EFFECT OF SQUARE HOLLOW SECTION ON THE STRENGTH OF FOAMED CONCRETE BEAM WITH PROCESSED SPENT BLEACHING EARTH AS PARTIAL REPLACEMENT OF CEMENT

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ABSTRAK

Rasuk berongga diperkenalkan untuk mengurangkan kos projek pembinaan serta penggunaan bahan dan formwork. Processed Spent Bleaching Earth (PSBE) adalah SBE yang telah dirawat dan boleh digunakan sebagai pengganti sebahagian untuk simen dalam konkrit berbuih disebabkan oleh kesan pozzolanicnya. Kepekatan konkrit berbuih direka untuk mendapatkan ketumpatan 1600 kg/m³. Objektif kajian ini adalah untuk menentukan beban maksimum rasuk lenturan, pesongan rasuk lenturan dan mod kegagalan rasuk lenturan dengan menggunakan lenturan ujian empat titik. Empat jenis balok telah disediakan iaitu balok FC dikawal sebagai balok pepejal (Beam 1) tanpa bahagian berongga, balok berongga (Beam 2) dengan saiz pembukaan (50mm x 50mm), balok berongga (Beam 3) dengan saiz pembukaan (60mm x 60mm), dan rasuk berongga (Beam 4) dengan saiz pembukaan (70mm x 70mm). Kesemua rasuk itu dipancarkan dengan 30% PSBE sebagai pengganti simen separa. Setiap jenis rasuk disediakan untuk 3 unit rasuk (150mm x 200mm x 1500mm) untuk mencari nilai purata beban maksimum dan pesongan. 4 unit Linear Variable Displacement Transducer (LVDT) digunakan untuk mengukur pesongan rasuk. Corak retak bagi rasuk diperhatikan sepanjang eksperimen dan retak kemudian dianalisis dengan sewajarnya. Dari hasil ujikaji, antara saiz bahagian berongga, Beam 2 menghasilkan beban maksimum yang lebih tinggi dengan 3.94 kN, kekuatan lenturan dengan 0.79 N/mm^2 dan pesongan dengan 0.30mm. Hasil kajian menunjukkan kekuatan lenturan rasuk menurun ke tahap tertentu sebanyak 12.7%, 37.3%, dan 51.1% bagi Beam 2, Beam 3, dan Beam 4. Selain itu, hasil untuk pesongan menunjukkan bahawa Beam 2, Beam 3, dan Beam 4 dibelokkan kurang berbanding Beam 1 dengan penurunan masing-masing 9.09%, 17.27% dan 25.76%. Kekuatan lenturan rasuk bergantung kepada momen inersia kedua manakala momen inersia kedua bergantung pada kawasan permukaan balok. Beban maksimum balok dengan bahagian berongga berkurang disebabkan oleh dimensi yang semakin meningkat pada bahagian berongga. Oleh sebab rasuk tidak diperkuat, rasuk-rasuk gagal tanpa sebarang keretakan kecil. Retakan menegak dipanggil retak utama. Oleh itu, kekuatan lenturan dan pesongan seksyen berongga segi empat semakin berkurangan apabila saiz rongga semakin meningkat.

ABSTRACT

Hollow beam is introduced to reduce the cost of the construction project by reducing the use of materials and formworks. Processed Spent Bleaching Earth (PSBE) is the SBE that has been treated and can be used as a partial replacement for cement in the foamed concrete due to its pozzolanic effect. Density of foamed concrete was designed to get 1600 kg/m³ density. The objective of the study is to determine the maximum load of the flexural beam, the deflection of the flexural beam, and the mode of failure of the flexural beam by using 4 point bending test. Four types of beams were prepared which namely controlled FC beam as known as solid beam (Beam 1) without the hollow section, hollow beam (Beam 2) with the opening size of (50mm x 50mm), hollow beam (Beam 3) with the opening size of (60mm x 60mm), and hollow beam (Beam 4) with the opening size of (70mm x 70mm). All the beams were casted with 30% of PSBE as a partial cement replacement. Each type of the beams were prepared for 3 units of beams (150mm x 200mm x 1500mm) to find the average value of maximum load and deflection. The 4 units of Linear Variable Displacement Transducer (LVDT) were used to measure the deflection of the beams. The crack pattern of beams were observed throughout the experiment and the cracking were then analysed accordingly. From the experimental result, in most of the size of hollow section, Beam 2 produced greater maximum load with 3.94 kN, flexural strength with 0.79 N/mm^2 and deflection with 0.30mm. The result showed that the flexural strength of the beams decreased to certain degree of percentage of 12.7%, 37.3% and 51.1% for Beam 2, Beam 3 and Beam 4 respectively. Also, result for deflection showed that Beam 2, Beam 3 and Beam 4 deflected less compared to Beam 1 with decrement of 9.09%, 17.27%, and 25.76% respectively. The flexural strength of the beams depends on the second moment of inertia while second moment of inertia depends on the surface area of the beams. The maximum loading of beam with hollow section decreased due to the increasing dimension of hollow section. Since the beams were un-reinforced, therefore, they failed without any appearance of tiny crack. The vertical crack was called ultimate crack. Hence, the flexural strength and deflection of square hollow section decreased as the size of hollow increased.

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%	Percentage
σ	Flexural Strength
δ	Deflection

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
C-H	Calcium Hydroxide
CIDB	Construction Industry Development Board
C-S-H	Calcium Silica Hydrate
GHG	Greenhouse Gases
IBS	Industrialised Building System
LVDT	linear variable displacement transducer
NGOs	Non-Governmental Organizations
PSBE	Processed Spent Bleaching Earth
SBE	Spent Bleaching Earth

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Over the past several decades, Malaysia is still unfamiliar with the usage of Industrialised Building System (IBS) although it is implemented in early 1960's. The practise of IBS has been widely promoted by Construction Industry Development Board (CIDB) in Malaysia Construction Industry since 1998. It is widely used when Cabinet of Ministers endorsed IBS Strategic Plan as the blueprint for the total industrialisation of the construction sector. The objectives of using IBS is to slowly decrease the usage of foreign labours, improve quality of project and increase productivity (Mohamad, Zawawi, & Nekooie, 2009). IBS also simplified construction work by reducing the time and as well reducing the cost of the construction.

For the construction of first floor beam, hollow beam is introduced to reduce the cost of the construction project by reducing the use of formwork when casting the secondary beam. As the hollow beam with reduced weight can be supported by lesser formwork during the process, lesser formwork is required to support the structure until the end of curing system. On the other hand, improper supervision and control of formwork systems can possibly affect the construction schedule and consequently impact the total cost of construction (Mansuri et al., 2017). Lightweight foamed concrete has a lot of advantages. Besides it is easily made, it is also lightweight which is easy to handle and also lightweight foamed concrete is a good heat insulator (Jones & McCarthy, 2005).

The idea of making hollow beam is the same as the introduction of concrete hollow-core panels which widely used for parking structures, bridges and concrete buildings (Baran, 2015). By referring to the law of second moment of inertia, there is an effect on the shear resistance and bending moment of beam when the surface area is reduced. Hence, this study is to investigate the effect of square hollow section on the strength of foamed concrete beam with processed spent bleaching earth as a partial replacement of cement.

1.2 Problem Statement

Cement is the basic element in construction field. Cement binds concrete particles tightly. Cement is mass-produced for construction purposes. Cement industry is also an energy intensive industry which contributes for greenhouse gases (GHG), CO_2, and other gases emission, NO_x and SO_x. About 6-8% of carbon production is responsible to cement industry and around 12-15% of total industrial energy consumed by cement industry (Ali, Saidur, & Hossain, 2011).

Spent bleaching earth (SBE) is a waste material which is derived from the refining process of crude edible oil. The past reports showed that Malaysia palm oil mills produce a significant sum of SBE yearly as a by-product of manufacturing process (Tan, Ahmad, & Hameed, 2009). Due to the huge amount produced each year, SBE is hard to manage because of the lack of technique to recover it (Krzyśko-Łupicka et al., 2014).

Formwork is actually cost a lot in a construction project. Formwork can possibly account for as much as 15% of the total construction cost and 33% of the cost of the concrete structure (Ko, Wang, & Kuo, 2011). The reduction of beam weight can definitely decrease the use of formwork to save the overall cost of the project.

1.3 Objectives

The purpose of this study is to investigate the effect of square hollow section on the strength of foamed concrete beam with processed spent bleaching earth as a partial replacement of cement and the objectives are shown as below:

i. To determine the maximum load of the flexural beam by using four point bending test.

ii. To determine the deflection of the flexural beam.

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

1.4 Scope of Study

In this study, the experiments were conducted in small scale laboratory test basis. American Society of Testing Material (ASTM) was used as reference standards for the laboratory tests involved in this study. To obtain the maximum load, deflection and mode of failure of the solid beam and hollow beam, four point bending test was conducted. Through this study, we worked on determining the maximum load, deflection and mode of failure of the flexural beam by using four point bending test. All the solid beam and hollow beam were tested to compare the maximum load that applied on the beams. The deflection of beams were determined and the mode of failure were identified. Therefore, in the end of this study, the feasibility of using hollow beam in reducing the cost and formwork used were verified.

1.5 Significance of Study

Government and NGOs are generally promote the implementation of sustainability issue in construction field and the construction industry is working hard to exercise it in their projects. By following the concept, both the social responsibility and economic growth were satisfied by construction industry to protect the environment. To adopt the usage of construction wastes in other construction activities, which will not only reduce the weight of beam, but also reduce the cost of construction by reducing the use of formwork, it will also reduce the waste disposal rate to landfills significantly, and it can be interpreted as an effort in preserving the environment. Recycling construction waste materials to be used in construction activities will also minimize the exploitation of the natural resources. As every construction uses secondary beam, lightweight hollow beam were the highly recommended beam to be widely used in Malaysia. It is very crucial to identify the effect of square hollow section on the strength of foamed concrete beam with processed spent bleaching earth as partial replacement of cement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The beam behaviour varies with the presence of opening. This chapter discussed the history, application, constituents of materials, properties of foamed concrete, and size of the opening. These factors are referred to the studies that have been done before.

2.2 Foamed Concrete

Foamed concrete with a minimum of 20% of mechanically entrained foam in the mortar is defined as a lightweight material. Foamed concrete consists of sand, cement, water and voids. The voids are usually introduced into the concrete by separately adding the foaming agent to the water at the required mix ratio in a foam generator to produce manufactured foam. This foam is then inserted into the cement slurry and allowed to blend and mix well to produce a foamed slurry. Foamed concrete was first patented in 1924, which that time mainly for use as an insulation material. Foamed concrete was not familiar until the late 1970s, when it began to be used in the Netherlands for filling voids and for ground engineering applications (Coker et al., 2016). In history, the Romans first realized that through adding animal blood into a mixture of coarse sand and small gravel with hot lime and water and stir it, small air bubbles were formed making the mix more workable and durable. However, the first Portland cement based foamed concrete was patented in 1923 by Axel Eriksson. Over the past 20 years, extensive enhancements in production equipment and better superplasticizers, foam agents have allowed the practice of foamed concrete in a larger scale and many efforts have been made to study the characteristics and behaviour of foamed concrete comprehensively in order to simplify its usage in structural applications (Alex & Tiwari, 2015).

