had affected mainly the strength of the beam (Jabbar et al., 2016) even there was reinforcement added to reinforce the hollow section. However, the reinforcement added around the hollow section had slightly helped the beam to gain some strength. The flexural strength of the solid beam was higher than the hollow beam and reinforced hollow beam. Therefore, solid can resist more loading compared to the hollow beam (Aik & Othman, 2018).

4.3 Deflection

In this research, the deflection of the beam obtained from the displacement of the linear variable displacement transducer (LVDT). There were three LVDT used to place under the beam to get the displacement during testing. The LVDTs labelled as LVDT1, LVDT2 and LVDT3 which were placed 550 mm, 750 mm, and 950 mm respectively from the end of the beam. LVDT2 was placed at the middle of the beam which produces the highest deflection of the beam. The deflection data were analyzed according to the percentage of maximum loading for every 10% of the maximum loading. There were P_{10} (10% of maximum loading), P_{20} (20% of maximum loading), P_{30} (30% of maximum loading), P_{40} (40% of maximum loading), P_{50} (50% of maximum loading), P_{60} (60% of maximum loading), P_{70} (70% of maximum loading), P_{80} (80% of maximum loading), P_{90} (90% of maximum loading), and P_{100} (100% of maximum loading). From the results obtained, the maximum deflection of the SB, HB and RHB were 8.597 mm, 5.131 mm and 14.048 mm respectiv,ely. Table 4.2, table 4.3 and table 4.3 show the summary of the deflection that collected from three LVDT for SB, HB and RHB respectively.

Table 4.2: Deflection data for SB

Loading (kN)		Displacement (mm)		
Maximum Loading = 31.003kN		LVDT1	LVDT2	LVDT3
P_0	0	0	0	0
P_{10}	3.112	0.484	0.476	0.441
P_{20}	6.196	1.109	1.073	0.985
P_{30}	9.281	1.734	1.677	1.518
P_{40}	12.361	2.302	2.232	1.989
P_{50}	15.472	2.701	2.643	2.381
P_{60}	18.606	3.048	3.033	2.745
P_{70}	21.680	3.497	3.579	3.302
P_{80}	24.883	3.965	4.139	3.877
P_{90}	27.930	5.045	5.246	4.901
P_{100}	31.003	8.265	8.597	8.314

Table 4.3: Deflection data for HB

Loading (kN)		Displacement (mm)		
Maximum Loading = 18.519kN		LVDT1	LVDT2	LVDT3
P_0	0	0	0	0
P_{10}	1.874	0.289	0.222	0.293
P_{20}	3.638	0.794	0.909	0.895
P_{30}	5.516	1.173	1.386	1.350
P_{40}	7.458	1.575	1.891	1.806
P_{50}	9.311	2.052	2.392	2.316
P_{60}	11.141	2.474	2.813	2.743
P_{70}	12.965	2.852	3.276	3.190
P_{80}	14.871	3.244	3.798	3.641
P_{90}	16.731	3.787	4.505	4.259
P_{100}	18.519	4.220	5.131	4.811

Table 4.4: Deflection data for RHB

Loading (kN)		Displacement (mm)		
Maximum Loading = 20.031kN		**LVDT1**	**LVDT2**	**LVDT3**
P_0	0	0	0	0
P_{10}	2.073	0.038	0.111	0.279
P_{20}	4.032	0.277	0.327	0.529
P_{30}	6.033	0.489	0.581	0.798
P_{40}	8.049	0.78	0.912	1.153
P_{50}	10.104	1.074	1.282	1.537
P_{60}	12.196	1.379	1.69	1.931
P_{70}	14.035	1.662	2.21	2.312
P_{80}	16.123	2.336	3.247	3.322
P_{90}	18.06	4.928	9.322	7.641
P_{100}	20.031	7.696	14.048	12.449

