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Finite Element Analysis on the Effect of Hollow Section on the Strength of Foamed Concrete Beam

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Abstract. The environmental impact of cement production has prompted innovative measures to reduce the usage of cement in accordance with the principle of sustainable construction. At the same time, the palm oil industry generates about 2 million tons of spent bleaching earth (SBE) are generated annually with most of it ends up in the landfill, causing environmental degradation. This research focuses on the effect of hollow section on the strength of foamed concrete beam by using processed spent bleaching earth (PSBE) as partial cement replacement. Hollow section of two shapes were implemented at three different locations along the beam specimen. The foamed concrete beams with 30% cement replaced with PSBE were subjected to tensile test at 28 days to observe the effect of hollow section on the maximum load and tensile strength. The deflection of the specimen was compared with theoretical value and the mode of failure was studied. Hollow section of circular and square shape was studied while the locations were on neutral axis, above neutral axis, and below neutral axis. Verification of experiment was conducted using Finite Element Analysis (FEA) software, ANSYS. Test result shows that beams with circular hollow section has higher strength than those with circular hollow sections. The best position of hollow was above the neutral axis as to not impact the weak tensile strength of foamed concrete. FEA analysis shows great accuracy in predicting the performance of the specimens.

1. Introduction

Concrete is the most-used material in the construction industry. Cement is the basic material for producing concrete. However, the production of cement involves greenhouse gas emission and is very dusty. Dust particle from about 1 to 100 μm in diameter is a hazard to human health and also causes smog [1]. In the modern day, the Global Goals, or Sustainable Development Goals (SDGs) had called for action to reduce the environment impact of urbanization. Foamed concrete has many advantages such as high strength-to-weight ratio, low dead weight, and economical [2]. Waste material can be used in foamed concrete mix to promote green construction. Researchers had attempted to recycle palm oil fuel ash, fly ash, glass powder, and more in concrete mix [3]. Spent Bleaching Earth (SBE) is a hazardous waste that causes environmental degradation. About 2,000,000 tons of SBE are generated annually [4]. As one of the biggest producers of oil, Malaysia generates huge quantity of the waste. However, most SBE in Malaysia ends up in the landfill. That is a huge waste because energy may be recovered from SBE as it contained about 20-40% residue oil [5]. The usage of cement can be reduced by using lightweight concrete as load-bearing members. With aggregate taking up about 65-80% of the weight of normal concrete, foam concrete which does not use aggregate is significantly lighter [6]. Hollow concrete beam optimizes the strength and weakness of concrete material. Hollow section can serve as a pathing for mechanical and electrical works [7]. Concrete is strong in compression but weak



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in tension. According to the loading condition of a concrete member, the concrete at the tension zone is often disregarded in design [8]. This has prompts various research reducing the volume of the member with hollow section at the area in which the strength loss is minimal [7-9]. Hollow lightweight concrete beam is applicable to the upper storey of buildings or the roof level, whereby the imposed load is the lowest. The lightweight nature of foamed concrete eases the usage of Industrialize Building System (IBS) in the project. The concept of IBS started in the 1960s, but Malaysia is now encouraging the usage of it due to various benefits. IBS saves time and labor cost while ensuring better quality and workmanship of the work [11]. IBS also reduces the usage of formwork, which may contribute up to one-third of the cost in a project [12].

2 Method of Research

2.1 Materials

The materials used to prepare concrete specimens in this research are cement, water, fine aggregate, foaming agent and PSBE. Ordinary Portland Cement (OPC) of grade 52.5N from YTL Cement was used. Silica sand was used as fine aggregate in this study. The size of silica sand was from 0.001mm to 0.6mm. Casting and curing of foamed concrete was done using Tap water from the laboratory. Protein forming agent was used. The forming agent was prepared with raw material in the presence of $\text{Ca}(\text{OH})_2$ and a small portion of NaHSO_3 . Foaming agent has no reaction with concrete, but it served as a layer to trap air for producing formed concrete. It also forms no fume and is non-toxic. The forming agent was diluted with a ratio of 1L forming agent with 25L water. PSBE was used as the pozzolanic material of foamed concrete. It is in fine powder form and mixes well with concrete to enhance secondary pozzolanic reaction which improves the performance of concrete. Figure 1 and 2 shows the forming agent and PSBE used in the experiment.

