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LIGHT-TRANSMITTING CONCRETE PROPERTIES OF SHORT WALL PANEL

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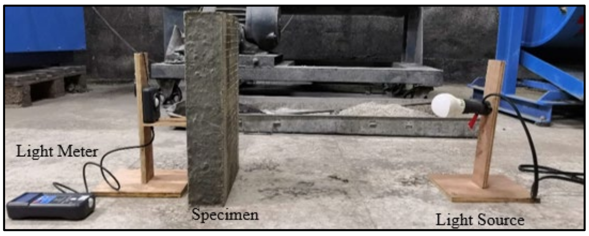
Graphical abstract



The 6 × 6 grid configurations of LTC under light transmittance test

Abstract

Consideration of fiber configuration and the distance between the light source or light meter and the LTC specimen in the previous studies is still limited. The incorporation of plastic optical fiber (POF) into concrete with fiber configurations of 5 × 5 and 6 × 6 grids is investigated in terms of short wall panel application to study its light intensity and strength properties. The light-transmitting concrete (LTC) short wall panel of 300 mm wide × 400 mm high × 75 mm thick is cast using self-compacting concrete (SCC) to ensure the flowability of the concrete during mixing. The fresh SCC is tested under slump flow, V-funnel, and L-box to verify its fresh properties, while compression test is carried out at 28-days on cube specimens to determine its compressive strength. Then, light transmittance and axial load test under compression are conducted for the LTC wall panel. The findings show that the light intensity of the LTC wall panel increased with the increased number of fiber configurations. However, regardless of fiber configurations, the light intensity reduced with the increase of both light source and light meter distances. In addition, the ultimate axial load of the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids are 662 kN and 643 kN, respectively. It implies that the fiber configuration does not affect the axial compression load. Furthermore, both LTC wall panels failed solely under pure compression load.

Keywords: Light-transmitting concrete, plastic optical fiber, self-compacting concrete, axial load, fiber configurations

1.0 INTRODUCTION

About 19 % of the total electricity worldwide is consumed by artificial lighting [1]. Light-transmitting concrete (LTC) could be one of the innovative ideas of reducing the consumption of man-made lighting while maintaining the structural purpose of the structure [2]. This innovative product could be categorized as a green building material. By incorporating translucent materials such as waste glass, resin, or optical fiber into concrete, it can allow light to pass through from one end to the other of the concrete block. This in turn cuts down the necessity of switching on the lighting fixtures in the interior of the building as natural light could transmit through the LTC. Amongst the translucent materials, optical fiber is commonly adopted in the production of LTC because of its good light transmittance properties whereby it utilizes the principle of total internal reflection to transmit the light ray [3]. Altlomate et al. [4] reported that as the percentage of the optical fiber increased, the light intensity passing through the samples increased. However, the transmission of light through LTC may not be optimized with the increase of POF. For light transmittance properties, Huang and Lu [5] proved that more light was transmitted through the specimen with an increase in the density of the optical fiber. Furthermore, Shen and Zhou [6] also claimed that light transmittance of the translucent concrete corresponding to the volume ratio of POF. Another valuable contribution is that incandescent light source has greater light intensity than halogen light source [7]. For the current experimental study, LED light source was used due to its excellent light intensity and power saving. Moreover, the optical power decreased with the increase in the distance between the specimen and light meter. This may account for the light scattering that occurs with the increase in the light meter distance, ultimately, the light intensity will decrease. Likewise, the transmission of light declined when the light source distance increased. This can be attributed to the fact that the light intensity approaches to the surface of the specimen decreased with an increasing distance [1]

Kumar and Ahlawat [8] reported that the inclusion of POF would have no significant influence on the compressive strength of LTC. Henriques et. al. [9] stated that there were no significant differences in the compressive strength for POF volume ranged from 0% to 2%. On the contrary, Sawant et. al. [10] reported that the compressive strength of LTC dropped when the percentage of optical fiber increased. This may attribute to the inclusion of POF in the concrete matrix did not significantly improve the compressive strength of LTC. In addition, the optimum diameter of POF to obtain higher compressive strength was 2 mm as compared with the 1.5 mm and 3 mm for different POF volumes [11]. Hence, POF with a 2 mm diameter is employed in this study.

Table 1 shows the testing parameters considered in the previous studies where the most considered parameters in evaluating of light transmittance of LTC are fiber volumetric fraction and fiber diameter. The consideration of fiber configuration (fiber spacing) and the distance between light source or light meter and the LTC specimen is only comprised of 5.56% and 2.77%, respectively, which the investigation on these parameters is still scarce. Yet, the investigation on the effect of fiber configurations and the distance between light source or light meter with the specimen on LTC light transmittance is essential especially when LTC is being considered in building construction to ensure adequate light intensity can be transmitted through LTC into the room. Hence, this study is aimed to develop a small-scale LTC wall panel using POF and to investigate the light transmittance properties of LTC with different fiber configurations, light source distances, and light meter distances together with its ultimate axial load under compression.