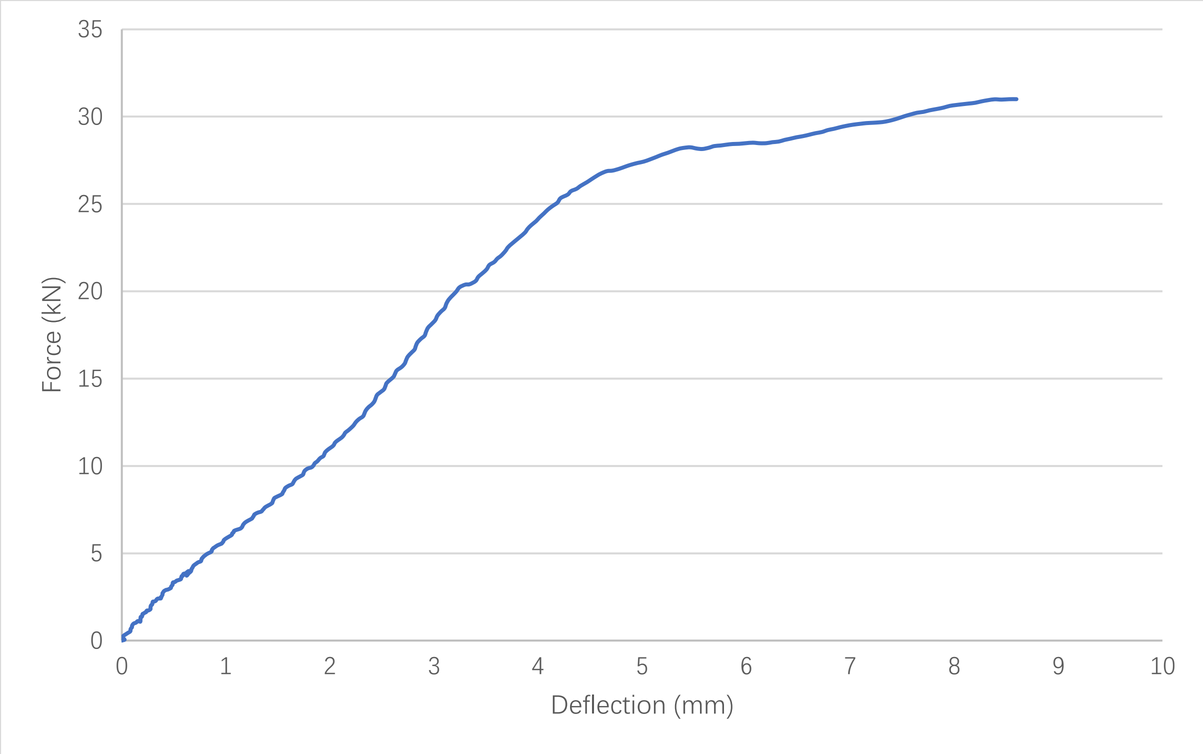


Figure 4.2: Graph of force against deflection for a solid beam.