2.2.1 Application of Foamed Concrete

Foamed concrete can be used in many application:

- Lightweight blocks or bricks for high-rise building.
- All types of insulation works, including cavity wall.
- Ceiling and roofing panels.
- Cast in-situ for low cost houses.
- Foundations for roads and sidewalks.
- Infill sections between beams of suspended floors.
- Sub-surface for sport arenas. For example, tennis court.
- Explosion-resistant structure.
- Highway sound barriers.
- Pre-cast or cast in-situ exterior wall facades for all sizes of building.
- Floating barge, jetties, floating homes, and slope protection.

2.3 Constituent Materials of Foamed Concrete

2.3.1 Cement

Cement is the most dominant binder in foamed concrete. The types of cement used in the foamed concrete are namely ordinary Portland cement, rapid hardening Portland cement, calcium sulfoaluminate cement, and high alumina cement, which can be used in ranges between 25% and 100% of the binder content. Portland cement in accordance with Malaysia national standard MS EN 197-1, Ordinary Portland Cement, was selected as the binding material for the preparation of foamed concrete beam instead of some rapid hardening or fast setting special cement, such as sulfoaluminate cement, on account of its reliable long term durability and low cost and its easy availability (Pan, Li, & Liu, 2014). However, other supplementary materials such as silica fume, fly ash, lime, incinerator bottom ash and Lytag can also be replaced with a percentage of cement ranging between 10% and 75%. The supplementary materials are used to improve mix design consistency, long term strength and to reduce costs. Each supplementary material may contribute to properties of foamed concrete in different fashions. For instance, the purpose of using silica fume is to strengthen the foamed concrete in a short time due to their filler characteristics and pozzolanic behaviour, while fly ash needs a longer time to reach the maximum strength comparing to cement (Kearsley & Wainwright, 2001). Therefore, the supplementary materials should be used as partial replacements according to desirable foamed concrete properties.

2.3.2 Sand

Strength of concrete can be controlled by sand to cement ratio. The amount of sand decreases will decrease the usage of cement. However, lower hydration process rate in lesser cement content concrete to normal concrete. Hence, the addition of waste material that can perform pozzolanic reaction and provide secondary C-S-H gel to concrete may cause the hydration process in normal rate. Natural sands have variety of mineralogical compositions and chemical characteristics. Different sand may give different strength of concrete (Hasdemir, Tuğrul, & Yilmaz, 2016).

2.3.3 Water

Water is an important factor in the production of foamed concrete as water affects the stability, firmness, constancy, solidity and strength of foamed concrete. When the water cement ratio is low, the bubbles in the mix will break because of the firm mix, on the other hand the bubbles will not hold together with the mix as the mix is too slurry, this may cause the mix to segregate (Nambiar & Ramamurthy, 2006). Water cement ratio used for foamed concrete should be in the range from 0.4 to 1.25 which is about 6.5% to 14% of the desired mix density. Yet, the optimum water cement ratio is 0.5 and 0.6. Besides, the quality of water is also an important factor in the making of foamed concrete. The water used for the mix design should be fresh, unsoiled and fit to drink as undrinkable water results in 90% of strength gains at 7-28 days compared to the strength of foamed concrete using drinkable water (Amran, Farzadnia, & Ali, 2015).

2.3.4 Foaming Agent

The air voids should be in the range between 6% and 35% of the total volume of concrete mix (Panesar, 2013). Density of foamed concrete is mainly depending on the foaming agent by creating the air bubbles in the mix where the bubbles are named as enclosed air-voids. Foaming agents are available in many types, namely, resin soap, glue resins, synthetics, detergents, hydrolysed protein, protein-based and saponin. Each of the types has their own advantages and benefits. Synthetic and protein-based are widely industrialised foaming agents. Protein-based foaming agent produces tougher and extra closed-cell bubble structure which enables more air capture and results in a more stable air void network compared to synthetic which has greater expansion but reduce the density of foamed concrete (Tikalsky, Pospisil, & MacDonald, 2004). There are two methods to produce foamed concrete which are pre-foaming method and mixed foaming method. In pre-foaming method, the firm preformed aqueous foam is produced separately and then blend the foam into the base mix thoroughly. Mixed foaming method mix the surface active agent together with the base mix in the mixing process, then foam is formed causing the cellular structure in concrete (Mohammed & Hamad, 2014). A strong and stable foam can withstand the mortar pressure and hence enable the cement to takes its early set. To produce a wet form, foaming agent is sprayed over a fine mash, 2-5 mm less firm bubble is then formed. A series of great concentration control and air compression are forced concurrently into mixing chamber to produce dry foam. The form produced is relatively stable and is smaller in size which less than 1mm which enables the easier blending process with the base mix. The concentration of foaming agent, compressed air pressure, density, forming process, and the adding and blending process may affect the foam quality. Foam quality signifies the stability of foamed concrete and affects the strength and toughness of the foamed concrete produced (Nambiar & Ramamurthy, 2006).

2.4 Effect of Pozzolanic Material

Pozzolan is a very fine siliceous or alumina-siliceous substance that can chemically reacts at regular temperature with calcium hydroxide in the presence of water to form products possessing cementing properties. The products that possessing cementing properties are secondary Calcium Silica Hydrate (C-S-H) gel which act as the binding glue of concrete. The pozzolanic reaction can be expressed as Equation 2.1:

$$2Ca_3SiO_5 + 7H_2O \rightarrow 3CaO \,.\, 2SiO_2 \,.\, 4H_2O + 3Ca(OH)_2 + 173.6\ Kj \qquad 2.1$$

Calcium Hydroxide (C-H) by products also can be found in the hydration process which is only about 25%. This percentage considered as no contribution to the cement solidity and strength but aggressively counter to the strength. The porosity induced by the C-H results in weaker and shorter life concrete. By replacing some Portland cement with the pozzolan enables the pozzolanic reaction to occur within the hydrated paste and finally transforming the bothersome C-H into supplementary C-S-H. The final C-S-H can densifies and toughens the concrete, holding the cement particles so that it becomes denser and last longer. C-S-H are also used to recover cracks and improve soil structures by injecting it into the healing zone (Saad et al., 2015).

From the past researcher, concrete can be more effective in lower water cement ratio by adding pozzolan (Shaikh & Supit, 2015). Generally, larger surface area of particles enable the higher rate of pozzolanic activities. Pozzolanic reaction is highly affected by the particle sizes. The particle size of pozzolan increases the surface area of SiO_2 and reduces the inconsistency of constituents (Jones, McCarthy, & Booth, 2006). Pozzolanic reaction is a slow reaction compared the hydration process because the secondary C-S-H gel is produced from the by-products of hydration process. This results in the concrete with higher ultimate strength and denser in the later ages of concrete.

Waste materials like fly ash, silica fume, rice husk ash, and palm oil fuel have been magnificently used in construction industry for decades (Hesami et al., 2016). Pozzolanic material can solve landfill problems, reduction in construction cost, and environmental friendly as the cement production consumes approximately 12-15% of total industrial energy used. Cement production can be said as the third industry that use the most energy. Besides, cement industry contributes the 7% of global CO_2 emissions (Zhang, Han, Yu, & Wei, 2018).

2.5 Processed Spent Bleaching Earth

Spent Bleaching Earth (SBE) is a by-product of edible palm oil which is suitable as partial cement replacement in foamed concrete. SBE can be further processed by using solvent extraction of residual oil from bleaching method to produce Processed Spent

Bleaching Earth (PSBE) which is in fine solid form and is fit to be used in the strengthen foamed concrete production.

2.5.1 Spent Bleaching Earth (SBE)

SBE is the remaining adsorbent in the crude palm oil filtering process in the cooking oil industry and it is the solid waste of the industry. Unwanted SBE has become the main concern of cooking oil industry as a significance of its increment. Additionally, approximately 0.5-1% of bleaching earth is spent in the production of 60 million tonne of cooking oil which all the BE in the end will become SBE waste. The global contribution of SBE waste is around 2,000,000 tonne per year (Beshara & Cheeseman, 2014).

In Malaysia, SBE waste is being disposed to landfills that have the possibilities to become the source of hazards, pollution, fire, and green-house gas emissions. Malaysia produced 240,000 tonne yearly of SBE waste (Loh, Cheong, & Salimon, 2017). Accordingly, not less than 600,000 tonne of SBE containing 20–40% of oil is produced per annum, which contains fatty acids, vitamins, grease, phospholipids, and natural pigments, etc. half of the SBE waste is straight thrown away as trash or burned because of the quicker process (Foo & Hameed, 2012).

2.5.2 Processed Spent Bleaching Earth (PSBE)

There are four process in the refining process of crude edible oil which are degumming, bleaching, neutralization and deodorization. Activated clay which is also known as bleaching earth is used in the bleaching process. Bleaching process causes excessive volume of solid waste that generally disposed into landfill (Mana et al., 2011). Bleaching earth refers to bentonite-based natural clays of mainly montmorillonite which having the ability to adsorb colouring substance (Loh et al., 2017)

PSBE is natural pozzolan that can be used as partial cement replacement in concrete production. Approximately 56.9% of reactive Silica (SiO_2) can be found in PSBE. The reactive silica reacts with Calcium Hydroxide ($Ca(OH)_2$)) and water to produce C-S-H gel in pozzolanic reaction where the Calcium Hydroxide is produced when cement reacts with water during the hydration process.

Hydration Process

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

Pozzolanic Reaction

$$SiO_2 + Ca(OH)_2 + H_2O = C\text{-}S\text{-}H\ Gel \qquad 2.3$$

Reactive Silica in PSBE reacts with Calcium Hydroxide in pozzolanic reaction and hence reduce the Calcium Hydroxide content which is vulnerable to leaching and chemical attack and weaken the concrete. The most soluble particle in the hydration process is Calcium Hydroxide, thus it is a weak connection in concrete and cement from the view of durability. Table 2.1 below shows the comparison between properties of SBE and PSBE.

Table 2.1 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 Compressive Strength

The capability of a concrete to maintain the initial state and resist the ultimate force until the concrete to fail is the compressive strength of concrete. It can be affected by a few factors, namely, water content, rate of foaming agent, cement content, size of sand, density and mixing proportions. Normally high cement content results in higher compressive strength concrete. Besides, density of foaming agent affects the strength of foamed concrete by affecting the amount of air void. The foaming agent in high proportion may lower the compressive strength of foamed concrete because of the high volume of air void. Water cement ratio affects the compressive strength because appropriate amount of water can produce a more stable and consistent mix. The recommended water cement ratio are 0.17 and 0.19 to obtain a higher foamed concrete strength (Amran et al., 2015). The strength of concrete can be improved by using fine sand with even distribution of pores.

2.7 Hollow Beam

Hollow beams are basically designed to reduce the self-weight and to increase the flexural rigidity. One characteristic of hollow beams is that they are light in weight compared to the traditional beams. Therefore, hollow section structures generally used in long span structure and construction with high considerations on the cost and weight (Namiq, 2012).

Construction industries results in enormous concrete leftovers. The main factor of construction cost is from the material. Material cost can varies from 25% to 70% depending on the scope of construction. Concrete consumption can be minimized by introducing hollow beam as the concrete in the neutral axis does not bear any significant strength. When the total volume is reduced the self-weight of the beam is also reduced (Joy & Rajeev, 2014). A massive amount of concrete that without abiding any force can be effectively saved up. When the usage of concrete reduces, the material cost reduces and eventually minimise the construction cost (N parthiban & M Neelamegam, 2017).