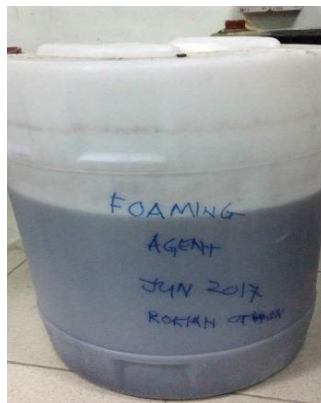


Figure 1: Forming agent before dilution



Figure 2: Processed spent bleaching earth

2.2 Sample Preparations and Testing

Seven concrete beams with different hollow shape and position were prepared in this experiment. The size of the specimen was $150\text{mm} \times 200\text{mm} \times 1500\text{mm}$. The mix proportion of the specimens were the same, except the control, which was shown in Table 1. The various condition of hollow was presented as in Figure 3. The size of square hollow section was $50\text{mm} \times 50\text{mm}$ while the size of circular hollow section was 50mm diameter. The design density of formed concrete was 1600 kg/m^3 and the cement sand ration used was 1:1.5. Water cement ratio was set to be 0.50. The control sample was casted without PSBE replacement and hollow section, while 30% PSBE was used to replace cement in the six studied specimens. Casting was done with mixing drum and the specimen was demoulded after 24 hours. All specimen was immersed in water for 28 days. Flexural test was conducted in accordance to BSEN 12390-5 [16]. At the same time, the specimens were modelled using ANSYS to conduct FEA. The result of flexural strength and deflection was compared for accuracy.

Table 1: Mix proportion of specimens

Mixes	Cement (kg/m^3)	Silica sand (kg/m^3)	Foam	PSBE	Water (kg/m^3)
Control	288	432	12.96	-	144
Specimens	201.6	432	12.96	86.4	144

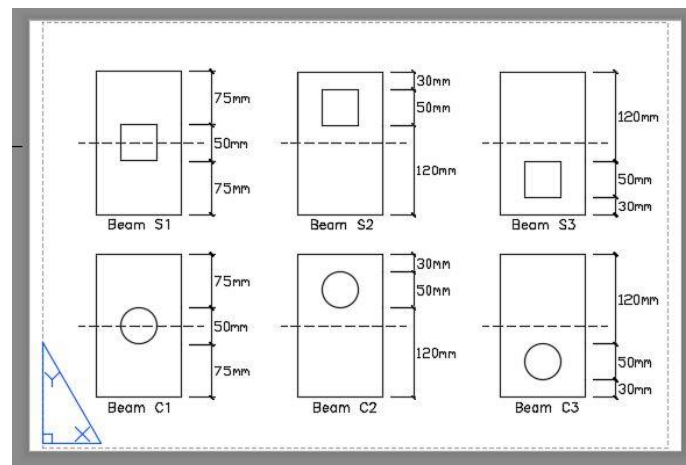


Figure 3: Hollow shape and position of specimens

3 Result and Discussion

3.1 Experimental Result

Figure 4 and 5 shows the result of flexural test. It was clear that the control without any hollow section sustained the highest amount of load before failure. For specimens were hollow section, two trends could be observed. First, specimens with circular hollow section performed slightly better than those with square hollow section. Second, specimen number 2 had the highest maximum load and flexural strength within the hollow shape group. The trend can be attributed to the properties of concrete. Concrete has strong compressive strength but weak tensile strength. The tensile strength of concrete material is only about 20% of its compressive strength. This applies even to form concrete. When an axial load was applied on the beam, the top half of the beam's cross section experienced compression while the bottom half of the beam experienced tension. In this study, the foam concrete beams were unreinforced, making them vulnerable at the tension zone, which is the section below the neutral axis [13]. The maximum load of the specimen decreased because the volume of concrete at the tension zone reduced. The effect followed the expectation of the study. When the hollow section was located above neutral axis however, the ultimate load became higher. This can be explained with the compressive strength of the specimen was adequate to resist the ultimate loading. All specimen failed

due to tensile force instead of compression force. Hence, shifting the hollow section to above neutral axis had no effect of weakening the beam [9]. Instead, the foam concrete beam resisted maximum loading as there was no hollow section on the tensile zone. As a result, the ultimate loading increased slightly.