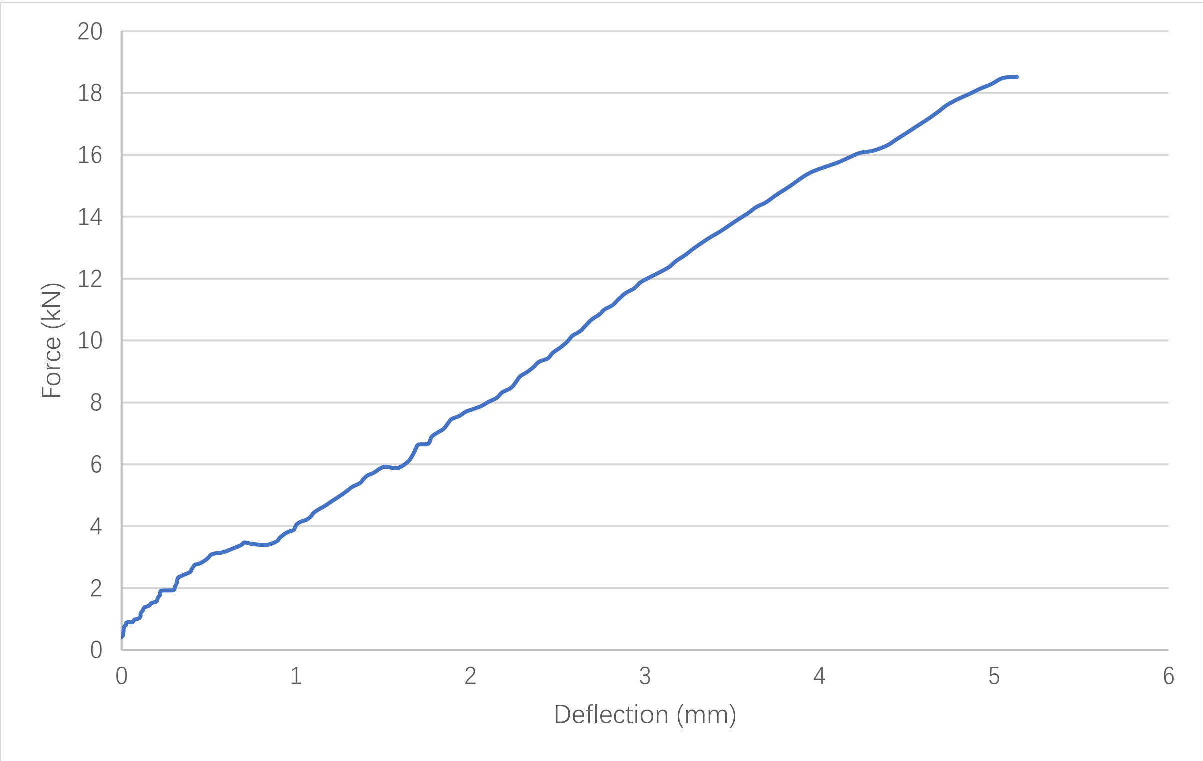


Figure 4.3: Graph of force against deflection for the hollow beam.

Figure 4.4: Graph of force against deflection for a reinforced hollow beam.

Figure 4.2, figure 4.3 and figure 4.3 show the relationship between the force and deflection for solid beam (SB), hollow beam (HB) and reinforced hollow beam (RHB). The maximum deflection of the SB, HB and RHB were 8.597 mm, 5.131 mm and 14.048 mm, respectively. From the analysis, the hollow beam (HB) had the lowest maximum deflection while reinforced hollow beam (RHB) had the highest maximum deflection. Table 4.5 shows the maximum deflection of SB, HB and RHB.

Table 4.5: Summary of deflection.

Specimens	**Maximum Deflection (mm)**
SB	8.597
HB	5.131
RHB	14.048

By comparison between the SB and HB, HB had the lowest maximum deflection than the SB. It was significant that the hollow section affected the deflection of a beam. Beam with hollow section results in lesser deflection value compared to solid beam(Aik & Othman, 2018). Meanwhile, the comparison between HB and RHB shows that RHB had the highest maximum deflection than the HB. It shows the added reinforcement around the hollow section had helped the beam to resist the load and deflect more (Al-kamyani et al., 2019). Besides that, I also found that the beam crack at the mean time of test loading, which means the beam is not crack at the maximum loading. From that, the deflection after the beam crack resisted by the reinforcement. Thus, RHB with added reinforcement around the hollow section had the highest maximum deflection compared to SB and HB. In short, the hollow beam had the lowest strength and lower deflection value than the solid beam (Alnuaimi et al., 2008).

4.4 Crack Pattern

The beams were crack while it reaches the limit to resist the loading. Thus, crack pattern of the beam observed after the loading test. Table 4.6 shows all the specimens having the same cracking pattern.

Table 4.6: Cracking Pattern of Beam

Specimen	Cracking Pattern	Failure Mode
1		Shear crack
2		Shear crack
3		Shear crack

As shown in Table 4.6, the crack pattern for all the specimens shows the same cracking pattern. The crack pattern for all the specimens was the same for the front and back also. It was two slanting cracks from the support to the loading point for both sides. Besides, this crack occurred at the mean time of loading. In other word, the beams do not crack at the maximum loading. It shows that the foamed concrete failed to resist loading in the meantime, but it resisted by the reinforcement after that. This slanting crack was also known as a shear crack, which the beams failed in shear (Autier, Boniol, Severi, & Doré, 2001). There is insufficient shear reinforcement designed to the beam.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter concluded the research finding and the results of the study based on the experimental value. Several recommendations had been provided based on the results and experience throughout this research. The recommendations could help and improve for future study in a structural application.

5.2 Conclusion

This study focused on analyzing the effect of reinforcement to the hollow section on the strength of the foamed concrete beam. The main concept of this study was the reinforcement around the hollow section, which results in improving the strength of the hollow beam. Below show several conclusions had been made through the experimental results.

i. Solid beam (SB) had the highest maximum flexural strength of 6.201 N/mm^2 as compared to hollow beam (HB) and reinforced hollow beam (RHB). Hollow section affects the strength of the beam.

ii. Reinforced hollow beam (RHB) had 4.87% more strength compared to the hollow beam (HB). Reinforcement around the hollow section had only a slight effect to help the hollow beam gain back the strength.

iii. Reinforced hollow beam (RHB) has the highest deflection of 14.048 mm as compared to SB and HB. The deflection of RHB was 38.80% more compared to the solid beam (SB).

iv. All the beams underwent shear cracking as slanting crack found on the beam due to the insufficient design of shear reinforcement.

