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Dynamic Responses of Sandwich Cemboard-Foamed Concrete Panels Subjected to Low-Velocity Impact

Z M Jaini[1], S N Mokhatar[1], J Hadipramana[2] and M Abu Seman[3]
[1] Jamilus Research Center, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
[2] Faculty of Engineering, Universitas Muhammadiyah Sumatera Utara, Medan 20238, Indonesia
[3] Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
Corresponding author: rizuan@uthm.edu.my

Abstract. Sandwich cemboard-foamed concrete panel (SCFCP) has sparked the attention due to green and sustainability requirements in construction of building. SCFCP is essentially made of fiber cement board as core component and foamed concrete as outer layers. Shear connectors act as joint mechanism and create compositeness behaviour. However, investigations on SCFCP remains passive, creating a number of uncertainties particularly in dynamic responses. Therefore, this study intends to investigate the dynamic responses of SCFCP under low-velocity impact. Nine cube specimens were prepared using size of 100 mm x 100 mm x 100 mm, while nine panel specimens were casting using size of 1220 mm x 300 mm x 76 mm. The compression and impact tests were conducted on cube and panel specimens. The compression test revealed that foamed concrete has compressive strength approximately 18 MPa with density of 1600 kg/m^3. Under low-impact of 1.39 m/s, it is noticeable that the impact force decreases from 8.41 kN to 6.73 kN in correspond to the spacing of shear connector. Contradictory, the displacement shows sprang off pattern with value between 87.90 mm to 96.50 mm.

1. Introduction

Either in residential or high-rise buildings, concrete panel is widely used for the entire construction. Concrete panel is one of component in precast concrete which has been extensively utilised as industrialised building system and received good merit from local councils. It can be used for interior element, landscaping, soundproofing and some can be bearing capacity wall with different size, function and design. In term of advantageous, concrete panel offers excellent durability and flexibility solutions. In addition, it has high potential for salvage and relocation due to high initial embodied energy which can be offset by its extended life cycle up to 100 years [1]. The design of concrete panel has been improved to suit with the latest demands. However, engineering specification still an issue that should be considered in the construction, irrespective of whether the concrete panel is in-situ or precast. In Malaysia, concrete panel has been promoted since the last decade to enhance the importance of precast. Unfortunately, the adoption of concrete panel is still low in current state. The lack of standardization and regulation were identified as major factors [2].

Basically, concrete panel can be classified as homogeneous or sandwich system. In recent years, sandwich panel has received most attention as it can be used for various applications and offer good strength. Sandwich panel is one of combining materials possibly to form composite element that enable optimum design to be composed for the particular application [3]. Basically, sandwich panel can be applied as vertical or horizontal structural component. However, Lakshmikandhan el al. [4] defined the sandwich panel as such system that is more suitable for wall. Because of composite element, it has various advantageous such high strength, better crack resistance and ductility as well as good energy absorption [5, 6]. According to Shutt [7], there are three types of sandwich panel depending on the degree of composite action; non-composite, fully composite and partial composite. Basically, the degree of composite action depends on the bond (naturally or using shear connectors) and rate of deformation between core and outer layers. Therefore, the selection of materials to be used in sandwich panel is paramount to ensure it has fully function as desired.

Lightweight materials are basically demanded for the fabrication and installation of sandwich panel as it not only easy to be combined but able to counter the weight penalty. Among the innovation, sandwich cemboard-foamed concrete panel (SCFCP) has sparked the attention due to green and sustainability requirements in construction. SCFCP is basically consists of fiber cement board as core layer and foamed concrete as outer layers, where shear connectors act as joint mechanism. Since SCFCP is categorized as lightweight structure and still a new product, more attention should be given to promote this type of sandwich panel. However, the investigations on SCFCP remain passive and hence create various uncertainties especially that related to dynamic responses. Under high loading such as seismic, impact, explosion and accidental, the structural behaviour, failure mode and energy absorbing are important parameters that must be fully acknowledged [8]. So that, sandwich panel able to maintain its serviceability at any conditions. Moreover, governing factors on the performance of sandwich panel must also be considered in the design criteria.