Table 1 Testing parameters considered in previous studies

Testing parameters considered in previous research	Percentage (%)
Diameter/ size of translucent element	19.44
Volumetric fraction / area fraction of translucent element	25.00
Spacing between translucent element	5.56
Translucent element configuration	1.39
Light wavelength	11.11
Light Intensity	5.56
Distance between light source/ light detector and specimen	2.77
Reflective index	1.39
Translucent element form	4.17
Translucent element type	4.17
Curing condition	1.39
Matrix constituents	6.94
Specimen thickness	4.17
Light beam angle of incidence	4.17
Light beam diameter	1.39
Presence of Compound Parabolic Concentrator (CPC) or Straight Cone (SC)	2.77

2.0 METHODOLOGY

2.1 Materials

Ordinary Portland Cement (OPC) CEM I 42.5N and Class F fly ash are adopted in this experimental study. Fly ash is added as a replacement to OPC at 30% to improve the concrete strength and workability by producing additional C-S-H gel through the pozzolanic reaction. The chemical composition of the fly ash is given in Table 2. It is noted that the Aluminum Oxide and Silicon Oxide in fly ash comprised of 21.3% and 59.5% respectively, which are essential for the production of C-S-H gel. This indicates that the fly ash possesses cementitious properties which is suitable to be used as partial cement replacement.

Table 2 Chemical composition of fly ash

Component	Content (%)
Al_2O_3	21.3
SiO_2	59.5
SO_3	0.6
Fe_2O_3	7.1
CaO	7.18
MgO	1.42
K_2O	1.53
Na_2O	1.42

The maximum size for coarse and fine aggregates are 10 mm and 4.75 mm respectively. Both aggregates are used in saturated surface dried conditions to manufacture the LTC. The 2 mm diameter with the polymethylmethacrylate type is chosen for the optical fiber. Normal tap water is used for concrete mixing and curing purposes. MasterGlenium ACE 8589, polycarboxylic ether-based superplasticizer is also added in the mixture.

2.2 Concrete Mix Design and Preparation of LTC Wall Panel

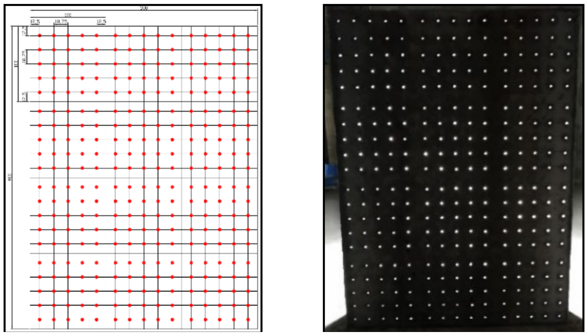
Self-compacting concrete (SCC) is adopted as per the European Guideline in EFNARC [12] to solve the problem during concrete placement whereby compacting the fresh concrete mixture with a tamping rod can break the optical fiber. Table 3 presents the finalized concrete mix proportion for the LTC wall panel after several trial mixes are done. Slump flow, V-funnel time, passing ability ratio, and the 28-days compressive strength are 635 mm, 3.08 s, 0.82, and 45.13 N/mm^2, respectively. This satisfies the desirable fresh concrete properties and the targeted compressive strength of 40 N/mm^2. It may be argued that the slump flow for the application of the wall should fall underclass of SF2 as suggested by Walraven [13]. However, in this case the concrete mix design with slump flow of 635 mm is selected to produce the LTC wall panel. This is because the slump flow being higher than 600 mm and nearly approaching the lower limit of Class SF2, which is 660 mm in accordance to EFNARC [12]. Moreover, the height of the wall panel in this experimental study is not considered as tall as in the normal application, thus, this mix proportion is chosen and adopted.

Table 3 Concrete mix design for 1 m^3

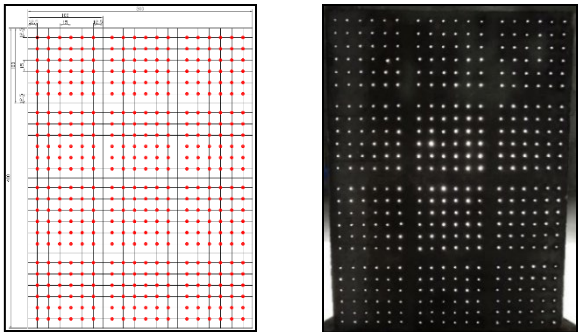
Cement (kg/m^3)	Fly Ash (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Water (kg/m^3)	Superplasticizer (kg/m^3)
385	165	590	910	253	9.62

