Experimental Study on Flexural Behaviour of Reinforced Foamed Concrete Square Hollow Beam

R Othman, K Muthusamy, P J Ramadhansyah, D Youventharan, M A Sulaiman, A A G Nadiatul Adilah

Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, 26300 Gambang, Kuantan, Pahang, Malaysia

Abstract. Nowadays construction industry continuously looking for new, better and efficient construction material and method due to environmental impact. This research reported the effect of reinforced foamed concrete square hollow beam in order to reduce the effect of the application of concrete materials. Foamed concrete with density of 1600kg/m³ is now widely used as a structural component like slab and wall due to it lighter than the normal concrete. Meantime, it helps in saving cost and reduce the use of formwork. The hollow section also can reduce the dead loads which contribute to seismic effect in high rise buildings. In addition, the Processed Spent Bleaching Earth (PSBE) is an industry waste which possess a good pozzolanic reaction is used as partial cement replacement in order to make it more environmentally friendly. The experimental program consists of casting and testing of foamed concrete beams of size 150 x 200 x 1500 mm with and without square hollow section. To study the flexural behaviour, all beams are tested after 28 days of curing subjected to four-points bending test in order to analyse the effect of the reinforcement of hollow section on the strength, deflection and mode of failure of foamed concrete beam. The performance of reinforced foamed concrete hollow square beam (RHB) under flexural shows better when compared with conventional solid beam (CSB) and hollow square beam without reinforcement (HB). The RHB exhibited greater strength with lesser deflection and cracking.

1. Introduction

In a double story house construction, there is lots of formwork being used to support the structural element on the upper floors where formwork constituent 60% of the total cost [1] of the construction. It will be the largest waste of the construction where the formwork like wooden formwork can only be used for one to two times. Even nowadays, there is other type of formwork being used in construction, but mostly construction still prefer the use of wooden as a formwork in construction. Generally, formwork is used to support the wet concrete to dry out and form to the shape. The heavier the concrete, more material will be used in formwork to support the wet concrete as a mould. Thus, a lightweight structural element can be a good way to solve the problem by having a hollow section in the middle and using a light weight foamed concrete. A hollow foamed concrete is a duality way to reduce the weight of a concrete elements. As a result, lightweight concrete needs less formwork to support the concrete. However, unreinforced hollow foamed concrete will largely reduce the strength of the concrete. Thus, reinforcement is introduced to boost the strength of hollow foamed concrete to the original strength or even stronger. Foamed concrete is a lightweight concrete used construction industry for light loaded structure like slab and wall. Foamed concrete is type of concrete with large amount of foam or air void inside the concrete in order to reduce the volume of concrete and make the foamed concrete light. Foamed concrete is constituent from cement, foaming agent, sand and water.

There is no aggregate used in foamed concrete to enhance its lightweight properties. Furthermore, foaming agent is the key to produce foam in the concrete and make concrete light. Only small amount of the foaming agent needed to mix with concrete to produce foam. The density of foamed concrete is around 400 kg/m³ to 1600 kg/m³ whereas foamed concrete with density of 400 kg/m³ is used for non-loading structure and foamed concrete with density of 1600 kg/m³ [2] can be used for light loading structure. In this study, since the design is based on the beam, thus, density of foamed concrete is chosen for 1600 kg/m³. Besides, concrete is indispensable in construction especially for the high-rise building. However, concrete need cement as an ingredient to mix up with other materials like aggregate and sand. Yet, the production of cement contributes lots of Carbon Dioxide (CO_2) [3] which will cause the greenhouse effect and global warming[4]. To make the concrete more environmentally friendly, the use of cement can be partial replace by waste materials. In this study, the waste material will be used is Processed Spent Bleaching Earth (PSBE). It is a refinery waste from palm oil industry. PSBE is chosen as a replacement of cement due to its pozzolanic properties.[5] Besides, it will be a good way to solve the landfill disposal problems cause by PSBE. By partially replacing cement with PSBE will surely make the concrete doubly friendlier to the environmental. In short, this study is conducted to determine the effect of reinforcement to the hollow section on the strength of foamed concrete beam with the flexural strength, deflection and the mode of failure.