2.8 Bending

The beam will bend when the load is applied on the beam. Solid reinforced rectangular beam can withstand the bending when the beam is designed with spreading the load to the bar and link in the beam. For hollow beam, "The hollow beam will failed near the design loads while the solid beam will failed more than the design loads", (Alnuaimi, Al-Jabri, & Hago, 2008). According to Alnuaimi et al. (2008) again, beam is the structure that bear more load, solid beam can resist more load than hollow beam so the displacement is maximum in solid beam. All the solid beams can resist greater loads than the hollow beams. With this review, solid beam proved to have higher strength than hollow beam. On the other hand, hollow and solid beam have different flexural strength although they have the same reinforcement. Hollow beam tends to bend with smaller load compared to solid beam which resist higher load with lesser bending (Fouad et al., 2000).

The strength of the beam is highly associated with the flexural and bending of the beam. Higher strength beam can result in a lower bending beam. The bending and flexural of the beam highly associated with the strength of the beam. Lower strength resulted a beam with more bending. When load is applied to the beam evenly, the beam will bend and give a result in LVDT. The bending moment is maximum at the mid-span of the beam as the mid-spin resist the most of the load and mid-span (Prasad, Saha, & Gopalakrishnan, 2010).

2.9 Deflection

The crack width in the hollow section should be measured together with the deflection of the hollow beam. The deflection behavior is depends on the hollow section of the beam. (Ding, You, & Jalali, 2010). The deflection of the hollow beam were affected because of the loss of material to bear the force. The hollow size will affect the vertical deflection at the shear zone which bear the shear force. Hence, the deflection profile of the beam is affected by hollow section (Benitez et al., 1998). According to (Campione & Minafò, 2012), hollow beam with vertical strut can deflect more than soild beam by 15%. The hollow beam without strut deflected 20% to 22%. It can be seen that the hollow beam with strut and without is only with a difference of 5%. The strut is seem to be ineffective in the case of hollow beam but it only the reinforcement in the beam contribute to the load. Besides that, the size of the opening can affect the deflection of the beam. The beam will deflect more with larger opening size (El Maaddawy & Sherif, 2009).

Deflection is the vertical displacement of beam when the beam is subjected to vertical load. It can also refer to a distance or angle. The angle of the deflected area is right associated to the deflection movement of the member under a specific load. Deflection also affected by the depth of the beam. When the depth of a beam increases, the maximum deflection of the beam decreases. For deflection, the maximum deflection decrease will when depth of beam increases (Al-Azzawi & Mahdy, 2010). In addition, deflection is maximum at the mid-span of the beam.

2.10 Mode of Failure

From the theory, linear elastic fracture mechanics explains that the crack propagates when the load applied on the point exceeds the limit of the material that can withstand. The crack will continue to propagate at the crack tip in the plane perpendicular to the direction of greatest tension.

The mode of failure can be classified into a few modes which affected by the bar strain, ultimate strength, crack pattern and analysis of strain distribution in the main reinforcement. The type of failure can be determined by observing the yielding of steel reinforcement and the crack pattern. Relative humidity of concrete can also affect the fracture mode of concrete. Concrete becomes brittle in dry condition. From the past result, concrete transformed from ductile behavior to brittle with the decreasing of curing humidity (Mi et al., 2018).

The most basic method to determine the crack pattern of the beam is by observing the crack appearance during the experiment process. The types of failure mode can be classified into the orientation of cracks, location and crushing of the concrete. From the past research, the beam cracks at the edge will affect the deformation of the beam and the beam will not back to its original state anymore. This happen because of the shear stress near to the crack tip. The deforming of the plain section will also affected. Moreover, bending stress may also contribute to the propagation of cracks at the mid-span (Behzad, Ebrahimi, & Meghdari, 2008).

2.11 Bending Test

Four point bending test is used to find the modulus of elasticity in bending, flexural stress, flexural strain and the flexural stress-strain response of the material. Four point bending test is identical to three point bending test. Four point bending test gives a larger proportion of the beam to the maximum stress while three point bending test only the material exactly underneath the central bearing.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains about the study that was carried out. This chapter also explains about the material used, the research planning and the testing conducted to determine the effect of square hollow section on the strength of foamed concrete beam with processed spent bleaching earth as partial replacement of cement. This chapter gives the strong view about the research and clearly show how the objectives were achieved. The four point bending test carried out under ASTM standard to support the physical test and properties of materials. The flexural strength tests were carried out at 28 days of curing for both types of beams. The discussion was crucial in order to improve and gain the knowledge and information regarding the scope of research. For this study, the material used were Portland cement, silica sand, foaming agent and processed spent bleaching earth.

3.2 Research Planning

Figure 3.1 shows the research experimental flow for this study.

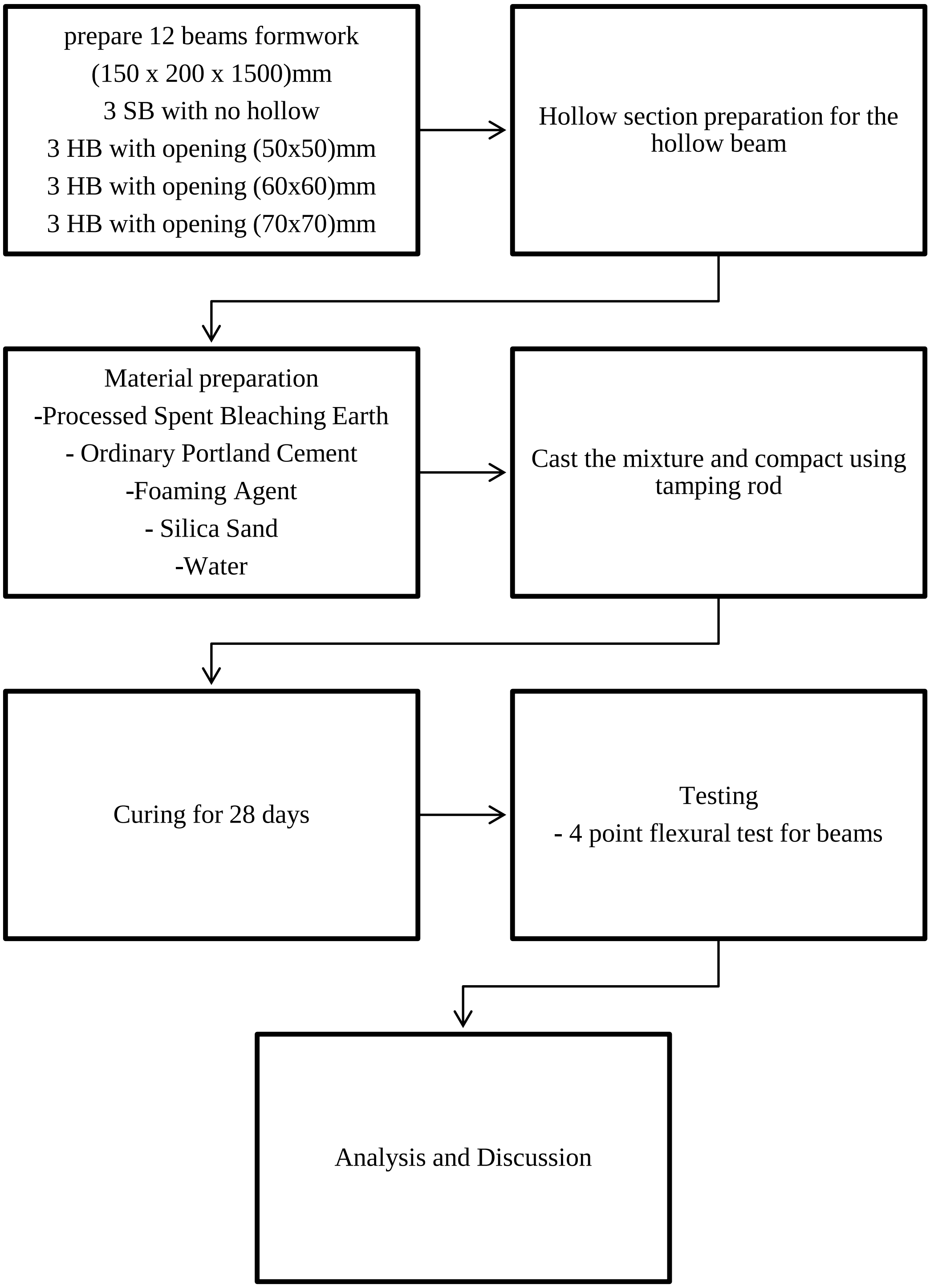


Figure 3.1 Research Experimental Works Flow

3.3 Specimen Preparation

The materials used in this study were Ordinary Portland Cement, silica sand, foaming agent, processed spent bleaching earth (PSBE), and water. Processed spent bleaching earth served as cement replacement in this concrete which substitute up to 30% of cement. The specimen preparation included preparation of formwork, concrete mixing, casting and curing of specimen.

3.3.1 Formwork Preparation

Formwork is the term given to either temporary or permanent moulds which concrete or similar materials poured. In the context of concrete construction, the formwork supports the shuttering moulds. Early stage of specimen preparations was to prepare the formwork for 12 beams specimen and for this research, timber formwork was used. The formwork was prepared using the same materials and dimension of 150mm x 200mm x 1500mm. The preparation of formwork was one of the crucial part as the defect occur in this part will affect the beam specimen. The problem that might occur was uneven size of the beam. For formwork preparations, main materials been used was plywood with 1.25cm of thickness and wood with dimensions of 2.5cm x 5cm. The formwork made up of 3 different part which were the base, the walls and the faces of the beam. The base was the strongest part of the formwork and it supported the overall weight of the concrete. For wall, it was build both side left and right, and its purpose was to shape and hold the concrete beam into desirable size and dimensions. Formworks face was the last part which purpose to seal the formwork and it was located at the front and end of the formworks. Figure 3.2 and Figure 3.3 show the preparation of formworks.

Figure 3.2 Preparation of Formwork

Figure 3.3 Square Hollow Section Formwork

3.3.2 Ordinary Portland Cement

Ordinary Portland Cement is the most basic material for concrete mix. The Portland Cement that used for this study was ‘Orang Kuat’ which was produced by YTL Cement Berhad. ‘Orang Kuat’ is suitable for structural concreting, precast, brickmaking and all general purpose applications where high strength is needed to improve productivity and it is certified to MS EN 197-1, CEM I 42.5N / 52.5N. ‘Orang Kuat’ is produced using the most advanced energy efficient cement production process. Every effort has been made to reduce the environmental foot print during the production of this product. ‘Orang Kuat’ is packed in 50kg paper bag and is available from leading building materials distribution companies and hardware dealers. ‘Orang Kuat’ is produced under stringent quality assurance, environmental management, health & safety and energy management systems. It is certified to MS ISO 9001, MS ISO 14001, OHSAS 18001 & MS ISO 50001. Figure 3.4 shows the type of Portland Cement used in this research.

