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# Stress-Strain Relationships Of Composite Foamed Concrete Panel With Different Number Of Shear Connectors Under Compression

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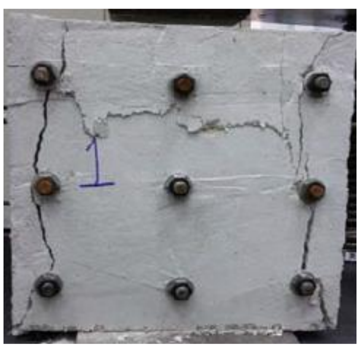
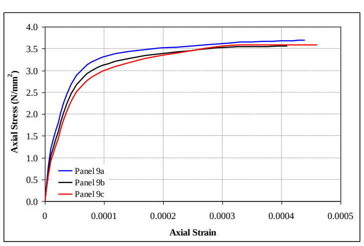
**Graphical abstract**






## Abstract

The present of the shear connectors with the sandwich composite foamed concrete panel system is to increase the strength of the panel. Therefore the objectives of experiment on effects of the shear connectors spacing is to determine the influence of shear connectors spacing on the axial stress-strain curve, to observe the failure mode sandwich composite foamed concrete panel system with different shear connectors spacing, and to establish ultimate load carrying capacity of different shear connectors spacing. In this study, there are four samples of shear connectors spacing which are 5, 7, 9 and 13 to composited foamed concrete with density of 1400 kg/m³ and 700 kg/m³. This study has showed the enhancement of ultimate compressive strength with increasing numbers of mechanical connectors. The failure of mode observed proved that sandwich panel failures decreasing with enhancement numbers of mechanical connectors, thus sandwich panels can sustained ultimate load carrying capacity.

*Keywords*: Lightweight foam concrete; sandwich panel; axial load, stress-strain

## Abstrak

Aplikasi konkrit ringan berbusa dalam pembinaan bangunan adalah agak terhad disebabkan kekuatan yang rendah dan sifat rapuh. Kajian ini dijalankan untuk mengkaji kesan penggunaan gentian keluli di dalam konkrit ringan berbusa pada peratusan kecil (0.2% dan 0.4%) ke atas sifat-sifat mekanikal seperti kekuatan mampatan, kekuatan lenturan dan kekuatan tegangan. Gentian keluli telah digunakan sebagai bahan tambahan. Konkrit ringan berbusa telah disediakan untuk mencapai hasil kesan daripada pecahan isipadu gentian keluli yang digunakan dengan ketumpatan yang berbeza iaitu 700 dan 1200 kg/m³ dan diuji pada usia 7, 28 dan 60 hari. Eksperimen terperinci telah disediakan bagi tujuan mengkaji tindak balas bahan tambahan yang dijangka memberikan hasil yang berbeza pada sifat mekanikal konkrit ringan berbusa. Hasil kajian menunjukkan bahawa gentian keluli memberi kesan kekuatan yang baik ke atas sifat mekanikal konkrit ringan berbusa.

*Kata kunci*: Gentian keluli, konkrit berbusa, konkrit ringan, mampatan, lenturan

## 1.0 INTRODUCTION

Concrete sandwich panels sandwich panels is a vertical structure located in between floors or roofs and foundations. The panel was used as an insulated exterior shell to buildings which support and carrying mostly axial loads [1]. In the industry, there is also an insulated concrete sandwich panels system [2]. Insulated concrete sandwich panels system have some benefits such as precast insulated sandwich panels have superior insulating properties, the insulated sandwich panels can prevent settling or shifting which can decrease the efficiency of thermal [3]. Besides that insulated wall panel was designed in a standard design which under controlled factory conditions, inexpensive, strong, durable, energy efficient and fire resistant cladding system [4].

The lightweight foamed concrete sandwich or precast lightweight foamed concrete sandwich panels, helps in ease the construction by produce reasonable and affordable development with lower cost. Therefore, many researcher have takes some effort to investigate more on lightweight foamed concrete sandwich panels, especially as a load bearing wall [5]. Some of lightweight foamed concrete sandwich panel is act as the wythes which enfold the polystyrene that act as the insulation layer. The polystyrene is used to decrease the amount of temperature that flow the building by convection. Structural lightweight concrete provides the most efficient strength-to weight ratio in structural elements. Structural behavior of the panels depends on the strength and stiffness of the connectors while the thermal resistance of the insulation wythe governs the insulative value of the panel [6].

