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Performance Of Hybrid Green-Tech Lightweight Prism Composite Floor Panel

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ABSTRACT

Hybrid Green-tech Lightweight Prism Composite (HGLC) is a lightweight panel floor structure compared to conventional concrete slab because it has a thin cross-section which can reduce the load transferred to the structure of beams, columns and even the foundation of the building. Flexural strength studies on lightweight composite floor structures previously focused on strength test on a composite prism that changed the cross section of the profiled steel sheeting from a trapezium to a rectangle cross section. The objective of this study is to identify the performance of flexural strength composite prism by focusing on various parameter including cross-section, the use of dry boards and concrete infill. Apart from that, a comparison of the flexural strength value will be made on the difference cross section between the trapezium and rectangle composite prism compared to the control sample. Data analysis results found the flexural strength increase in rectangular composite prisms without dry board concrete infill (P6 Sample), which is 69% compared to trapezoidal composite prisms (P3 Sample) of only 37%. The bending moment for the P6 sample also increased by 74% compared to the P3 sample which was only 34%. Overall, the objective of this study was achieved when it was possible to identify a significant increase driven by the change in cross-section from the original shape of a trapezoid to a rectangle where there was a 27% increase in the moment of inertia. Therefore, this study has a positive impact, where the proposed rectangular cross-section profiled steel panel can be made into a high- performance lightweight composite panel structure for domestic buildings to support the use of the Industrialized Building System (IBS) in the future.

1.0 Introduction

The floor structure is the most important element for a building, upon which the flat surface receives all forms of loads- live or dead loads. Among the functions of the floor is that it is able to support the load, absorb sounds, that it serves as a heat insulator, as a ceiling for the 1st floor and a place for electrical equipment such as wires, PVC conduits and so on. Other than that, the characteristics of the floor also fulfill the criteria such as the fact that it has high durability, it provides comfort to the occupants, including being able to absorb sounds and prevent moisture. There are two categories of the floor, namely the bottom level floor and the upper-level floor. Normally, the conventional floor structure is the solid floor made using a formwork with concrete where there is a reinforcement or BRC (British Reinforce Concrete) wire mesh1.1 Agent B Theory

However, there are a lot of weaknesses for reinforcement concrete slab as shown in Figure 1, some including the fact that the formwork is from plywood, the cost is high for reinforcement, the preservation process is time-consuming, the concrete volume is high and it uses a great amount of manpower. The above factors cause an increase in terms of the cost of construction. One of the methods that can considerably reduce this cost is by using the Industrialized Building System (IBS) method. The adoption of IBS is confirmed to be helpful to increase and enhance the project value and production, as well as save the cost and duration of the project (Nasrun 2015, Mohsen 2019). As of today, the method of construction has begun to change from the conventional construction system to the IBS.

Figure 1 Concreting works for reinforcement slab

IBS system is a building construction method where the component is produced in a controlled manner (in the factory or on-site), transported and installed on-site with a minimum number of workers. Among the IBS prefabricate floor systems are the lightweight floor panel (Figure 2) and the interlocking floor panel (Figure 3).

Figure 2 Lightweight floor panel

Figure 3 Interlocking floor panel

To achieve a wider IBS implementation scale in Malaysia, the government has granted a full exemption on the tax imposed by the Construction Industry Development Board (CIDB) to the developers who use more 50 percent IBS component (Mohamad Kamar et. al. 2009). This wise ruling enforced by the government will truly generate a lot of interest from the industry to use the IBS as an alternative to the construction method. To futher support this IBS system, additional studies are needed to be conducted to identify a prefabricated floor system that is light, sturdy, easy to install and saves cost for the use of domestic buildings.

2.0 Literature review

The composite structure that uses a metal deck started to be used in the 1930s in the United States of America. In 1966, Iowa State University conducted a research on the use of steel bars in the construction sector according to the standard determined (Johnson 1975, Viest et. al. 1997). The composite steel deck floor system began to be introduced in the construction industry as an alternative to replace the conventional concrete floor system (Namdeo et. al. 2012) as shown in Figure 4.

