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

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ABSTRAK

Beam adalah anggota struktur yang terdiri daripada keluli, konkrit, kayu dan bahan komposit yang melintang mendatar antara pendukung. Secara umumnya, rasuk konkrit bertetulang adalah pilihan pilihan sebagai unsur struktur di kawasan pembinaan. Walau bagaimanapun, berat diri konkrit pancaran bertetulang telah memberi kesan yang ketara kepada jumlah beban mati jika struktur dan tegasan dikenakan dipindahkan ke asas. Masalah berat telah diatasi dengan menggunakan konkrit berbuih (FC) kerana ia mempunyai kepadatan yang lebih rendah daripada konkrit biasa. Pemprosesan Spent Diproses (PSBE) adalah SBE yang telah dirawat dan boleh digunakan sebagai pengganti sebahagian untuk simen dalam konkrit berbuih akibat kesan pozzolanicnya. Objektif kajian ini adalah untuk menentukan beban maksimum lenturan lentur dengan menggunakan lenturan ujian empat titik (mengikut ASTM D6272), pesongan rasuk, dan mod kegagalan rasuk lenturan. Ketumpatan konkrit berbuih yang direka ialah 1600 kg / m3. 30% daripada PSBE yang dimasukkan adalah penggantian simen. Terdapat empat jenis rasuk yang disediakan termasuk rasuk FC dikawal sebagai rasuk padu tanpa bahagian berongga (Rasuk 1), rasuk berongga dengan pembukaan pekeliling diameter 20mm (Rasuk 2), rasuk berongga dengan Pembukaan pekeliling diameter 50mm (Beam 3), dan rasuk berongga dengan pembukaan pekeliling diameter 60mm (Beam 4). Dimensi semua rasuk adalah sama iaitu (150mm x 200mm x 1500mm) dan setiap rasuk disediakan untuk 3 unit untuk ujian. 4 Transduser Pemindahan Variasi Lineari diperuntukkan semasa 4 titik ujian lenturan dan pesongan direkodkan dan dianalisis. Rasuk berwarna putih dicat agar corak retakan visi. Corak retak dicatatkan apabila beban digunakan sehingga kegagalan rasuk. Kekuatan lenturan Beam 1, 2, 3 dan 4 masing-masing adalah 0.902 N / mm^2, 0.754 N / mm^2, 0.664 N / mm^2 dan 0.576 N / mm^2. Rasuk yang mengalami retakan menegak juga dikenali sebagai retak utama kerana tidak ada tetulang dalam rasuk. Untuk meningkatkan kekuatan lenturan dan pesongan rasuk, tetulang perlu dilaksanakan. Kawalan kualiti buih mesti dipantau untuk mendapatkan ketumpatan yang dikehendaki dan kekuatan konkrit. Oleh itu, kekuatan lenturan dan pesongan bahagian berongga bulat berkurangan kerana saiz rongga meningkat. Oleh itu, pesongan balang berongga menurun dengan peningkatan saiz pembukaan. Semua balang telah mengalami retakan tegak kerana tidak ada tetulang.

ABSTRACT

Beam is a structural member made up of steel, concrete, wood and composite material which span horizontally between supports. Generally, the reinforced concrete beam is the preferred choice as structure element in the construction areas. However, the self-weight of reinforced concrete beam had significantly affected the total dead loads if the structures and applied stresses transferred to the foundation. The weight problem has been overcome by using foamed concrete (FC) because it has lower density than normal concrete. 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. Objective of this study is to determine the maximum load of flexural beam by using four point bending test (according to the ASTM D6272), the deflection of beam, and the mode of failure of the flexural beam. The density of designed foamed concrete was 1600 kg/m3. 30% of PSBE inserted are the replacement of cement There are four types of beam were prepared include controlled FC beams as solid beam without hollow section (Beam 1), hollow beam with the 20mm diameter circular opening (Beam 2), hollow beam with the 50mm diameter circular opening (Beam 3), and hollow beam with the 60mm diameter circular opening (Beam 4). The dimensions of all beams are same which are (150mm x 200mm x 1500mm) and each beam prepared for 3 units for testing. 4 Linear Variable Displacement Transducer are allocated during the 4 point bending test and the deflection are recorded and analysed. The beams were white painted in order to vision cracking pattern. The cracking pattern are recorded when load applied until the beams failure. The flexural strength of the Beam 1, 2, 3 and 4 was 0.902 N/mm^2, 0.754 N/mm^2, 0.664 N/mm^2, and 0.576 N/mm^2 respectively. The beams experienced vertical crack also known as ultimate crack because there is no reinforcement in the beams. In order to increase the flexural strength and deflection of beam, the reinforcement should be implemented. The quality control of foam must be monitored in order to get the desired density and concrete strength. Hence, the flexural strength and deflection of circular hollow section decreased as the size of hollow increased. Thus, the deflection of hollow beam decreased with the increase of size of opening. All the beams were undergo vertical cracking as there is no reinforcement.

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
$Ca(OH)_2$	Portlandite
C_3S	Tricalcium silicate
C_2A	Dicalcium silicate
C_3A	Tricalcium aluminate
C_4AF	Tetracalcium aluminoferrite
C-H	Calcium Hydroxide
CIDB	Construction Industry Development Board
C-S-H	Calcium Silica Hydrate
FKASA	Faculty of Civil Engineering & Earth Resources
GHG	Greenhouse Gases
H_4SiO_4	Silicium acid
IBS	Industrialised Building System
LVDT	linear variable displacement transducer
PSBE	Processed Spent Bleaching Earth
SBE	Spent Bleaching Earth

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Concrete is a material used mostly in building construction. It is a composite material that consists of essentially of a binding medium such as mixture of Portland cement and water within which embedded particles of aggregates, usually a combination of fine and coarse aggregate. Global production of cement has grown and become one of the largest emission source of carbon dioxide.(Andrew, 2017) Cement production are requires a lots of mineral sources such as calcium, limestone and silicon. (Deng, Gao, & Qian, 2014) They are many disadvantages to the environmental which lead to many pollution and health problems. Refer to the Global carbon budget 2015, carbon dioxide (CO^2) emission was recorded as 5.6% distribute among coal, oil, gas and gas flaring. The CO^2 emission of cement production had increase slight around 0.5% to 6.1% compared to year 2015.(Andrew, 2017). Therefore, some cement industry had started to replace partially by other industrial waste in order to reduce the cost and make it more eco-friendly uses.

Spent Bleaching Earth (SBE) is a solid waste originating from edible oil refinery process which generates high quantities of waste due to refining process of crude edible oil. (Beshara & Cheeseman, 2014). 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. Spent bleaching earth contain about 57% of silicon dioxide which were increase the strength of concrete. (Loh et al., 2013) The resulting calcium silicate hydrated into an extended network bonds which binds together the aggregates. This will increase the density of concrete and improve its strengths.

Foamed concrete was defined as a cementitious material that consists of minimum 20% of foam which is entrained into plastic mortar by mechanically. High rise building or skyscrapers had become trend in construction development and those buildings higher than 100 meters. (Access, 2017) For those building, the lightweight concrete are very useful in this construction sector. The lightweight concrete can reduce the dead load of building. Thus, lightweight concrete are important as they also can perform well structurally as normal weight concrete.("Structural lightweight concrete," 1981) The dry density of foamed concrete vary from 300 to 1600 kg/m^3. There are many advantages such as the use of lightweight concrete doesn't not cause freezing problem as well as thawing. The larger pores size in aggregate become more saturated and the air entrainment protected cement paste. The fire resistance of lightweight concrete also higher than the normal concrete. In addition, the lightweight concrete has lower thermal expansion and low tendency to break compared to normal concrete. High rise building is more advantaged to use the lightweight due to the reduction of weight of concrete can help easy transport and installation.

1.2 Problem Statement

The cumulative carbon dioxide emission were contributed by the cement production and fossil fuel combustion have increased by approximately 40%. (Allevi, Oggioni, Riccardi, & Rocco, 2017). Spent bleaching earth (SPE) is the bleaching of crude palm oil from physically refined palm oil and commonly direct landfill to the ground. (Beshara & Cheeseman, 2014) This type of disposal is expensive method and led to environmental degradation. (Loh et al., 2013) The disposal of oil were cause highly polluted waste water and solid waste containing waste vegetable oil (Park, Kato, & Ming, 2004). So, by using the Processed Spent Bleaching Earth (PSBE) can reduce the usage of cement and produce higher quality of concrete.

Weight of conventional concrete with high density are the main problem concerned by the structural designer. By imply the lightweight concrete, it can reduce the self-weight and total dead load to the foundation of the structures. In addition, the additional of hollow section along the beam can allow more mechanical works included wiring, electrical to pass through the beam. Besides this, the application of foamed concrete beam suitable for precast first floor and second floor beams.