One of the criteria for the wall design is the length should be greater than or equal to four times the thickness of the wall. In this experimental study, the panel is designed as short wall. Therefore, the limiting ratio should be greater than the slenderness ratio of the wall panel. Therefore, the wall panel with the dimension of 300 mm wide × 75 mm thick × 400 mm high is adopted. There are two types of fiber configurations employed for the LTC wall panel, that is, 5 × 5 and 6 × 6 grids, as depicted in Figure 1. Both configurations are designed with side spacing of 12.5 mm to allow the placement of the 10 mm maximum size of coarse aggregate within the concrete mixture. The number of POF, POF spacing, and POF volume are presented in Table 4. Since the maximum aggregate size used is 10 mm, the minimum spacing between optical fibers is fixed at 15 mm to ensure coarse aggregates can pass freely between optical fibers during concrete placement. This determines the fiber configurations of 6 × 6 grid for LTC fabrication. On the other hand, to investigate the effect of different fiber spacing on the LTC light transmittance, another fiber configuration of 5 × 5 grid was chosen.

In this study, higher number of fiber configurations indicated higher POF volume which is done by increasing the number of POF in the wall panel and decreasing the spacing between the POF. The reason for using the naming of fiber configuration instead of POF volume is to ease the practicality of the design and the production of the LTC wall panel with uniform spacing between the POF.



(a) 5 × 5 grid



(b) 6 × 6 grid

Figure 1 Fiber configurations employed for the LTC wall panels

Table 4 Fiber configurations used for the LTC wall panel

Fiber Configuration	No. of POF	Spacing (mm)	POF Volume (%)
5 × 5	300	18.75	0.80
6 × 6	432	15.00	1.10

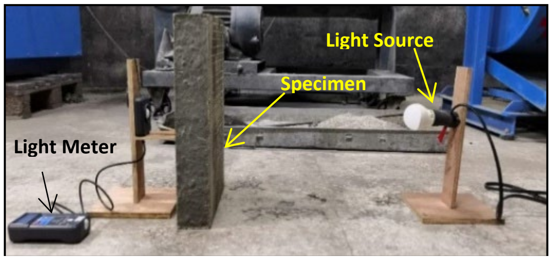
2.3 Experimental Test and Setup

The fresh properties of SCC are determined from the slump flow, V-funnel, and L-box tests, following BS EN 12350-8 [14], BS EN 12350-9 [15], and BS EN 12350-10 [16], respectively. The test for each setup is shown in Figure 2. The characteristics of SCC in terms of flowability, viscosity, and passing ability are determined and the verification of the mix design for application of LTC wall is done following the recommendation by Walraven [13].

(a) Slump flow (b) V-funnel (c) L-box

Figure 2 Fresh properties test of SCC

Figure 3(a) illustrates the setup for the light transmittance test for the LTC wall panel. The setup includes an 11-Watt LED bulb for the light source, LTC wall panel, and a light meter to measure the optical power. The test is conducted inside a dark room so that the disturbance from the external natural light could be omitted. In this test, the parameter configurations include fiber configurations (5 × 5 and 6 × 6 grids), light source distance, and light meter distance (100 mm, 200 mm, 300 mm, 400 mm, and 500 mm).



(a) Light-transmittance test

(b) Compression test on concrete cube (c) Axial compression test

Figure 3 LTC wall panel tests

In compliance with BS EN 12390-3 [17], three SCC cubic specimens (also known as the control) with dimension of 100 mm × 100 mm × 100 mm are tested under compression to determine the average compressive strength at 7-days, 14-days and 28-days as shown in Figure 3(b). This is to ensure that the concrete mixture meets the requirement design compressive strength of 40 N/mm^2 at 28-days. The cube specimens are compressed at a loading rate of 6 kN/s until failure for each curing age. On the other hand, axial compression test of the LTC wall panel at 28-days is carried out using a Universal Testing Machine (UTM), where the loading is applied continuously until failure under a constant loading rate of 0.06 mm/s. The test is carried out to determine the ultimate load of the wall panel, strain relationships and to observe the failure mode. To measure the concrete strain, strain gauges with a gauge factor of 2.08 are attached at mid-span on the front and back of the wall panel. In addition, the strain gauges are installed parallel to the direction of the applied loading as shown in Figure 3(c).

3.0 RESULTS AND DISCUSSION

3.1 Light Transmittance of LTC Wall Panel at Different Fiber Configurations

The fiber configuration affects the light transmittance properties of the LTC wall panel. Figure 4 presents the effect of fiber configuration on the light intensity of the LTC wall panel with different light meter distances at a constant 100 mm light source distance.