2 Method of Research

2.1 Materials

Among the materials used to prepare specimens in this research are cement, water, silica sand, foaming agent and PSBE. Ordinary Portland cement (OPC) from a single source was used throughout the experimental work. Tap water was used for mixing and curing purposes. Foaming agent was manufactured by LCM Technology Sdn. Bhd. Kuantan, Silica sand was supplied by Johor Silica Industries Technology Sdn. Bhd and PSBE was provided by Eco Innovation Sdn. Bhd.

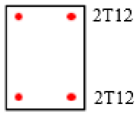
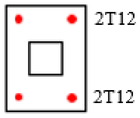
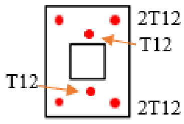
2.2 Sample Preparations and Testing

Table 1 shows the summary details of specimens. In this research, three types of beam specimens were prepared with three number for each specimen. Specimen 1, also known conventional solid beam (CSB) as control beam with no hollow section. The reinforcement for CSB was 2T12 to both top and bottom of the beam; and shear reinforcement R6 with range of 250 mm. Specimen 2 is the hollow beam (HB) with hollow section (50 mm x 50 mm) to the centre of the beam in the view of x-axis. Reinforcement of HB was used similar to CSB which is 2T12 to both tension and compression reinforcement and R6-250mm for shear reinforcement. Specimen 3 also known as reinforced hollow beam (RHB) with additional reinforcement at the hollow section (50 mm x 50 mm). The reinforcement for RHB was 2T12 to both tension and compression reinforcement and R6-250mm for shear reinforcement also. In this research, the reinforcement 1T12 was added to the top and bottom of the hollow section. All the beams were casted with 30% of PSBE as partially cement replacement. Flexural strength of the beam was calculated using the formula for four-point bending test which involved the maxing loading of the beam. Equation (1) shows below was the formula used to calculate the flexural strength.

$$\sigma = \frac{FL}{bd^2} \qquad \text{Eq. 1}$$

The beams were air cured for 28 days and painted to ease the observation of cracking pattern. All the specimens were tested using 4 points bending test to collect the data of maximum loading, deflection and cracking pattern. The load was applied constantly until the beams were failed to resist loading. Three LVDT were used to record the deflection of the beams. two of the LVDT were placed under the loading point while one LVDT was placed to the centre of the beams. The supports were placed to 150 mm from both end of the beam. Meanwhile, the loading points were set to 200 mm from the centre of the beam to the both sides. The data was record and analysed to obtain the result of testing. The testing was according to the ASTM D6272 where the span of loading was one third of the support span. Figure 1 below shows the testing set up of 4 points bending test. Figure 2 shows the setup of LVDT under the beam. Figure 3 shows the specimen setup of 4 points bending test.

Table 1: Summary detail of specimens

Specimen	Hollow Section	Shear Link	Details
1 Conventional Solid Beam (CSB)	-	R6-250mm	
2 Hollow Beam (HB)	50 x 50	R6-250mm	
3 Reinforced Hollow Beam (RHB)	50 x 50	R6-250mm	