1.3 Objectives

The goal of this research is to study the effect of circular hollow section on the strength of foamed concrete beam with processed spent bleaching earth (PSBE) as partial replacement of cement.

i. To determine the maximum load of the flexural beam by using 4 point bending test

ii. To determine the deflection of the beam

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

1.4 Scope of Study

This study is focused on effect of circular hollow section on foamed concrete beam with processed spent bleaching earth as partial replacement of cement. Processed spent bleaching earth foamed concrete beam were designed with density 1600 kg/ m^3 with 30% PSBE as replacement of cement. In this study, they different size of circular hollow beam were prepared and tested based on ASTM C393 for four point bending test. The ultimate loading, deflection of beam and mode of failure were obtained from the four point bending test. The test were carried out after the foamed concrete undergo 28 days of water curing. This study was carried out at the Concrete Laboratory of Faculty of Civil Engineering & Earth Resources (FKASA) in Universiti Malaysia Pahang.

1.5 Significance of Study

This study can help to reuse the waste material like Processed Spent Bleaching Earth (PSBE) for the cement replacement materials. By commercialize the PSBE into construction sector also provide alternative material for future development. This can help to save the cost of disposal of PSBE for landfill and reduce the impacts of pollution towards environment. Beside this, the hollow section beam can also decrease the usage of cement in concrete. This not only save costs and also reduce the total load towards the foundation of structures.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter was discussed about the application, physical and chemical properties of materials, constituent of materials and the properties of foamed concrete that have been review from previous researchers.

2.2 Foamed Concrete

According to Jones, the foamed concrete has a surprisingly long history and was first patented in 1923, mainly for use as the material of insulation (Ravindra, 2005). Foamed concrete are classifies as lightweight concrete as it has density about 400-1800 Kg/m^3. It also recognised by for its low cement content, low aggregate usage, and high workability. These properties can reduce dead loads and also the total loading of structure. Therefore, the reinforcement materials used in the structures such as rebar and shear links can be reduced. This also helps in reduction of foundation size, labour, transportation fees and operating costs. Nowadays, foamed concrete is widely used in the industry because its low cements content. This can reduce the cost of cement and also reduce the usage of cement impacted to environment. Furthermore, this type of concrete is considered as more economical solution in fabrication of lightweight construction material such as structural element members, partitions and other components (Amran, Farzadnia, & Ali, 2015). This is because its high workability, the concrete can easily shape to produce the designed shape and orientation.

Foamed concrete has excellent physical properties such as low self-weight, high strength, relatively superb thermal, insulation properties and audial insulation properties

(Kozłowski, 2018). Besides, it enhances the resistance and thermal conductivity of concrete. Foamed concrete also have sound absorption affect due to the surface texture and micro-structural cells. The fines surface of concrete and air voids in the foamed concrete can absorb the reflection of sound thus reduce the volume of sound.

2.2.1 Application of Foamed Concrete

Applications of foamed concrete are widely used in civil and structural engineering areas. For instant, the low density foamed concrete mainly used in cavity filling and insulation (Just & Middendorf, 2009). The high density foamed concrete also used for structural elements such as pre-cast panels and lightweight blocks. Its flow ability properties also suitable to use as a superlative material for voids such as storage tanks, basement, ducts under roadways occurred by cliff of heavy rains (Bindiganavile & Hoseini, 2008).

2.3 Constituent Materials of Foamed Concrete

2.3.1 Cement

Foamed concrete is a composite material that consists of a binder which is cement, sand and water. These comprise the constituent material of concrete. The different ratio of these material combine will form different variable, there may have problem to appear in the concrete.

Various types of Portland cement have been standardized for different uses. The type of cement depends on the condition such as the type of construction, the chemical composition of soil, the speed of construction and others factors. There are main five types Portland cement that are available in the industry. Type I, II and III are the most common and used in many situations while Type IV and V are used for specific applications.

Type I cement is normal Portland cement. Type I cement is widely used in construction such as building, retaining wall, slab and other structural elements. For example, this type of cement used for pavement construction where the concrete does not subjected to sulphate attack and heat generated during hydration process (Grove & Lahue, 1963). The cement does not cause huge rise in temperature to the structure itself and suitable for cold weather.

Type II cement is modified Portland cement. The heat content of Type II cement generates lower compared to Type I cement (Imbabi, Carrigan, & McKenna, 2012). Thus, it is more resistance to sulphate. This type of cement suitable used in hot weather because moderate heat helps in minimise the rise in temperature.

Type III cement is high early strength Portland cement. Type III cement usually used to achieve the development high strength very early in the construction. About 50-70 % out of 100% compressive strength can be reached in one day and a week after casting under ambient temperature (Lee, Lee, & Nguyen, 2016). When the concrete reached the early strength, the formwork can be removed in a short time. This can save the duration of casting and more economical compared to Type I cement.

Type IV cement is low heat Portland cement. It is used for mass project such concrete dam. The cement generate minimum amount of heat to combat the change of temperature during hardening. Type IV cement develops strength slower than Type I cement.

Type V cement is sulphate resistance Portland cement. The rate of strength of Type V cement is slower than Type I. Sulphate resistance cement is used for the structure that exposed to sulphate attack and the surround water with high acid content.

2.3.2 Sand

Different of sand to cement ratio will directly affect the strength of concrete. Different types of sand will affect the strength development of concrete (Suresh & Manjunatha, 2016). There are many properties of sand such as compression strength, moisture, permeability, flowablitiy. Thermal stability etc. When the sand mixed with water, it must adequate strength and plasticity. The heat generated during the casting caused rapid expansion of the sand surface and affect the strength development of concrete. The amount of sand used for casting increase, the amount of cement will be decreased. However, the rate of hydration will be decrease due to the low consumption of cement. The rate of hydration will be slower when compared to normal concrete.

2.3.3 Water

Water plays an important role in the preparation of concrete. The different water types will contain different percentage of impurities that may affect the setting of cement. This will adversely affect the strength and the durability of concrete. The optimum water cement ratio is 0.5 and 0.6. When the high content of water, the resulting may pores inside the concrete and then results low concrete strength, low durability and high penetrability (Apebo, Shiwua, Agbo, Ezeokonkwo, & Adeke, 2013). Besides, the quality of water used for foamed concrete must be potable and clean.

2.3.4 Foaming Agent

Foaming agent is defined as a chemical liquid which facilities the process of foaming as well as increase the stability and strength of each bubble foam, There are numerous types of foaming agent consists of protein-based, resin soap, hydrolysed protein synthetic and detergent. There are two main type of foaming agent like protein-based and synthetic foaming agent. Protein-based foaming agent is made to form lightweight concrete. The foam itself does not have any chemical reaction with concrete but it forms a layer of air trapped and no fumes are formed. This type of agent requires more energy to make foam. Calcium hydroxide and Sodium sulphate acid is the raw material to prepare this foaming agent. By adding in alkyl benzene sulfonate will improve its workability.

2.4 Effect of Pozzolanic Material

During the hydration process of conventional cement, the dominated hydration products are Calcium Silicate Hydrate (C-S-H) compound and portlandite ($Ca(OH)_2$) (Saad, Nuruddin, Shafiq, & Ali, 2015). It will produce four main compounds namely tricalcium silicate (C_3S), dicalcium silicate (C_2a, tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF).

Pozzolan is a type of additional material that improve the concrete properties like concrete strength, durability, workability and impermeability. Generally, pozzolanic reaction is an acid-base reaction between silicium acid (H_4SiO_4), which come from the reactive amorphous silica and calcium hydroxide ($Ca(OH)_2$). All pozzolanic reaction are occur when lime reactions with the siliceous pozzolanic materials. The reaction tends to occur when the hydration process is fast then create large amount of lime. The reaction also required initial water curing about 7 days. There are many waste products that consists of pozzolanic properties which can used to replace cement. The waste products such as fly ash, hazel nutshell ashes, rice husk ash can be used and there are environmental friendly materials. However, the pozzolanic materials do not have cementitious properties, they need to mix with portland cement to form cementitious properties to contribute towards the development of concrete strength. The following are the reactions occur in pozzolanic reaction mechanism.

Pozzolan	+ H2O	→	H2Sio42-	(1)
Ca(OH)2	+ H2O	→	Ca2+ + OH-	(2)
H2SiO42-	+ Ca2+	→	C-S-H (additional C-S-H)	(3)

Firstly, the pozzolan with react with water in the concrete and formed silicium ions. Secondly, the calcium hydroxide also react with water to form calcium ions and hydroxide ions. The existing silicium ions and calcium ions will then combine together with chemical reaction and formed additonal Calcium Silicate Hydrate (C-S-H) gel. The C-S-H gels will fill up the voids inside the concrete. This will make the concrete become denser. Furthermore, the amount of calcium hydroxide will be reduced and it enhance the durability of concrete (Dembovska, Bajare, Pundiene, & Vitola, 2017).

2.5 Processed Spent Bleaching Earth

Processed Spent Bleaching Earth (PSBE) is the refined product of Spent Bleaching Earth. It can produced by using solvent extraction of crude oil from bleaching method. The PSBE is in solid form and have the pozzolanic properties that are suitable as pozzolans material for foamed concrete.

