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A Review on Foamed Concrete Filled Hollow Section

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Abstract: Concrete Filled Hollow Sections (CFHS) are quickly becoming an on-demand composite element in the construction industry because of its high ductility and energy absorption, ease of construction, and elimination of formwork. However, this combination of concrete and steel makes the structural elements heavier and the overall design uneconomical. Therefore, lightweight concrete such as foamed concrete is suggested. Since foamed concrete has lower strength, steel fibre or polypropylene fibre is added to increase the strength of foamed concrete. The aim of this study is to review the strength of different types of foamed CFHS which are plain foamed CFHS, steel fibre foamed CFHS, and polypropylene foamed CFHS. This is done by analysing the data obtained from the laboratory tests conducted in previous studies. The test conducted was the axial compression test to evaluate the compressive strength of the foamed CFHS. From the review analysis, steel fibre foamed CFHS is found to have the highest compressive strength and ductility.

Keywords: Fibrous Foamed CFHS, Steel Fibre, Polypropylene Fibre

1. Introduction

In a concrete filled hollow section (CFHS), the steel section functions as a formwork during concrete casting, thus reducing forming and stripping costs. The concrete infill also increases the steel section's resistance to elastic local buckling [1]. Besides that, the CFHS is a structural member that efficiently combines the tensile strength and ductility of steel with the compressive strength of concrete. The concrete infill not only improves the strength but also to the ductility of the CFHS [2]. Steel and concrete work together where the steel section confines the concrete laterally, allowing it to develop its maximum compressive strength, while the concrete, in turn, enhances resistance of the steel section to elastic local buckling [3]. Instead of using normal concrete, lightweight concrete has been proposed in many studies to decrease the weight of the structure. Compared with conventional concrete which uses natural aggregate, the unit mass of lightweight aggregate concrete (LAC) with a similar strength level is 20–30% lighter, yet its mechanical performance, such as the ductility may be even better in some

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cases [4]. A study shows that lightweight aggregate concrete produces a higher bond strength with the steel section compared to normal concrete [5].

Foamed concrete, also known as Lightweight Cellular Concrete (LCC) or Low-Density Cellular Concrete (LDCC) is defined as a cement-based slurry, with a minimum of 20% (per volume) foam entrained into the plastic mortar [6]. However, plain foamed concrete is brittle by nature. Common stresses like impact, fatigue and loading lead to cracking and failure. Therefore, in order to make the foamed concrete stronger, steel fibre or polypropylene fibre is added. Hence, adding reinforcement to the concrete helps to absorb these stresses and to mitigate cracking, increasing the load bearing capacity and ductility of the CFHS. This review is aimed at comparing the performances of different types of foamed CFHS from past experimental programs. The types of foamed CFHS tested were foamed CFHS, steel fibre foamed CFHS, and polypropylene foamed CFHS. Steel fibre is the most common among all other fibres. With excellent durability, steel fibre is used in many construction applications. However, in foamed concrete, steel fibre should be used with caution, because it can exponentially increase the weight of the CFHS. Meanwhile, polypropylene fibre, despite having a low modulus of elasticity (1.5–10 GPa), also has relatively high durability. Both fibres improve the foamed CFHS in terms of ductility and compressive strength [7].

2. Method of specimen testing

For comparison purposes, only the axial compressive test was analysed in this review [8] [9] [10] [11]. Each specimen was filled with various types of foamed concrete, which were polypropylene fibre foamed concrete (PF), steel fibre foamed concrete (SF), and normal foamed concrete (FC). Figure 1 shows the equipment setup for the CFHS specimens form previous studies [9].