The used of lightweight concrete in construction industry have been introduced since very long time ago [7]. Technology of concrete has been move and circulate with the times and ages. The existence of lightweight concrete in early 1920 has been founded in United State of America [9]. These include the construction of wall, column and beams, concrete blocks and heat retaining wall [8]. Most of the lightweight concrete was used for structural purposes are usually produced using expanded clay, shale or slate as aggregates. The density of normal concrete is around 2400 kg/m$^3$ and while in the experimental report, it has stated that the density of normal concrete is between 2240 kg/m$^3$ till 2400 kg/m$^3$. A low density concrete have a few special characteristic especially due to a light self weight [10]. The low density makes it more light compared to normal concrete. In construction, the dead load is the most important factor that needs to be considered [11]. The rising of the dead load causes the more loads that need to be support by the structure. Lightweight concrete is lighter compared to the normal concrete with a dry density of 300 kg/m$^3$ till 1840 kg/m$^3$. Thus, lightweight concrete is 87% to 23% lighter compared to conventional concrete [6]. Recently investigation of a lightweight foamed concrete sandwich panel system is one of the strategies to study the effectiveness of implementing sandwich composite foamed concrete panel system to reduce the construction cost.

## 2.0 MATERIALS AND SAMPLE PREPARATION

The panel was designed in size of 300 mm x 300 mm x 150 mm for the 1400 kg/m$^3$ density lightweight foamed concrete and the filler was designed in trapezium size of 60 mm length and 40 mm thickness for the 700 kg/m$^3$ density lightweight foamed concrete as been shown in Figure 1. The mechanical connectors are used for the sandwich panel to help in distribution of load impact onto the panel. This study is intended to observe the effects used of mechanical connectors in lightweight foamed concrete sandwich panel not only increase the strength of the lightweight foamed concrete. Otherwise, it helps in distributing the load impact on the panel. Furthermore, the lightweight concrete is less density compared to normal concrete. Therefore the load bearing capacity of the lightweight concrete is less compared to normal concrete. The application of the mechanical connectors in the lightweight foamed concrete can enhance the load bearing capacity of the panel. The capability to carry the ultimate load bearing capacity of the panel and the failure mode impact during the compressive test based on the sample with different spacing mechanical connectors have been observed.

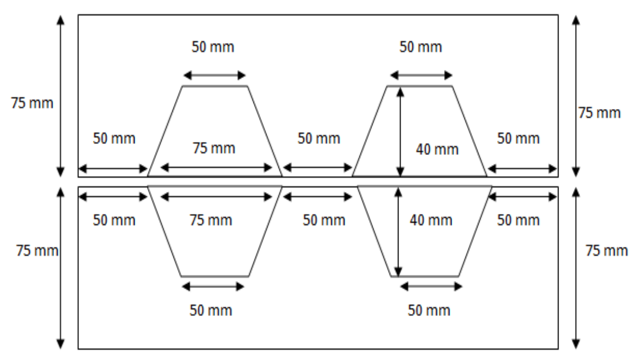



**Figure 1** The dimensional view of sandwich composite panel sample

This experiment was made up of composite of lightweight foamed concrete. The differences in density used in this experiment are to reveal the mechanical properties and structural behavior upon the different shear connectors spacing. In this experiment, two number of density of lightweight foamed concrete have been used, which is 700 kg/m$^3$ and 1400 kg/m$^3$. The outer layer of panels with density of 1400 kg/m$^3$ respectively have protects the insulation layer of panel and lessen the pressure impact of the loads. The composite of 700 kg/m$^3$ is to lessen the dead load of overall specimen. This paper will present the results of effects of shear connectors spacing on load bearing capacity of lightweight foamed concrete sandwich panel system. Table 1 shows the details of mix design of both densities used in this study.

**Table 1** Details of mix design

| Dry Density (kg/m³) | Cement to sand ratio | Water to cement ratio | Cement content (kg/m³) | Sand content (kg/m³) |
|---|---|---|---|---|
| 1400 | 1:2.3 | 0.43 | 45.15 | 103.84 |
| 700 | 1:2.3 | 0.43 | 10.68 | 16.02 |

### 2.1 Cement

In this study, the cement used was Ordinary Portland Cement, OPC. Based on ASTM, Type I Portland Cement was used in this study. The ratio of the cement was 1. Therefore, for density of 1400 kg/m³ mix, the cement used was 45.15 kg/m³. While for the density of 700 kg/m³ mix, the cement used was 10.68 kg/m³.