2.5.1 Spent Bleaching Earth (SBE)

Spent Bleaching Earth (SBE) is a solid waste material that originating from edible oil process. SBE usually dispose through incineration, animals' feeding food sources, landfill method and also practising concrete manufactures. In Malaysia, this type of waste materials are practically used for the landfill disposal. This disposal method is costly and side effect of landfill practise. For example, the SBE will cause fire and pollution hazard as the degradation of residue oil. Besides, the wastes also potentially create the association green-house gas emissions (Loh et al., 2013).

2.5.2 Processed Spent Bleaching Earth (PSBE)

Through the process of refining crude edible oil, the large amount of SBE generated as waste material. The spent bleaching earth further undergo bleaching method then produces Processed Spent Bleaching Earth. Processed Spent Bleaching Earth (PSBE) is suitable used for cement replacement in concrete mixing. The percentage content of silica (SiO2) in the PSBE is approximately 56.9% which less 5% compared to Spent Bleaching Earth after bleaching process. The pozzolanic reaction take place when the silica in PSBE meet with Calcium Hydroxide (Ca $(OH)_2$) in the presence of water. The reaction will produce additional C-S-H gels which can help to increase the durability of concrete. Thus, the content of calcium hydroxide also decrease.

Hydration Process

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

Pozzolanic Reaction

$$SiO_2 + Ca\,(OH)_2 + H_20 = \text{C-S-H gel}$$

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

Compressive strength is defined as the ability to withstand the maximum loading until it failed to resist. Compressive strength of concrete refers to several aspects such as porosity of hardened concrete, strength of aggregates, and bonds strength hold between hydrated cement. The porosity of concrete depends on the gradation of aggregates, mixture proportion, the amount of air entrapped and entrained inside concrete and the protocol placement. The strength of aggregates refer to the maximum size and shape of aggregate. The bond strength of hydrated cement may affect by the cement proportion, cement degree of hydration as well as the shape, size and types of aggregate (Larrard, 1999). Besides these, water cement ratio also affect the strength of concrete. The higher the water cement ratio, the greater the volume of residua voids will affect the compressive strength. The compressive strength of concrete is relating to the function of water – cement ratio and density ratio (Neville, 2011). The ratio between the actual density of concrete and the density of the fully compacted concrete is the density ratio of concrete (Kearsley & Wainwright, 2001). Density of foam plays important role in the density of foamed concrete. The amount of foam used in concrete higher, the compressive strength will lower because the greater amount of foaming air voids in the concrete. Moreover, the size of fine aggregate also affect the strength of concrete. The pores size of concrete directly affected by the size of fine aggregate. The finer the size of sand will create smaller pores size and enhanced the strength of concrete.

2.7 Hollow Beam

Hollow beams are designed for the purpose of reduction of beam self-weight. This also help to decrease the total dead load on the structure elements. However, the specification of hollow beam must be design accordingly to ensure the capacity provided by hollow section is sufficient. The hollow section within the beam can used for passing the electrical utilities such as wiring parts. It also can reduce story height and construction cost. The application concrete increase very much and cause acute shortage of raw materials. Therefore, the application of hollow beam can saving the raw materials of concrete, usage of cement as well as reduce the construction cost. It was proved that there are not much difference in the load carrying capacity of solid beams when compared to the beam section with hollow neutral axis. Yet, the load capacity of hollow beam decrease when the corresponding deflection act on it increase compared to the similar properties of solid control beams (-N parthiban, 2017).

2.8 Bending

Beams made up by materials such as steel or timber are categorised as homogenous beams while concrete beam is non-homogenous beam. Within the limits of elastic behaviour, the internal bending stress distribution developed at any cross section is linear or straight line. It varies from zero at the neutral axis to the maximum at the outer fibres. The second moment of area also known as the area of moment of inertia is a property of a cross section that can be used to predict the resistance of beam to bending. Beam with higher area moment of inertia such as I-beams are common seen in building construction compared to the other beams with the same cross sectional area. The higher the moment of inertia, the greater the resistance of bending.

2.9 Deflection

The deflection of a beam are the most concern of an engineer as the structure are large and unstable. Design of beams mostly control by rigidity rather than strength. For instant, building code limits on deflections and stresses. When the beam encounter excessive deflection, there may visually disturbing and cause damage to the structure.

Furthermore, there are many analytical methods are used for determining the deflections of beams. Their basic common is the differential equation that relates the deflection to the bending moment. When a load are applied to a beam, the originally straight axes will become curve. A displacement from initial axes are bending or flexural deflections. Besides, the geometry beam's cross section also affected the deflection of beam. According to previous research, the deflection of beam is depending on the size of opening (Chin & Doh, 2015). The larger the size of the opening inside the concrete beam, the more the beam deflected (El Maaddawy & Sherif, 2009). The finite element analysis tested that the maximum deflection decreased when depth of beam decreased ((Al-Azzawi & Mahdy, 2010).

2.10 Mode of Failure

Theories from linear elastic fracture mechanics state that fractures propagate when the stress intensity factor exceed the material toughness threshold. Loading cause a crack continue propagating in its own plane perpendicular to the direction of greatest tension direction at the crack tips. Observe the crack pattern and the yielding of the steel reinforcement to determine the resulting failure. There are many failure mode classification included by the use of crack pattern, bar strain, ultimate strength, analysis of strain distribution in the main reinforcement. Fracture mode of concrete change gradually from ductile to brittle with the hydration time (Mi, Hu, Li, & An, 2018).

In order to determine the resulting failure mode of crack pattern, the basic method would be rely on the cracks appearing during the progress of the experiment. Location, orientation of the cracks, crushing of the concrete also taking consideration of classifying the type of failure mode. According to Behzad and Meghdari (2008), the research state that the shape of beam will not remain plane anymore after the deformation when the beam cracks at the edge. This is due to the shear stress near the crack tip and also affect the warping of the plane section. Besides this, the propagation of crack at mid-span of the beam may subjected by bending stress.

2.11 Bending Test

The elastic modules in bending can be determined from a flexural test. There are two types of bending test to test the flexural strength which are 3 point bending test and 4 point bending test. 3 point bending test can produces its peaks stress at the material mid-point and reduced stress elsewhere. On the other hand, 4 point bending test can produce peak stresses along the extended region of the material hence exposing a longer length of the material.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the research methodology has been carried through as well as this study were discussed. The explanations about the testing methods, the procedures of these tests, material were explained in this chapter. The study discussed about the different size of circular hollow section on the strength of foamed concrete beam with processed spent bleaching earth as partial replacement of cement. The materials used in this methodology are Portland cement, silica sand, protein foaming agent and processed spent bleaching earth powder. There are several tests were carried out based on British and ASTM standard procedure in order to support the laboratory test such as 4 point bending test. The flexural strength test were carried out after the ages of concrete reached 28 days. The concrete were curing using immersed water curing.

3.2 Research Planning

Figure 3.1 shows the research experimental flow for this study.