It can be deduced that the light intensity increased with the increasing number of fiber configurations. This is because the higher number of fiber configurations has higher POF volume, which in turn increased the amount of light transmitted through the LTC wall panel. Also, it is due to the superposition of the light intensity from the higher number of optical fibers. The findings agreed with the results obtained by Tuaum et. al. [1] and Huang and Lu [3].

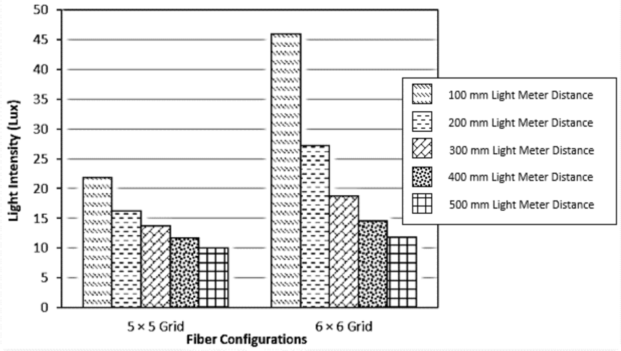


Figure 4 Light intensity of LTC wall panel with variable fiber configurations and light meter distances at a fixed 100 mm distance of the light source

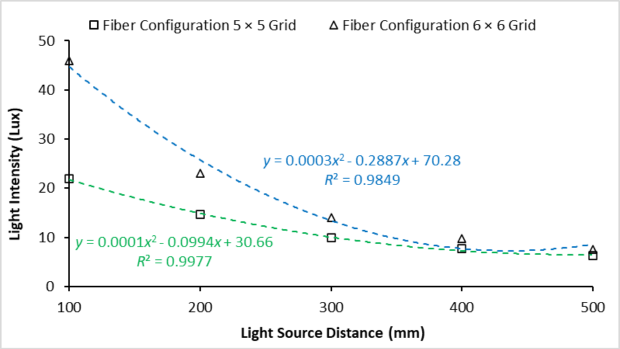
For example, the highest and lowest light intensity of the LTC wall panel with fiber configuration of 6 × 6 grid (46 lux and 11.8 lux) is higher than the LTC wall panel with fiber configuration of 5 × 5 grid (21.9 lux and 10 lux). As a result, the fiber configurations significantly affected the light transmittance properties of the LTC wall panel. Sawant et. al. [6] stated that the light level between 100 lux and 300 lux would be sufficient for normal indoor activities. It is possible to speculate that this small-scaled LTC wall panel can be employed for normal-sized wall application. The light intensity would be adequate in approaching within the range of the normal indoor light level because of the greater superposition of the light from the POF.

3.2 Light Transmittance of LTC Wall Panel at Varying Light Source Distances

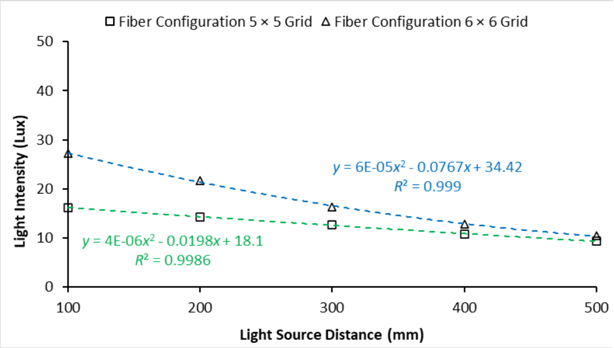
Figure 5(a) – 5(e) shows the relationship between light intensity of the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids and the distance of the light source. In this relationship, the light meter distances are fixed at 100 mm, 200 mm, 300 mm, 400 mm and 500 mm.

The results demonstrate that when the light source distance increased from 100 mm to 500 mm, the light intensity of the LTC wall panel decreased regardless of the fiber configurations. These results support the findings by Li et al. [18] stating that the light transmission through LTC reduced with the increase of the light source distance. One plausible explanation is that when the light source is further distanced, the light ray that approached the wall panel surface will be lessened, thus reducing the light intensity. From Figure 5, it can also be seen that there is a strong correlation between the light intensity and the light source distance in terms of a quadratic function where the proportion of variance, R^2 is near to 1.0.