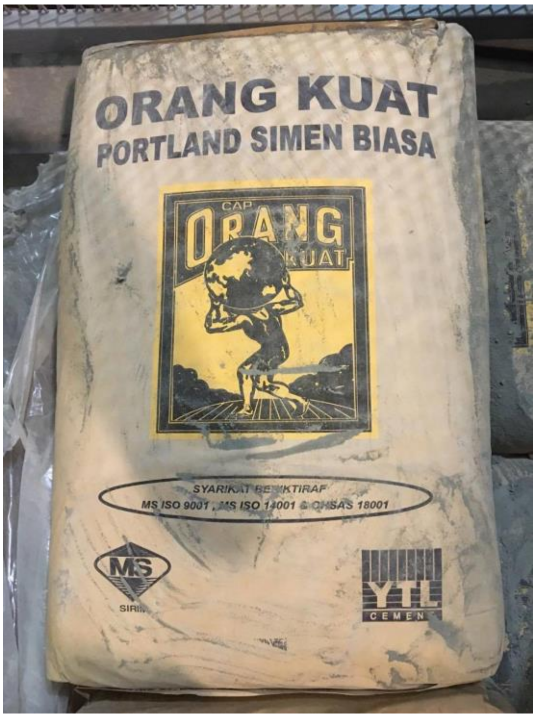


Figure 3.4 Ordinary Portland Cement ‘Orang Kuat’

3.3.3 Silica Sand

The fine aggregate used in this study was silica sand. Silica sand is also the basic main component for wide variety of construction products and building. Silica sand has high compressive strength that ensures the integration of the shell mould or core while pouring. Silica sand can shortened the craving time of shell mould or shell core, thus increasing productivity and decreasing production cost. The silica oxide content must be more than 98% in silica sand. The size of silica sand used for this study was from 0.001mm to 0.6mm. Figure 3.5 shows the silica sand used in this research.

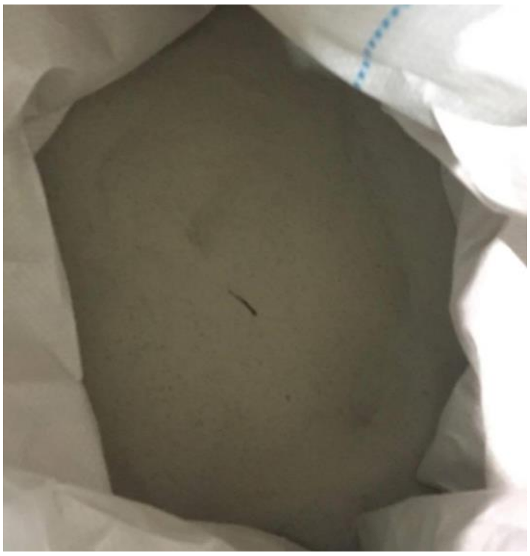


Figure 3.5 Silica Sand

3.3.4 Protein Foaming Agent

The foaming agent used in this study was protein foaming agent. The foaming agent is made to form light weight concrete and other concrete materials. A less consumption of foaming agent is enough to produce light weight concrete beam. Foaming agent is widely applied in heating and roof insulation engineering, it is significantly reduce the construction cost. Foam produce no reaction on concrete but it serves as a layer which is air trapped and forms no fumes or toxic. It is prepared with raw material in presence of $Ca(OH)_2$ and a small portion of $NaHSO_3$. Figure 3.6 shows the foaming agent that has been used.

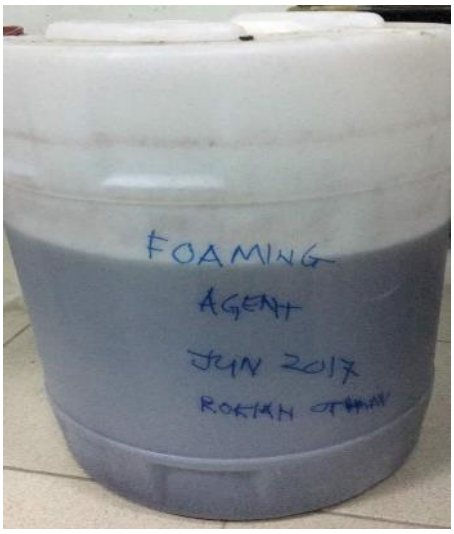


Figure 3.6 Protein Foaming Agent

3.3.5 Processed Spent Bleaching Earth (PSBE)

Processed spent bleaching earth (PSBE) was the pozzolanic material used in this study. PSBE is a cement replacement that can reduce the cement used in concrete production. PSBE replace up to 30% of cement in this study. The silica oxide (SiO_2) content in PSBE is around 56.9%. PSBE is different from normal SBE because PSBE is in very fine powder form and can easily mix with concrete therefore it enhance the secondary pozzolanic reaction and increase the secondary C-S-H gel. The C-S-H gel produced can enhance the durability, workability and ultimate strength of the concrete. Figure 3.7 shows the PSBE used for this research.

Figure 3.7 Processed Spent Bleaching Earth

3.3.6 Water

The water used in this study was clear, free and clean impurities tap water which supplied by the concrete laboratory, UMP. The amount of water used in this study was based on the concrete mix design table. The water/cement ratio was very important as to maintain the workability, strength, permeability, durability, potential of cracking, and water shrinkage.

3.4 Mix Design

In this study, the strength of the foamed concrete depends on its constituent proportion such as cement, silica sand, water and density. Desired density of this study was 1600 kg/m^3 and the cement sand ratio used was 1:1.5. The water cement ratio was 0.5 as per designed. Furthermore, the PSBE was added to 30% of the cement as a cement replacement. The mix proportion of foamed concrete that used for production of beams is shown in Table 3.1.

Table 3.1 Mix Proportion of foamed concrete

Mixture	kg/m³	s/c	w/c	Cement	PSBE	Sand	Foam
FC	1600	1.5	0.5	288	-	432	12.96
PFC (30%)	1600	1.5	0.5	201.6	86.4	432	12.96

3.5 Casting, Moulding and Unmoulding of the Specimens

The concrete beams were casted in the plywood formwork with dimension 150mm x 200mm x 1500mm. The amount of materials were mixed according to the mix design ratio. Before mixing the concrete, the materials were weighted. Then the materials were mixed into the barrel and poured into formworks. Before casting, the formworks were cleaned and greased for easier dismantle of formwork. The concrete were filled into 3 formworks for each design. Then it was compacted with the aid of tamping rod. Then the specimens were covered up by the wetted sack to avoid water evaporation from the surface of concrete. After the specimens were left for 24 hours and finally they were dismantled. Next, the curing process started. Figure 3.8 shows the casting process for all the specimens.

Figure 3.8 Casting of the Specimen

3.6 Curing Process

Water curing was used in this study for the curing process. It is the most efficient curing method that prevent the evaporation and shrinkage of concrete. It also develops the performance and strength of concrete. Concrete settling when the chemical reaction between cement and water occurs. Curing process took place immediately after the dismantled of concrete from formworks to maintain the concrete temperature conditions and desired moisture, both at depth and near to the surface, for delay the periods of time. Properly cured concrete had a sufficient volume of wetness for continued hydration and hence developed strength, resistance to freezing and thawing, volume stability and resistance to scaling and abrasion. The beams were cured 28 days before testing process. Figure 3.9 shows the curing process of the beams.

Figure 3.9 Curing Process

3.7 Painting

The purpose of painting was to make the cracks to be observed easier during the testing process. White paint was used after the beams fully cured for 28 days. Figure 3.10 shows how the painting been applied on the beams.

Figure 3.10 Painting of the Beams

3.8 Testing Method

All the solid beams and hollow beams undergone 4 point bending test. The details are discussed below.

3.8.1 Four Point Bending Test

Four point bending test provides values for modulus of elasticity in flexural stress, bending, flexural strain and the flexural stress-strain response of the material. Four point bending test comes with two base supports and two top loading points. In this study, the beams were tested using four point bending test to collect the data of the flexural strength, deflection and crack pattern. The load were applied constantly to the beam until the beam was failed to resist more loading. Four LVDT were placed to record the deflection of the beams. Two LVDT were placed below each of the loading point, one was placed at the centre of the beam and one was placed at the support position. The support of the beams was placed 150mm from the end of the beam. The loading rod were at 200mm from the centre of the beam to the both sides. The data was analysed and process before the result obtained. Four point bending test used to investigate the flexural behaviour of the composite beam will have applied loads close to the centre of the beam, inducing flexural failure. Four point bending test arrangement used to determine the shear capacity of the beam is to have applied loads closer to the supports of the beam, inducing shear failure and reducing the bending moment at the centre of the beam. Figure 3.11 and Figure 3.12 show the testing set up for four point bending test and position of LVDT.

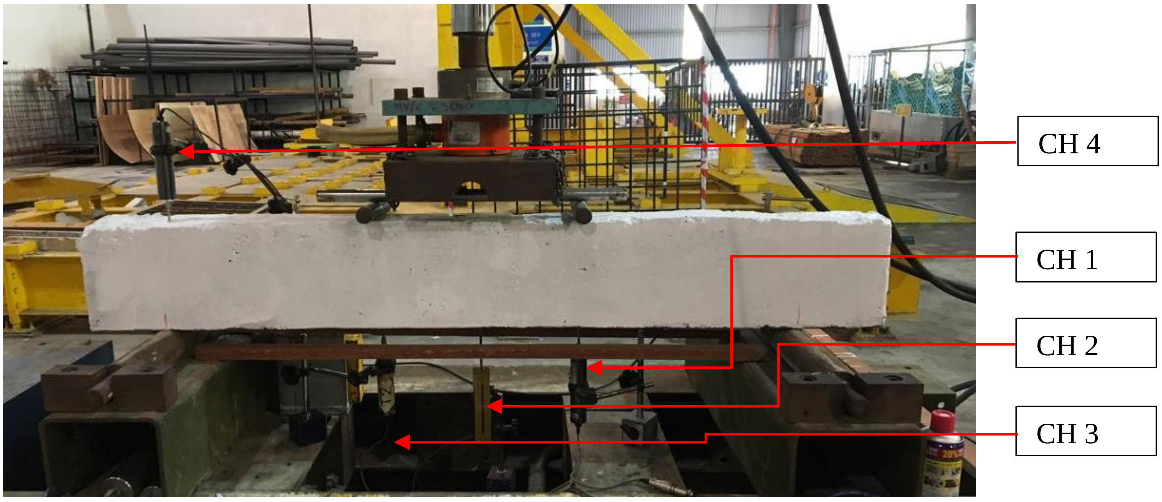


Figure 3.11 Testing Set Up of the Beam

Figure 3.12 Position of LVDT

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter shown the results and analysis that had been collected from the testing were discussed in this chapter. The results was about the effect of square hollow section on the strength of foamed concrete beam with processed spent bleaching earth as partial replacement of cement. There were four main objectives to be discussed in this research which were the maximum load, flexural strength, deflection profile and the cracking pattern of the beams. The results obtained and relationship between the objectives was evaluated and analysed. The maximum loading of the beams were determined by four point bending test. Besides, the deflection of the beams was measured and obtained by the Linear Variable Transducer Displacement (LVDT) which placed under the beam during testing. The cracking pattern of beams were recorded by marking every crack that appeared until the beams failure.

4.2 Flexural Strength

The flexural strength for all the beams were obtained by using four point bending test. The loads were applied continuously until the beams failed to resist any more load during the test. Every cracking appeared on the beams was marked and the value of loading was recorded until the beam failed. Relationship between every beams which were Beam 1, Beam 2, Beam 3, and Beam 4 was analysed. Beam 1 was the controlled beam without hollow section, Beam 2 was the square hollow beam with opening size of 50mm x 50mm, Beam 3 was the square hollow beam with opening size of 60mm x 60mm and Beam 4 was the square hollow beam with opening size of 70mm x 70mm. From the result obtained, the maximum loading were 4.510kN, 3.937kN, 2.830kN, and 2.206kN for Beam 1, Beam 2, Beam 3, and Beam 4 respectively. The calculations of the flexural strength were shown in Appendix A. The flexural strength value for each beams were 0.902 N/mm², 0.787 N/mm², 0.566 N/mm² and 0.441 N/mm² for Beam1, Beam 2, Beam 3 and Beam 4 respectively. Table 4.1 shows the maximum loading and flexural strength for every beams that obtained from the testing.