Therefore, this study intends to investigate the dynamic responses of SCFCP under low-velocity impact. Low-velocity impact is not a new matter as various works have previously been done on concrete panel [9, 10] and sandwich panel [11, 12]. However, there is still no established information on SCFCP. The effects of shear connector, in term of spacing, on the force-time history and displacement time-history as well as the failure mode are of interest. This study contributes to the in-depth understanding about the performance of SCFCP. In the design prospective, the vital intention is to establish the structure that able to withstand the entire feasible loads for imposed period of time. Therefore, it is necessary to investigate the strength, stability and rigidity of the structure to resist force, whether in static or dynamic. In addition, this study able to solve various issues related to the serviceability of SCFCP. Hence, SCFCP can be used confidently in the construction of building. Whereby, SCFCP could be the figurative structural component that can contribute to an extraordinary performance.

2. Materials and specimens

Foamed concrete with density 1600 kg/m^3 was produced using ordinary Portland cement, sand, rice husk ash, foaming agent, superplasticizer and water. Rice husk ash was used as partially sand replacement at 40%. The mix design is based on the prescribed volume as suggested by Abd Rahman et al. [13] and Jaini et al. [14], where the ratios 0.50 for cement-sand, 0.55 for water-cement, 0.07 for foaming agent-cement and 0.05 for water-foaming agent. The targeted compressive strength of foamed concrete is approximately 18 MPa that deemed suitable for structural component. Foamed concrete was used as outer layers, while fiber cement board based on Primaflex as core layer. There are nine cube specimens of foamed concrete ware prepared using mould of 100 mm width, 100 mm length and 100 mm depth. After the demoulded process, cube specimens were placed at the ambient condition for air curing along 7, 14 and 28 days. Meanwhile, nine panel specimens were prepared using size of 300 mm width, 1220 mm length and 76 mm thickness. Three different spacings of shear connectors were used as detailed in Table 1, while the schematic design of SCFCP can be referred in Figure 1.

Table 1. Details of panel specimens.

Spacing of Shear Connector	Label of Panel Specimen	Quantity
100 mm	SCFCP-100	3
150 mm	SCFCP-150	3
200 mm	SCFCP-200	3

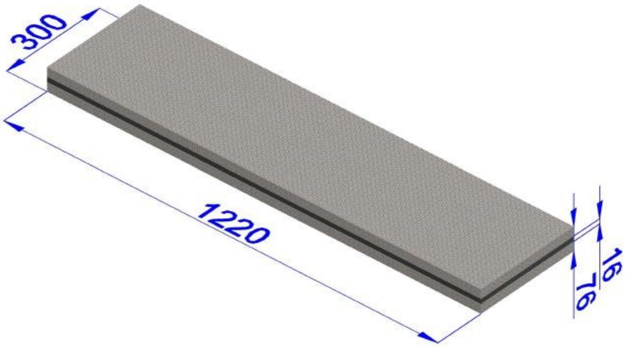
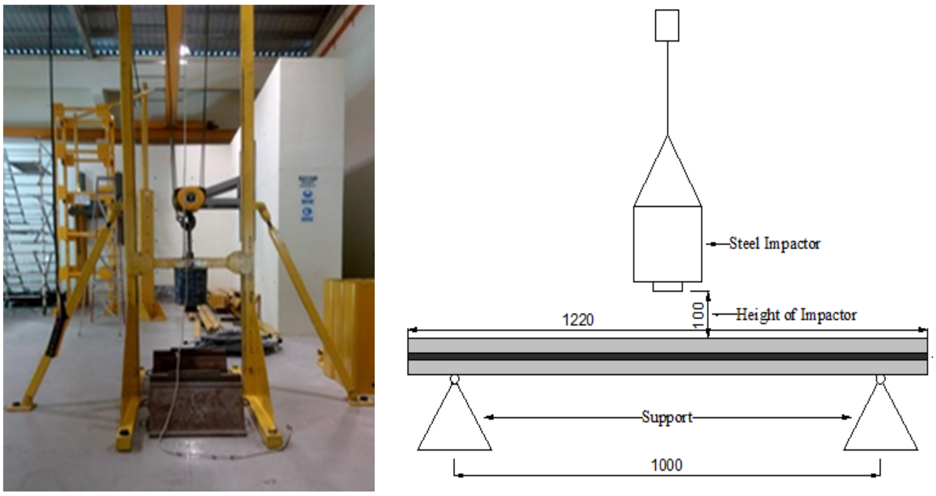


Figure 1. Schematic design of panel specimen SCFCP.