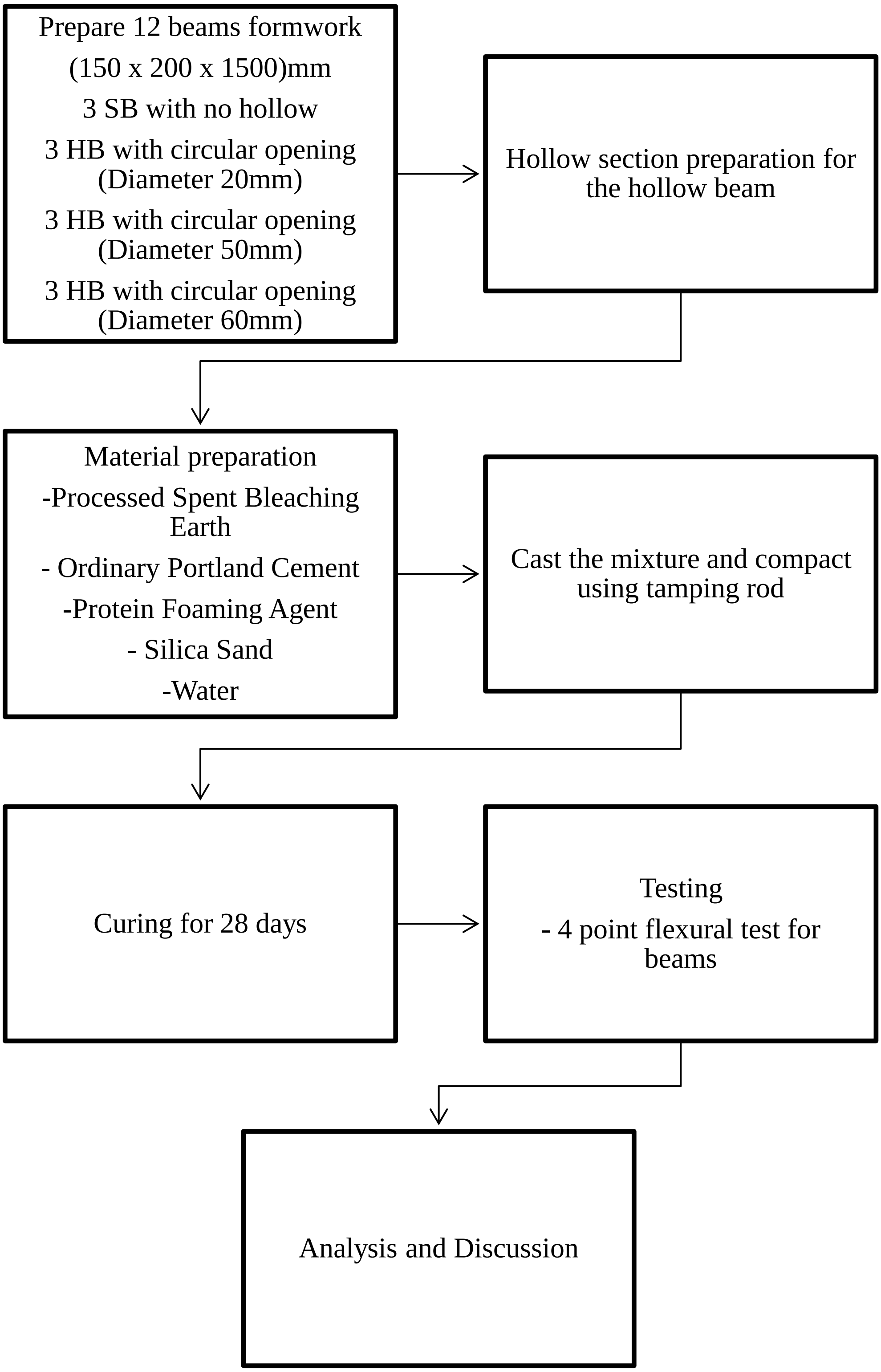

Figure 3.1 Research Experimental Works Flow

3.3 Specimen Preparation

The materials used in this study are Ordinary Portland Cement, Silica sand (fine aggregate), protein foaming agent, Processed Spent Bleaching Earth (PSBE), water. Processed Spent Bleaching Earth are the treated material from as partial replacement for cement which is substitute about 30% in this study. The sample preparation included preparation of formwork, concrete mixing, casting and curing of sample.

3.3.1 Formwork Preparation

Formwork was usually made up of steel or timber. Its function is to provide temporary or permanent molds for casting of concrete. In construction site, the formwork usually build skilled workers such as carpenter and provide support for shuttering molds.

First stage of preparation, a total number of 12 timber formwork were prepared the for the beam specimens in this research. All the formwork are in same dimension which is 150mm x 200mm x 1500mm. 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. The formwork face also cut the circular hollow section part with the designed diameter. Figure 3.2 and Figure 3.3 show the preparation of formworks.

Figure 3.2 Preparation of Formwork

Figure 3.3 Circular Hollow Section Formwork

3.3.2 Ordinary Portland cement

Ordinary Portland cement with brand "ORANG KUAT" has been selected to use in this mix proportion. ORANG KUAT cement is a product which produced by YTL Company under stringent quality assurance, environmental management, health & safety and energy management systems. Besides this, it is also certified to MS ISO 9001, MS ISO 14001, OHSAS 18001 and MS ISO 50001.

ORANG KUAT cement is a type of high strength Portland cement which suitable to use in mix proportion, easily handling and dismantle of formwork. It is also can generate high strength concrete within short period to improve the productivity. In addition, ORANG KUAT is produced by using the most advanced energy efficient cement production process. The cement also reduces the environment foot print during its production. 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

In this research, the river sand as fine aggregate were replace with alternative silica sand. Silica sand is a type of industrial sand with particularly contains high silica levels. It is normally required to be well-sorted to have grain of an approximately uniform size. The size of silica sand used is between 0.001mm to 0.6mm. Silica sand contained a high proportion of silica which is 99% of Silicon dioxide in the form of quartz. Silica sand has high compressive strength that ensures the integration of the shell mould or core while pouring. Figure 3.5 shows the silica sand used in this research.

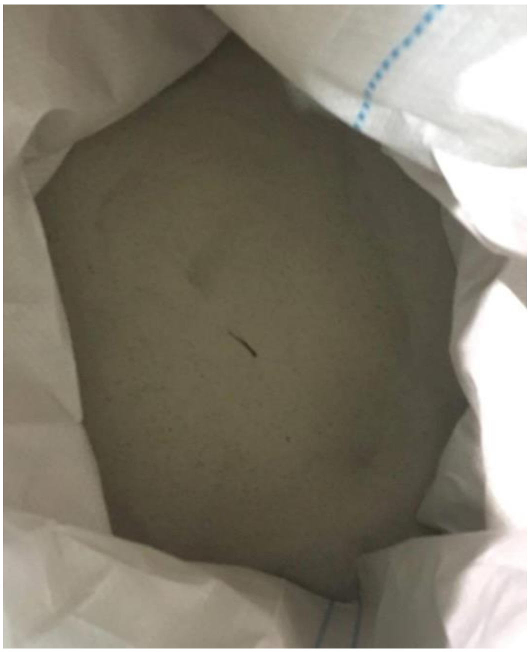

Figure 3.5 Silica Sand

3.3.4 Protein Foaming Agent

The role of foaming agent in concrete was to create small and enclosed air bubbles by reducing the surface tension of a solution and increase the stability if air bubbles. It made to form lightweight concrete and other concrete materials. The foam does not produce reaction on concrete but it serves as a layer which is air trapped and forms no fumes and toxic. Protein foaming agent requires more energy to make foam and it prepared with raw materials in the presence of Ca $(OH)_2$ and a small portion of $NaHS0_3$. Figure 3.6 shows the foaming agent that has been used.

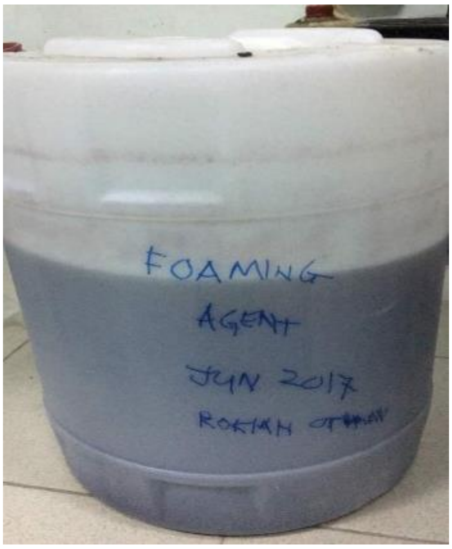

Figure 3.6 Protein Foaming Agent

3.3.5 Processed Spent Bleaching Earth (PSBE)

Processed Spent Bleaching Earth (PSBE) is the processed and treated solid waste called Spent Bleaching Earth (SBE). It is originating from edible oil refinery process which generates high qualities of waste due to refining processed of crude edible oil. PSBE is additive material that used as the cement replacement in this study. A total amount of 30% of PSBE will be replace partially the total cement used. In addition, the content of Silica Oxide (SiO_2) is 55.82% in PSBE is higher than the Ordinary Portland Cement which is 26.49%. This will help in the pozzolanic reaction where increase the amount of C-S-H gel during reaction. As a result, PSBE increase the density, workability and strength of 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 is very important as to maintain the workability, strength, permeability, durability, potential of cracking, and water shrinkage.

3.4 Mix Design

Concrete mix design is refer to the correct relative proportion of selecting ingredient of concrete, aggregates, and water in order to achieve the desirable strength. The characteristics strength of concrete is 10 N/mm^2 at 28 days and the mix design proportion of 1: 1.5. The water/cement ratio was designed as 0.5. The PSBE was added into concrete mix to replace 30% of cement. The mix proportion of PSBE foamed concrete that used for production of beams is as shown below. The mix proportion of foamed concrete that used for production of beams is as shown in Table 3.1.

Table 3.1 Mix Proportion of foamed concrete

Mixture	kg/m^3	s/c	w/c	Cement	PSBE	Sand	Foam
Foamed Concrete	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 plywood with dimension 150mmX 200mmX 1500mm. The concrete mix was mixed according to designed mix proportion. The mixtures were poured into the pre-greased formwork. This will allow to easier during dismantle the formworks. The formworks were then put on vibrating table to eliminate all the air bubbles inside by vigorously shaking the fresh pouring concrete. Then the specimens will left for 24 hours and undergo water curing after dismantle from formwork. Figure 3.8 shows the casting process for all the specimens.