Table 4.1 Maximum loading and Flexural Strength of Beams

Specimen	**Maximum Loading (kN)**	**Flexural Strength (N/mm²)**
Beam 1	4.510	0.902
Beam 2	3.937	0.787
Beam 3	2.830	0.566
Beam 4	2.206	0.441

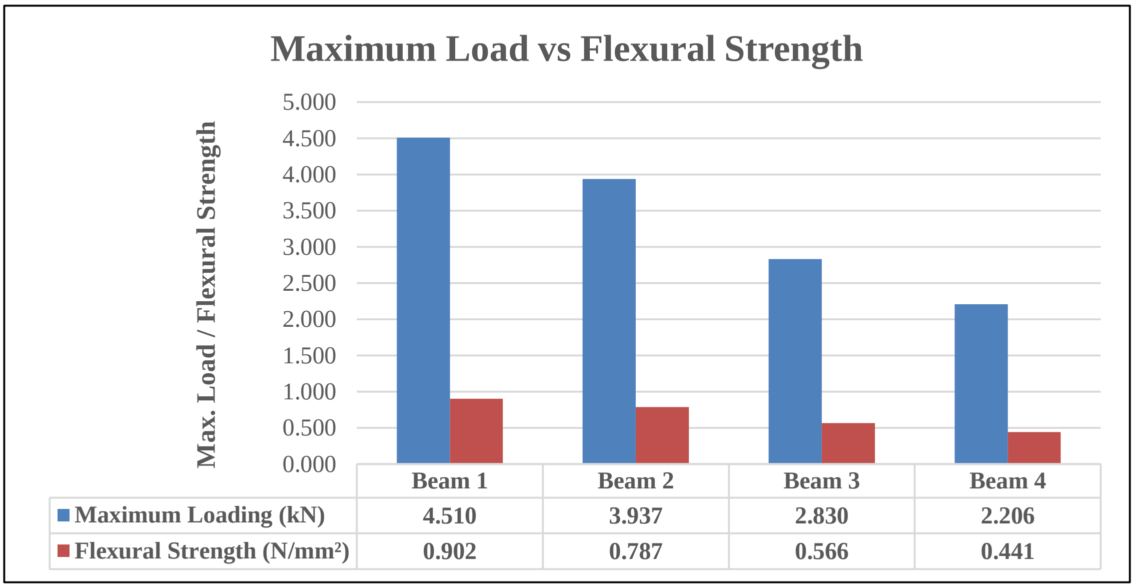


Figure 4.1 Maximum Loading and Flexural Strength of Beams

Figure 4.1 shows the relationship of maximum loading and flexural strength of the beams. From the analysis of the results, the percentage of loading and strength lost for each beam was 12.7%, 37.3%, 51.1% for Beam 2, Beam 3, and Beam 4 respectively. The maximum loading could be resisted by the beam decreased when the size of the hollow section increased. This was because the lesser concrete to resist the load from the testing if the hollow section increased.

The discussion that could be made was the flexural strength of beam was decreased according to the second moment of inertia or surface area of the beam. The surface area decreased when the opening size increased. The surface area of Beam 1, Beam 2, Beam 3, and Beam 4 was $3.00x10^4$ mm^2, $2.75x10^4$ mm^2, $2.64x10^4$ mm^2, and $2.51x10^4$ mm^2 respectively. As the surface area decreased, the stresses that can withstand by the beam also decreased. From this, the reasoning of reduction in flexural strength observed through the experiment was clearly identified. The flexural strength of the beams depends on the second moment of inertia while second moment of inertia depends on the surface area of the beams. The maximum loading of beam with hollow section decreased due to the increasing dimension of hollow section (Salaman, 2015). The flexural loading capacity affected by the hollow beam when compared to the solid beam (Jabbar, Hejazi, & Mahmod, 2016a). The Flexural strength of hollow beam was less compared to solid beam. Thus, solid beam with the more concrete area can withstand higher load compared to hollow beam.

4.3 Deflection Profile

The deflection profile of the beams has been obtained by using the Linear Variable Displacement Transducer (LVDT). In this research, the result of the deflection profile was obtained by recording the displacement of the LVDT when the beam was deformed due to the loading applied during testing. In the testing process, there were three LVDT placed under the beam to obtain the deformation profile of the beam. Three LVDT were labelled as LVDT 1, LVDT 2, and LVDT 3 which placed 550mm, 750mm, and 950mm from the end of the beam, respectively. The displacement data from the mid transducer (LVDT 2) was taken for Beam 1, Beam 2, Beam 3, and Beam 4 as to produce the deflection profile for every beam. The deflection data were analysed by calculated the percentage of maximum loading applied to the beam which were P_{10} (10% maximum loading), P_{20} (20% maximum loading), P_{30} (30% maximum loading), P_{40} (40% maximum loading), P_{50} (50% maximum loading), P_{60} (60% maximum loading), P_{70} (70% maximum loading), P_{80} (80% maximum loading), P_{90} (90% maximum loading), and P_{100} (100% maximum loading). The maximum deflection was produced by LVDT 2, which located at the middle of the beam. From the observation, the maximum deflection produced by LVDT 2 for Beam 1, Beam 2, Beam 3, and Beam 4 were 0.330mm, 0.300mm, 0.273mm, and 0.245mm respectively. Table 4.2, Table 4.3, Table 4.4, and Table 4.5 show the summary of deflection profile that gained from three LVDT for Beam 1, Beam 2, Beam 3, and Beam 4 respectively.

Table 4.2 Deflection Data for Beam 1

Loading (kN)		Displacement (mm)		
Max Loading: 4.510		LVDT 1	LVDT 2	LVDT 3
P_0	0.000	0.000	0.000	0.000
P_{10}	0.476	0.015	0.023	0.013
P_{20}	0.887	0.058	0.067	0.057
P_{30}	1.348	0.096	0.092	0.103
P_{40}	1.860	0.107	0.127	0.111
P_{50}	2.208	0.113	0.151	0.115
P_{60}	2.678	0.150	0.174	0.145
P_{70}	3.197	0.193	0.206	0.194
P_{80}	3.578	0.201	0.236	0.207
P_{90}	3.991	0.214	0.259	0.217
P_{100}	4.510	0.293	0.330	0.288

Table 4.3 Deflection Data for Beam 2

Loading (kN)		Displacement (mm)		
Max Loading: 3.937		LVDT 1	LVDT 2	LVDT 3
P_0	0.000	0.000	0.000	0.000
P_{10}	0.381	0.021	0.034	0.019
P_{20}	0.772	0.066	0.076	0.063
P_{30}	1.307	0.083	0.106	0.081
P_{40}	1.502	0.095	0.118	0.091
P_{50}	1.997	0.137	0.168	0.135
P_{60}	2.295	0.155	0.186	0.159
P_{70}	2.670	0.178	0.198	0.173
P_{80}	3.008	0.187	0.213	0.184
P_{90}	3.418	0.231	0.244	0.226
P_{100}	3.937	0.265	0.300	0.258

Table 4.4 Deflection Data for Beam 3

Loading (kN)		Displacement (mm)		
Max Loading: 2.830		**LVDT 1**	**LVDT 2**	**LVDT 3**
P_0	0.000	0.000	0.000	0.000
P_{10}	0.285	0.019	0.032	0.016
P_{20}	0.531	0.046	0.056	0.039
P_{30}	0.878	0.055	0.075	0.049
P_{40}	1.135	0.074	0.093	0.065
P_{50}	1.419	0.086	0.111	0.079
P_{60}	1.634	0.105	0.121	0.094
P_{70}	1.943	0.122	0.149	0.113
P_{80}	2.219	0.150	0.184	0.147
P_{90}	2.555	0.172	0.207	0.163
P_{100}	2.830	0.204	0.273	0.194

Table 4.5 Deflection Data for Beam 4

Loading (kN)		Displacement (mm)		
Max Loading: 2.206		**LVDT 1**	**LVDT 2**	**LVDT 3**
P_0	0.000	0.000	0.000	0.000
P_{10}	0.219	0.008	0.014	0.009
P_{20}	0.414	0.017	0.036	0.023
P_{30}	0.673	0.039	0.061	0.046
P_{40}	0.875	0.051	0.084	0.056
P_{50}	1.130	0.076	0.107	0.085
P_{60}	1.313	0.108	0.143	0.113
P_{70}	1.489	0.126	0.161	0.134
P_{80}	1.734	0.157	0.193	0.168
P_{90}	1.960	0.191	0.217	0.194
P_{100}	2.206	0.216	0.245	0.219