3. Experimental test

The compression test was performance to investigate the compressive strength of foamed concrete. The cube specimens were tested using Ele-Compact Machine 150. The compression test was conducted in accordance to BS EN 12390-2 [15]. After undergone the air curing at 7, 14 and 28 days, cube specimens were cleaned, measured and weighted. A compressive axial load with a specific load rate was applied to cube specimens up to failure, where the load reduces after reaching the maximum value. The maximum load carried by cube specimens was recorded. On the other hand, the setup of impact test requires rolled supports, frame and impactor as can be seen in Figure 2. The effective span of support to support was fixed at 1000 mm. The impact test was performed as accordance to ASTM D7126-15 [16]. The impactor with mass of 94.55 kg and located at the height of 1000 mm was used to initiate the free-fall with constant low-velocity of 1.39 m/s. When the impactor hits the panel specimen, the load cell was used to record the load-time history. On the other hand, the dynamic LVDT was used to capture the displacement-time history. These data are safely stored on data logger.



a) Frame of impact test b) Schematic design of impact test

Figure 2. Setup of impact test.

4. Results and discussion

4.1. Compressive strength

Compression test on cube specimens provided the results of compressive strength as can be seen in Figure 3. In general, the compressive strength is significantly increased in corresponds to the curing age. This is the typical trend that can be observed in foamed concrete and normal concrete. It was identified that the compressive strength achieved the targeted characteristic with value of 18.33 MPa, which is slightly over than 18 MPa as required by BS EN 1992-1-1 [17]. Within 7 days, the compressive strength increases around 47.40% followed by 38.90% and 12.71% at the sequent period of 14 and 28 days. The percentage of increment shows better performance than normal concrete. According to Aldrige [18] and British Cement Association [19], the compressive strength of foamed concrete should be in the range of 7.50 MPa to 10.50 MPa. This is particularly for foamed concrete with density of 1600 kg/m^3. However, the compressive strength of this study is slightly lower than obtained by Jaini et al. [20] that also employed rice husk ash as sand replacement in foamed concrete. The type of foaming agent and dilution process during the production of foamed concrete were identified as variance factors.

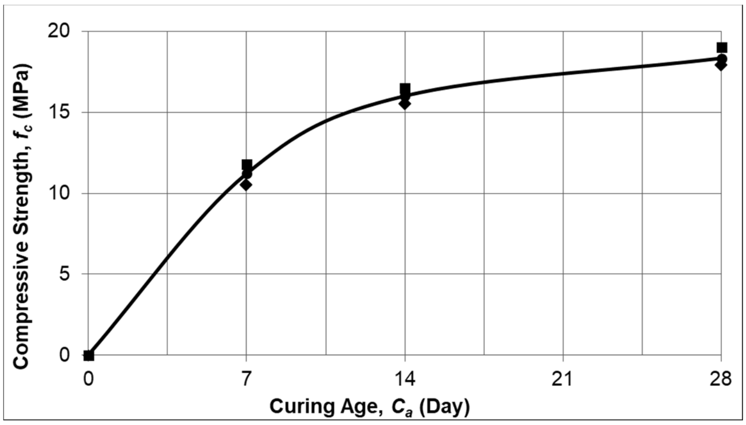
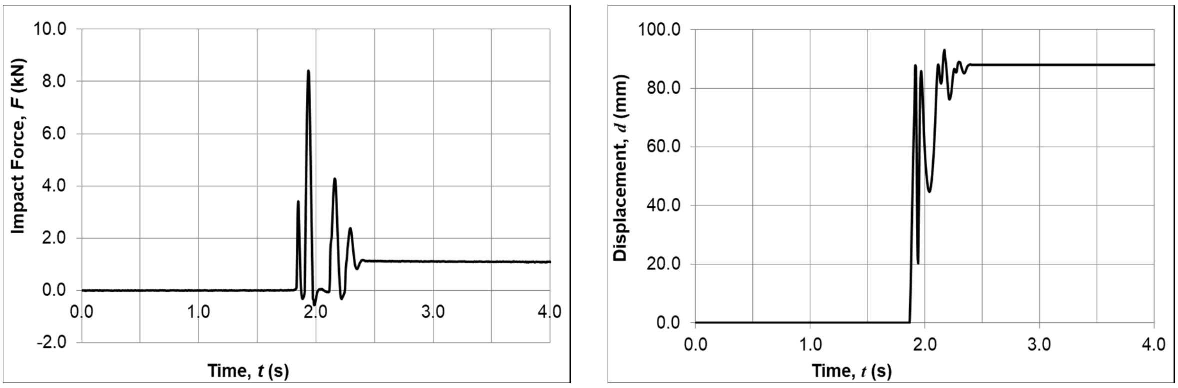