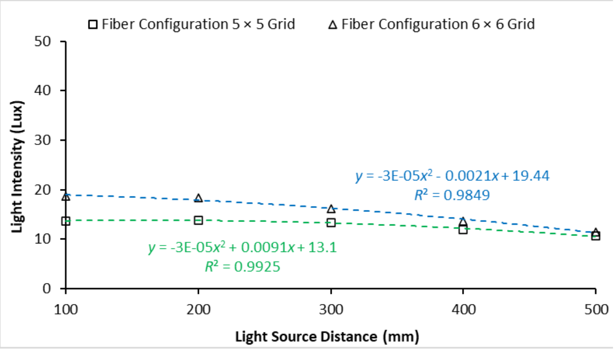
Besides, at constant 100 mm light meter distance, the rate of light intensity declined rapidly when the light source distance increased from 100 mm to 200 mm as well as from 200 mm to 300 mm; the rate declined gradually when the light source distance is beyond 300 mm. For example, the light intensity is reduced by 33.33% and 50% for the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids, respectively when the light source distance increased from 100 mm to 200 mm. Nevertheless, when the light source distance increased from 400 mm to 500 mm, the light intensity reduced by 18.18% and 22.68% for the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6, grids respectively. As the constant light meter distance exceeded 200 mm, there are changes in the relationship between the light intensity of the LTC wall panel and the light source distance. Based on Figures 5(c), 5(d) and 5(e), the peak light intensity tends to move to the 200 mm light source distance despite the overall trend is that the light intensity decreased with the increase of the light source distance. For instance, at a fixed 500 mm light meter distance, the light intensity increased by 18% and 11.02% when the light source distance increased from 100 mm to 200 mm for the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids, respectively. A possible reason will be when the light meter distance exceeded 200 mm, the light meter possessed a wider area of receiving the transmitted light ray from the POF. Meanwhile, the light intensity only concentrated at the mid-span section of the wall panel but with weaker light intensity received by the POF at the edge of the wall panel when the light source distance is 100 mm. Therefore, the light intensity would be optimized at 200 mm light source distance when the light meter distance exceeded 200 mm.



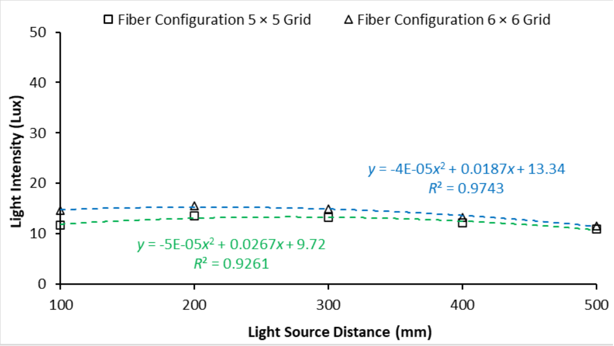
(a) At 100 mm light meter distance



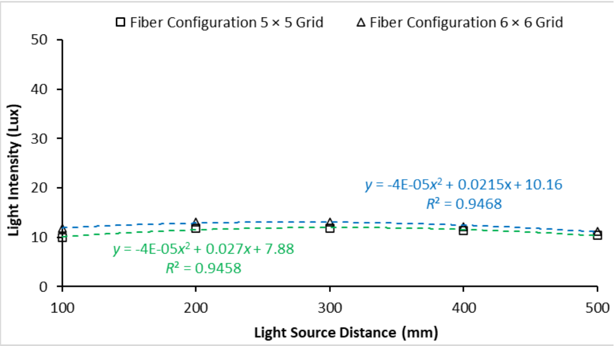
(b) At 200 mm light meter distance



(c) At 300 mm light meter distance



(d) At 400 mm light meter distance



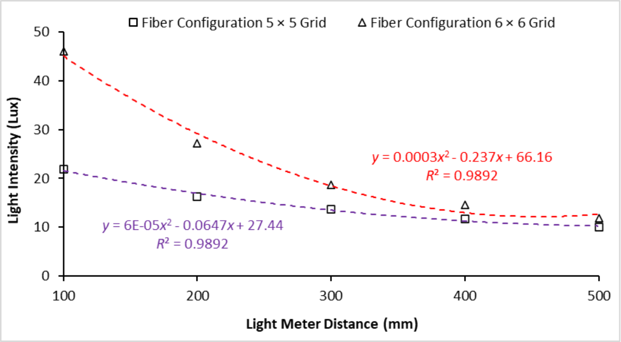
(e) At 500 mm light meter distance

Figure 5 Relationship between light intensity of LTC wall panel and light source distance

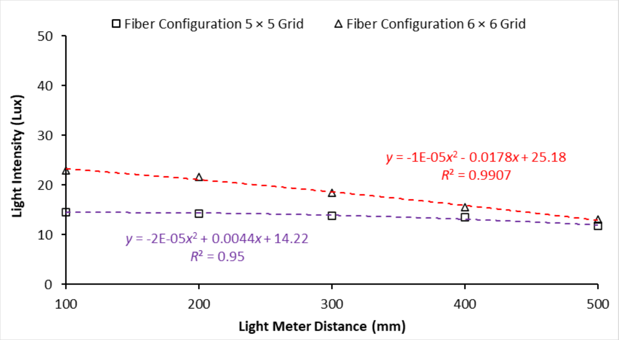
3.3 Light Transmittance of LTC Wall Panel at Varying Light Meter Distances

Figure 6(a) – 6(e) depicts the relationship between light intensity of the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids and the light meter distance. The relationships were derived based on the fixed light source distance of 100 mm, 200 mm, 300 mm, 400 mm and 500 mm.

