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Original Article

Performance of Modified Foam Concrete-Filled Column Hollow Sections

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Abstract - *Concrete-filled hollow sections (CFHSs) with foam concrete (FC) are a lightweight material used to reduce structural members' deadweight. Research on applying FC filled into steel hollow sections (SHSs) is still ongoing. The ultimate and compressive strengths of FC-filled SHSs are unsatisfactory, and buckling occurs on the tops or bottoms of their specimens. Therefore, this study aimed to improve the strength and reduce the buckling of CFHSs by using FC added with steel fibre (SF) and rice husk ash (RHA). Rectangular SHS columns with the cross-section dimensions of 100 mm × 100 mm × 2000 mm and 2 and 4 mm thicknesses were tested under static load to determine their strength. The cube test was conducted to determine the compressive strength of the modified FC. Results showed that CFHSs filled with RHA- and SF-modified FC had higher strength than CFHSs filled with RHA-modified FC. Therefore, using modified FC as concrete material in CFHSs is acceptable.*

Keywords - *Concrete-filled hollow section, Foam concrete, Rice husk ash, Steel fibre.*

1. Introduction

The use of concrete-filled hollow section (CFHS) columns in structures, such as buildings, bridges, and subway platforms, is increasing. CFHSs are widely applied in earthquake-resistant structures, traffic-impacted bridge piers, railway bridge decks, and columns in storage tanks and tall buildings; they are also utilised as piles [1]. They have several advantages, such as high axial load capacity and excellent seismic performance, and can act as formwork for building structures [2]. CFHSs confer compressive strength and flexural stiffness to sections to avoid local buckling [3].

CFHSs are composite members commonly used in civil engineering structures due to their high flexibility, stiffness and load-carrying, and energy absorption capacities [4]. A steel member confines a concrete core in composite members, enabling it to develop optimal compressive strength, while the concrete core supports the steel tube to avoid elasticity and buckling [5].

Lightweight and slender CFHSs are usually applied to replace traditional steel and reinforce concrete by putting down steel at the exterior perimeter of a section. In addition, filling lightweight concrete into hollow sections reduces the weight of the final structure. Several parameters influence the strength and flexibility of CFHSs. They include size, concrete and loading type, and concrete–steel bonding [6-7].

The strength of CFHSs is reflected by the strength index (SI), which is the sum of the strength of the composite column and the ultimate load capacity of a CFHS column. The SI value shows the interaction between the concrete core and steel. Jamaluddin et al. [8] and Abd Rahman et al. [9] stated that SI values of more than 1.00 indicate positive interactions between the concrete core and steel tube. The SI value is calculated by using Eq. (1):

$$SI = \frac{N_e}{N_u} \quad (1)$$

Where Nc is the ultimate strength capacity from the experimental value of CFHS, and Nu is the load-bearing capacity of the steel tube and concrete core. As proposed by Ghannam et al. [10], Nu can be calculated by using Eq. (2):

$$N_u = A_s\, f_{sk} / \gamma_{ms} + A_c\, f_{ck}\, \gamma_{mc}, \quad (2)$$

Where (γ_{ms}) and (γ_{mc}) are taken as unity for the factor safety for steel and concrete with the characteristic concrete strength (f_{ck}) = 0.83f_{cu} [11].

The ductility index (DI) refers to the ductility of CFHSs. It can be defined as the ratio of the axial strain at 85% load to axial strain at the ultimate load *e*u. The ductility of CFHSs increases when D/t decreases [12]. According to Khairuddin [13], filling hollow sections with lightweight concrete, such as foam concrete (FC), yields CFHSs that are more malleable than CFHSs filled with normal concrete. The DI is calculated by using Eq. (3):

$$DI = \frac{U_{eu}}{U_{ey}} \tag{3}$$

Where u_{ey} is the end of the deflection of the CFHS column at the lateral peak strength, and u_{eu} is the end deflection when loading is decreased to 85% of the lateral peak strength.

Buckling is one of the failure behaviours due to the application of load on a structure. CFHSs show lower deformation or buckling than unfilled steel hollow sections (SHSs) [14]. SHSs filled with lightweight aggregate concrete fail through local buckling. Ghannam, Al-Rawi, and El-Khatieb [15] showed that CFHS specimens experience outward local buckling at their centres. Wang and Moore [16] defined the failure mode of columns as elastic-plastic buckling failure along the minor axis.