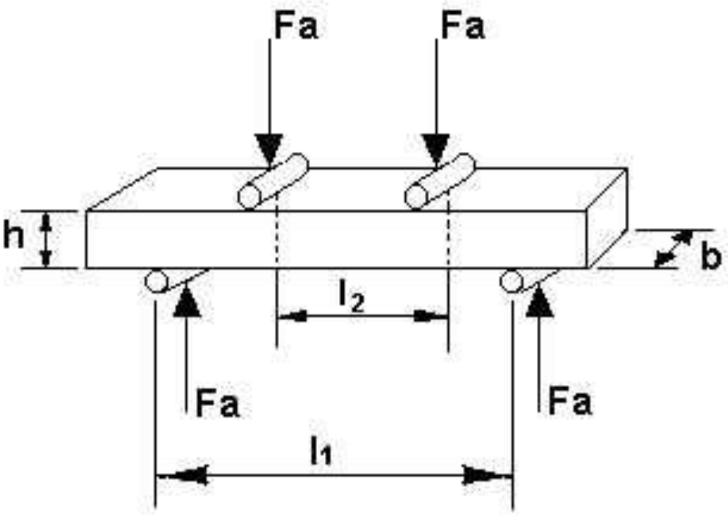


Figure 1: Four points bending test

Figure 2: Setup of LVDT

Figure 3: Specimen Setup of four points bending test

3 Result and Discussion

3.1 Flexural Strength

Flexural strength was determined from the maximum loading obtained from the testing and the parameter of the beam. Table 2 shows the summary of maximum loading obtained from testing and the flexural strength calculated based on equation 1. Specimen 1 (CSB) can resist highest loading of 31kN and continuously by specimen 3 (RHB) and specimen 2 (HB) with 20kN and 18kN respectively. While, the values of flexural of each specimen of CSB, HB and RHB were 6.20 N/mm², 3.70N/mm² and 4.00 N/mm² respectively. Hence, the flexural strength presents the strength capacity [7] of the beam.

Table 2: Summary of maximum loading and flexural strength of specimens.

Specimen	Max Loading (kN)	Flexural Strength (N/mm²)
1 (CSB)	31.00	6.20
2 (HB)	18.00	3.70
3 (RHB)	20.00	4.00

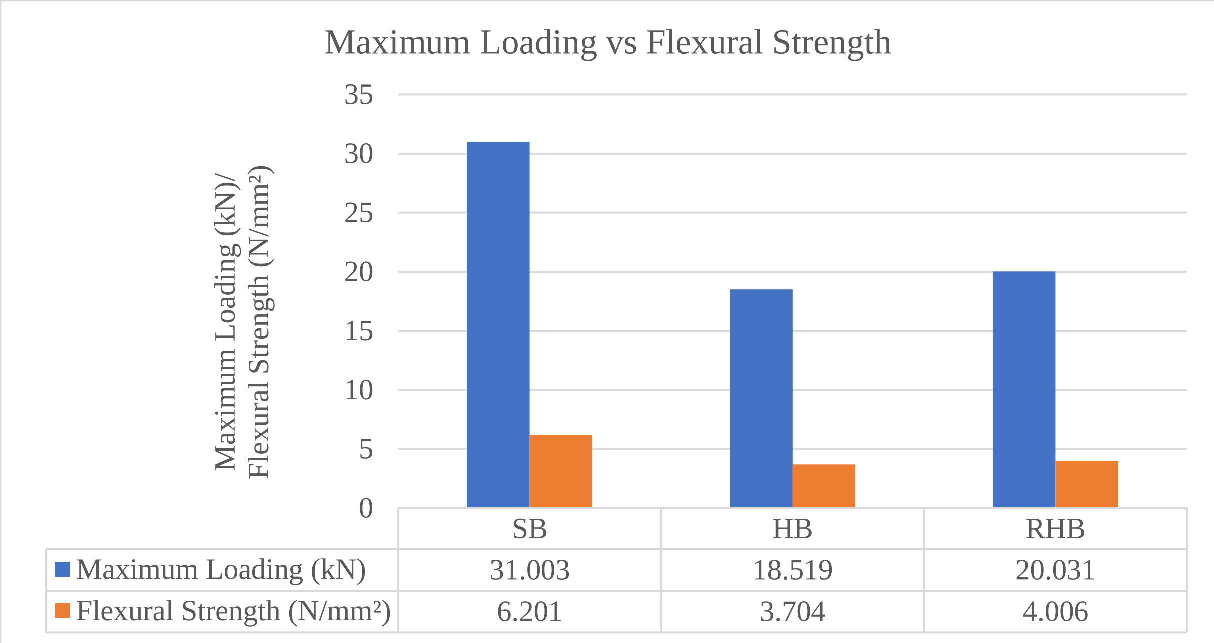


Figure 4: Maximum loading and Flexural strength

Figure 4 shows the comparison between the maximum loading and flexural strength for each specimen. Based on the analysis, the maximum loading HB and RHB specimen were lower 40% and 35% respectively compared to CSB. It shows that the hollow section was affecting the strength of the beam. Even though there was reinforcement added to both top and bottom of the hollow section, but solid beam still resists more loading compared to the beam with hollow section. However, RHB specimen with reinforcement around the hollow section having 7.5% higher flexural strength than the HB specimen. Thus. the reinforcement increased the strength of the beam. Nevertheless, the flexural strength of hollow beam was less compared with solid beam [8].The solid beam can resist more loading compared to the hollow beam.