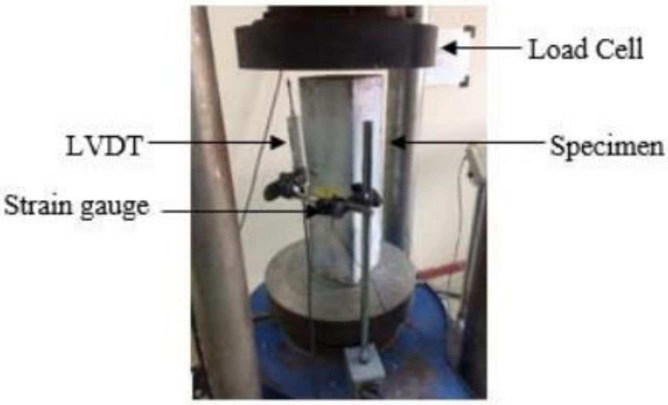


Figure 1: Test Specimen Set Up [9]

3. Materials and Methods

General materials required in producing the foamed concrete mixture are Portland Cement, water, fine and stable foam, rice husk ash (RHA) or sand, and fibre. Steel fibre and polypropylene fibre are used in the foamed concrete mixture to produce two different specimens of CFHS, which are steel fibre CFHS and polypropylene fibre CFHS. Specimens of normal foamed concrete are used as a control.

3.1 Materials

The mix design in each research paper varies slightly with one another. The process in the concrete mix design involves preparation of materials such as water, foaming agent, RHA or sand, and fibre. These materials are mixed together to form the fibrous foamed concrete which will be used as the infill in the steel hollow section. All the foamed concrete specimens have a density of 1600 kg/$m^3$and the type of foaming agent used was Sika AER 50/50 Table 1 shows the mix design used in the experimental programs. The specimens with a size of 100 mm × 100 mm × 350 mm and thicknesses of 2 and 4 mm were tested under axial compression. Figure 2 shows the dimensions of the steel section.

Table 1: Foamed concrete mix design

Mixture in plain foamed, SF, and PF foamed concrete	**Authors**			
	[8]	[9]	[10]	[11]
Cement-Sand Ratio (C/S)	0.50	0.65	0.50	0.73
Foamed-Water Ratio (F/W)	0.05	0.05	-	0.05
Foamed–Cement Ratio (F/C)	0.07	0.07	0.7	0.07
Water–Cement Ratio (W/C)	0.55	0.55	0.55	0.55
RHA (%)	40	-	40	-
Steel Fibre (%)	-	0.8	0.8	0.8
Polypropylene Fibre (Mega Mesh Type) (%)	-	0.4	0.4	0.4

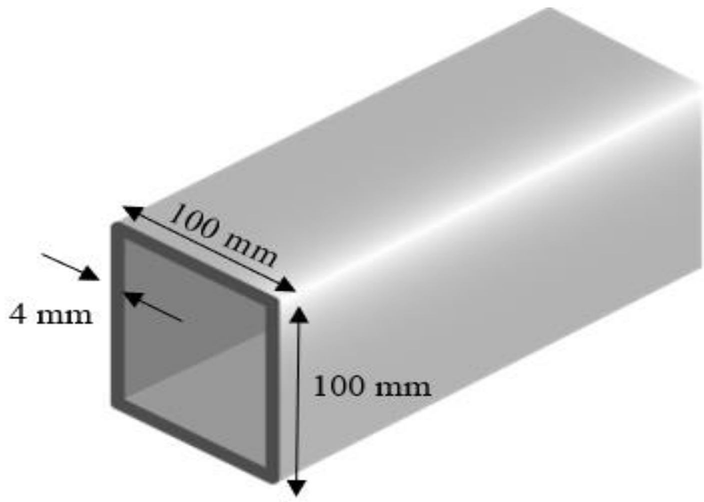


Figure 2: Dimensions of the hollow section [9]