### 2.2 Sand

In this study, the maximum size of 5 mm of aggregates was used based on BS 812: 102. The fine aggregates used in this experiment was natural sand with ratio of 2.3. Therefore, for density of 1400 kg/m³ mix, the sand used was 103.84 kg/m³. While for the density of 700 kg/m³ mix, the cement used was 16.02 kg/m³.

### 2.3 Water

Water used in this study was from water pipe. The allowable pH value of the water used was 6. The water need to be clean from any substances that can influence the mix concrete [16]. The water cement ratio used was 0.43. A mix of density of 1400 kg/m³, the water used was 19.41 kg. While for the density of 700 kg/m³ mix, the water used was 4.81 kg.

### 2.4 Shear connectors

In this study, the shear connectors used was bolt nuts with diameter of screws are 10 mm. The sample was categorized different numbers of shear connectors which is 5 screws, 7 screws, 9 screws and 13 screws.

## 3.0 EXPERIMENTAL SETUP

The dimension of test samples was 300 mm high by 300 mm wide by 150 mm thick. A total of 12 sandwich panel samples were tested under compression. Every 3 samples consisted of different numbers of mechanical connectors; there are 5, 7, 9 and 13 screws. In this experiment there two profiled of density of lightweight foamed concrete was casted to form a sample, 700 kg/m³ and 1400 kg/m³. The both panel were connected to foam a sandwich panel using 5 x 10 mm screws, 7 x 10 mm screws, 9 x 10mm screws, and 13 x 10 mm screws. The compression test was conducted to determine the compressive strength, maximum stress and mode of failure of samples 3 cylinders of 700 kg/m³ and 1400 kg/m³ are tested as control samples. The test as carried out after 28 days of curing using the universal testing machine as been shown in Figure 2 [17].

The strength of this prototype will determine the properties of the big scale sandwich composite panel. The sandwich composite panels were tested 28 days after casting. The top and bottom of the samples were placed flat prior to the test to ensure equal load distribution. Observations were made on the general behaviour and also on the cracks on the concrete.

Also, the buckling on the concrete and the pattern of the failure mode based on the graph were recorded for further analysis.


**Figure 2** The Universal testing machine

## 4.0 RESULTS AND DISCUSSION

### 4.1 Mechanical Properties

The three lightweight foam concrete cylinders were cast and tested on the same days as the sandwich composite samples. The cylinder tests after 28 days gave an average strength of 0.47 N/mm2 and 3.37 N/mm2. Below is the result of control sample in Table 2.

**Table 2** Compressive strength of control lightweight foamed concrete cylinder tests for 700kg/m³ and 1400kg/m³

| Density (kg/m³) | Compressive Strength (N/mm²) | | | Average Strength (N/mm²) |
|---|---|---|---|---|
| | Test 1 | Test 2 | Test 3 | |
| 700 | 0.43 | 0.46 | 0.52 | 0.47 |
| 1400 | 3.38 | 3.41 | 3.32 | 3.37 |

The data obtained from the experiment described that there is an enhancement of compressive strength of the sample with the inclusion of mechanical connectors (screws). As can be seen in Table 2, average compressive strength obtained by the control sample of 700 kg/m³ is 0.47 N/mm² and 1400 kg/m³ is 3.37 N/mm². But the compressive strength of the control which composite of 700 kg/m³ and 1400 kg/m³, is only 2.91 N/mm². Therefore, the average strength of control sample without mechanical connectors is 2.91 N/mm².

**Table 3** Summary of test results of composite panel under axial compression

| Test designation | Number of Mechanical Connectors | Ultimate Strength (N/mm²) | Average Strength (N/mm²) |
|---|---|---|---|
| Panel 5a | 5 | 3.28 | 3.29 |
| Panel 5b | | 3.20 | |
| Panel 5c | | 3.38 | |
| Panel 7a | 7 | 3.52 | 3.44 |
| Panel 7b | | 3.43 | |
| Panel 7c | | 3.37 | |
| Panel 9a | 9 | 3.69 | 3.61 |
| Panel 9b | | 3.56 | |
| Panel 9c | | 3.59 | |
| Panel 13a | 13 | 3.92 | 3.82 |
| Panel 13b | | 3.84 | |
| Panel 13c | | 3.71 | |

Table 3 present the result of ultimate compressive strength of the samples. While Figure 3 shows the comparison of average ultimate strength of composite panel under axial compression with different number of shear connectors.