5.3 Recommendations

i. The depth of the beam can be increased to show the more precise effect of the reinforcement to the hollow section. This is because of the reinforcement around the hollow section is too close to the main reinforcement, which can be considered as primary reinforcement.

ii. The size of the hollow section can be conducted in various depth to find the most suitable depth for constructing the foamed concrete beam.

iii. Compare the result with advance software stimulation to identify the most suitable beam size.

iv. The workmanship should be standardized to ensure the uniformity beam compaction.

REFERENCES

Aik, L. S., & Othman, R. B. (2018). Effect Of Square Hollow Section On The Strength Of Foamed Concrete Beam With Processed Spent Bleaching Earth As Partial Replacement Of Cement.

Al-Azzawi, A., Mahdy, A., & Farhan, O. (2010). Finite element analysis of deep beams on nonlinear elastic foundations. *Journal of the Serbian …*, *4*(2), 13–42. Retrieved from http://www.singipedia.com/attachment.php?attachmentid=2372&d=1306496315

Al-kamyani, Z., Guadagnini, M., & Pilakoutas, K. (2019). Impact of shrinkage on crack width and deflections of reinforced concrete beams with and without steel fibres. *Engineering Structures*, *181*(November 2018), 387–396. https://doi.org/10.1016/j.engstruct.2018.12.031

Ali, N., Jaffar, A., Anwer, M., Alwi, S. K. K., Anjum, M. N., Ali, N., … Ming, X. (2015). The Greenhouse Gas Emissions Produced by Cement Production and Its Impact on Environment A Review of Global Cement Processing. *International Journal of Research*, *2*(2), 488–500. Retrieved from http://edupediapublications.org/journals/index.php/ijr/article/view/1455

Alnuaimi, A. S., Al-Jabri, K. S., & Hago, A. (2008). Comparison between solid and hollow reinforced concrete beams. *Materials and Structures/Materiaux et Constructions*, *41*(2), 269–286. https://doi.org/10.1617/s11527-007-9237-x

Amran, Y. H. M., Farzadnia, N., & Ali, A. A. A. (2015). Properties and applications of foamed concrete; A review. *Construction and Building Materials*, *101*, 990–1005. https://doi.org/10.1016/j.conbuildmat.2015.10.112

Arpornpong, N., Charoensaeng, A., Khaodhiar, S., & Sabatini, D. A. (2018). Formulation of microemulsion-based washing agent for oil recovery from spent bleaching earth-hydrophilic lipophilic deviation concept. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *541*(October 2017), 87–96. https://doi.org/10.1016/j.colsurfa.2018.01.026

Autier, P., Boniol, M., Severi, G., & Doré, J. F. (2001). Effect of initial blast response on RC beams failure mode. *British Journal of Dermatology*, *144*(2), 288–291. https://doi.org/10.1016/j.nucengdes.2017.06.019

Babiak, M., Gaff, M., Sikora, A., & Hysek, Š. (2018). Modulus of elasticity in three- and four-point bending of wood. *Composite Structures*, *204*(July), 454–465.

https://doi.org/10.1016/j.compstruct.2018.07.113

Behzad, M., Ebrahimi, A., & Meghdari, A. (2008). A new continuous model for flexural vibration analysis of a cracked beam. *Polish Maritime Research*, *15*(2), 32–39. https://doi.org/10.2478/v10012-007-0062-5

Beshara, A., & Cheeseman, C. R. (2014). Reuse of spent bleaching earth by polymerisation of residual organics. *Waste Management*, *34*(10), 1770–1774. https://doi.org/10.1016/j.wasman.2014.04.021

Binici, H., & Aksogan, O. (2018). Durability of concrete made with natural granular granite, silica sand and powders of waste marble and basalt as fine aggregate. *Journal of Building Engineering*, *19*(August 2017), 109–121. https://doi.org/10.1016/j.jobe.2018.04.022

Chhorn, C., Hong, S. J., & Lee, S. W. (2018). Relationship between compressive and tensile strengths of roller-compacted concrete. *Journal of Traffic and Transportation Engineering (English Edition)*, *5*(3), 215–223. https://doi.org/10.1016/j.jtte.2017.09.002