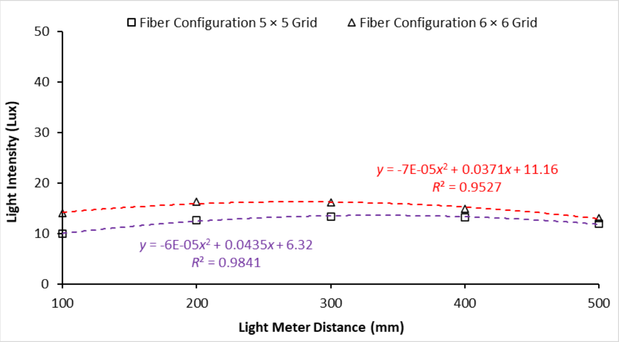
The results suggested that when the light meter distance increased from 100 mm to 500 mm, the light intensity of the LTC wall panel decreased regardless of the fiber configurations. These results are in agreement with the findings by Robles et. al. [19]. They claimed that the light transmission of LTC decreased with the increasing distance between the light meter and the specimen. A plausible reason is that the light ray scattered when the light meter is further distance, thus, the light intensity dropped. From the relationship in Figure 6, it also proved that there is a strong correlation between the light intensity and light meter distance in terms of a quadratic function since the proportion of variance, R^2 is near to 1.0.



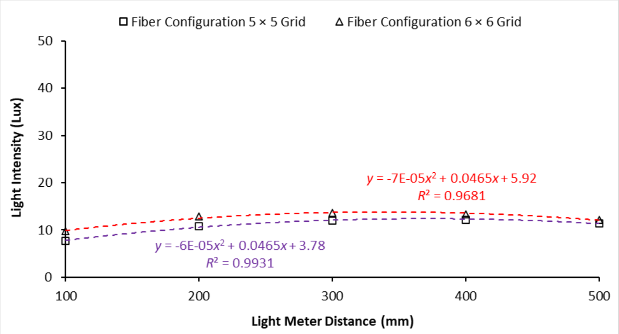
(a) At 100 mm light source distance



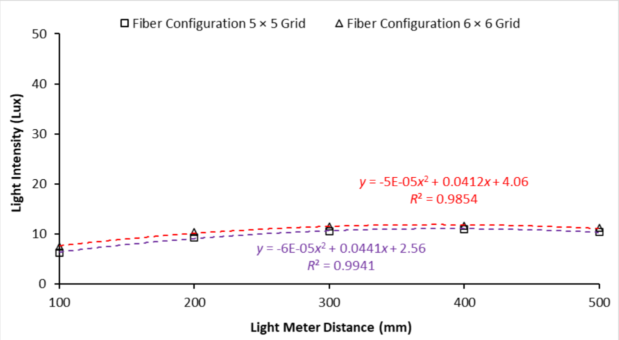
(b) At 200 mm light source distance



(c) At 300 mm light source distance



(d) At 400 mm light source distance



(e) At 500 mm light source distance

Figure 6 Relationship between light intensity of LTC wall panel and light meter distance

Moreover, at a fixed 100 mm light source distance, the rate of light intensity dropped rapidly when the light meter distance increased from 100 mm to 200 mm as well as from 200 mm to 300 mm; the rate dropped gradually when the light meter distance is beyond 300 mm. For instance, the light intensity reduced by 26.03% and 40.87% for the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids, respectively when the light meter distance increased from 100 mm to 200 mm. Nonetheless, when the light meter distance increased from 400 mm to 500 mm, the light intensity reduced by 14.53% and 19.18% for the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids, respectively.

The relationship from Figure 6 also suggested that as the fixed light source distance exceeded 200 mm, the light intensity of the LTC wall panel and light meter distance is altered. Based on Figures 6(c), 6(d), and 6(e), the peak light intensity is observed when the light meter distance is between 300 mm and 400 mm. For clarification, at fixed 400 mm light source distance, the optimum light intensity of LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids are 12.2 lux and 13.6 lux at 400 mm and 300 mm light meter distance, respectively. This may be because of the wall panel having more surface area exposed to the light source when the distance exceeded 200 mm. Vice versa, when the light meter distance is short, the light meter will receive lesser light ray as the area of receiving the transmitted light ray from the POF is restrained. Hence, for optimum transmittance, the light intensity is optimized between 300 mm to 400 mm the of light meter distance when the light source distance exceeded 200 mm.