Figure 3.8 Casting of the Specimen

3.6 Curing Process

In this research, the beams undergo water curing. Curing process is very important to ensure the strength development of beams under the desired moisture and temperature conditions. When Portland cement is mixed with water, a chemical reaction called hydration takes place. The reaction completed can influences the strength and durability of the concrete. Curing allow the concrete cured under sufficient moisture content in order to for further hydration. In addition, it is important for water to be retained in the concrete to prevent the evaporation and substantially reduced. As the size of beam is longer than 1 meter, the casted beams were cured by using wet gunny bag. Those beams are fully covered and must be wetted twice a day. In this research, the beams are cured for 28 days in order to achieve the desired strength. Figure 3.9 shows the curing process of the specimens.

Figure 3.9 Curing Process

3.7 Painting

Painting is the best method to observe the cracking pattern of the beams during testing. White paint was painted on the beams after 28 days of cured process. Figure 3.10 shows how the painting been applied on the specimens.

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 is a method of determining both uniaxial loading and compression stress-strain curves. The four point bending method allows for the uniform distribution between two loading blocks. There are four Linear Variable Displacement Transducers (LVDT) placed under the beam to test the deflection of the beams. One LVDT places in the middle bottom of the beam. Two LVDT placed vertically to the applied loading. One LVDT placed above the support of the beam which is 150mm from the end of the beam. These transducers are placed 1/3, 1/2, 2/3 from the effective span to measure the deflection. The effective span of the beam is 1200mm which is the position of loading applied on. All the results and reading of loading and deflection was recorded by data-logging system. The objective of the test method is to determine the maximum load of the beams and flexural behaviour. Besides, 4 point bending test can reduce the bending moment at the centre of the beam and determine the shear capacity of beam when applied load close to the support 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 have been collected from the testing were been discussed in this chapter. The results is about the effect of circular hollow section on the strength of foamed concrete beam with processed spent bleaching earth as partial replacement of cement. There are four main objectives to be discussed in this research which are the maximum load, flexural strength, deflection profile and the cracking pattern of the beams. The results obtained and relationship between the objectives have been evaluated and analysed. The maximum loading of the beams were determined by the four point bending test. Besides, the deflection of the beams is 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 are obtained by using four point bending test. During the test, the loads were applied continuously until the beams failed to resist any more load. Every cracking appear on the beams were marked and the value of loading was recorded until the beam failure.

Table 4.1 Maximum loading and Flexural Strength of Beam

Sample	**Maximum Loading (kN)**	**Flexural Strength (N/mm²)**
Beam 1	4.510	0.902
Beam 2	3.769	0.754
Beam 3	3.320	0.664
Beam 4	2.879	0.576

Table 4.1 shown the maximum loading and flexural strength for every beams that obtained from the testing. Beam 1 is the controlled beam. Beam 2 is the 20mm circular hollow section at the centre of the beam, 50mm circular hollow section for Beam 3 and 60mm circular section for Beam 4. From the result obtained, the maximum loading of Beam 1 is 4.510kN, 3.769kN for Beam 2, 3.320kN for Beam 3 and 2.289kN for Beam 4. The calculations of the flexural strength were shown in Appendix A. The flexural strength value for each beams are 0.902 N/mm², 0.754 N/mm², 0.664 N/mm² and 0.576 N/mm² for Beam1, Beam 2, Beam 3 and Beam 4 respectively.

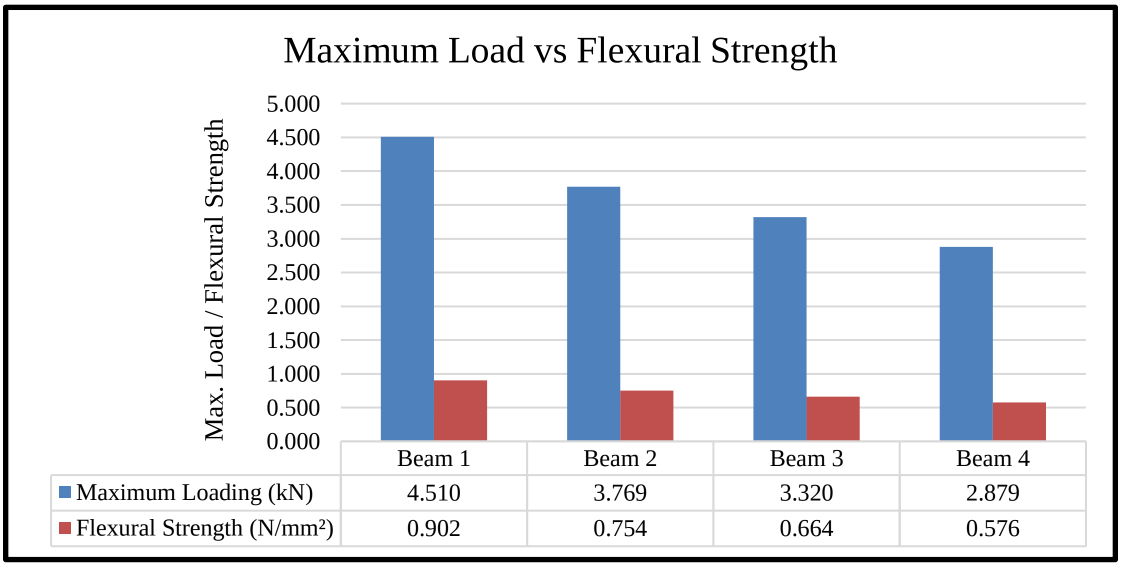

Figure 4.1 Maximum Loading and Flexural Strength of beams

Figure 4.1 shown the relationship of maximum loading and the flexural strength of the beams. From the analysis of the results, the percentage of strength lost for each beam was 16%, 26%, 36% for Beam 2, Beam 3, and Beam 4 respectively. The discussion that can be made was the maximum loading of the beam that can be resists will decrease with the increasing size of circular hollow section of the beam.

The flexural strength of beam was decreased according to the second moment of inertia or surface area of the beam. The surface area calculated was decrease gradually due to the opening size of hollow section. The surface area of controlled Beam 1, Beam 2, Beam 3, and Beam 4 was 3×10^4 mm^2, 2.97×10^4 mm^2, 2.80×10^4 mm^2, and 2.72×10^4 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 samples depends on the second moment of inertia while second moment of inertia depends on the surface area of the samples. The maximum loading of beam with hollow section decrease due to the increasing diameter of hollow section (Salaman, 2015). The flexural loading capacity affected by the hollow beam when compared to the solid beam (Jabbar, Hejazi, & Mahmod, 2016). Thus, solid beam can withstand higher load compared to hollow beam due to the reduction in concrete area.

4.3 Deflection Profile

The deflection profile of the beams are collected by using Linear Variable Displacement Transducers (LVDT). From the Four point bending test, the beams deformed when the loading applied on the beams. Three units of LVDT have been put under the beams in order to obtain the deformation profile of beams. The displacement of LVDT measured and recorded. The transducers are labelled as LVDT 1, LVDT 2 and LVDT 3. There have been place at 550mm, 750mm and 950 mm from the end of beam accordingly. As in the table, the deflection data were analysed by the percentage of the maximum loading applied to the sample which is 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). Table 4.2, Table 4.3, Table 4.4, Table 4.5 shown the results of deflection profile that gained from the three transducers from Beam 1, Beam 2, Beam 3 and Beam 4. The maximum displacement of Beam 1, Beam 2, Beam 3 and Beam 4 occurred at the LVDT 2 which is 0.330m, 0.275mm, 0.249mm and 0.212mm.

Table 4.2 Deflection Data for Beam 1

LOADING (kN) MAX LOADING = 4.510		DISPLACEMENT (mm) 1	2	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) MAX LOADING = 3.769		DISPLACEMENT (mm) 1	2	3
P_0	0.000	0.000	0.000	0.000
P_{10}	0.398	0.015	0.023	0.012
P_{20}	0.763	0.038	0.042	0.033
P_{30}	1.154	0.047	0.056	0.044
P_{40}	1.457	0.057	0.073	0.059
P_{50}	1.877	0.101	0.126	0.097
P_{60}	2.279	0.114	0.150	0.103
P_{70}	2.614	0.136	0.170	0.131
P_{80}	3.037	0.155	0.192	0.149
P_{90}	3.338	0.191	0.229	0.187
P_{100}	3.769	0.235	0.275	0.194

Table 4.4 Deflection Data for Beam 3

LOADING (kN)		DISPLACEMENT (mm)		
MAX LOADING = 3.320		**1**	**2**	**3**
P_0	0.000	0.000	0.000	0.000
P_{10}	0.361	0.010	0.023	0.014
P_{20}	0.657	0.033	0.055	0.029
P_{30}	0.984	0.047	0.061	0.052
P_{40}	1.320	0.065	0.078	0.059
P_{50}	1.708	0.075	0.103	0.079
P_{60}	1.950	0.089	0.118	0.097
P_{70}	2.252	0.108	0.127	0.111
P_{80}	2.657	0.123	0.149	0.128
P_{90}	2.865	0.144	0.177	0.147
P_{100}	3.320	0.225	0.249	0.218