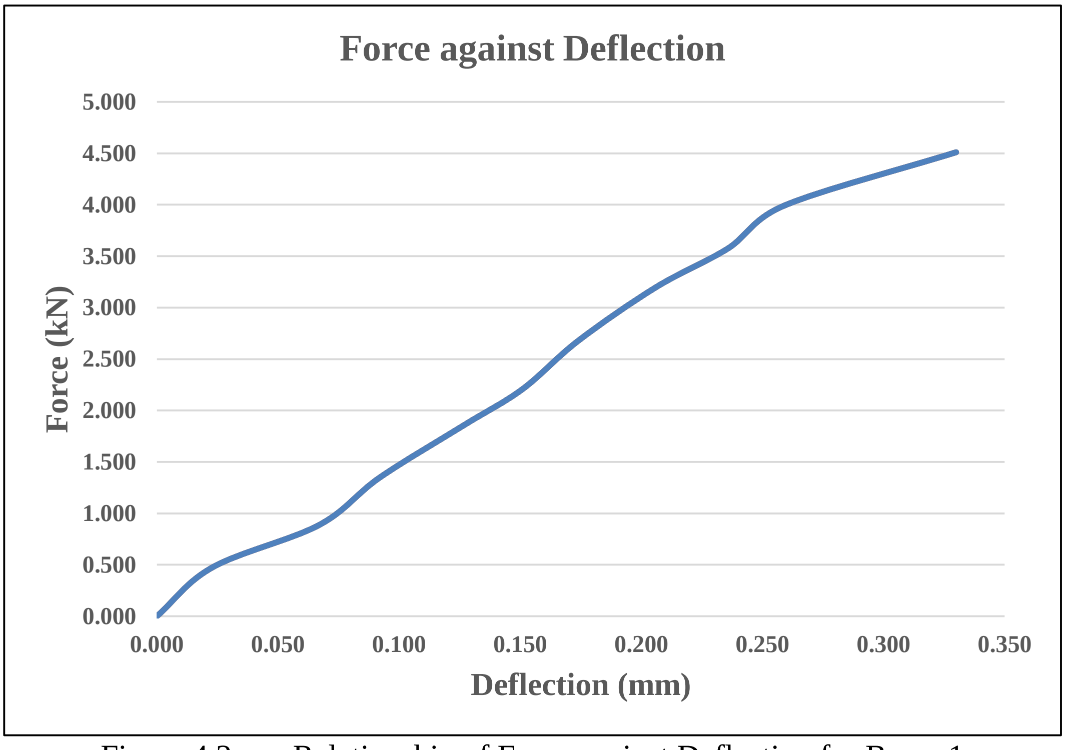


Figure 4.2 Relationship of Force against Deflection for Beam 1

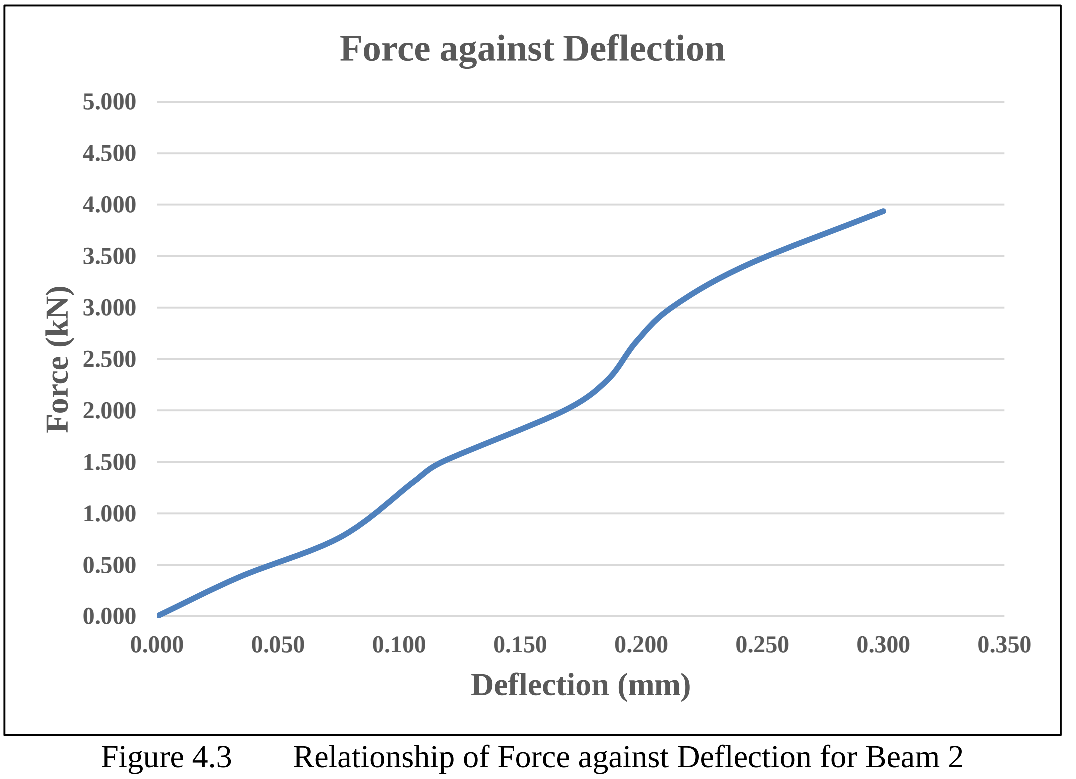


Figure 4.3 Relationship of Force against Deflection for Beam 2

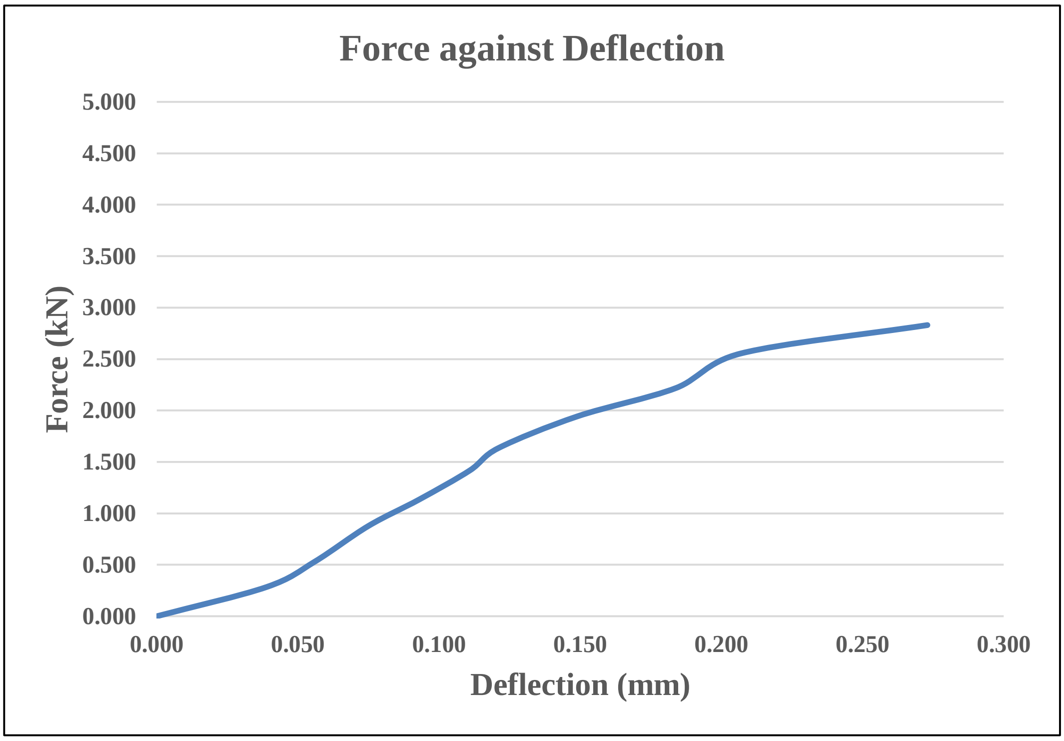


Figure 4.4 Relationship of Force against Deflection for Beam 3

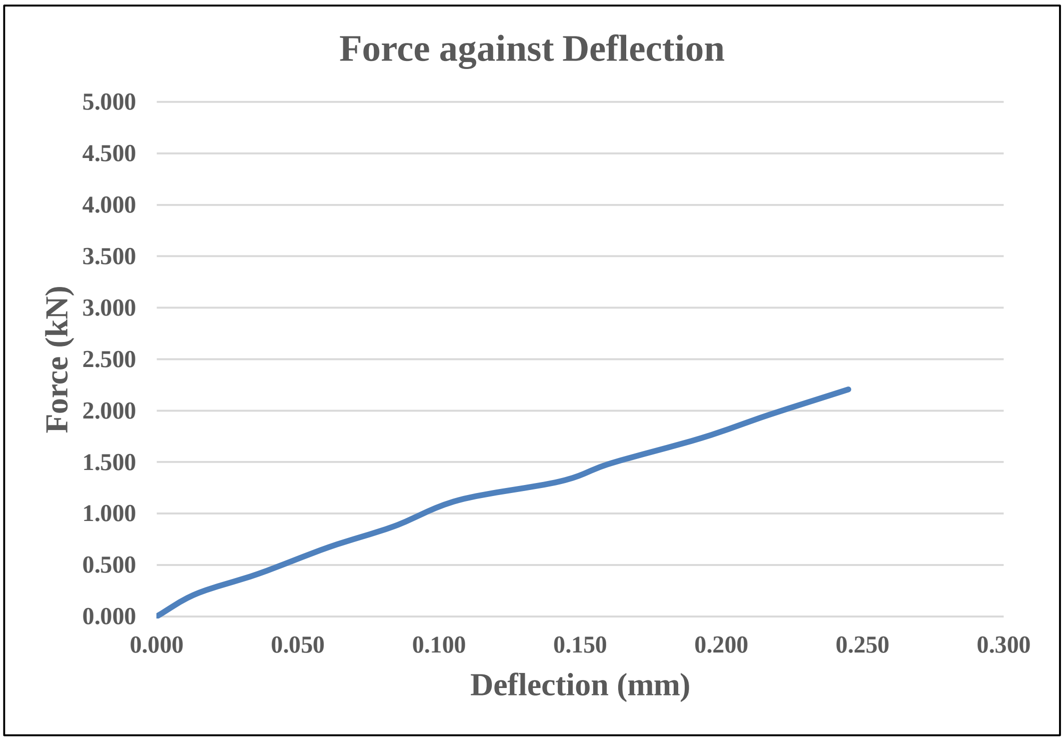


Figure 4.5 Relationship of Force against Deflection for Beam 4

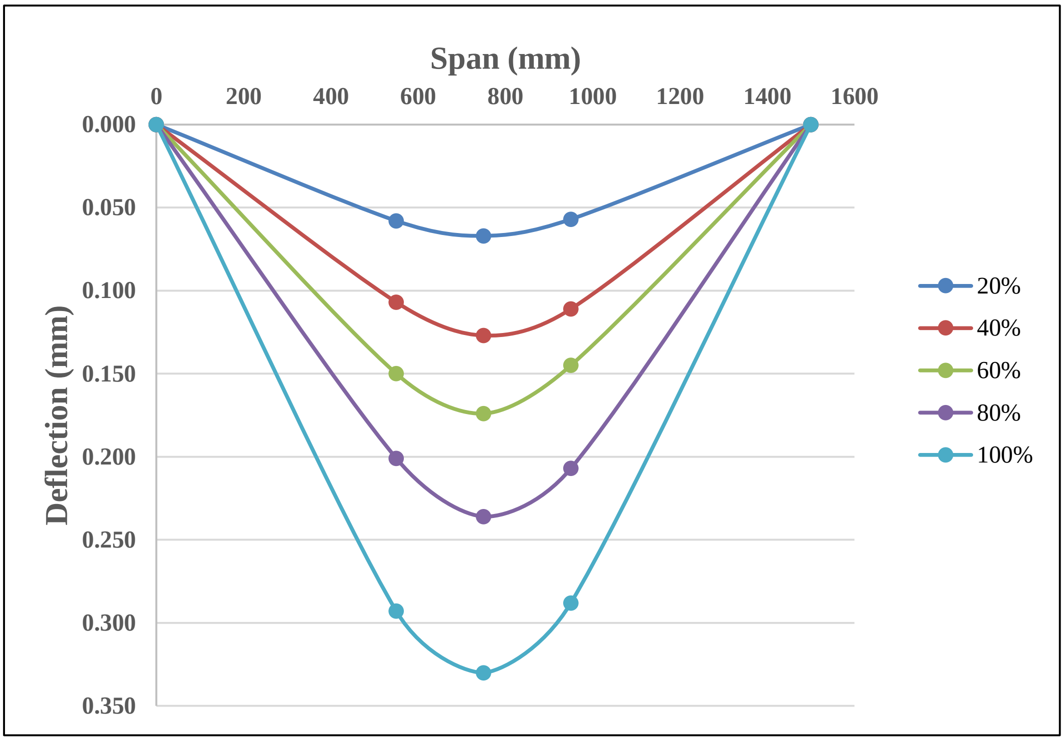


Figure 4.6 Deflection Profile for Beam 1

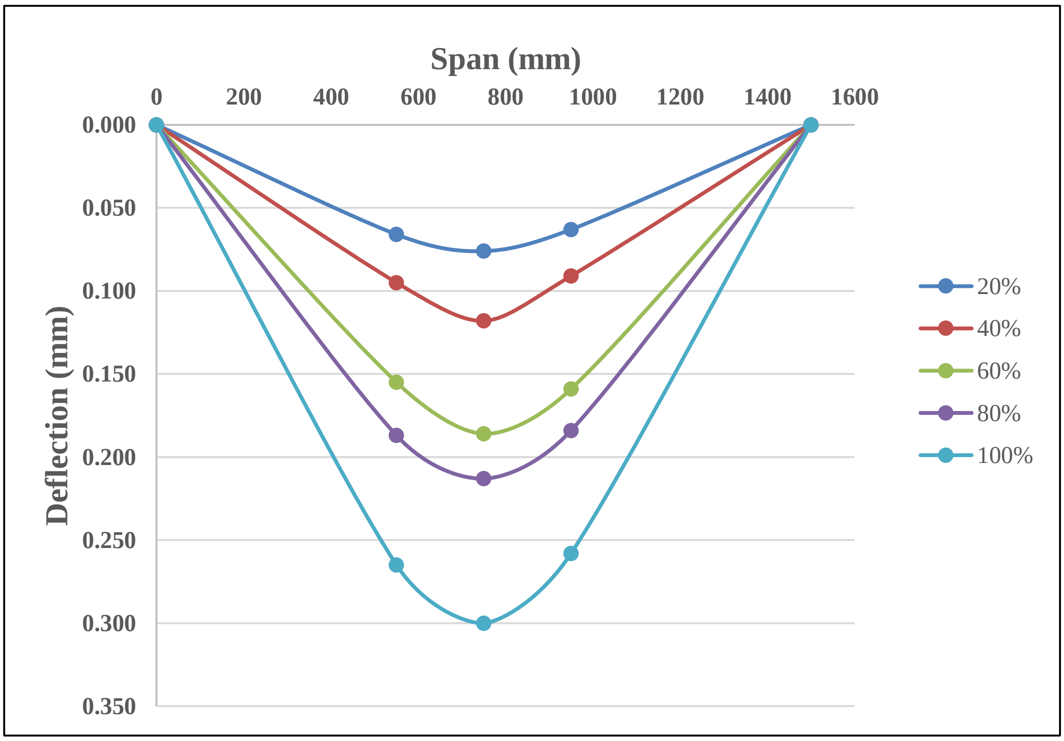


Figure 4.7 Deflection Profile for Beam 2

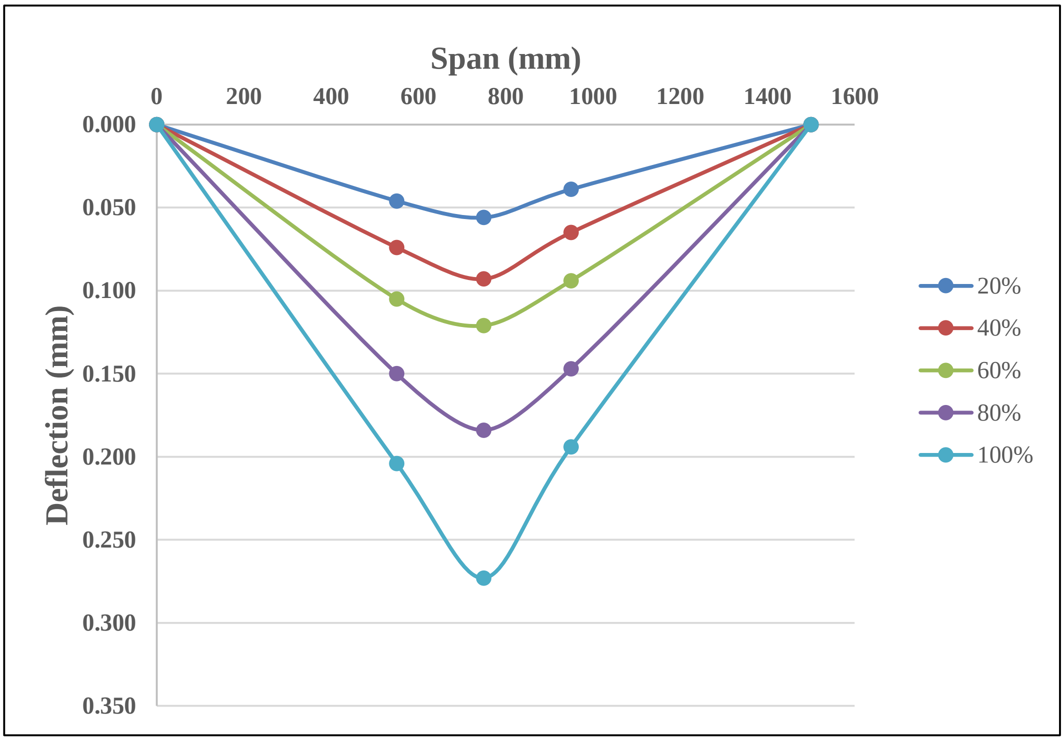


Figure 4.8 Deflection Profile for Beam 3

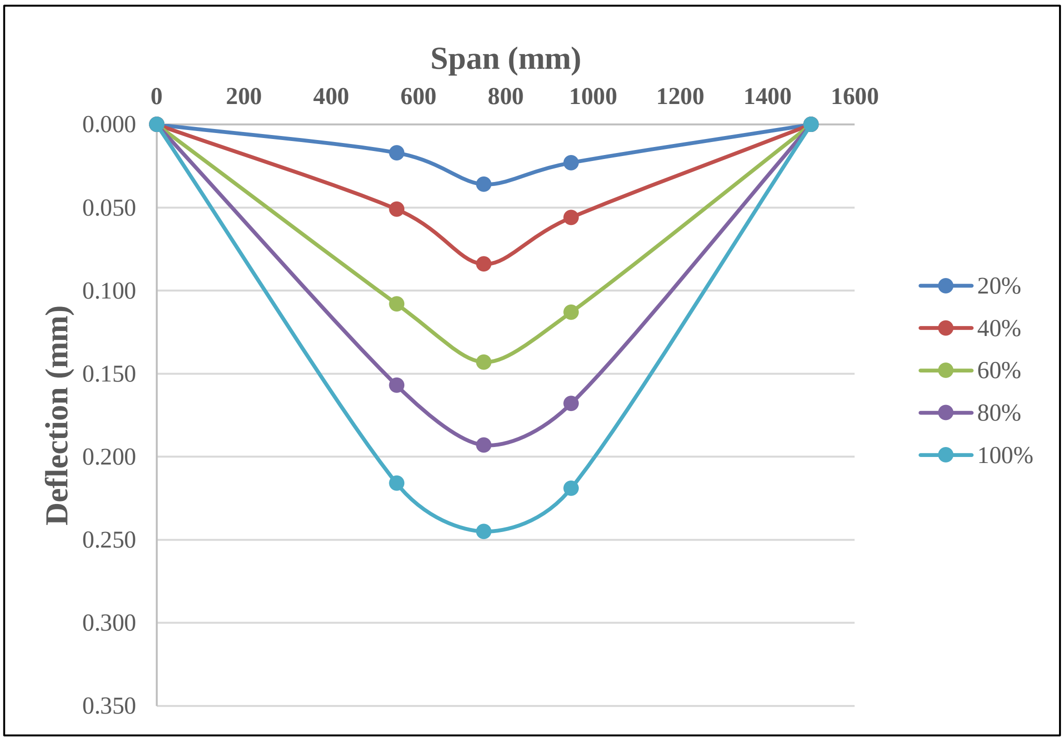


Figure 4.9 Deflection Profile for Beam 4

Figure 4.2, Figure 4.3, Figure 4.4, and Figure 4.5 show the relationship of force against deflection for Beam 1, Beam 2, Beam 3, and Beam 4 respectively. Based on the graph, the values of maximum deflection occurred on each beam have been obtained by observing the deflection value during the testing of applying maximum loading on the beams. The maximum deflection values for Beam 1, Beam 2, Beam 3, and Beam 4 were 0.330mm, 0.300mm, 0.273mm, and 0.245mm. From the table, the maximum deflection occurred in Beam 1 and the lowest deflection occurred in Beam 4**.** The deflection decreased when the size of hollow section increased. The deflection profile for all beams are shown in Figure 4.6, Figure 4.7, Figure 4.8, and Figure 4.9 for Beam 1, Beam 2, Beam 3, and Beam 4 respectively. The deflection profile graph was developed based on maximum applied loading acted on the beam by 20%, 40%, 60%, 80% and 100%. As for the deflection value, the comparison of experimental deflection compared to theoretical deflection was calculated. The difference in percentage between the experimental deflection value and theoretical deflection value by using formula was analysed.

From the result obtained, it was very significant that the deflection of beam affected by the hollow section area (Ding et al., 2010). Beam 4 with the lowest deflection value of 0.245mm when the constant rate of loading applied and it was proved that the larger the hollow size resulted lesser deflection value on unreinforced beam. The reduction in displacement in hollow section was almost 10 times compared with the solid beam (Jabbar, Hejazi, & Mahmod, 2016). Therefore, it was proved that the beams with hollow section has lower strength and deflected less than the solid beam.

The theoretical value of the deflection calculated using the equation of deflection for four point bending test. The calculation examples provided in Appendix B. The comparison of theoretical and the experimental value for deflection at the mid span of all beams were shown in Table 4.6.

Table 4.6 Deflection Profile Comparison

Specimens	**Theoretical Value (mm)**	**Experimental Value (mm)**	**Difference (%)**
Beam 1	0.135	0.330	144.44
Beam 2	0.118	0.300	154.24
Beam 3	0.085	0.273	221.18
Beam 4	0.066	0.245	271.21

