

Strength of Cockle Shell Foam Concrete-Filled Hollow Added Steel Fibre

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Abstract

Building columns made of concrete-filled sections have become increasingly popular due to their architectural and structural benefits. Foamed concrete, in particular, has been receiving attention as a potential construction material for hollow sections because of its unique structural characteristics. However, its performance as an infill material requires further investigation. Therefore, a study to assess the strength of hollow sections filled with fibrous cockle shell foam concrete was carried out. 3 specimen with cockle shell filled hollow section with the size of 100 x 100 x 2 mm thickness was prepared. This 350 mm long specimen later was tested under compression load. A comparison with unfilled concrete was carried out. From the result, it was found that the ultimate strength capacity of the experimental values is lower than the theoretical values based on Eurocode 4. The largest percentage deviations between theoretical and experimental results, for a thickness of 2mm, are 70% for cockle shell foam concrete with added steel fiber and 36% for cockle shell foam concrete without steel fiber.

1. Introduction

The construction industry is increasingly favoring steel hollow sections due to their superior structural performance and versatility. However, the conventional use of concrete infill in these sections presents challenges in terms of weight, cost, and overall performance. Therefore, the use of lightweight concrete filled is one of the alternative. Foamed concrete is a lightweight alternative to normal weight concrete, offering high flowability, minimal aggregate consumption, light self-weight, controlled small strength, and excellent thermal insulation properties. Its properties depend on the foam quality and quantity, and can be customized within the dry density range of 300-1850 kg/m. Foamed concrete has traditionally been used for insulating foundations, retaining walls, backfill, and filling roof tiles for soundproofing. However, it takes longer to prepare and has higher drying shrinkage due to the lack of coarse aggregates (Kozlowski, 2018).

The compressive and flexural strengths of lightweight foamed concrete decrease with a decrease in density. The compressive strength of foam concrete filled hollow sections (FCFHS) with added polypropylene fiber is higher than the one without fibre (Ramli & Abd Rahman, 2022). Foamed concrete is permeable to water vapor and carbon dioxide, making it potentially corrosive. However, foam concrete is fire and water-resistant due to its aeration agent, which absorbs humidity for as long as the product is exposed to the atmosphere.

Reinforced foamed concrete filled in 100x100x350mm hollow steel has improved compressive strength by adding fibers. However, research shows that 2mm thick steel fibre foamed concrete filled hollow sections experience concrete crushing failure, while 4mm thick specimens fail due to local buckling (Pilai & Abd, 2023).

Currently, the study on improving the foam concrete by replacing fine sand such as rice ash and fly ash was carried out. A study by Khairuddin (2020) on concrete filled hollow section using steel fiber in short columns found that adding rice husk ash (RHA) resulted in good strength and bonding between concrete and steel hollow section. Another study by Murad (2021) about the use of fly ash (FA) as sand replacement to foam concrete shows higher strength compared with normal foam concrete. Cockle shell is one of the potential material to add in foam concrete as sand replacement. Both of this material is considered as a green material. Cockleshell is one the green materials and has a potential material to add to foam concrete as a sand replacement. Cockleshell, the outer layer of small edible clams, is a durable and cost-effective biomaterial with a high calcium concentration. Its structure is light, lightweight, and low thermal conductivity. The inclusion of cockle shells in concrete affects its compressive, flexural, tensile, and elastic strengths, as well as its modulus of elasticity. However, the introduction of cockle shells typically reduces early strength and results in lower strength when used as a partial cement replacement. Cockle shell concrete has greater load resistance than control samples, and the resistance depends on the volume of the replacement material. Using less cockle shells can prevent concrete isolation and bleeding, while adding more sand can increase density and weight.

This research explores the integration of foam concrete, steel hollow sections, and steel fibers to develop lightweight, robust, and long-lasting composite structures. The study specifically investigates the tensile characteristics of cockle shell foam concrete filled within steel hollow sections and reinforced with steel fibers.

The research adds an eco-friendly and cost-effective dimension by using cockle shell, a locally accessible waste material. The experimental program aims to evaluate mechanical properties such as compressive strength, flexural strength, and energy absorption capacity, contributing valuable insights to structural engineering. The findings are expected to have practical implications for designing and constructing efficient structural systems, particularly in weight-sensitive applications like tall buildings, offshore platforms, and modular construction.