Table 4.5 Deflection Data for Beam 4

LOADING (kN)		DISPLACEMENT (mm)		
MAX LOADING= 2.879		**1**	**2**	**3**
P_0	0.000	0.000	0.000	0.000
P_{10}	0.294	0.002	0.014	0.006
P_{20}	0.579	0.035	0.045	0.032
P_{30}	0.894	0.047	0.053	0.049
P_{40}	1.186	0.063	0.076	0.055
P_{50}	1.432	0.081	0.094	0.079
P_{60}	1.718	0.089	0.101	0.091
P_{70}	2.021	0.103	0.118	0.102
P_{80}	2.304	0.117	0.138	0.115
P_{90}	2.604	0.139	0.197	0.134
P_{100}	2.879	0.166	0.212	0.159

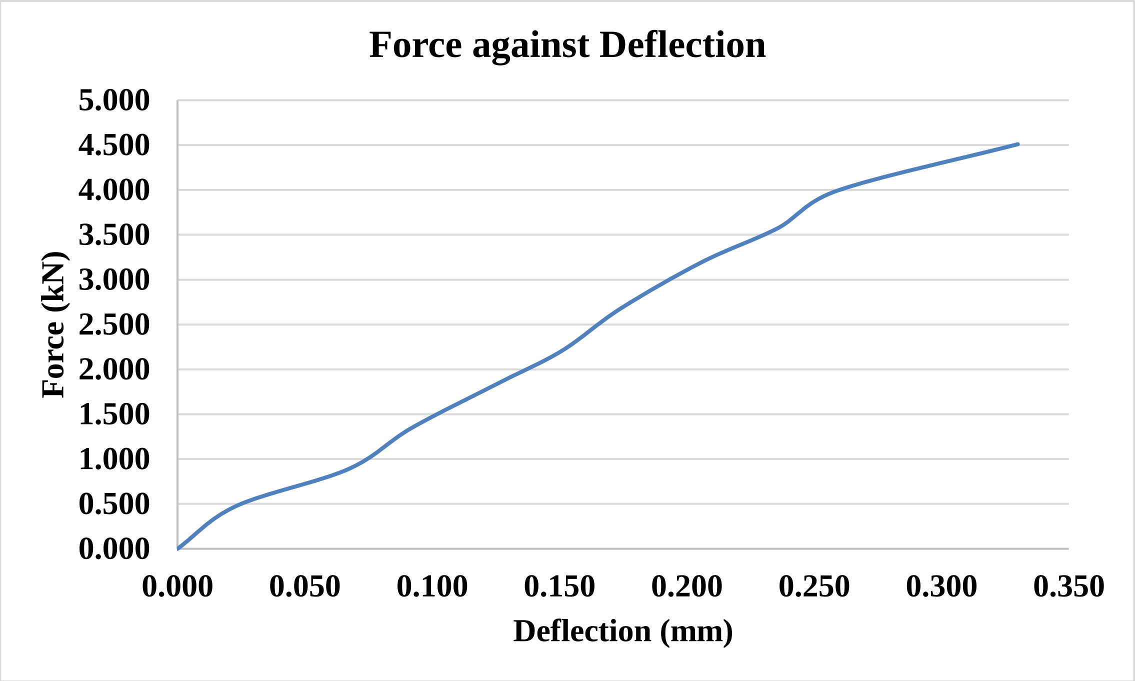

Figure 4.2 Force against deflection for Beam 1

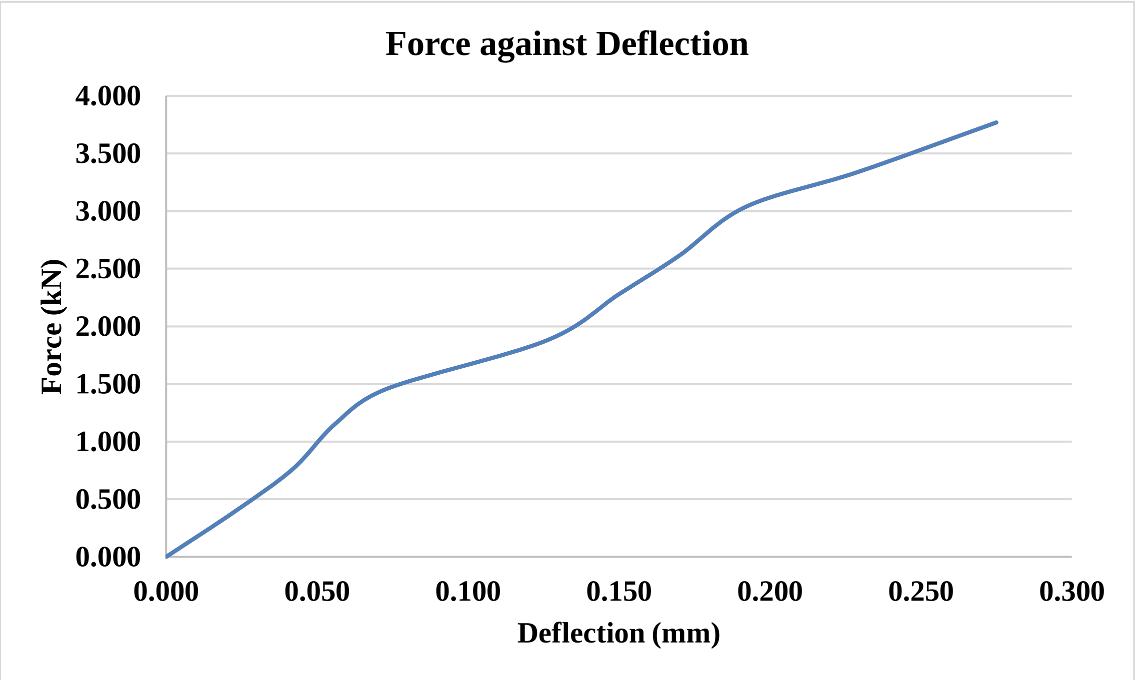

Figure 4.3 Force against deflection for Beam 2

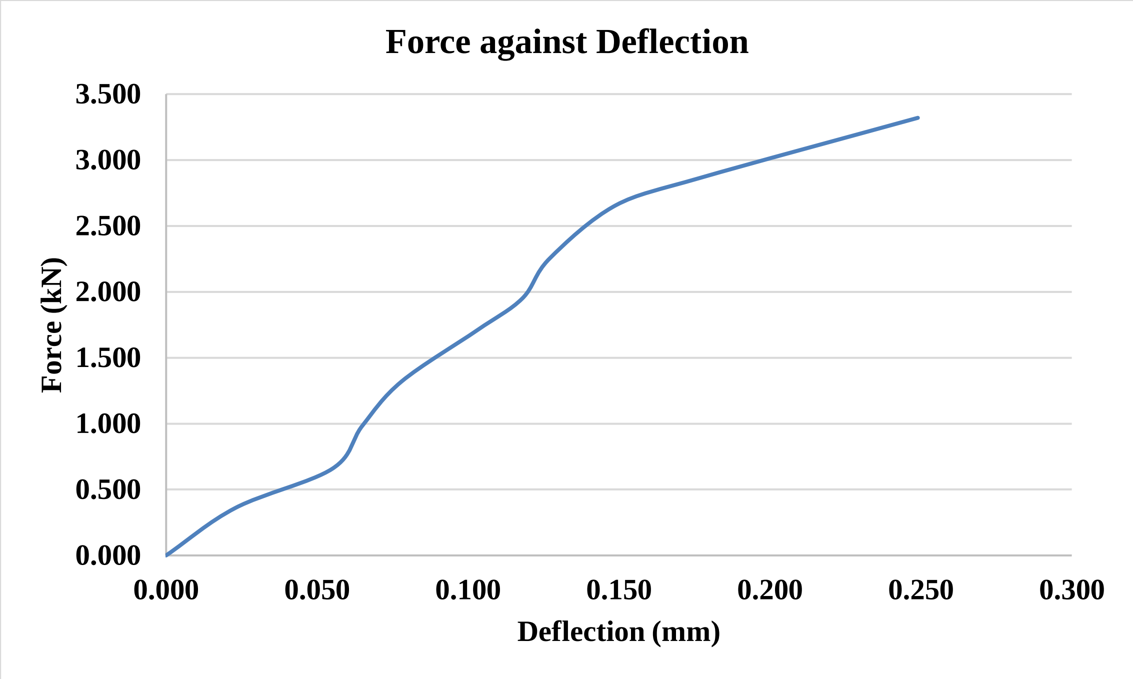

Figure 4.4 Force against deflection for Beam 3

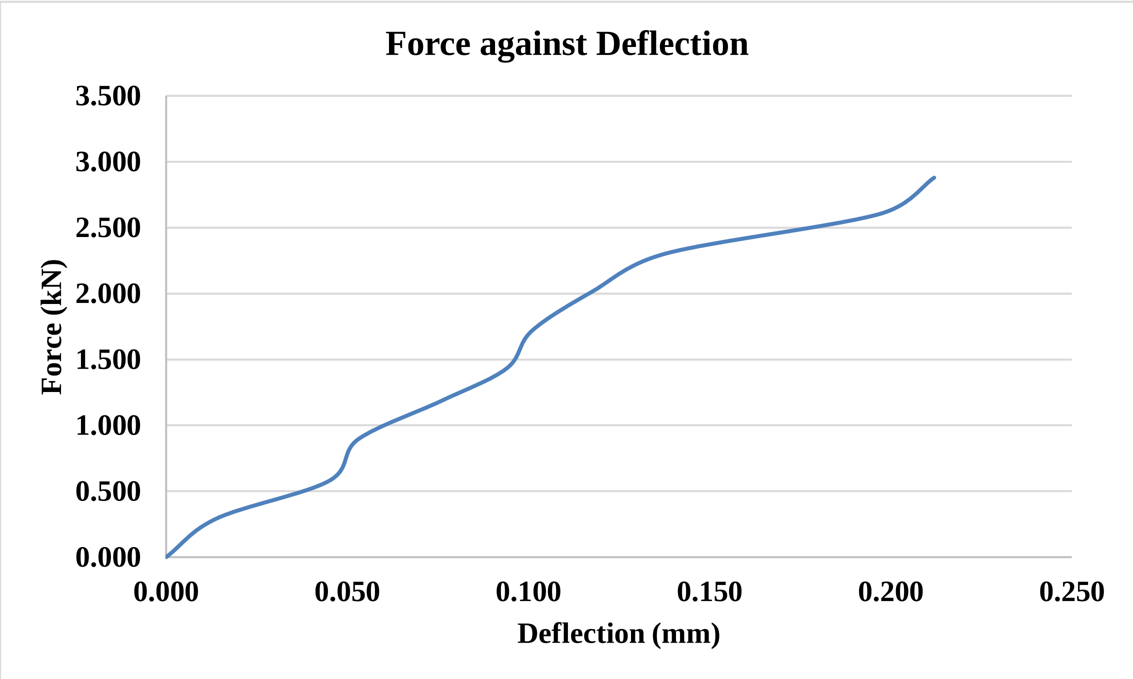

Figure 4.5 Force against deflection for Beam 4

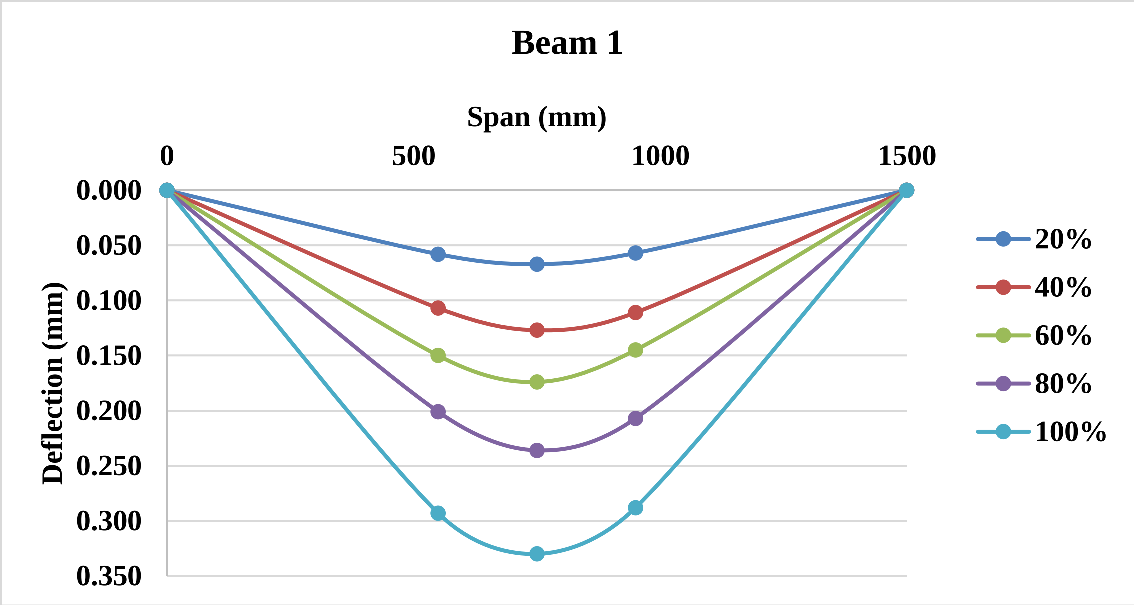

Figure 4.6 Deflection profile Beam 1

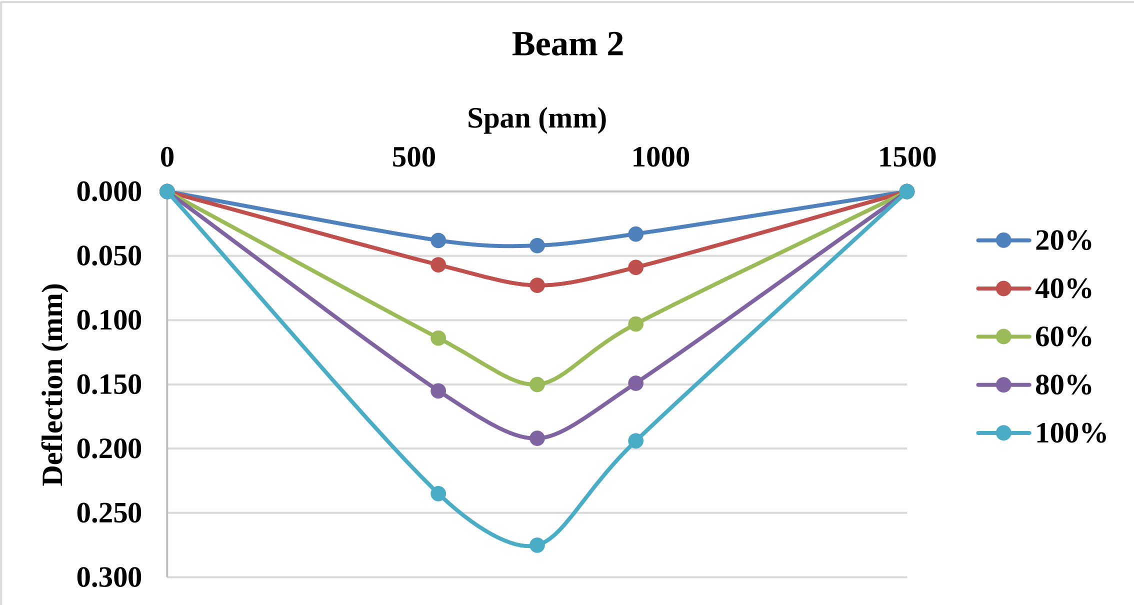

Figure 4.7 Deflection profile Beam 2

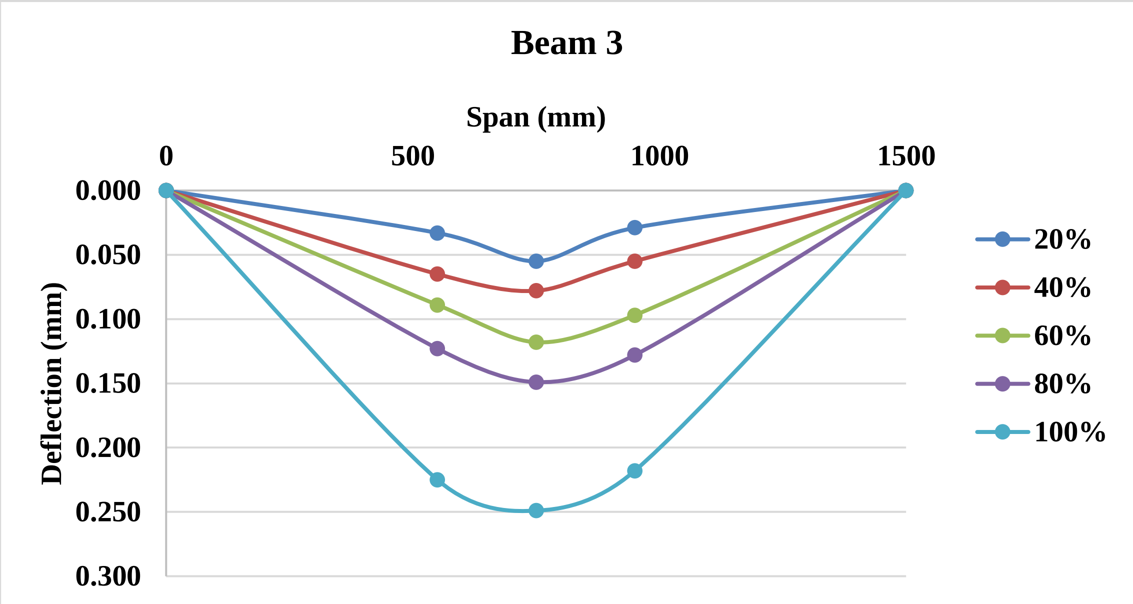

Figure 4.8 Deflection profile Beam 3

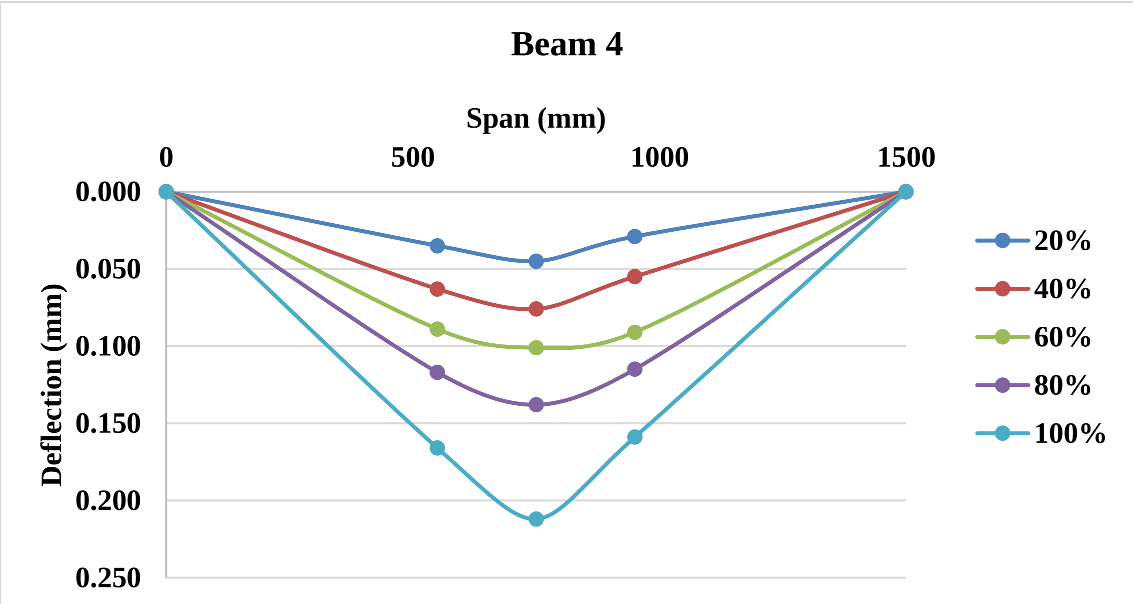

Figure 4.9 Deflection profile Beam 3

The relationship between force against deflection for Beam 1, Beam 2, Beam 3 and Beam 4 had shown in the Figure 4.2, Figure 4.3, Figure 4.4 and Figure 4.5 respectively. Refer to the plotted graph, the value of maximum deflection obtained from each beams when the maximum loading applied on the beam during testing. The deflection values for Beam1, Beam 2, Beam 3 and Beam 4 are 0.330mm, 0.275mm, 0.249mm and 0.212mm. From the result, the maximum deflection was occurring on Beam 1 as a controlled beam while the lowest deflection value was on Beam 4 which

60mm circular hollow section at centre. The deflection profile were plotted based on the various percentage of maximum loading applied on beam and the span length of the beams. The percentage of loading from 20%, 40%, 60%, 80% and 100%. The experimental deflection result were compared with the theoretical deflection by using the formula.

From the result obtained, Beam 4 has the lowest deflection value of 0.212mm among the hollow beams. Previous research stated that the deflection of hollow beam affected by the hollow sectional area (Ding, You, & Jalali, 2010). The hollow section area of Beam 4 is the biggest, thus its deflection value is the smallest compared to other beams. Therefore, the beam with hollow section has lower flexural strength and deflected less than the solid beam with the similar properties.