Choi, S. H., Lee, D. H., Hwang, J. H., Oh, J. Y., Kim, K. S., & Kim, S. H. (2018). Effective compressive strengths of corner and exterior concrete columns intersected by slabs with different compressive strengths. *Archives of Civil and Mechanical Engineering*, *18*(3), 731–741. https://doi.org/10.1016/j.acme.2017.11.001

Eliche-Quesada, D., & Corpas-Iglesias, F. A. (2014). Utilisation of spent filtration earth or spent bleaching earth from the oil refinery industry in clay products. *Ceramics International*, *40*(PB), 16677–16687. https://doi.org/10.1016/j.ceramint.2014.08.030

Harith, I. K. (2018). Study on polyurethane foamed concrete for use in structural applications. *Case Studies in Construction Materials*, *8*(September 2017), 79–86. https://doi.org/10.1016/j.cscm.2017.11.005

Haseeb Jamal. (2017). Ordinary Portland Cement - Tests, Properties, Manufacture & Uses. Retrieved November 20, 2018, from https://www.aboutcivil.org/ordinary-portland-cement.html

Jabbar, S., Hejazi, F., Mahmod, H. M., Jabbar, S., Hejazi, F., & Mahmod, H. M. (2016). Effect of an Opening on Reinforced Concrete Hollow Beam Web Under Torsional, Flexural, and Cyclic Loadings. *Latin American Journal of Solids and Structures*, *13*(8), 1576–1595. https://doi.org/10.1590/1679-782512629

Jeong, S., & Yoo, H. H. (2017). Flexibility modeling of a beam undergoing large deflection using the assumed mode method. *International Journal of Mechanical Sciences*, *133*(August), 611–618. https://doi.org/10.1016/j.ijmecsci.2017.08.059

Jones, M. R., McCarthy, A., & Booth, A. P. P. G. (2006). Characteristics of the ultrafine component of fly ash. *Fuel*, *85*(16 SPEC. ISS.), 2250–2259. https://doi.org/10.1016/j.fuel.2006.01.028

Kuzielová, E., Pach, L., & Palou, M. (2016). Effect of activated foaming agent on the foam concrete properties. *Construction and Building Materials*, *125*, 998–1004. https://doi.org/10.1016/j.conbuildmat.2016.08.122

Loh, S. K., James, S., Ngatiman, M., Cheong, K. Y., Choo, Y. M., & Lim, W. S. (2013). Enhancement of palm oil refinery waste – Spent bleaching earth (SBE) into bio organic fertilizer and their effects on crop biomass growth. *Industrial Crops and Products*, *49*, 775–781. https://doi.org/10.1016/J.INDCROP.2013.06.016

Mana, M., Ouali, M. S., de Menorval, L. C., Zajac, J. J., & Charnay, C. (2011). Regeneration of spent bleaching earth by treatment with cethyltrimethylammonium bromide for application in elimination of acid dye. *Chemical Engineering Journal*, *174*(1), 275–280. https://doi.org/10.1016/j.cej.2011.09.026

Mi, Z., Hu, Y., Li, Q., & An, Z. (2018). Effect of curing humidity on the fracture properties of concrete. *Construction and Building Materials*, *169*, 403–413. https://doi.org/10.1016/j.conbuildmat.2018.03.025

Nakamura, H., Nanri, T., Miura, T., & Roy, S. (2018). Experimental investigation of compressive strength and compressive fracture energy of longitudinally cracked concrete. *Cement and Concrete Composites*, *93*(June), 1–18. https://doi.org/10.1016/j.cemconcomp.2018.06.015

Namiq, Z. F. (2012). Design of Beam As a Hollow Cross Section By Using Steel Fiber Under, (February).

Neenu Arjun. (2017). Foam Concrete -Materials, Properties, Advantages and Production. Retrieved November 20, 2018, from https://theconstructor.org/concrete/foam-concrete-materials-properties-advantages-production/15921/

Nemati, K. M. (2007). *DEPARTMENT OF Construction Management CM 420 TEMPORARY STRUCTURES Formwork for Concrete*. Retrieved from http://courses.washington.edu/cm420/Lesson1.pdf

Reddy Babu, G., Madhusudana Reddy, B., & Venkata Ramana, N. (2018). Quality of mixing water in cement concrete "a review. *Materials Today: Proceedings*, *5*(1), 1313–1320. https://doi.org/10.1016/j.matpr.2017.11.216

