Flatwise and edgewise compression strengths of sandwich panel with silica aerogel mat

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Abstract. Facade of building are mainly made up from red clay brick and concrete block. However, both materials are having high thermal mass and promote high indoor thermal discomfort level. Therefore, it is necessary to invent new building material that have low thermal mass and able achieve strength required. Silica aerogel possesses properties of lightweight and low thermal conductivity as compared to other construction materials. In this study, sandwich panel with silica aerogel mat was studied where the properties of sandwich panel silica aerogel mat are rarely found in previous investigations. Before checking its reliability as thermal insulation panel, the mechanical properties of this panel was investigate. The panel was made-up by concrete wythes with type N mortar and the silica aerogel mats with different thickness. Both concrete wythes were casted and then attached together with silica aerogel mat as the cover. 3 types of panel with different insulation thickness were then tested for flatwise and edgewise compression test. From the results, it was found that core thickness of silica aerogel mat has less influence in flatwise and edgewise compression strengths of the sandwich panel. All specimens achieved minimum strength of type N mortar. Therefore, it is recommended to be used in construction that has equivalent application of type N mortar.

1. Introduction
Scholars, architect, contractor, government and developers are paying attention to the issues related with indoor thermal comfort. Building envelope is the physical divider between the indoor and outdoor of a building. There is a close relationship between building envelope and indoor thermal comfort. In order to maintain thermal comfort, absorptivity of external surfaces, thermal capacity, and thermal conductivity of the building envelope greatly influence the internal environment and consequently the energy consumption inside the building [1]. Construction materials such as brick and concrete are having criteria such as high thermal mass and thermal conductivity. Those materials tend to store heat during daytime and release the heat at night with high rate of heat transfer across the material itself. Therefore, application of thermal insulation material to control heat transfer is an easier and practical way to maintain indoor thermal comfort level. However, conventional thermal insulation materials are either non-environment friendly or causing health issues.

Composite sandwiched structures are recently being widely applied by the world especially the marine and aviation industries [2]. Sandwiched materials are knowns to be able to provide high
stiffness coupled with lightweight [3]. Good shock resistance, flexural rigidity, low heat and sound transfer and easy to install [4] make sandwiched structure an ideal and promising structures in the future. Precast concrete sandwiched panel is one of the types of composite structures with 2 layers of concrete wythes separated by layer of insulation. It is gaining attention of researchers recently due to its potential to become non-load bearing wall and provide thermal insulation. Concrete sandwiched panel able to act as multi purposes construction material compare to the normal brick and concrete. At the same time, Ern et al. (2017) [5] and Huang et al. (2020) [6] suggest more researches are needed on concrete sandwiched panel as concrete sandwiched panel crucial to replace conventional construction material.

The study of silica aerogel mat as core insulation materials are limited [4]; [5]; [7]. Studies by Parra and Moehle (2014) [7] and Amran et al. (2019) [8] mainly discussed about structural properties and application for load bearing panel or wall. Sandwich panels are normally applied in wall construction where they resist most of the compression actions from the loadings generated in buildings. Therefore, the flatwise and edgewise compression strengths are the important input data for building design, even though is for non-bearing wall application. To follow the suggestion of [9] and [10], this study is about silica aerogel mat sandwiched panel. This paper provides important data and information of an innovation of future product in design stage which bridge the knowledge gap and promote sustainability. The mat/core thicknesses tested are 9, 12 and 15 mm. The composite mortars are tested for flatwise and edgewise compression strength.

2. Experimental procedure

2.1. Material
Sand that pass through 600 µm sieve and Ordinary Portland cement (CEM I 42.5N) were used for the concrete wythes mixing. In the meantime, silica aerogel mat, as shown in figure 1, with the properties given by supplier, as displayed in Table 1, is casted as the insulation material at the centre of the sandwich panel specimens.