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 specimens 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	0.113	0.275	143.36
Beam 3	0.099	0.249	151.52
Beam 4	0.086	0.212	146.51

4.4 Crack Pattern

In four point bending testing, cracking pattern of the beams observed and analysed after the beam failure. Throughout the testing, the cracking pattern, position of cracks and type of cracks are marked and observed. All the beams experienced vertical cracking at the middle section. This vertical crack also known as ultimate cracking since there are no reinforcement steel beam. From the Table 4.7, the value of loading when the beam crack was recorded for Beam 1, Beam 2, Beam 3 and Beam 4.

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 In four point bending testing, cracking pattern of the beams observed and analysed after the beam failure. Throughout the testing, the cracking pattern, position of cracks and type of cracks are marked and observed. All the beams experienced vertical cracking at the middle section. This vertical crack also known as ultimate cracking since there are no reinforcement steel beam. From the Table 4.7, the value of loading when the beam crack was recorded for Beam 1, Beam 2, Beam 3 and Beam 4.

Table the crack pattern for all the beams were similar to each other's. Yet, the crack behaviour of Beam 1 was tend to open less wide at all loads compared to the other beams (Verbruggen, Tysmans, & Wastiels, 2016). While Beam 2, Beam 3, and Beam 4 showed the same behaviour which the crack pattern almost the same. The load applied on the beam was increased gradually with time until the beam failure to resists. When the loads applied to the rupture strength of the concrete, the beams will start to crack. Since the beams without reinforced steel, therefore, it will directly crack and this vertical crack known as ultimate crack.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

In this chapter, all the results and discussion were concluded and recommendation were stated based on this research. The result was found that the 20mm circular hollow section beam achieved the higher maximum load, higher flexural strength and higher deflection compared to the others size of circular hollow beams. There were some recommendation to improve the performance of hollow beams for the future applications.

5.2 Conclusion