4.4 Crack Pattern

Cracking pattern analysed by observing the cracking pattern produced after the beams in failure state. During the testing, the cracking of beam was observed for pattern, position and the type of crack failure. All the beams showed the same pattern of failure which shown in Table 4.7.

Table 4.7 Cracking Pattern of Beams

Specimens	Cracking Pattern	Failure Mode
Beam 1		Ultimate crack
Beam 2		Ultimate crack
Beam 3		Ultimate crack
Beam 4		Ultimate crack

From Table 4.7, it has been observed that the crack pattern for all the beams were the same and all the beams cracked at ultimate load. Beam 2, Beam 3, and Beam 4 showed the same behaviour as Beam 1 which the crack was developed and propagated from bottom part to upper part of beam. Initially, the load increased gradually with time but all the beams were still in un-cracked mode. When the applied load reached the rupture strength of the beams, the beams failed in a brittle manner. Since the beams were un-reinforced, therefore, they failed without any appearance of tiny crack. The vertical crack was called ultimate crack. When the applied load reached the peak load, the crack propagated in an unstable manner under load testing environment (Prasad et al., 2010).

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

In this chapter, it concluded the research findings and results of the study based on the experimental data. The findings exhibited that the beam with square hollow section of size 50mm x 50mm at the centre achieved higher load, higher flexural strength and higher deflection compared to the other sizes of square hollow sections. After that, several recommendations were provided based on the results getting from the experimental study. The recommendations could be used for future works and improve the performance for the structural application

5.2 Conclusion

This study focused on the analysing the effect of square hollow section on the strength of foamed concrete beam with Processed Spent Bleaching Earth as partial replacement of cement. The main concepts for this study was the size of square hollow section which resulted in the reduction of foamed concrete beam strength. Based on the experimental results, it could be concluded that the size of square hollow section had greatly influence on the flexural strength and deflection of the beams. The percentage of strength lost for each beams were 12.7%, 37.3% and 51.1% for Beam 2, Beam 3, and Beam 4 respectively. There were several conclusions have been made as follows:

i. The beam with the opening size 50mm x 50mm had the highest maximum flexural strength of 0.787 N/mm² as compared to hollow beam with bigger opening size. The flexural strength was 12.7% less than controlled beam.

ii. Hollow beam with opening size 50x50mm had the highest deflection of 0.300mm as compared to hollow beam with bigger opening size. The deflection was 9.09% less than controlled beam.

iii. All the beams undergone ultimate crack as the beams were unreinforced.