Saad, S. A., Nuruddin, M. F., Shafiq, N., & Ali, M. (2015). Pozzolanic Reaction Mechanism of

Rice Husk Ash in Concrete – A Review. *Applied Mechanics and Materials*, *773–774*, 1143–1147. https://doi.org/10.4028/www.scientific.net/AMM.773-774.1143

Shaik Nasima. (2016). Cellular Lightweight Concrete Materials, Applications and Advantages. Retrieved November 20, 2018, from https://www.linkedin.com/pulse/cellular-lightweight-concrete-materials-applications-shaik-nasima

Shaikh, F. U. A., & Supit, S. W. M. (2015). Compressive strength and durability properties of high volume fly ash (HVFA) concretes containing ultrafine fly ash (UFFA). *Construction and Building Materials*, *82*, 192–205. https://doi.org/10.1016/j.conbuildmat.2015.02.068

Sim, S., & Quenneville, E. (2016). Mach-1 – 3-point or 4-point Bending Test, 9.

Sun, C., Zhu, Y., Guo, J., Zhang, Y., & Sun, G. (2018). Effects of foaming agent type on the workability, drying shrinkage, frost resistance and pore distribution of foamed concrete. *Construction and Building Materials*, *186*, 833–839. https://doi.org/10.1016/j.conbuildmat.2018.08.019

Un, C. H., Sanjayan, J. G., San Nicolas, R., & Van Deventer, J. S. J. (2015). Predictions of long-term deflection of geopolymer concrete beams. *Construction and Building Materials*, *94*, 10–19. https://doi.org/10.1016/j.conbuildmat.2015.06.030

Xu, W., Wen, X., Wei, J., Xu, P., Zhang, B., Yu, Q., & Ma, H. (2018). Feasibility of kaolin tailing sand to be as an environmentally friendly alternative to river sand in construction applications. *Journal of Cleaner Production*, *205*, 1114–1126. https://doi.org/10.1016/j.jclepro.2018.09.119

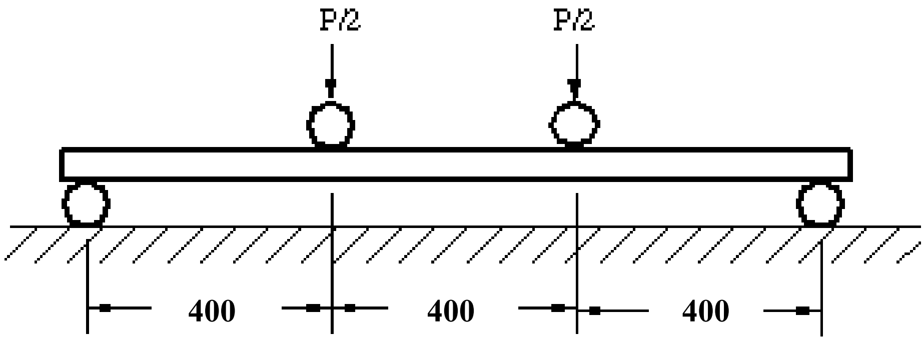
Yoo, D. Y., & Moon, D. Y. (2018). Effect of steel fibers on the flexural behavior of RC beams with very low reinforcement ratios. *Construction and Building Materials*, *188*, 237–254. https://doi.org/10.1016/j.conbuildmat.2018.08.099

Zheng, C., & Lu, M. (2016). Optimized Reinforcement Detailing Design for Sustainable Construction: Slab Case Study. *Procedia Engineering*, *145*, 1478–1485. https://doi.org/10.1016/j.proeng.2016.04.186

Zou, C., Long, G., Ma, C., & Xie, Y. (2018). Effect of subsequent curing on surface permeability and compressive strength of steam-cured concrete. *Construction and Building Materials*, *188*, 424–432. https://doi.org/10.1016/j.conbuildmat.2018.08.076

APPENDIX A

CALCULATION (FLEXURAL STRENGTH)



$$\sigma = \frac{FL}{bd^2}$$

Beam SB, σ $= \dfrac{(31.003x10^3)(1200)}{150(200)^2}$

$= 6.201\ N/mm^2$

Beam HB, σ $= \dfrac{(18.519x10^3)(1200)}{150(200)^2}$

$= 3.704\ N/mm^2$

Beam RHB, σ $= \dfrac{(20.031x10^3)(1200)}{150(200)^2}$

$= 4.006\ N/mm^2$