4. Results and Discussion

4.1. Ultimate load capacity

Table 2 shows the results from the axial compression test on the CFHS. From the table, two important observations can be made. Firstly, steel fibre foamed CFHS has the highest load bearing capacity. Secondly, the thicker the steel section, the higher the load bearing capacity and bond strength of the FCFHS. The first observation is due to the fact that the steel fibre foamed concrete is stronger than plain foamed concrete and polypropylene fibre foamed concrete. Similar to the foamed concrete infill, the steel fibre foamed CFHS has the highest compressive strength because of the higher relative density of the steel fibres compared to polypropylene fibres. Polypropylene fibre has a lower relative density (0.92) compared to steel fibre (7.85) [12]. Because steel fibre yields the highest experimental compressive strength, it is safe to say that the incorporation of steel fibre improves the ductility and deformation behaviour of the CFHS specimen [13]. There is a similar trend in all the specimens where the thicker the steel section, the higher the load bearing capacity of the FCFHS. A graph of load vs displacement was plotted to observe the ductility of the specimens. Figure 3 shows the load-displacement graphs for 2 mm and 4 mm thick steel sections.

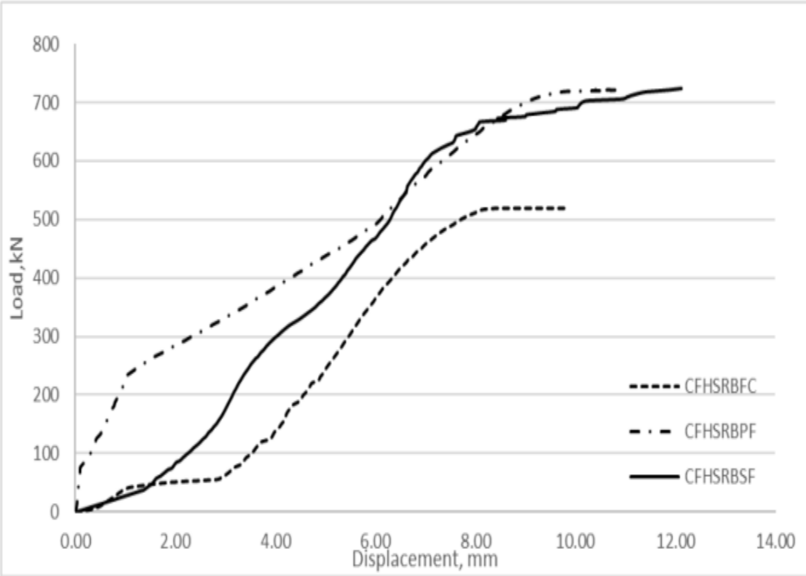
Table 2: Ultimate load bearing capacity of the CFHS

Authors	Strength	Pure foamed CFHS		Polypropylene fibre foamed CFHS		Steel fibre foamed CFHS	
		Thickness of CFHS (mm)					
		2 mm	4mm	2mm	4 mm	2 mm	4 mm
[9]	Ultimate load bearing capacity (kN)	520	910	722	1074	725	1161
[10]	Ultimate bond strength (kN)	16.02	29.13	19.22	39.73	19.74	55.52
[11]	Ultimate load bearing capacity (kN)	520	910	538	954	752	971

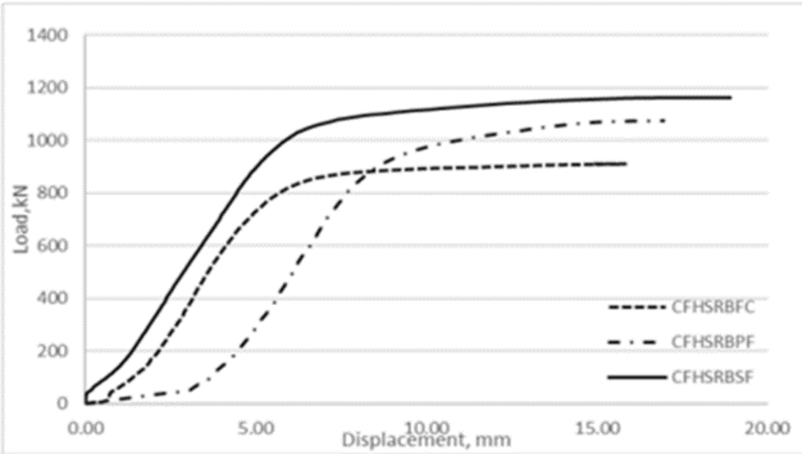
*PF = Polypropylene Fibre, SF = Steel Fibre, FC = Foamed Concrete