Nonetheless, the steel-concrete bar floor system still carries some weaknesses, where it still uses a more concrete volume and the use of the reinforcement is very costly. Professor Wright dan Professor Evans (Wright & Evans 1986) from the University of Wales, Cardiff through the UK Science and Engineering Research Council (SERC) research grant started to introduce a composite system known as the Profiled Steel Sheeting Dry Board (Wright et al. 1989) system as an alternative to the traditional floor system of plywood and beams in buildings in the United Kingdom. Some of the problems identified in the composite floor system are that, despite the light nature of the floor system, the use of materials like plywood for the floor surface is very unsuitable as plywood is known to have a lot of weaknesses, especially with regard to its moisture, termite attacks and its vulnerability to the weather (Wan Badaruzzaman et. al 1995, Norhaiza 2014). These days, there are more durable materials that can be used to build a composite floor system that is lighter, cheaper and easier to install. For example, the PRIMAflex cement board is a more durable dry board compared to plywood, as it uses fibre cement that can withstand the weather and attacks by termites. Awang (2008) review a comparison between the use of cemboard dry wood and PRIMAflex in his study on the behavior of the individual panel of the composite roofing system, and he discovered that the strength of the panel improves by 21.1% compared to the system using the Cemboard.

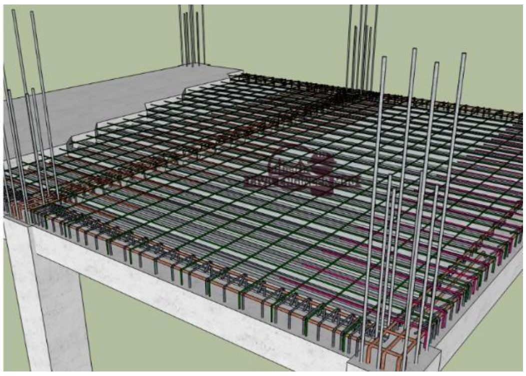


Figure 4 Composite deck slab

Cost 1 m^2 with the thickness of 100 mm of the conventional floor is more expensive which is RM82.40 compared to the profiled steel sheeting dry board (PSSDB) system costing RM 69.50 where the saving cost is up to 15%. Shodiq (2004) had conducted an experiment on the PSSDB system with the concrete infill material can reduce the deflection in the middle of the span by 20.2% compared to the panel that does not use any infill material. However, referring to the previous studies, focus was only given to the trapezium shape and there have yet to be studies that focus on the cross-section modified to be a rectangle. The light composite floor system is seen to be able to support the IBS where the Finance Ministry has instructed all the public sector projects worth more than RM10 million have to obtain more than 70 as their IBS score. Even so, the achievement of the IBS system use was around 40% in 2020, where this is considered to be low, according to the Construction Industry Transformation Programme (CITP) 2016-2020.

As the outcome from the literature review conducted, it is found that there is a gap analysis in the studies of the light composite floor system. They include the fact there has been no studies done on the profiled steel sheeting with the rectangle cross section compared to the trapezium. Thus, further studies will be done with the highlight on the flexural strength on the composite prism with multiple parameters including different cross sections. Thus, there should be more detailed studies on the light composite floor system by taking into consideration the performance of the flexural strength. Nevertheless, there are some limitations to test the composite floor panel in the actual scale as there is no experiment equipment facility in the concrete laboratory in Politeknik Kota Kinabalu. This serves as an alternative experiment on the sample using the composite prism to represent the actual lightweight composite floor panel. The lightweight composite floor panel is named the Hybrid Green-tech Lightweight prism composite floor panel.

The objective of this study is to identify the strength of the composite prism flexural strength in various parameter. Furthermore, it seeks to identify the difference between the flexural strength of the composite prism with concrete infill and the control sample without infill. Next, it seeks to analyse the flexural strength of the composite floor and the cross- section of the profile steel sheeting between the trapezium and rectangle cross section.

3.0 Methodology

To test the performance of the Hybrid Green-tech Lightweight composite prism floor panel, the study focuses on two methods. The first method involves making a derivation using the inverted trapezium formula, which will be adapted for the composite prism experiment in the laboratory. The second method is by conducting a flexural strength test on the composite prism in various parameters. which is making a derivation by the inverted trapezium formula to be adapted with the composite prism experiment in the laboratory, whereas the second method is by conducting the flexural strength test on the composite prism in various parameters.