2. FC-Filled Hollow Sections

Using lightweight concrete as a filling material in SHSs offers an advantage not only as a sustainable material but also reduces the deadweight of a structure. Hence, it can delay buckling and increase compressive strength [17]. Many researchers have studied the strength of lightweight concrete by using lightweight aggregate concrete, aerated concrete, and FC. FC is a type of lightweight concrete, and its use as lightweight concrete has increased. FC is a highly economical material for structural members and walls [18] and is a green building material [19].

FC has high flowability, low aggregate usage, and cement content and is thus a suitable infill for hollow steel [20]. However, FC-filled column specimens cannot reach the predicted ultimate load values [21], and the low strength of FC-filled SHSs reduces the performance and strength of CFHSs. Saleh [6] reported that CFHSs with FC induce local buckling on the top or bottom of the column. Therefore, adding fibre into the mixture has been proposed to overcome the low strength of CFHSs using FC [18]. Ahmed [22] stated that increasing the content of steel fibres (SFs) will improve concrete strengths.

A study by Khairuddin et al. [23] on CFHSs using SFs in short columns found that adding rice husk ash (ASH) resulted in good strength and bonding between concrete and SHSs. According to Bhuvaneshwari et al. [24] and Jaini, Rum, and Boon [25], using RHA as a sand replacement in FC increased compressive strength due to the high pozzolanic reaction and ability produced by RHA. Therefore, RHA is a suitable material for increasing the strength and durability of FC because of its good chemical reaction.

3. Materials and Methods

3.1. Material Preparation

The materials used to prepare modified FC were ordinary Portland cement, sand, RHA, SF, foaming agent, and water. Figure 1 shows the materials for modified FC. The sand was partially replaced with RHA at the replacement rate of 40%. Meanwhile, SF was added at 0.8% of the total material. The percentage of RHA and SF in the mixture was suggested by Khairuddin et al. [23] under the optimal strength of modified concrete. Table 1 shows the mixed design for the FC.

a) Portland cement **b) Sand** **c) Water**

d) Foam agent **e) Steel fibre** **f) Rice husk ash**

Fig. 1 Material of modified FC

3.2. Specimen Preparation

A total of 18 cube samples of modified FC were prepared to determine concrete strength. Moulds with a width of 100 mm, length of 100 mm, and depth of 100 mm were used for concrete casting. Cube samples were air-cured for 7, 14, and 28 days before the compression test. A total of 12 CFHS specimens were prepared with the dimensions of 100 mm × 100 mm × 2000 mm and thicknesses of 2 and 4 mm. Figure 2 shows the dimensions of the CFHS column. After filling with modified FC, the CFHS column specimens were placed under ambient air curing conditions 28 days before the axial load test.

Table 1. Mix proportion of FC

Mixture	Modified FC (FC–RHA)	Modified FC added with steel fibre (FC–RHA–SF)
Cement:sand ratio	0.5	0.5
Foamed cement ratio	0.7	0.7
Water: cement ratio	0.55	0.55
RHA (%)	40	40
Steel fibre (%)	-	0.8

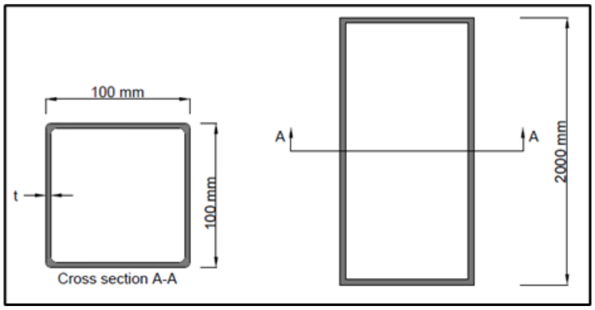

Fig. 2 Cross-section of hollow rectangular steel

3.3. Steel Properties

The coupon test was conducted to determine the properties of the SHSs. The specimens were prepared under BS EN ISO 6892-1 [24], as shown in Figure 3. They were tested using a universal tensile testing machine and subjected to constant tensile load. The strength of the steel was determined based on the stress-strain curve from the test (Table 2)