4.2. Load displacement curve

The load-displacement graphs in figure 4 show that the 4 mm thick steel fibre foamed CFHS has the highest ductility because it buckled at the highest load. This means that it can undergo larger compressive loads before failing. The 4 mm thick foamed CFHS for all types of concrete infill achieved a plastic state before it failed whereas the 2 mm thick CFHS did not achieve a plastic state because the load kept increasing until it failed. From these results it is can be concluded that a thicker steel section produces a stronger CFHS compared to a thinner steel section. This behaviour was proven by the failure modes of the steel fibre foamed CFHS specimens as shown in figure 4



(a) 2 mm thickness



(b) 4 mm thickness

Figure 3: Load vs displacement of foamed CFHS [9]

4.3 Strength Index

The strength of the CFHS is measured using the Strength Index (SI) value where SI values greater than 1 indicate the effectiveness of the interaction between the concrete core and steel section. This interaction postpones the local buckling effect in the specimens and indicates excellent concrete confinement [14]. Table 2 is the results of a compression test where the SI values are obtained by dividing the experimental value, N_e by the theoretical value, N_u. All specimens possess an SI of at least 1.4. This shows that the interaction between the foamed concrete and steel section produces a very strong CFHS regardless of the type of fibre used in the concrete mix.

Table 2: Ultimate load bearing capacity of the CFHS

Specimen	b/t	Thickness (mm)	Compressive strength, f_{cu} (MPa)	Theoretical value, N_u (kN)	Experimental value, N_e (kN)	Strength Index, SI
FC21	50	2	14.5	323	495	1.53
FC22	50	2	14.5	323	520	1.61
FC41	25	4	14.5	608	870	1.44
FC42	25	4	14.5	608	910	1.50
PF21	50	2	17.2	336	513	1.52
PF22	50	2	17.2	336	538	1.60
PF41	25	4	17.2	621	954	1.54
PF42	25	4	17.2	621	949	1.53
SF21	50	2	17.9	340	752	1.59
SF22	50	2	17.9	340	535	1.57
SF41	25	4	17.9	624	971	1.56
SF42	25	4	17.9	624	964	1.54

*PF = CFHS with polypropylene fibre foamed concrete
SF = CFHS with steel fibre foamed concrete
FC = CFHS with normal foamed concrete

4.4 Buckling mode

From the observations in the previous studies, the 2 mm thick steel fibre foamed CFHS failed by concrete crushing and the 4 mm thick specimen failed by local buckling. The concrete crushing failure mode indicates that the FCFHS has reached its yield stress and has failed completely. For the 4 mm thick specimen, local buckling occurred first due to high compressive loads. This proves that a thicker steel section provides a higher compressive strength to the FCFHS compared to a thinner steel section. The steel section in the outer limit directly carries the applied load and ensures confinement to the inner concrete core, thus avoiding damage to the inner concrete core which can lead to the buckling of the steel section [15]. However, the buckling effect is not clearly visible because fibre can postpone the buckling effect of CFHS.

(a) 2 mm thickness (b) 4 mm thickness

Figure 4: Failure mode of the 2 mm and 4 mm steel fibre foamed CFHS specimens [9]

4.5 Bond strength

When the ratio of breadth to thickness (b/t) increases (i.e., the thickness of steel section is smaller), the bond strength between the steel hollow section and concrete core decreases. This is because the bond strength is evaluated by dividing the maximum load by the contact area of the interface. A high b/t ratio indicates a high contact area between the steel tube and concrete core. This phenomenon is caused by the gap induced by concrete shrinkage [16]. A thinner steel tube indicates the possible formation of a larger gap between the steel tube and concrete.

5 Conclusion

In order to produce the strongest foamed CFHS, steel fibre foamed concrete should be used as the concrete infill in the steel section because of the high density of the steel fibres. Furthermore, the steel section should be thick enough to increase the ductility of the FCFHS so that concrete crushing and sudden failure will not occur.

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