Figure 3. Compressive strength of foamed concrete.

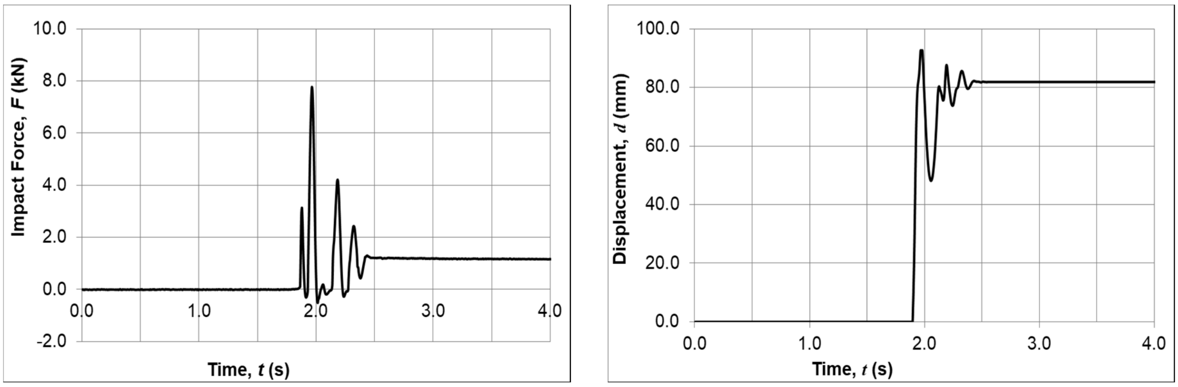
4.2. Impact force and displacement

The results of impact force-time history and displacement-time history are presented in Figure 4 to Figure 6. Basically, these results are combined to produce the impact force-displacement curves. It should be emphases here that impact force-time history and displacement-time history are based on average value. Under the low-velocity of 1.39 m/s and height approximately 1000 mm, the time taken for the impactor to hit the surface of panel specimens was relatively 1.70 to 2.15 split second. It can be observed that the force raised abruptly during the impact stage. This cause the panel specimens experienced excitation state as the force keep oscillate until it behaves static. However, the force remains at the certain value due to the reflected stresses induced by impactor. High energy is transferred from impactor to the panel specimens and create incident stresses that propagate along the thickness and span of SCFCP. Similarly, the displacement also experiences fluctuate condition after imposed by impactor. During which the displacement remains constant at the particular value, the panel specimens were observed break up into two pieces.