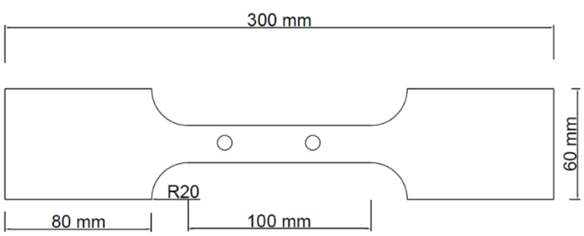

Fig. 3 Geometry of the coupon test specimen

Table 2. Tensile strength of SHS

SHS (mm)	Thickness (mm)	Yield strength, f_{yk} (MPa)
100 × 100 × 2000	2	349
100 × 200 × 2000	4	387

3.4. Experimental Work

Cube samples were subjected to the compression test at 7, 14, and 28 days. The CFHS column specimens were tested using a compression machine and underwent the static load test after 28 days, as shown in Figure 4.

Fig. 4 Cube test

4. Results and Discussion

4.1. Compressive Strength of Modified FC

FC's compressive strength after adding SFs increased by 22% to 30%. After the addition of SFs, the compressive strength of FC increased to 15.27 and 21.1 MPa because SFs increased compressive strength and durability [18]. The compressive strength of the modified FC corresponded to that of FC, which had strengths of 10–17 MPa at the density of 1600 kg/m^3 under its composition and properties [25]. The compressive strength of concrete was higher than that of concrete subjected to standard curing [26]. Figure 5 shows the FC modified with RHA and SF compressive strength.

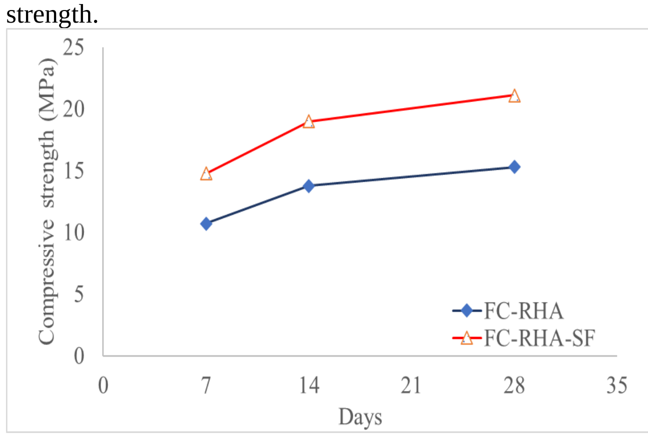

Fig. 5 Compressive strength results of the cube test

4.2. Strength of Modified FCFHS

The graphs of the CFHSs filled with RHA- and SF-modified FC and the thicknesses of 2 and 4 mm are shown in Figures 6 and 7, respectively. The result of the CFHS with SF was higher than that of the CFHS with RHA. The average ultimate load of the CFHS with the thickness of 2 mm increased from 441 kN to 460 kN, whereas that of the CFHS with the thickness of 4 mm increased from 677 kN to 687 kN. The addition of SF to FC improved the ultimate load of the CFHS. Hence, SF concrete infill improved the strength of SHSs. The results of this experimental work are similar to the finding presented by Zuhan et al. [27].

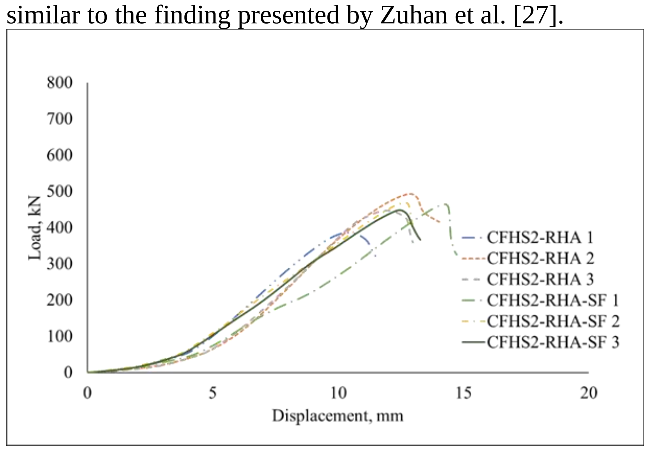

Fig. 6 Summary of the axial compression test results of specimens with a thickness of 2 mm