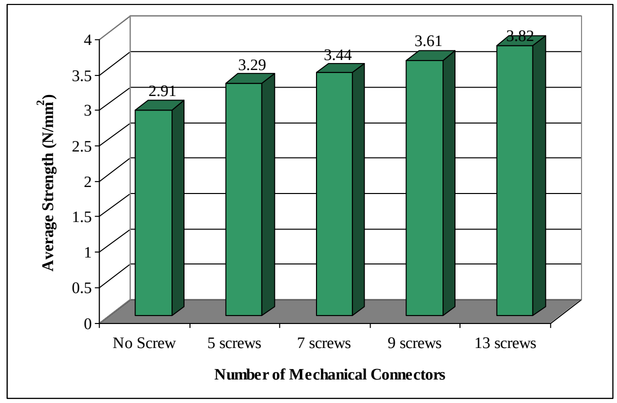



**Figure 3** Comparison of average ultimate strength of composite panel under axial compression with different number of shear connectors

## 4.2 Stress-strain Relationships

Figures 4, 5, 6 and 7 present that graph of stress versus strain relationship of every specimen. Every graph described that stress-strain curve gradually increase. From all the figures, as the increase of numbers of shear connector used, the ultimate compressive strength is increased. Besides that, the more mechanical connector is used, the less axial strain value. The top and bottom of the prototype were placed flat in the machine prior to testing to ensure the distribution of equal load throughout the sample. Fracture patterns highlight the differences between the failure modes of the specimens [12, 13, 14]. The test samples were able to sustain the maximum load applied for considerable axial deformation. The displacement recorded for all samples to reach failure mode is almost similar but different amount of forces were obtained. The specimen reached early failure under lower force and was unable to withstand with pressure exerted [15, 16]. All 4 types showed an initially linear reading, and after certain displacement the graph experienced an increasing pattern where the load increased gradually by means of a compression machine until it reached its peak strength [17, 18].

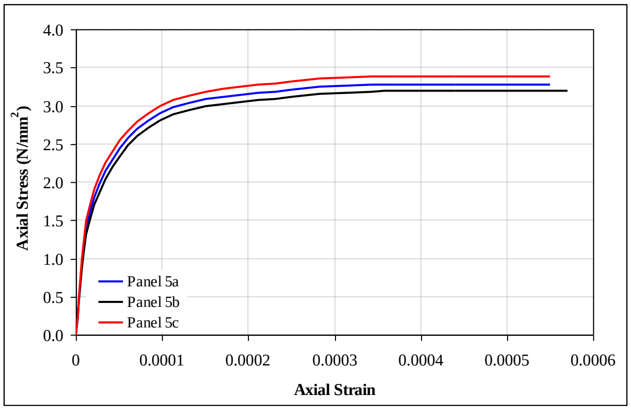



**Figure 4** Load versus mid-height strain relationships for the sandwich panel with 5 nos of shear connectors

It can be seen from Figures 4-7 that in all cases, the strain recorded more elastic strains indicating participation of the mechanical fasteners. In all cases, the test sample was able to sustain the maximum applied load for a considerable axial deformation [19, 20]. The descending branch of all the load-strain curves was sudden, indicating brittle failure of the sandwich composite panel [21, 22].

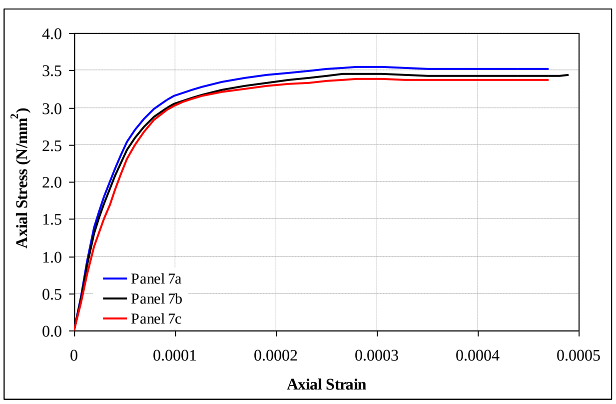



**Figure 5** Load versus mid-height strain relationships for the sandwich panel with 7 nos of shear connectors

It should be pointed out that all sandwich composite panels with sufficient shear transfer mechanisms exhibited deflections well below the limiting value and sustained loads prior to failure in excess of their factored design loads. However, sandwich composite panel, which had 5 mechanical connectors (screws), failed prematurely prior to the service load with high deflections [23].