3.4 Axial Compression Load Test of LTC Wall Panel

Figure 7 displays the relationship between the axial force and vertical displacement when the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids are subjected to axial compression load test at 28-days. The test found that the ultimate axial load resisted by the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids is 662 kN and 643 kN, respectively. It is worth noting that the LTC wall panel with 6 × 6 grids had slightly higher compressive strength than the wall panel with 5 × 5 grids. This is due to the optical fibers for 6 × 6 grids were more closely arranged where the distance between optical fibers was smaller. This contributed to a smaller interconnecting distance for microcracks propagation when subjected to compression. Nevertheless, the difference between the wall panels of both fiber configuration is only 19 kN or 2.87%, which is insignificant.

It is noted that the vertical displacement at failure for the wall with fiber configuration of 6 × 6 grid is 20.08% lower than the configuration of 5 × 5 grids. This proved that the smaller interconnecting distances between optical fibers accelerated the microcracks propagations and eventually lead to concrete failure. However, based on Figure 7, it can be seen that the LTC wall panel with 6 × 6 grids seems to fail in a more ductile manner compared with the wall panel with 5 × 5 grids, as the wall panel with 6 × 6 grids has residual strength over at least 2 mm of vertical displacement after reaching the ultimate load, but the compression load of wall panel with 5 × 5 grids dropped drastically with insignificant difference in vertical displacement after reaching the ultimate load.

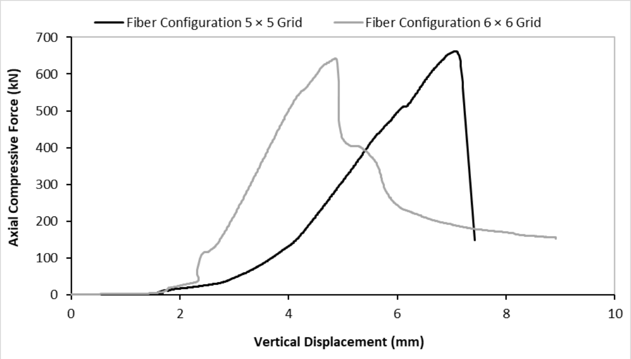
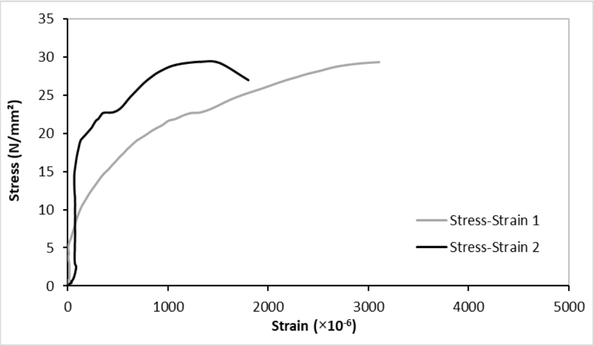
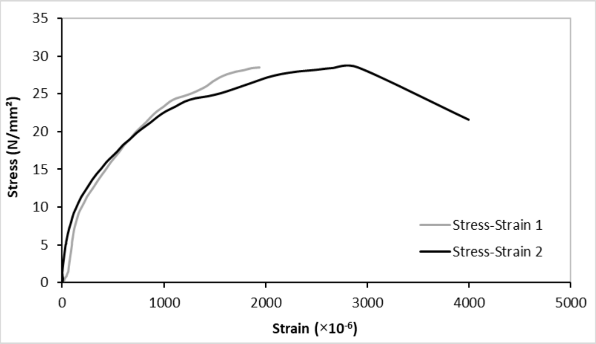


Figure 7 Relationship between axial compressive force and vertical displacement of LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids

The stress-strain curve of the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids is exhibited in Figure 8(a) and 8(b), respectively. As seen in the figures, the results appear to confirm that both LTC wall panels are under pure compression load because there is only compressive strain experienced at the front and back sides where the strain gauges are fixed. Nonetheless, the stress-strain curve for the wall panel with fiber configuration of 5 × 5 grids have a slightly different trend at the front and back of the LTC wall panel. It may be accounted where the applied load may not be perfectly aligned to the center of the LTC wall panel specimen during the test. At ultimate strength, the compressive strain at the front and back positions is 3110 × 10^{-6} and 1323 × 10^{-6}, respectively for the LTC wall panel with fiber configuration of 5 × 5 grids; 1938 × 10^{-6} and 2906 × 10^{-6} at the front and back positions, respectively for the LTC wall panel with fiber configuration of 6 × 6 grids. This result validates that both LTC wall panels are within the materials requirement established in BS EN 1992-1-1 [20] as the concrete ultimate strain is less than 3500 × 10^{-6}.