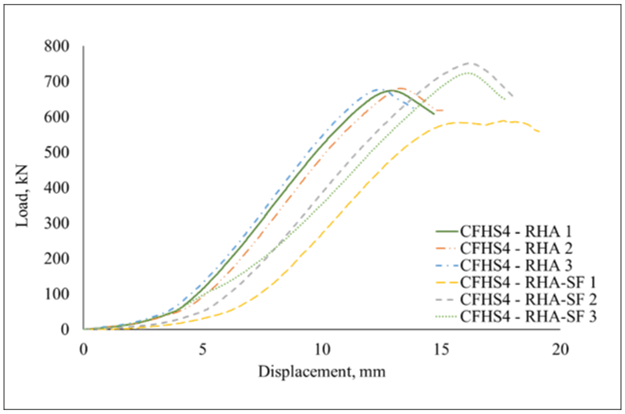

Fig. 7 Summary of the axial compression test results of specimens with a thickness of 4 mm

4.3. SI as a Function of Load-bearing Capacity

The strength of the CFHS also is discussed in terms of its SI. CFHSs with high SI delay failure and postpone local steel tube buckling [8,28]. Table 3 shows the SI values of the CFHSs with FC with and without the addition of SF. The table shows that the SIs of the SHSs with thicknesses of 2 and 4 mm exceeded 1.00. This result showed that the use of modified FC as a filler material delayed specimen failure and postponed the local buckling of the steel section. As can be concluded from the results, high SI values were associated with high ultimate loads [29].

4.4. Ductility of Modified FCFHS

The ductility test on the CFHSs with 2 and 4 mm thickness revealed that the CFHS specimens filled with FC with additional RHA had higher ductility than the other specimens (Figure 8). Furthermore, the DI of the CFHS with high ultimate strength decreased. The CFHS filled with FC with additional SF and the thickness of 4 mm had a strength of 751 kN and the DI of 1.142. Meanwhile, the CFHS filled with FC with RHA had a strength of 680 kN and the DI of 1.152. Adding SF improved the flexibility and strength of the CFHS specimens [30]. Kassoul et al. [31] reported that the parameters of specimens influence the elasticity of a local section.

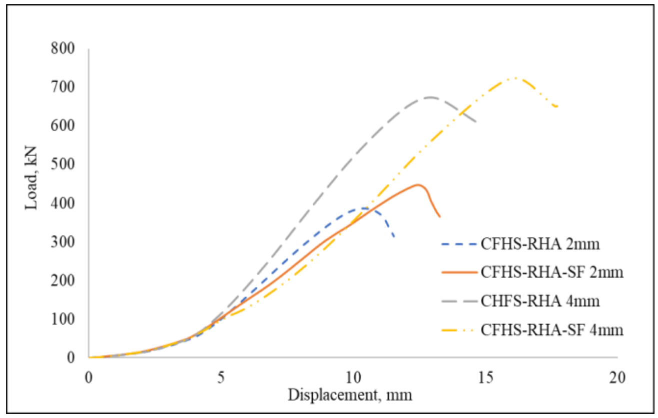

Fig. 8 Load versus displacement of the specimens with the thicknesses of 2 and 4 mm

4.5. Effect of Hollow Section Thickness

Geetha [32] reported that increased b/t value influences load-carrying capacity. In b/t, b is the size of the section, and t is the thickness of the hollow section. In this study, hollow sections with two different thicknesses were investigated. Figure 9 clearly shows that CFHS with lower b/t had higher ultimate strength than that with the higher b/t. This result showed that decreasing the value of b/t increased the strength of the CFHS filled with modified FC.

