Preliminary Study on Modified Foamed Concrete-Filled Hollow Section under Cyclic Load

Siti Amirah Azra Khairuddin¹, Norashidah Abd Rahman², Mohd Luqman Rossam¹ and Anis Nazirah Mustafa³

¹Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, MALAYSIA
²Jamilus Research Centre Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, MALAYSIA
Corresponding author: nrashida@uthm.edu.my

Abstract. The use of green materials has become a hot topic for discussion in steel construction. Foamed concrete is a green and lightweight material used in concrete mix. The use of foamed concrete as a fill in steel construction has been discussed by many researchers. However, the performance of foamed concrete under cyclic load has not been evaluated. Therefore, this study employed a modified foamed concrete-filled hollow section under cyclic load to determine the performance of concrete-filled hollow section under cyclic load. The modified foamed concrete consists of foamed concrete added with rice hush ash and fibre. Different types of fibres (steel and polypropylene fibres) were utilised. Results showed that the concrete-filled hollow section with steel fibre slightly improved the strength and ductility of the hollow section.

1. Introduction
The use of concrete-filled hollow section (CFHS) as a steel structure has been widely discussed. However, the use of normal concrete increases structure dead weight and construction costs. Therefore, many researchers studied lightweight concrete [1-3]. As an example of a lightweight concrete, foamed concrete has a density of 400–1600 kg/m³ and a strength of 10–35 MPa [4]. Hunaiti [5] assessed the performance of foamed CFHS and found that the strength of the hollow section is insufficient. Jaini et al. [6] reported that adding rice hush ash (RHA) in the foamed concrete mix increases the strength of CFHS.

The design of the structure has become increasingly critical with the recent earthquakes. Many construction works nowadays consider the effect of earthquakes to the structure. Therefore, the performance of foamed CFHS under cyclic load should be investigated. Previous studies reported that the strength of CFHS under cyclic load is decreased, which leads to high ductility [7-9]. The present study determined the strength and ductility of steel structure in accordance with the recommendation of the European Convention Construction Steelwork (ECCS). The parameters considered in the equation are yield strength (Fy) and yield displacement (εy). The values of Fy and εy can be determined from the intersection of the two tangents from the F-e graph as shown in Figure 1.
The earthquake-resistance model for steel structure under continuous conditions must be established to analysis the behaviour of steel structure under cyclic load. Therefore, the graph was recorded of one cycle, interpret from the whole test. Figure 2 shows the parameters obtained for one cycle.

To analyse the data, the ductility and the strength in terms of resistance ratio can be used as a recommended procedure [10]. The ductility and strength can be measured using Equations 1 to 8:

Partial ductility

\[ \mu_{pl}^+ = \frac{e_i^+}{e_y^+} \]  \hspace{1cm} (1)

\[ \mu_{pl}^- = \frac{e_i^-}{e_y^-} \]  \hspace{1cm} (2)

Full ductility

\[ \mu_{i}^+ = \frac{\Delta e_i^+}{e_y^+} \]  \hspace{1cm} (3)

\[ \mu_{i}^- = \frac{\Delta e_i^-}{e_y^-} \]  \hspace{1cm} (4)
Full ductility ratio

\[ \psi_i^+ = \frac{\Delta e_i^+}{e_i^+ + (e_i^- - e_y^-)} \]  \hspace{1cm} (5)

\[ \psi_i^- = \frac{\Delta e_i^-}{e_i^- + (e_i^+ - e_y^+)} \]  \hspace{1cm} (6)

Resistance Ratio

\[ \varepsilon_i^+ = \frac{\varepsilon_i^+}{\varepsilon_y^+} \]  \hspace{1cm} (7)

\[ \varepsilon_i^- = \frac{\varepsilon_i^-}{\varepsilon_y^-} \]  \hspace{1cm} (8)

2. Experimental work

2.1. Material

Nine samples of CFHS with 350 mm length and 2 mm thickness were prepared (Figure 3). The samples were divided into three groups: unfilled hollow section (HS), modified foamed concrete (CFHS–RHA–FC) and modified foamed concrete containing steel fibre (CFHS–RHA–SF). A foamed concrete mix was prepared with a density of 1600 kg/m\(^3\). The modified foamed concrete mix contained ordinary Portland cement, sand, foaming agent and RHA to improve the strength of foamed concrete. Details of the modified foamed concrete are shown in Table 1. Nine (9) samples of cube specimen with a size of 100 mm × 100 mm × 100 mm were prepared and placed under compression test to determine the compressive strength of the modified foamed concrete. The cube samples were tested under compression load for 7, 14 and 28 days. The compression test result is summarised in Table 2.

| Table 1. Material composition |
|-----------------------------|
| Mixture | Foamed Concrete | SF Foamed Concrete |
| Cement–Sand Ratio (C/S)       | 0.5                | 0.5                |
| Foamed–Cement Ratio (F/C)     | 0.7                | 0.7                |
| Water–Cement Ratio (W/C)      | 0.55               | 0.55               |
| RHA (%)                       | 40                 | 40                 |
| Steel Fibre (%)               | -                  | 0.8                |

| Table 2. Modified foamed concrete compressive strength |
|----------------|
| Sample | Compressive strength (MPa) |
|        | 7 days | 14 days | 28 days |
| FC     | 7.6    | 13.9    | 15.1    |
| SF     | 10.1   | 15.3    | 16.6    |
Modified foamed concrete was later poured on 100 mm × 100 mm × 350 mm with 2 mm thickness short column steel hollow section (Figure 3). The strength \( f_{yk} \) of the steel is 349 MPa.