3.2 Deflection profile

In this study, deflection profile was analysed through linear variable displacement transducer (LVDT) while beam undergoes deformation. Table 3 shows the deflection data of the specimens. From the analysis, the CSB specimen was the highest maximum deflection compared to HB and RHB specimen with 8.60 mm, 5.10mm, and 4.0 mm respectively. By comparison of the specimens, the deflection of beam decreased with beam with hollow section. It should be noted that the beam with hollow section exhibits in lesser deflection compared to solid beam[9,10]. Through comparison of HB and RHB, deflection decreased with beam with higher reinforcement.

Table 3: Summary of deflection data.

Specimen	Deflection (mm)
1 (SB)	8.60
2 (HB)	5.10
3 (RHB)	4.0

3.3 Crack pattern

Figure 6 shows the crack pattern in the all the tested beams. The beams were crack while it reaches the limit to resist the loading. The crack pattern of the beam was observed after the loading test. The crack pattern for all the specimens were slanting crack as shown in Figure 6. The slanting crack was also known as a shear crack which the beams were failed in shear due to insufficient shear reinforcement designed to the beam.

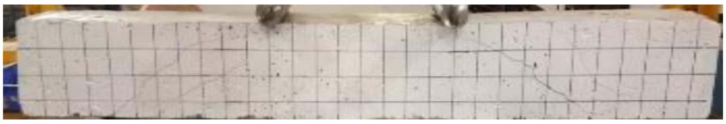
Specimen	Cracking Pattern	Failure Mode
1 (SB)		Shear crack
2 (HB)		Shear crack
3 (RHB)		Shear crack

Figure 6: Crack pattern of beam

4 Conclusions

Based on the experimental results, the hollow section affects the behaviour of the beam even more reinforcement added to reinforce the hollow section. Conventional solid beam (CSB) exhibits the highest maximum flexural strength and deflection as compared to hollow beam HB and RHB. However, the reinforced hollow beam (RHB) gain 5% strength compared to hollow beam (HB) due to slightly effect of the reinforcement around the hollow section. In addition, the RHB exhibits lower deflection compared to CSB and HB. While, all the beams experienced shear cracking as slanting crack due to insufficient design shear reinforcement. Thus, the RHB can be used as a light structure beam of a building especially for the roof beam which receive less loading from roof.

References

[1] Nemati KM 2007 Formwork for concrete University of Washington

[2] Harith IK 2018 Study on polyurethane foamed concrete for use in structural applications *Case studies in construction materials* **8** 79-86

[3] Andrew RM 2018 Global CO 2 emissions from cement production. *Earth System Science Data* **10(1**):195.

[4] Ali N, Jaffar A, Anwer M, Khan S, Anjum M, Hussain A, Raja M, Ming X 2015 The greenhouse gas emissions produced by cement production and its impact on environment: A review of global cement Processing *International Journal of Research* **2(2**) 488-500

[5] Arpornpong N, Charoensaeng A, Khaodhiar S, Sabatini DA 2018 Formulation of microemulsion-based washing agent for oil recovery from spent bleaching earth-hydrophilic lipophilic deviation concept. Colloids and Surfaces A *Physicochemical and Engineering Aspects* **541** 87-96.

[6] Loh SK, James S, Ngatiman M, Cheong KY, Choo YM, Lim WS 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** 775-81.

[7] Nakamura H, Nanri T, Miura T, Roy S 2018 Experimental investigation of compressive strength and compressive fracture energy of longitudinally cracked concrete *Cement and Concrete Composite*s **93** 1-8

[8] Alnuaimi AS, Al-Jabri KS, Hago A 2008 Comparison between solid and hollow reinforced concrete beams. *Materials and Structures* **41(2)** 269-86.

[9] Al-Azzawi AA, Mahdy AH, Farhan OS 2010Finite element analysis of deep beams on nonlinear elastic foundations *Journal of the Serbian Society for Computational Mechanics* **4(2)** 13-42.

[10] Abidin AF 2014 The Behaviours of Lighweight Foamed Concrete Beam with Different Size of Square Hollow Section (Doctoral dissertation, UMP).

Acknowledgement

The authors would like to acknowledge the help and co-operation received from the lecturers and technical staff of Universiti Malaysia Pahang in conducting the experimental work. The financial support received from Universiti Malaysia Pahang through grant RDU150383 is highly appreciated.