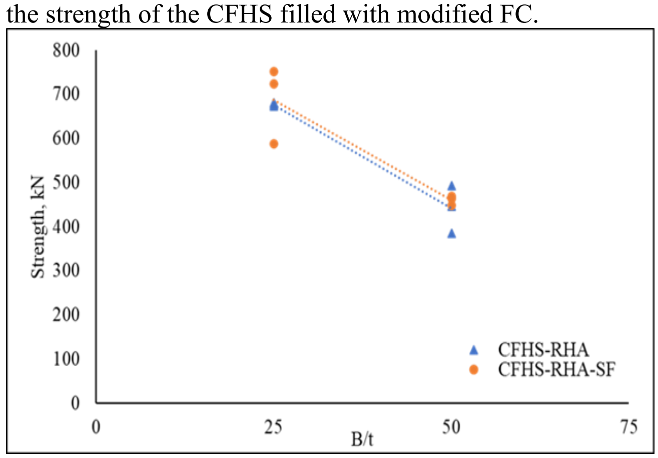

Fig. 9 Ultimate strength of specimens with the b/t of 25 and 50

Table 3. Strength of CFHS

Specimen	b/t	Compressive strength, f_{cu} (Mpa)	Yield strength of steel	Theoretical value, N_{uo}	Experimental value, N_{ue}	Strength index, SI
CFHS2-RHA 1	50	15.27	396	259.93	386.22	1.49
CFHS2-RHA 2	50	15.27	396	259.93	493.05	1.89
CFHS2-RHA 3	50	15.27	396	259.93	446.63	1.72
CFHS4-RHA 1	25	15.27	784	420.21	674.26	1.6
CFHS4-RHA 2	25	15.27	784	420.21	680.61	1.62
CFHS4-RHA 3	25	15.27	784	420.21	677.27	1.62
CFHS2-RHA-SF 1	50	21.1	396	306.4	464.23	1.52
CFHS2-RHA-SF 2	50	21.1	396	306.4	469.37	1.53
CFHS2-RHA-SF 3	50	21.1	396	306.4	448.07	1.46
CFHS4-RHA-SF 1	25	21.1	784	464.81	588.96	1.27
CFHS4-RHA-SF 2	25	21.1	784	464.81	751.52	1.62
CFHS4-RHA-SF 3	25	21.1	784	464.81	723.79	1.56

4.6. Failure Mode

Figures 10 and 11 show the failure modes of the CFHS with 2 and 4 mm thicknesses, respectively. The loading on the CFHS specimens increased until the displacement value became constant. The results showed that the CFHS specimen with the thickness of 4 mm underwent local buckling failure, whereas that with the thickness of 2 mm underwent local and global buckling failure. Crushing failure occurred at the top and bottom columns. Local buckling occurred near the centre of the CFHS. The analysis in Table 3 and the buckling modes illustrated in Figures 10 and 11 showed that the low SI value of the CFHS resulted in the strengthening and buckling of the hollow section. This finding was similar to the result reported by Du [33].

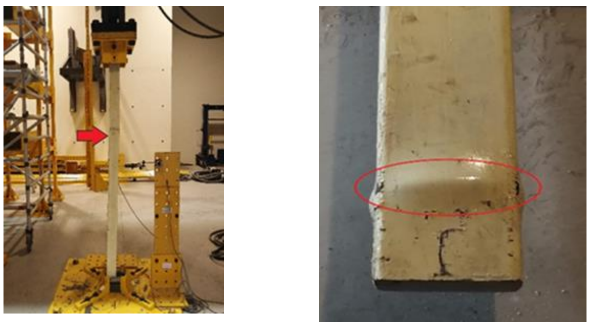

Fig. 10 Local and global buckling in the CFHS specimen with the thickness of 2 mm

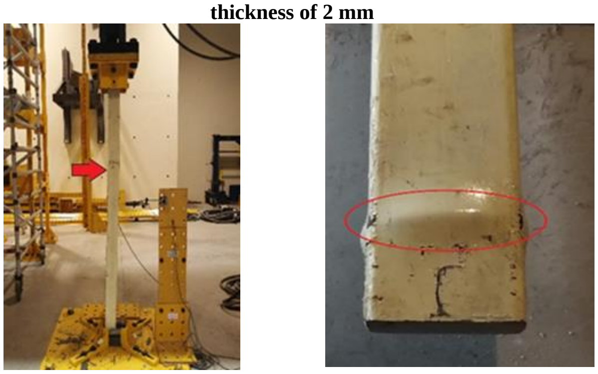

Fig. 11 Local buckling in the CFHS specimen with a thickness of 4 mm

5. Conclusion

The SHS filled with normal FC with a density of 1600 kg/m^3 achieved the theoretical value for short columns. The ultimate load of the CFHS with FC and thickness of 4 mm was higher than 2 mm. The application of SHSs filled with FC added with RHA and SF as a structural material was discussed in this research. This structural material has numerous advantages and is still being investigated by other researchers.

The CFHS filled with SF-modified FC showed improved strength. Adding FC with SF increased strength and thus the ultimate load of the CFHS specimen. SF increased the strength and load-carrying capacity of FC. This effect delayed the buckling of the steel section.

The CFHS filled with SF-modified FC was stronger than the CFHS filled with RHA-modified FC because SF strengthened and densified the FC, forming a mass with increased compactness and solidity. Furthermore, the ductility term of this material was different from that of the material added with RHA because of the influence of the properties of SFs.

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