![Figure 1. Silica aerogel mat.](image)
Table 1. Properties of silica aerogel mat.

| Properties                      | Value                        |
|---------------------------------|------------------------------|
| Material                        | Fiberglass + Nano silica aerogel |
| Colour                          | White                        |
| Density                         | 180-220kg/m³                 |
| Applicable temperature          | -200°C to +1000°C            |
| Thermal conductivity (25 °C W/ m·K) | 0.012-0.018                 |
| Low temperature bending         | ≤99%                         |
| Breaking elongation             | 65%                          |
| Surface chemistry               | Hydrophobic                  |
| Bending strength                | 45kP                         |
| Compressive strength            | 32N                          |

2.2. Mix design
Mix ratio for cement to sand was 1:3 to produce normal mortar for concrete wythes. 3 different core/mat with thickness of 9, 12 and 15 mm sandwiched between normal mortar were casted and tested for flatwise compression test according to ASTM C365 with the dimension of 50 mm³. Whereas, samples testing for edgewise compression by following ASTM C364 were in the dimension of 200 mm (length) × 200 mm (width) × 100 mm (thickness) and 3 different core/mat thickness which are, 9, 12 and 15 mm. Three specimens were casted for each core thickness and testing. A total of 18 specimens were casted. All specimens were tested for 28 days of concrete ages for characteristic strength. Figure 2 shows the 15 mm thick mat sandwiched mortar for flatwise strength testing.

![Figure 2. 15mm thick mat sandwiched mortar for flatwise strength testing.](image)

2.3. Mixing procedure
Ordinary Portland cement (CEM I 42.5N), oven-dried fine aggregate (pass through 600 µm sieve) and water with the water cement ratio of 0.83 (to achieve flow rate of 110 ± 5) were weighted accordingly prior mixing. After that, OPC, fine aggregate was mixed together with addition of water. Fresh mortar was then poured into moulds prepared in advanced. After that, samples water-cured for 28 days.
2.4. Testing procedure

2.4.1. Flatwise compression test. Sample was placed at the center of machine (Universal Testing Machine) prior to loading. Based on standard, specimen is encouraged to be clamped at both ends to prevent movement during testing. Due to unavailable of clamps, specimen was not fixed by clamp during testing. Load was then equally distributed over the entire loading surface of specimen. A load rate of 1 kN/s was applied to specimens with pace rate of 10mm/min. However, ASTM C 365 suggest pace rate of 0.5mm/min. Load was applied until failure happened. Set up of sample for flatwise compression testing is shown in figure 3.

2.4.2. Edgewise compression test. Sample was placed at the center of machine (Universal Testing Machine) prior to loading. 2kN/s of load was applied with pace rate of 10mm/min. However, ASTM C 364 suggest pace rate of 0.5mm/min. Load was equally distributed over the entire loading surface of specimen until failure happened. Despite the suggestion to clamp both ends of specimen to prevent movement, it was unable to carried out due to unavailable of clamps. Set up of sample for edgewise compression testing is shown in figure 4.
3. Result and discussion

3.1. Flatwise compression test

Equation (1) shows the formula for flatwise compressive strength and results are shown in figure 5.

\[
\text{Flatwise compressive strength} = \frac{P}{A}
\]  

where \( P \) is the maximum load in N and \( A \) is the area of loaded surface in mm\(^2\).  

![Figure 5. Flatwise and edgewise compression strength.](image)

From the results as in figure 5, sandwich mortar with 15 mm thickness silica aerogel mat achieved the highest flatwise compression strength compared to 12 mm and 9 mm thickness mats. In the study of [11], it is observed that height or thickness of core is positively contributing to flatwise compressive strength of composite product. It is interesting to note that the higher the core thickness, the higher the load carrying capacity. This is because insulation layer is well known to play a role in thermal conductivity and not contribute to overall strength. It is no doubt that there is a lack of study about the relationship of core thickness with flatwise compression strength. Hence, relationship of core thickness with compression strength is worth to be further investigated.

3.2. Edgewise compression test

Equation (2) shows the formula for edgewise compressive strength. The results are shown in figure 5.

\[
\text{Edgewise compressive strength} = \frac{P_{\text{max}}}{w(2t_{fs})}
\]  

where \( P_{\text{max}} \) is the maximum load in N, \( w \) is the width of sample in mm and \( t_{fs} \) is the thickness of a single facesheet in mm.

In term of edgewise compression strength, core thickness of 12 mm achieved the highest strength among the others. Meanwhile, 9 mm core thickness had the lowest edgewise compression strength. Despite of 12 mm core thickness had larger area of mortar in contact with load during testing, results showed reduction of mortar able to increase the strength. It is undeniable that, the higher the core thickness, the higher the strength to withstand load.