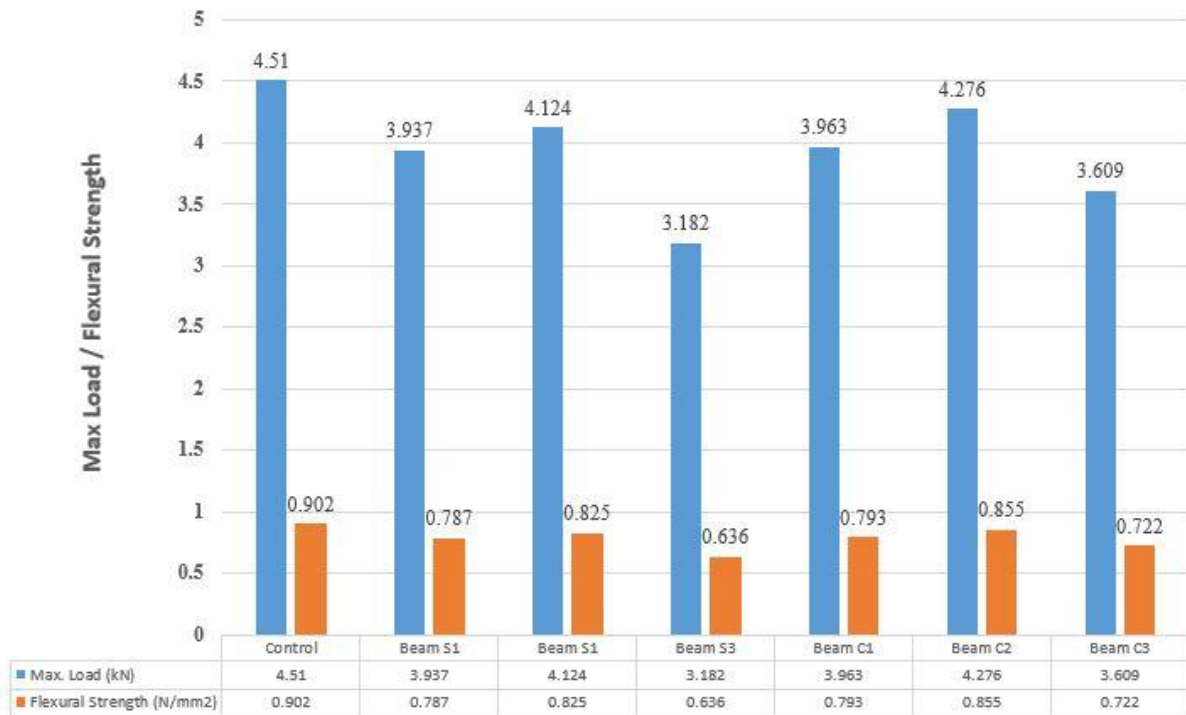


Figure 4: Maximum load and flexural strength



Figure 5: Flexural test of specimen

3.2 Finite Element Analysis

Table 2 and 3 shows the comparison between experimental, FEA, and theoretical data. For flexural strength, the greatest differences between laboratory experiment and ANSYS modelled value was only 6.31%. This indicates that FEA method is a very accurate approach to conduct structural analysis of foamed concrete with hollow sections. The result also agreed with similar study of finite element analysis on flexural behaviour on concrete beam [14]. For deflection, approximately 30% error was recorded when comparing the result between ANSYS software and theoretical value. The error was

however minor, and more importantly the result pattern agreed with theoretical value. The consistent deviation happened because hollow foam concrete beam did not fully obey the theory of an ideal concrete beam.

Table 2: Flexural strength differences

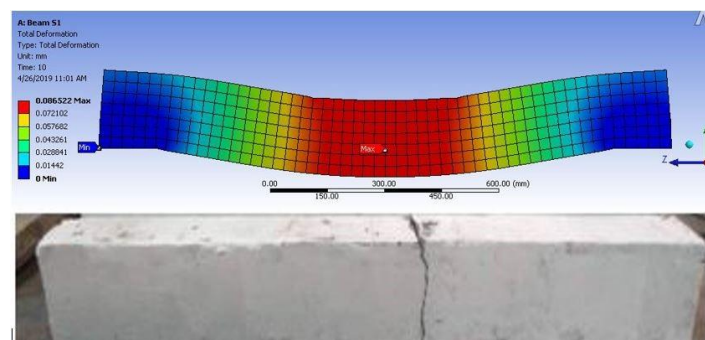
Sample	Experimental		FEA		Differences (%)
	Maximum Load (kN)	Flexural Strength (N/mm ²)	Maximum Load (kN)	Flexural Strength (N/mm ²)	
Control	4.510	0.902	4.571	0.914	1.35
Beam S1	3.937	0.787	3.940	0.788	0.08
Beam S2	4.124	0.825	3.980	0.796	3.49
Beam S3	3.182	0.636	3.338	0.668	4.90
Beam C1	3.963	0.793	3.989	0.798	0.66
Beam C2	4.276	0.855	4.015	0.803	6.10
Beam C3	3.609	0.722	3.837	0.767	6.31

Table 3: Deflection differences

Sample	Maximum Deflection (mm)		Differences (%)
	Modelled Value	Theoretical Value	
Control	0.0865	0.125	30.8
Beam S1	0.0882	0.126	30.0
Beam S2	0.0758	0.106	28.5
Beam S3	0.0858	0.126	31.9
Beam C1	0.0870	0.127	31.5
Beam C2	0.0849	0.122	30.4
Beam C3	0.0865	0.125	30.8

3.3 Mode of Failure

Finite Element Analysis did not show the failure of specimen directly, but it was possible to predict the development of crack through the deformation profile. Since this study simulated four-point bending test, the critical region where stress was the highest was the area between the two loading points. From Figure 6, it was shown that the 'red zone' of the deformation chart fell in between two points where load was being applied. The maximum deformation occurred at the mid-span of the beam, so the first crack of the specimen was located at the mid-span and propagated through the beam in a line. This agreed with the laboratory study. All beam failed under the same condition of ultimate crack. Ultimate crack refers to a crack that occurs abruptly due to the lack of reinforcement on a concrete member. The result is similar with the similar study of crack propagation using finite element method [15].

**Figure 6:** Deflection profile of modelled and actual specimen

4 Conclusions

Based on the results from both experimental and modelling, it is concluded that beam with circular hollow section has better performance compared to square hollow section. The best position for unreinforced foamed concrete beam is above the neutral axis. Verification with ANSYS shows great accurate for flexural strength and deflection of beam with minor deviation.

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