3.1 Derivation Formula Inverted Trapezium Cross Section

This test refers to BS EN12390-5:2009 Part 5: Flexural Strength of Test Specimens (3 points) as shown in Figure 5, where;

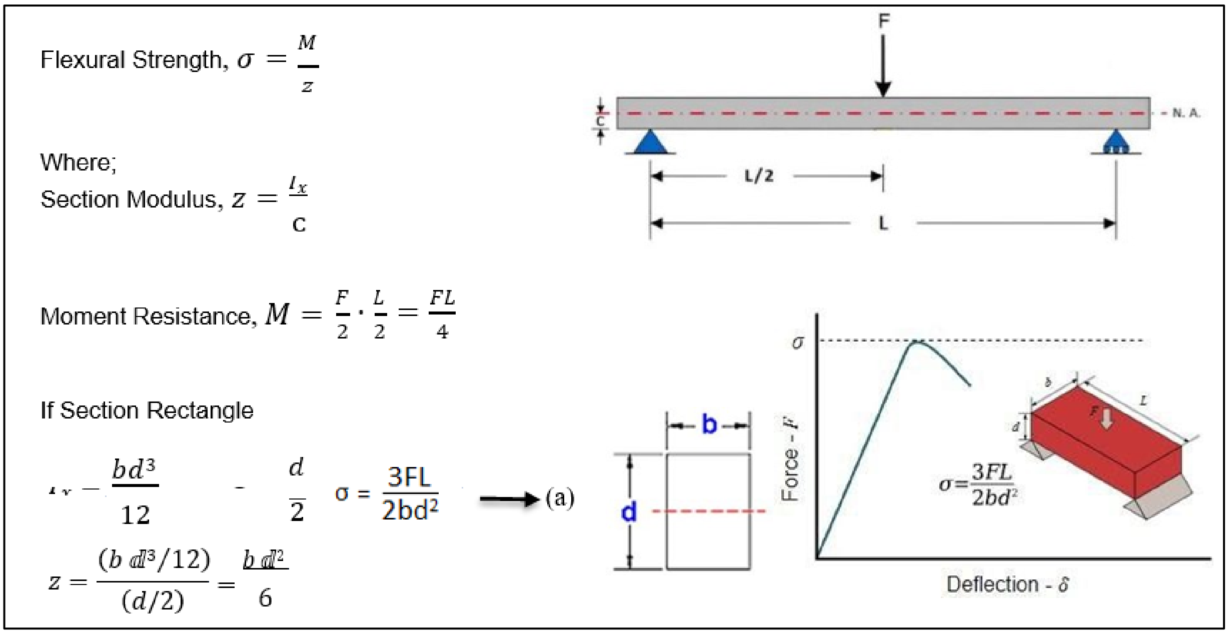
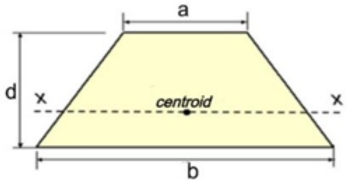


Figure 5 Flexural strength formula for rectangle section

If Section Trapezoid (Normal)

Refer to the diagram below, the value of the second moment area (I_x) and elastic section modulus (Z_x) (StructX, 2022) as stated where to find the flexural strength value of the formula below:



$$I_x = \frac{d^3(a^2 + 4ab + b^2)}{36(a+b)}$$

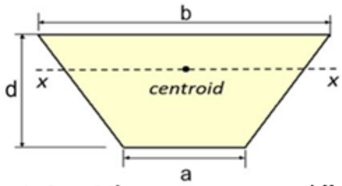
$$C = \frac{d}{3}\left(\frac{2a+b}{a+b}\right)$$

$$Z = \frac{I_x}{C_v} = \frac{d^3\,(a^2 + 4ab + b^2)/36\,(a+b)}{\frac{d}{3}\left(\frac{2a+b}{a+b}\right)}$$

$$\sigma = \frac{3FL(2a+b)}{d^2(a^2 + 4ab + b^2)} \longrightarrow \text{(b)}$$

If Section Trapezoid (Inverted)