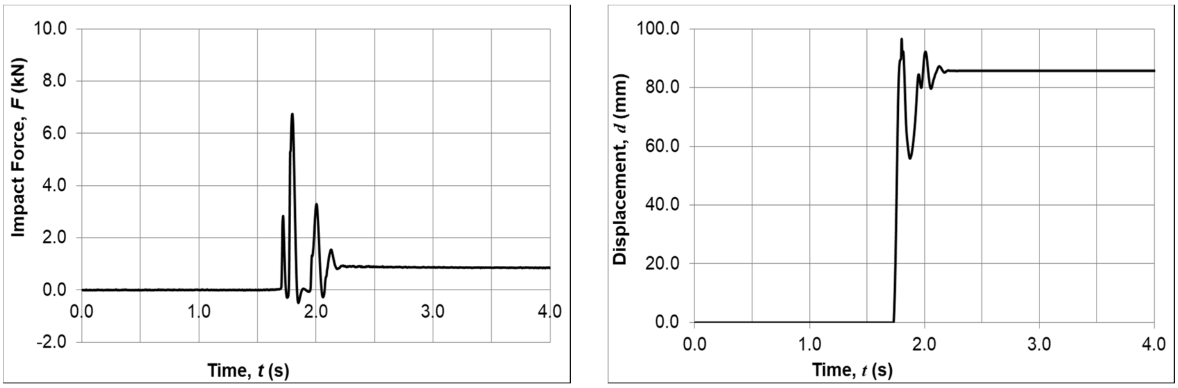
a) b)

Figure 4. Results for SCFCP-100: a) Impact force-time history and b) displacement-time history.



a) b)

Figure 5. Results for SCFCP-150: a) Impact force-time history and b) displacement-time history.



a) b)

Figure 6. Results for SCFCP-200, a) Impact force-time history and b) displacement-time history.

Figure 7 shows the impact force of SCFCP in corresponds to the spacing of shear connector. The impact force decreases when the spacing of shear connector become bigger from 100 mm to 200 mm. It can be clearly observed that the closest spacing produce high impact force. This happens because of shear connectors contribute to the good stiffness mechanism and subsequently improve the bearing capacity of panel specimens to withstand the loading. As spacing of shear connector is small, hence more bolts can occupy the panel specimens and create almost a perfect bond in between core and outer layers. The relation between impact force and spacing of shear connector can be presented by the best fitted line of inverse linear function, in which the impact force of SCFCP can be predicted by a simple formulation of $F = -0.00168S + 10.155$. Here, F and S are the impact force and spacing of shear connector respectively. The forward and backward forecasts revealed that the impact force for SCFCP with spacing of shear connector at 50 mm, 250 mm and 300 mm are 9.38 kN, 6.26 kN and 5.48 kN respectively.

The displacement of SCFCP against the spacing of shear connector is plotted as shown in Figure 8. The displacement was found become higher as the spacing of shear connector changes from 100 mm to 200 mm. The displacement was recorded at 87.90 mm, 92.60 mm and 96.50 mm for panel specimens SCFCP-100, SCFCP-150 and SCFCP-200 respectively. At the constant thickness and dimension of SCFCP, the displacement is significantly diverse due to the spacing of shear connector. The consumption of input energy by reducing the spacing of shear connector indicates the drop off in displacement. This specifies that the spacing of shear connector at 100 mm able to enhance the strength and geometry property of SCFCP. The presence of bolts expands the rigidity that prevent the bending to be formed excessively although under high impact force. The positive correlation was established by the displacement of SCFCP and the spacing of shear connector. By depending on the spacing of shear connector at 100 mm, 150 mm and 200 mm, the displacement of SCFCP can be depicted as $d = 0.086S + 79.433$ where d is the displacement whilst S is the spacing of shear connector.

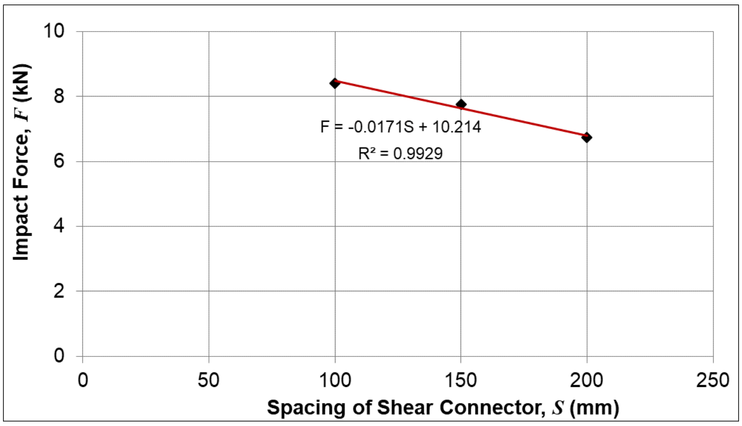


Figure 7. Impact force in corresponds to the spacing of shear connector.