This study focused the effect of circular hollow section on the strength of foamed concrete beam with Processed Spent Bleaching Earth as partial replacement of cement. The various size of the circular hollow section is the manipulation variable to study the maximum load, flexural strength, deflection and mode of failure of respectively foamed concrete beam. Based on the experimental result, the circular hollow beam with 20mm diameter had the highest strength which 0.754 N/mm^2 when compared to the other hollow beam but slightly difference with solid beam. The flexural strength was 16% less than controlled beam. The size of circular hollow vary from 20mm, 50mm and 60mm. The circular hollow beam with 20 mm diameter had the highest deflection which is 0.275mm. Thus, the deflection of hollow beam decreased with the increase of size of opening. All the beams were undergo vertical cracking as there is no reinforcement.

5.3 Recommendations

i. The results should compared with the Ansys stimulation to find the most suitable beam design for the first floor beam construction.

ii. The various shape and size of the opening hollow beams should be tested to find out the most suitable beam to apply as structural element such as first floor beam.

iii. The quality control of workmanship should be standardized to ensure the quality of beam during the experiment.

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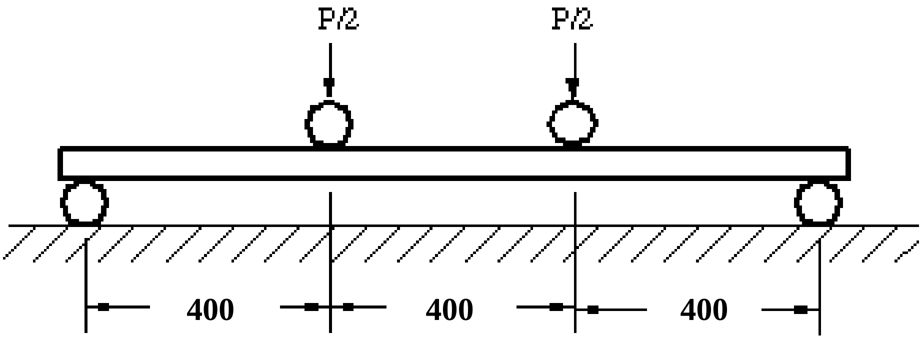
APPENDIX A
CALCULATION (FLEXURAL STRENGTH)



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

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

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

Beam 2 - $\sigma = \frac{(3.769x10^3)(1200)}{150(200)^2}$

$$\sigma = 0.754\ N/mm^2$$

Beam 3 - $\sigma = \frac{(3.320x10^3)(1200)}{150(200)^2}$

$$\sigma = 0.664\ N/mm^2$$

Beam 4 - $\sigma = \frac{(2.879x10^3)(1200)}{150(200)^2}$

$$\sigma = 0.576\ N/mm^2$$

APPENDIX B
CALCULATIONS (THEORETICAL DEFLECTION)

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

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

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

$\delta = 0.135\,mm$

Beam 2 - $\delta = \frac{(3.769x10^3)(1200^3)}{48(12030)(10^8)}$

$\delta = 0.113\,mm$

Beam 3 - $\delta = \frac{(3.320x10^3)(1200^3)}{48(12030)(10^8)}$

$\delta = 0.099\,mm$

Beam 4 - $\delta = \frac{(2.879x10^3)(1200^3)}{48(12030)(10^8)}$

$\delta = 0.086\,mm$