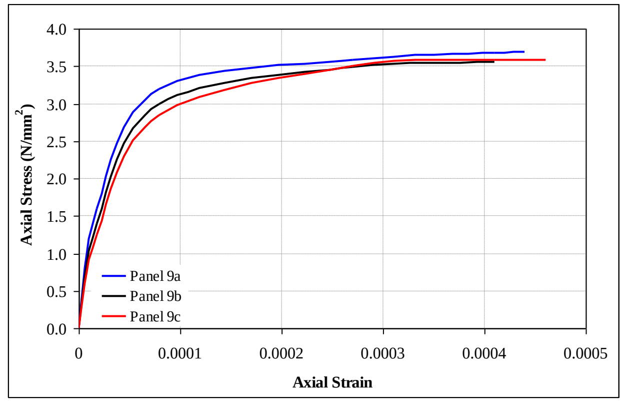



**Figure 6** Load versus mid-height strain relationships for the sandwich panel with 9 nos of shear connectors

The strain profile at ultimate load indicates that the neutral axes of these panels were located closer to the elastic centroid of the composite cross section rather than the elastic centroid of each individual mechanical connector (screw). The measured strains for all sandwich composite panels indicated that each screw acted independently in carrying the applied loads and the neutral axis was located within the thickness of each screw. This behaviour indicated non-composite action [18]. A significant discontinuity in the strain at ultimate load was observed for these sandwich composite panels, indicating a partial composite behaviour at ultimate load

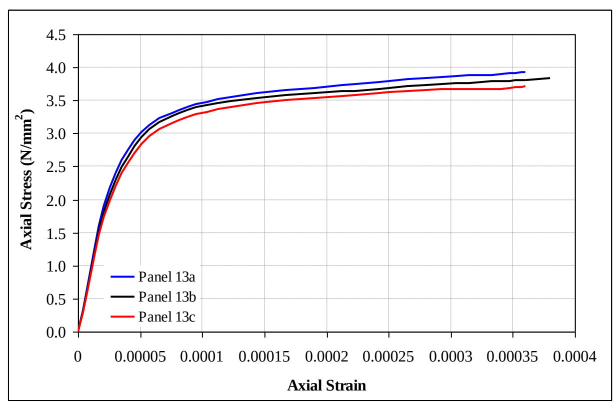
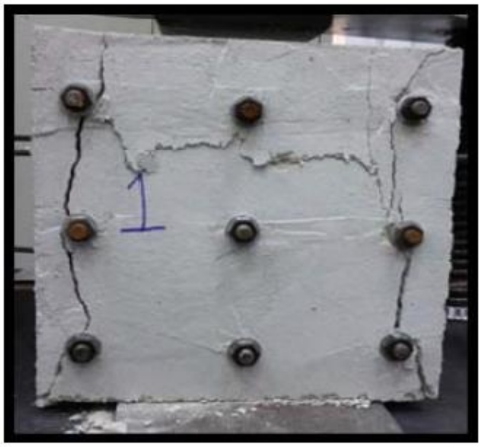



**Figure 7** Load versus mid-height strain relationships for the sandwich panel with 13 nos of shear connectors

## 4.3 Mode of Failure

During the axial load compression test, all the samples were being observed for the mode of failure. For control sample which made of lightweight foamed concrete without connectors, the cracking occurred as the load is applied on the sample. While for the sandwich panel samples, the failure takes time to occur. The ultimate strength obtained by the sandwich composite samples revealed that the samples is able sustain the ultimate load as compared to control sample. Thus, the control sample is failed in brittle manner [21]. Premature failure was observed, which was related to pore distribution and larger air voids during casting as confirmed during post-experiment observations. The development of cracks was more vigorous on the side of the face of the panels than in the middle portion as been shown in Figure 8.




(a) Sample with 9 screws


(b) Sample with 13 screws

**Figure 8** Mode of failure after compression test

## 5.0 CONCLUSION

Through all the experiment that have been conducted, The sandwich composite foamed concrete revealed that can sustained the load bearing with increasing the numbers of shear connector. It also can be concluded the sample made up of sandwich composite foamed concrete with the shear connector achieved the high performance in compressive strength as compared to control sample without mechanical connector. The insulation layer of 700 kg/m$^3$ was able to contribute in compressive strength with the external composite of 1400 kg/m$^3$. Besides that the mechanical connector proved it's effectiveness in compressive strength of samples. In future, the sandwich composite with mechanical connector have the potential to be widely use in lightweight construction industry.

## Acknowledgement

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