The trend of data obtained was increased by 1.64 N/mm\(^2\) and then dropped from 12 mm core thickness to 15 mm core thickness. The drop of strength by 0.64 N/mm\(^2\) for 15 mm core thickness may due to the misplacement of samples during testing. Samples may not place in the center for the testing setup, causing uneven distribution of load. The weakest point is the bonding area between the facesheet and core. When load was applied parallel to the weakest point, it further weakens the bonding. Lack of clamp at end of samples during testing also assumed to be one of the factors for concrete failure. Samples may slip without clamp to fix during application of loading, causing inaccurate of the reading.
Based on ASTM C364 / C364M, there are 5 types of failure mode and 1 unacceptable mode can be observed. Type of failure modes for 9 mm, 12 mm and 15 mm thick mat sandwiched mortar were shown in figure 6 and it was facesheet compression failure. It is because both the facesheets have the largest contact area to load being applied and tend to compress due to the load. Due to the smaller contact area of silica aerogel mat, it was protected by mortar facesheet. Based on observation, silica aerogel mat for all 3 types of specimens still in good contact.

![Figure 6. Facesheet compression failure mode.](image)

3.3. Comparison of both compression strength test
When compared both compression strength for 9 mm core thickness, it is found that the difference between both tests is only 1.42 MPa. In the meantime, the differences for 12 mm and 15 mm core thickness are 0.15 MPa and 1.1 MPa respectively. Generally, the differences between both strength test is not more than 1.5 MPa. However, compression strength for 9 mm and 15 mm samples for flatwise compression test is higher than edgewise compression test might due to the slenderness. The higher the slenderness ratio, the higher the instability and lead to buckling as observed [7] [8]. Apart from that, 12mm core thickness sample for edgewise compression observed to have higher strength by 0.15 MPa than flatwise compression strength.

3.4. Comparison with previous research
Composite sandwiched panel can be made up from various material for the cover and core. Previous researches have done by using different cover and core material such as concrete, foam concrete, polyethylene and etc based on the purpose of the final product. The aims to produce product with characteristic of lightweight, fire resistant, thermal insulation, structural strength or combination of the listed properties. Concrete cover with sandwiched insulation has the potential to act as non-load bearing wall or cladding. Even the composite product studied by Oh et al. (2013) [12] and Jennise et al. (2014) [13] are potentially attached to existing wall to provide additional functions. Moreover, shear connectors were widely used for composite panel to increase strength of the samples. Despite of that, shear connector is not used for this experiment as results came out able to reach the minimum requirement of Type N mortar. Previous researches are shown in table 2.
Table 2. Previous research of flatwise and edgewise compression tests

| Reference | Material                        | Compression test (MPa) |
|-----------|---------------------------------|------------------------|
|           |                                 | Flatwise   | Edgewise  |
| Current study | Type N mortar 9 mm silica aerogel mat | 8.81       | 7.39      |
|           | Type N mortar 12 mm silica aerogel mat | 8.88       | 9.03      |
|           | Type N mortar 15 mm silica aerogel mat | 9.49       | 8.39      |
| [5]       | Foamed concrete gypsum          | -          | 2.35      |
|           | Foamed concrete with POFA gypsum| 3.3        | -         |
| [4]       | 3D high density polyethylene foam | 3.41       | 7.53      |
| [7]       | Glass fiber polyurethane coconut foam | 1.74 – 2.04 | -         |

4. Conclusion
In conclusion, 3 types of core thickness had not much different in flatwise and edgewise compression strength. For flatwise compression strength, it was less than 1N/mm² and only 1.64N/mm² in term of different among the 3 type of thickness. Besides that, when compared with type N mortar, all 3 types of core thickness achieved minimum strength of 6.2N/mm² at 28 days of concrete curing age. Furthermore, flatwise and edgewise strength obtained are higher than previous researches, even though edgewise compression from study of [4] was higher by 0.14 MPa compared to 9 mm core thickness mortar. It is concluded that mortar panel is potentially to replace type N mortar in construction industry. It is recommended to further study the flexural strength of silica aerogel sandwich mortar as well as its thermal properties.

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