(a) 5 × 5 grids

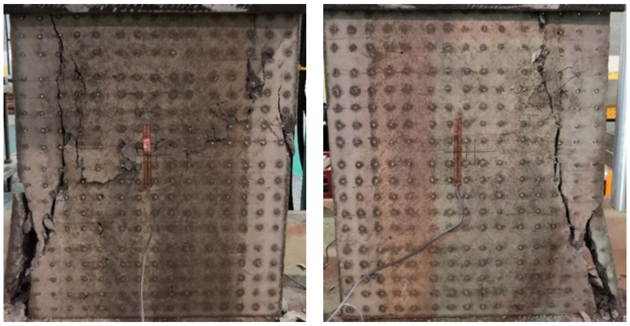


(b) 6 × 6 grids

Figure 8 Stress-strain relationships for the LTC wall panel with different fiber configurations

Note: Stress-Strain 1: Front position and Stress-Strain 2: Back position

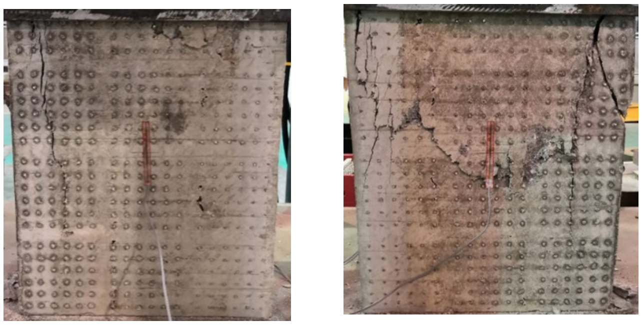
Figure 9 and Figure 10 shows the failure mode of the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids, respectively. It appears that there are vertical cracks initially developed at the top of the wall panel and then propagated to the bottom edge of the wall panel. Likewise, horizontal cracks existed at the mid-height of both LTC wall panels. Nonetheless, the number of cracks developed in the LTC wall panel with fiber configuration of 5 × 5 grid is more than the 6 × 6 grids. Furthermore, the failure pattern of the LTC wall panel with fiber configuration of 5 × 5 grid is more severe as there is falling of concrete at the edge side of the wall. This could be due to the load eccentricity caused by the applied load which was not aligned to the center of the LTC wall panel. Besides that, wall panel with 6 × 6 grid had less severe crush may also be due to the reinforcement effect which held the concrete matrix from being dismantled. However, this requirement further investigation in the future.



(a) Front wall (b) Back wall

(c) Left side wall (d) Right side wall

Figure 9 Crack pattern of LTC wall panel with fiber configuration of 5 × 5 grids


(a) Front wall (b) Back wall


(c) Left side wall (d) Right side wall

Figure 10 Crack pattern of LTC wall panel with fiber configuration of 6 × 6 grids

4.0 CONCLUSIONS

A few conclusions can be drawn from the study of the experimental test:

(a) The satisfactory concrete mix proportion with the slump flow, V-funnel time, passing ability ratio, and 28-days compressive strength of 635 mm, 3.08 s, 0.82, and 45.13 N/mm^2 respectively are used to manufacture the LTC wall panel with the dimension of 300 mm wide × 75 mm thick × 400 mm high. The LTC wall panel is casted with fiber configurations of 5 × 5 and 6 × 6 grids.

(b) The light intensity of the LTC wall panel increased with the increasing number of fiber configurations. Besides that, the light intensity of the wall panel decreased when the light source distance increased regardless of the fiber configurations. With the increasing light source distance, the rate of light intensity dropped rapidly; and then gradually become constant when the light source distance is beyond 300 mm. When the constant light meter distance exceeded 200 mm, the peak light intensity moved to the 200 mm light source distance. In addition, the light intensity of the wall panel decreased when the light meter distance increased regardless of fiber configurations. With the increasing light meter distance, the rate of light intensity dropped rapidly; and then gradually became constant when the light meter distance is beyond 300 mm. When the fixed light source distance exceeded 200 mm, the light intensity would be optimized at the light meter distance of 300 mm and 400 mm.

(c) At 28-days, the ultimate axial compression load resisted by the LTC wall panel with fiber configurations of 5 × 5 and 6 × 6 grids are 662 kN and 643 kN, respectively. This proves that the difference in fiber configuration in the current study does not have significant effect on the ultimate axial compression force. Besides, both LTC wall panels are under pure compression load as there is only compressive strain experienced by each wall panel. In addition, both LTC wall panels are within the materials requirement where the concrete ultimate concrete strain not exceeding 3500×10^{-6}.

(d) It is recommended that LTC short wall with 6 × 6 fiber grid performed better than LTC with 5 × 5 grid based on the consideration on structural performance and light transmittance properties. However, further investigation is required since the light transmittance of LTC also strongly depends on initial light intensity, to ensure a comprehensive understanding on LTC light transmittance properties before applying in building construction.

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