The problem statement highlights the difficulties with traditional approaches of filling steel hollow sections with regular concrete and identifies the limitations of normal foam concrete. The research addresses the feasibility of using cockle shell as a mixture substitute to enhance the overall performance of foam concrete-filled steel hollow sections. The study aims to determine the strength index of cockle shell foam concrete-filled hollow sections and compare the strength difference between cockle shell foam concrete-filled hollow sections with added steel fibers and hollow sections without.

2. Methodology

2.1 Raw Material

The research uses Portland Cement, sand, foaming agent, water, and cockle shells in foam concrete construction. The mixture is mixed until homogeneous, with overmixing causing foam collapse. Clean water is used, and cockle shells are crushed for 5mm size resembling sand. Steel fibers are used for cube testing and reinforcement.

2.2 Sample Preparation

The study aimed to evaluate the strength of concrete by building 18 cube samples of foam concrete as shown in figure 1. Nine normal foam concrete and nine 20% cockle shell foam concrete were poured into moulds of 100 millimeters in width, 100 millimeters in length, and 100 millimeters in depth. The cube samples underwent air cures for 7 days, 14 days, and 28 days before the compression test.

Fig. 1 Foam Concrete Samples

The foam concrete-filled hollow section (FCFHS) was constructed using plastic-coated steel hollow sections and dried through self-drying. The foam concrete was mixed using a design mix of sand, cockle shell, and cement, and water was added to the dry mix. The density of foam was set at 1600kg/m^3 , and a foam generator

was used to generate foam. The concrete was then poured into the moulds and steel hollow sections, with steel fiber placed layer by layer. The curing process was crucial for the concrete's strength, with 18 cubes subjected to air curing for 7, 14, and 28 days.

(a) (b)

Fig. 2 (a) Foam Concrete Filled Hollow Section Samples; (b) Curing Process.

Table 1 Mixture Design for Foam Concrete and Cockle Shell Foam Concrete

Mixture	Foam Concrete	CS Foam Concrete
Cement-sand ratio	0.5	0.5
Foaming agent	1:20	1:20
Water-cement ratio	0.55	0.55
CS (%)	-	20
Steel Fiber (%)	-	0.8

3. Result and Discussion

3.1 Cube Test

An overview of the compressive strength of the foam concrete cube is given in Table 2. It is worth noting that the strength of cockle shell foam concrete with added steel fiber was 6.45 MPa and 8.73 MPa at 7 and 14 days, respectively. By the 28th day, the compressive strength of cockle shell foam concrete with added steel fiber had increased to 9.83 MPa compared to cockle shell foam concrete without steel fiber was 3.73 MPa

Table 2 Compressive Strength of the Foam Concrete Cube After 28 Days

Samples	Compressive Strength (Mpa)
	28 days
Cockle Shell Foam Concrete added Steel Fibre (CSFC-SF)	9.83
Cockle Shell Foam Concrete without Steel Fibre (CSFC)	3.73

3.2 Coupon Test

A tensile coupon test was performed to determine the strength of the steel hollow section. An overview of the yield strength of the mild steel is given in Table 3.

Table 3 Yield Strength for Mild Steel

Thickness	f_y (N/mm ²)
2 mm	334

3.3 Axial Compression Test

After conducting an analysis of the 2.0mm thickness of CFSHS-SF, it appears that specimen 1 has the highest load-bearing capacity among the two specimens. The load-bearing capacity of specimen 1 was measured at

20.33 MPa, which exceeds the capacity of specimen 2, which can only withstand 16.97 MPa. Additionally, specimen 3 demonstrates an ultimate axial load capacity of 19.42 MPa. Compared to CFHS, the highest load-bearing capacity was specimen 2 with 20.73MPa, exceeds the capacity of specimen 2 with 19.41MPa. Additionally, specimen 1 was measured at 18.96Mpa. In contrast, for SHS without concrete fill, specimen 1 achieves the highest load resistance at 10.97 MPa, followed by specimen 2 at 11.83 MPa, and specimen 3 sustaining a maximum load of 9.13 MPa. These findings highlight that SHS with concrete fill enhances load-bearing capacity.

Table 4 Yield Strength for Mild Steel

Steel Hollow Section	Maximum Load (Mpa)
CFHS-CSFC-SF S1	20.33
CFHS-CSFC-SF S2	16.97
CFHS-CSFC-SF S3	19.42
CFHS-CSFC S1	18.96
CFHS-CSFC S2	20.73
CFHS-CSFC S3	19.41
SHS S1	10.97
SHS S2	11.83
SHS S3	9.13

Fig. 3 Load-Displacement Graph for Concrete Filled Steel Hollow Section and Steel Hollow Section

3.4 Strength Index

To evaluate the robustness of concrete-filled steel hollow sections, we utilize a strength index obtained through equation (1). To determine this strength index (SI), we record the necessary data outlined in Table 5.