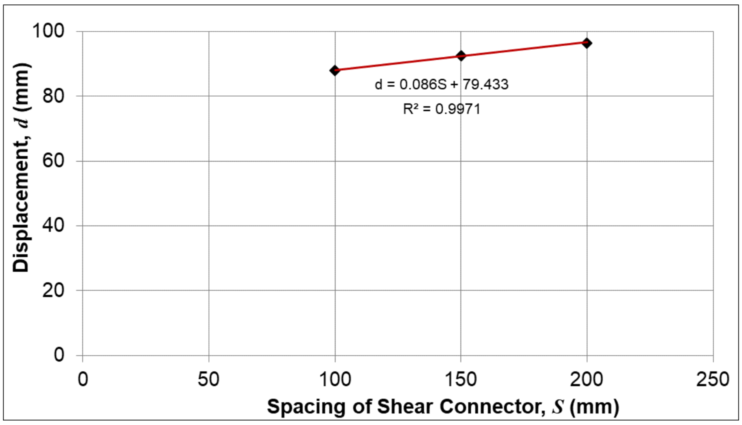
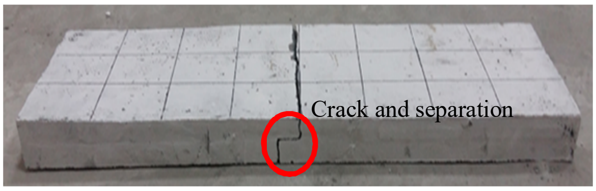


Figure 8. Displacement in corresponds to the spacing of shear connector.

4.3. Failure mode

Under low-velocity impact, the panel specimens were dominated by flexural and horizontal cracks as can be seen in Figure 9. These cracks can be observed occur at the mid-span, exactly under the location of impact. Unlike Yao et al. [21] that discovered the failure mode in compression zone, there is no crater happens at the top surface of panel specimens. The delamination failure in between the core element and outer layers is invisible. However, fracture by spalling appears at the end of impact which is happen in panel specimens SCPCP-150 and SCFCP-200. The spalling led to a phenomenon as similar as shear plug but propagate from beneath to top surface (around 70 degrees) and edge to edge of panel specimens. After the impact, the panel specimens are totally break into two pieces. The separation occurs mainly due to joint failure that indicate the high stresses were transferred from shear connectors to the surrounding area. Noroozi et al. [22] stated that size of bolt and distance arrangement are important factors in observing the failure mode. By understanding the link between the load distribution and configuration of bolt, failure mode can become part of criteria in design of sandwich panel.



a)

b)

c)

Figure 9. Failure mode of panel specimens, a) SCFCP-100, b) SCFCP-150 and c) SCFCP-200.

5. Conclusion

This study offers a comprehensive investigation on dynamic responses of sandwich cemboard-foamed concrete panel (SCFCP) under low-velocity impact. During the impact test, low-velocity impact was conducted using velocity 1.39m/s that induced from free-fall of impactor at the height of 1000mm. This study was concentrated on the effect of shear connector particularly the spacing at 100mm, 150mm and 200mm. The compression and impact tests pleasant the tremendous results of compressive strength, impact force-time history, displacement-time history and failure mode. In term of impact force and displacement, it was affirmed that SCFCP with the closest spacing of shear connector offers a great strength and serviceability. Meanwhile, failure mode is dominated by the flexural and horizontal cracks. However, this study has deficiency to capture the exact event of failure mode especially that related to the crack propagation and progressive of spalling. It is well understood that the spacing of shear connector plays an important role in governing the dynamic responses of SCFCP as it creates the degree of composite action in which affecting the stiffness mechanism and geometry property.

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