2.2. Specimen test.
The HS and CFHS were tested under cyclic load as shown in Figure 4. The displacement amplitude was applied as shown in Figure 4. In accordance with the cyclic test by ECCS [10], yield displacement \( e_y \) was measured from the F-e curve as discussed. The displacement \( e_y \) was taken from a previous study on CFHS using foamed concrete by Khairuddin et al. [11], where \( e_y = 4.28 \) mm at yield strength \( f_y = 371 \) kN. Given the limited load (400 kN) applied at the cyclic loading machine, all specimens applied the \( e_y \) for the foamed concrete. The effect of CFHS at the same range of amplitude was also determined. The amplitude range applied is shown in Figure 4, and the frequency for the test is 0.25 Hz.

3. Results and discussion
The hysteretic loops of HS, CFHS–RHA–FC and CFHS–RHA–FC are shown in Figures 5–7. The hysteretic loops illustrate that the columns were elastic at the initial stage of the test. The tensile loading capacity was maintained after the peak for all samples. In the infilled hollow section columns, the strength dropped drastically after the compressive peak load. Under the tension side, the CFHS and the inclination insignificantly influenced the tension-resisting behaviour.

The hysteretic loop of the CFHS under compression was more stable than that of the unfilled columns. The compressive capacity gradually decreased after the peak compressive load. Equations 1–8 were used to discuss the strength and ductility of the sample.
One complete cycle of each sample as shown in Figure 8 at 3 mm displacement cycle was examined. The maximum tensile and compressive resistances occurred during the first cycle at each amplitude. The specimens exhibited high stiffness under compressive load. Furthermore, the modified foamed concrete exerted minimal influence on the shape of the hysteresis loop. From the graph, the resistance ratio and ductility of the sample were calculated by using Equations 1–8. Table 3 shows the resistance ratio and ductility of the sample under cyclic load. On the basis of the result of resistance ratio, the strength of the CFHS with steel fibre was smaller than that of the CFHS without steel fibre because the hysteresis loops of one cycle were small as shown in Figure 8. From the data, the resistance ratio of the CFHS without steel fibre was higher than that of the CFHS with steel fibre. However, the strength of the CFHS with steel fibre was slightly higher than that of the unfilled hollow section. The structure performance of the steel fibre was not achieved, which resulted in poor strength. This result indicates the small energy dissipation in the system is ineffective to maintain under cyclic load. Consequently, there is no failures occurred. Overall, the results indicated that the concrete infill did not greatly enhance the load per cycle but delayed the local buckling.

CFHS–RHA–SF also showed a better ductility behaviour than CFHS–RHA–FC and HS. The presence of steel fibre delayed the local buckling of the specimen. When the inward local buckling was prevented and delayed by concrete as an infill, the ductility of CFHS increased. The buckling effect was not clearly observed because the fibre can postpone the buckling effect of CFHS [11]. Usami et al. [12] concluded that the ductility of CFHS can be increased by filling the steel section with concrete, allowing the column to undergo large inelastic deformation during earthquakes.
Figure 8. One cycle of hysteresis loop

Table 3. Resistance ratio and ductility of column under cyclic test.

| Specimen          | Resistance ratio | Partial ductility | Full ductility | Full ductility ratio |
|-------------------|------------------|-------------------|----------------|----------------------|
|                   | $\varepsilon^+_i$ | $\varepsilon^-_i$ | $\mu^+_i$ | $\mu^-_i$ | $\mu^+_i$ | $\mu^-_i$ | $\psi^+_i$ | $\psi^-_i$ |
| HS                | 0.157           | -0.162            | 1.038        | -0.692       | 1.055        | -0.588       | -1.614      | 0.899       |
| CFHS–RHA–FC       | 0.213           | -0.184            | 0.687        | -0.477       | 0.848        | -0.360       | -1.074      | 0.456       |
| CFHS–RHA–SF       | 0.167           | -0.164            | 0.273        | -0.176       | 0.327        | -0.145       | -0.362      | 0.160       |

4. Conclusion

Nine specimens of CFHS were prepared and tested under cyclic load. Results showed that the modified foamed concrete with SF as an infill demonstrated good performance because of its high compressive strength. SF also delayed the local buckling of the specimen. Thus, the high compressive strength on the modified foamed concrete delayed the local buckling behaviour and enhanced the strength of the foamed concrete with large load-carrying capacity. In addition, the CFHS with steel fibre showed better ductility than the foamed concrete and hollow section because of the inclusion of fibre in the structure. The inclusion of concrete infill with fibre not much improved the cyclic performance due to limited load applied. Therefore, Further investigation need to be conducted by applying the displacement control higher than $\varepsilon_y$, let say $2.0\varepsilon_y$, $3.0\varepsilon_y$.

5. References

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