Table 5 Mixture Design for Foam Concrete and Cockle Shell Foam Concrete

Specimen	B/t	Fcu (Mpa)	Fy (Mpa)	Nu (kN)	Ne (kN)	SI
CFHS-CSFC-SF S1	50	9.83	334	289.4	203.3	0.702488
CFHS-CSFC-SF S2	50	9.83	334	289.4	169.66	0.586247
CFHS-CSFC-SF S3	50	9.83	334	289.4	194.18	0.670974
CFHS-CSFC S1	50	3.73	334	257.1	189.65	0.737651
CFHS-CSFC S2	50	3.73	334	257.1	207.29	0.806262
CFHS-CSFC S3	50	3.73	334	257.1	194.14	0.755114

The SI value is determined using Equations (3.1) and (3.2). From the equation the SI value for all the specimen show that the SI were less than 1.00. According to Tao, Z. (2008), stiffened composite columns exhibited SI values larger than unity, indicating effective postponement of local steel tube buckling due to

stiffeners. However, when SI values are smaller than unity, the effectiveness of buckling postponement is diminished.

$$SI = N_e/N_u \quad (1)$$

$$N_u = A_s f_{sk}/\gamma_a + A_c f_{ck}/\gamma_c \quad (2)$$

3.5 Failure Mode

The local buckling of the steel hollow section results in the gradual concentration of strains under axial loads applied to the specimen, leading to the tearing of the section and subsequent loss of carrying capacity. All specimens exhibit this local buckling phenomenon. As depicted in Figure 4, local buckling is observed in specimens lacking infilled cockle shell foam concrete with added steel fibre. In the case of concrete-filled steel hollow sections (CFSHS) with steel fibre, buckling failure mode occurs at the top. For steel hollow sections without infilled concrete, buckling failure happens both at the top and bottom of the specimen. However, the extent of buckling in specimens of the same size is inconsistent, with some specimens showing more buckling and others displaying less. This variability is attributed to the insufficient strength of the bond between the concrete and the steel hollow section.

(a)

(b)

(c)

Fig. 4 (a) SHS; (b) CFHS-CSFC-Sf; (c) Height Difference Before and After Failure.

4. Conclusion

The aim of this study to determine the strength of the cockle shell foam concrete-filled hollow section added steel fiber and to compare the difference in strength between cockle shell foam concrete filled hollow section

added steel fiber with cockle shell foam concrete filled hollow section, it is possible to draw the following conclusion:

1. After a 28-day curing process, the compressive strength of concrete was assessed by cube test. The data revealed that the inclusion of steel fiber in cockle shell foam concrete resulted in the highest compressive strength value, measuring at 9.83 MPa. The highest load-bearing capacity among the two specimens of CFHS-SF, the load-bearing capacity of specimen 1 is measured at 20.33 MPa, which exceeds the capacity of specimen 2, which can only withstand 16.97 MPa. Additionally, specimen 3 demonstrates an ultimate axial load capacity of 19.42 MPa.
2. The examination of the 2.0mm thickness concrete filled steel hollow section with added steel fiber (CFSHS-SF) reveals that specimen 1 demonstrates the highest load-bearing capacity at 20.33 MPa, surpassing specimens 2 and 3. Comparing CFSHS-SF to traditional concrete filled steel hollow section (CFSHS), the highest load-bearing capacity in CFSHS-SF (specimen 1) outperforms CFSHS specimen 3 but falls slightly below the top capacity in CFSHS specimen 2. Notably, CFSHS-SF demonstrates competitive load-bearing capabilities, showcasing the potential benefits of incorporating steel fiber.

5. Recommendation

The research work on cockle shell foam concrete added steel fibre-filled steel hollow section is still limited. Therefore, further study can be done to expand knowledge in this area. There are some recommendations for further research:

1. Investigate the thermal properties and fire resistance of cockle shell foam concrete-filled hollow sections with added steel fiber. Assess how these materials perform under elevated temperatures.
2. Explore how the size of cockle shell aggregates in foam concrete influences the strength of the filled hollow sections. Analyse the impact on compressive strength and structural behavior.

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