5.3 Recommendations

i. Various size of hollow beams should be tested to find the most suitable beam size to be used as first floor beam.

ii. Compare the result with Ansys stimulation to find the most suitable beam design for first floor beam construction.

iii. The workmanship should be standardised to ensure the uniformity beam compaction.

iv. Reinforcement can be added to increase the flexural strength of foamed concrete.

REFERENCES

-N parthiban, M. N. (2017). Flexural Behavior of Reinforced Concrete Beam With. *International Research Journal of Engineering and Technology(IRJET)*, *4*(4), 2263–2274. Retrieved from https://www.irjet.net/archives/V4/i4/IRJET-V4I4573.pdf

Al-Azzawi, A., & Mahdy, A. (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

Alex, S., & Tiwari, A. (2015). Properties and Applications — A Review. *Construction & Building Materials*, *15*(3), 1869–1894. https://doi.org/10.1166/jnn.2015.9718

Ali, M. B., Saidur, R., & Hossain, M. S. (2011). A review on emission analysis in cement industries. *Renewable and Sustainable Energy Reviews*, *15*(5), 2252–2261. https://doi.org/10.1016/j.rser.2011.02.014

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

Baran, E. (2015). Effects of cast-in-place concrete topping on flexural response of precast concrete hollow-core slabs. *Engineering Structures*, *98*, 109–117. https://doi.org/10.1016/j.engstruct.2015.04.017

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

Benitez, B. M. A., Darwin, D., Fellow, Z., & Donahey, R. C. (1998). DEFLECTIONS OF COMPOSITE BEAMS WITH WEB OPENINGS By Manuel A. Benitez; Member, ASCE, David Darwin,:Z Fellow, ASCE, and Rex C. Donahey,3 Member, ASCE, *124*(October), 1139–1147.

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

Campione, G., & Minafò, G. (2012). Behaviour of concrete deep beams with openings and low shear span-to-depth ratio, *41*, 294–306.

Coker, E. B., Sadiku, S., Aguwa, J. I., & Abdullahi, M. (2016). Study of the Strength Characteristics of Protein-Based Lightweight Foamed Concrete With Cement. *Nigerian Journal of Technology*, *35*(4), 699–706.

Ding, Y., You, Z., & Jalali, S. (2010). Hybrid fiber influence on strength and toughness of RC beams. *Composite Structures*, *92*(9), 2083–2089. https://doi.org/10.1016/j.compstruct.2009.10.016

El Maaddawy, T., & Sherif, S. (2009). FRP composites for shear strengthening of reinforced concrete deep beams with openings. *Composite Structures*, *89*(1), 60–69. https://doi.org/10.1016/j.compstruct.2008.06.022

Foo, K. Y., & Hameed, B. H. (2012). Dynamic adsorption behavior of methylene blue onto oil palm shell granular activated carbon prepared by microwave heating, *203*, 81–87.

Hasdemir, S., Tuǧrul, A., & Yilmaz, M. (2016). The effect of natural sand composition on concrete strength. *Construction and Building Materials*, *112*, 940–948. https://doi.org/10.1016/j.conbuildmat.2016.02.188

Hesami, S., Modarres, A., Soltaninejad, M., & Madani, H. (2016). Mechanical properties of roller compacted concrete pavement containing coal waste and limestone powder as partial replacements of cement. *Construction and Building Materials*, *111*, 625–636. https://doi.org/10.1016/j.conbuildmat.2016.02.116

Jabbar, S., Hejazi, F., & Mahmod, H. M. (2016a). 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/10.1590/1679-78251828

Jabbar, S., Hejazi, F., & Mahmod, H. M. (2016b). Effect of an Opening on Reinforced Concrete Hollow Beam Web Under Torsional, Flexural, and Cyclic Loadings . *Latin American Journal of Solids and Structures* . scielo .

Jones, M. R., & McCarthy, A. (2005). Preliminary views on the potential of foamed concrete as a structural material. *Magazine of Concrete Research*, *57*(1), 21–31. https://doi.org/10.1680/macr.2005.57.1.21

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

Joy, J., Rajeev, R., & Student, P. G. (2014). Effect of Reinforced Concrete Beam with Hollow Neutral Axis. *IJSRD -International Journal for Scientific Research & Development|*, *2*(10online), 2321–613. Retrieved from www.ijsrd.com

Kearsley, E. ., & Wainwright, P. . (2001). The effect of high fly ash content on the compressive strength of foamed concrete. *Cement and Concrete Research*, *31*(1), 105–112. https://doi.org/10.1016/S0008-8846(00)00430-0

Ko, C., Wang, W., & Kuo, J. (2011). Improving Formwork Engineering Using the Toyota Way. *Journal of Engineering, Project, and Production Management*, *1*(1), 13–27.

Krzyśko-Łupicka, T., Cybulska, K., Wieczorek, A., Możdżer, E., & Nowak, M. J. (2014). The effect of spent bleaching earth ageing process on its physicochemical and microbial composition and its potential use as a source of fatty acids and triterpenes. *Environmental Science and Pollution Research*, *21*(18), 10765–10774. https://doi.org/10.1007/s11356-014-3021-6

Loh, S. K., Cheong, K. Y., & Salimon, J. (2017). Surface-active physicochemical characteristics of spent bleaching earth on soil-plant interaction and water-nutrient uptake: A review. *Applied Clay Science*, *140*, 59–65. https://doi.org/10.1016/j.clay.2017.01.024

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

Mansuri, D., Chakraborty, D., Elzarka, H., Deshpande, A., & Gronseth, T. (2017). Building Information Modeling enabled Cascading Formwork Management Tool. *Automation in Construction*, *83*(July), 259–272. https://doi.org/10.1016/j.autcon.2017.08.016

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

Mohamad, M. I., Zawawi, M., & Nekooie, M. a. (2009). I Mplementing I Ndustrialised B Uilding S Ystem (Ibs) in. *Malaysian Journal of Civil Engineering*, *21*(2), 219–234.

Mohammed, J. H., & Hamad, A. J. (2014). Materials, properties and application review of Lightweight concrete, *37*(2), 10–15.

Nambiar, E. K. K., & Ramamurthy, K. (2006). Influence of filler type on the properties of foam concrete. *Cement and Concrete Composites*, *28*(5), 475–480. https://doi.org/10.1016/j.cemconcomp.2005.12.001

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

Pan, Z., Li, H., & Liu, W. (2014). Preparation and characterization of super low density foamed concrete from Portland cement and admixtures. *Construction and Building Materials*, *72*, 256–261. https://doi.org/10.1016/j.conbuildmat.2014.08.078

Panesar, D. K. (2013). Cellular concrete properties and the effect of synthetic and protein foaming agents. *Construction and Building Materials*, *44*, 575–584. https://doi.org/10.1016/j.conbuildmat.2013.03.024

Prasad, B. K. R., Saha, R. K., & Gopalakrishnan, A. R. (2010). Fracture behavior of plain concrete beams – experimental verification of one parameter model, *14*(3), 65–83.

Saad, S. A., Nuruddin, M. F., Shafiq, N., & Ali, M. (2015). Pozzolanic Reaction Mechanism of Rice Husk Ash in Concrete – A Review, (July), 1143–1147. https://doi.org/10.4028/www.scientific.net/AMM.773-774.1143

Salaman, T. S. (2015). Reinforced Concrete Moderate Deep Beams with Embedded PVC Pipes. *Wasit Journal of Engineering Sciences*, *3*(1), 19–29.

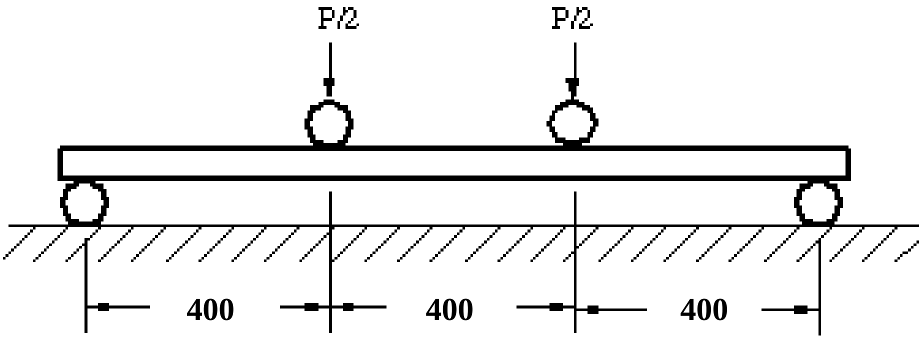
Shaikh, F. U. A., & Supit, S. W. M. (2015). Compressive strength and durability properties of high volume fly ash (HVFA) concretes containing ultrafine fly ash (UFFA). *Construction and Building Materials*, *82*, 192–205. https://doi.org/10.1016/j.conbuildmat.2015.02.068

Tan, I. A. W., Ahmad, A. L., & Hameed, B. H. (2009). Fixed-bed adsorption performance of oil palm shell-based activated carbon for removal of 2,4,6-trichlorophenol. *Bioresource Technology*, *100*(3), 1494–1496. https://doi.org/10.1016/j.biortech.2008.08.017

Tikalsky, P. J., Pospisil, J., & MacDonald, W. (2004). A method for assessment of the freeze-thaw resistance of preformed foam cellular concrete. *Cement and Concrete Research*, *34*(5), 889–893. https://doi.org/10.1016/j.cemconres.2003.11.005

Zhang, C. Y., Han, R., Yu, B., & Wei, Y. M. (2018). Accounting process-related CO2emissions from global cement production under Shared Socioeconomic Pathways. *Journal of Cleaner Production*, *184*, 451–465. https://doi.org/10.1016/j.jclepro.2018.02.284

APPENDIX A
CALCULATION (FLEXURAL STRENGTH)



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

Beam 1 - $\sigma = \frac{(4.510x10^3)(1200)}{150(200)^2}$

$$\sigma = 0.902\ N/mm^2$$

Beam 2 - $\sigma = \frac{(3.937x10^3)(1200)}{150(200)^2}$

$$\sigma = 0.787\ N/mm^2$$

Beam 3 - $\sigma = \frac{(2.830x10^3)(1200)}{150(200)^2}$

$$\sigma = 0.566\ N/mm^2$$

Beam 4 - $\sigma = \frac{(2.206x10^3)(1200)}{150(200)^2}$

$$\sigma = 0.441\ N/mm^2$$

APPENDIX B
CALCULATIONS (THEORETICAL DEFLECTION)

$$\boldsymbol{\delta = \frac{WL^3}{48EI}}$$

$$\boldsymbol{I = \frac{bd^3}{12} = \frac{(150)(200)^3}{12} = 1x10^8}$$

Beam 1 - $\delta = \frac{(4.510x10^3)(1200^3)}{48(12030)(10^8)}$

$\delta = 0.135\,mm$

Beam 2 - $\delta = \frac{(3.937x10^3)(1200^3)}{48(12030)(10^8)}$

$\delta = 0.118\,mm$

Beam 3 - $\delta = \frac{(2.830x10^3)(1200^3)}{48(12030)(10^8)}$

$\delta = 0.085\,mm$

Beam 4 - $\delta = \frac{(2.206x10^3)(1200^3)}{48(12030)(10^8)}$

$\delta = 0.066\,mm$