Refer to the diagram below, the value of C_y Distance to Centroid, different from the trapezium in normal conditions. The results of the derivation of the formula made to find the flexural strength (Inverted Trapezium) value of the formula below:



$$I_x = \frac{d^3(a^2 + 4ab + b^2)}{36(a+b)} \qquad C = d - \frac{d}{3}\left(\frac{2a+b}{a+b}\right)$$

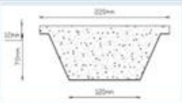
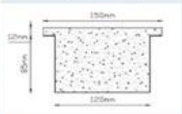
$$Z = \frac{I_x}{C_y} = \frac{d^3\,(a^2 + 4ab + b^2)/36\,(a+b)}{d - \frac{d}{3}\left(\frac{2a+b}{a+b}\right)}$$

$$\sigma = \frac{M}{Z} = \frac{(F\,L/4)}{\left(\frac{d^3\,(a^2 + 4ab + b^2)/36\,(a+b)}{d - \frac{d}{3}\left(\frac{2a+b}{a+b}\right)}\right)}$$

$$\sigma = \frac{3FL(a+2b)}{d^2(a^2 + 4ab + b^2)} \longrightarrow \text{(c)}$$

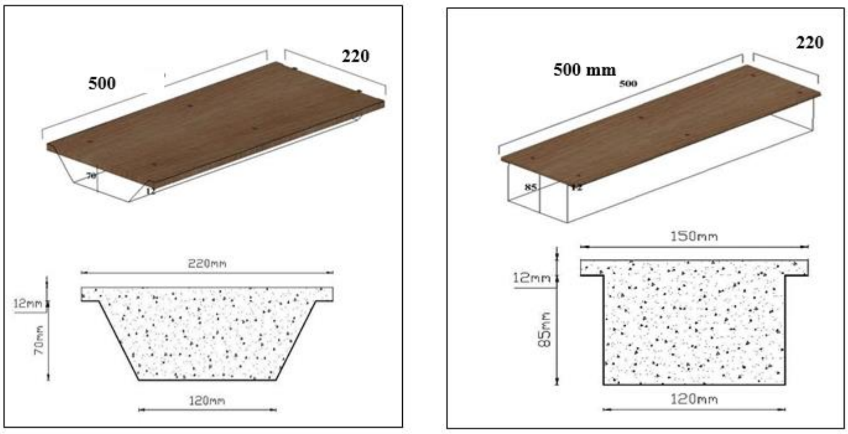
From the derivation formula, equation (a) will be used to determine the flexural strength value for the rectangle cross section whereas equation (c) will be used to determine the flexural strength value for the trapezium cross section. Table 1 shows the formula for the centroid, moment of inertia, section modulus and flexural strength for both the trapezium section and the rectangle cross section.

Table 1 Trapezium and Rectangle cross section formula

Cross Section	Cross-Section	Centroid, C_y (mm)	Moment of Inertia, I_x (mm^4)	Section Modulus, $Z = I_x/C_y$ (mm^3)	Flexural Strength, σ (N/mm^2)
Trapezium		$d - \frac{d}{3}\left(\frac{2a+b}{a+b}\right)$	$\frac{d^3(a^2+4ab+b^2)}{36(a+b)}$	$\frac{d^3\,(a^2+4ab+b^2)/36\,(a+b)}{d-\frac{d}{3}\left(\frac{2a+b}{a+b}\right)}$	$\sigma = \frac{3FL(a+2b)}{d^2(a^2+4ab+b^2)}$
Rectangle		$\frac{d}{2}$	$\frac{b\,d^3}{12}$	$\frac{b\,d^2}{6}$	$\sigma = \frac{3FL}{2bd^2}$

3.2 Experimental Specimens and Material Properties

For the laboratory experiment, there has been a restriction to conduct a test on the composite panel in the actual scale which is 1000 mm x 3000 mm. As an alternative method, the composite panel experiment was test a composite prism sample as shown in Figure 6(a) and 6(b). The original cross-section of the composite prism is trapezium in shape, and a conversion process was carried out to transform it into a rectangle shape. This was done to identify the different flexural strengths for different cross-sections



6(a) 6(b)

Figure 6(a) and 6(b) Detail composite prism for Trapezium and Rectangle Cross Section

Table 2 gives the specification and material properties of every component of the composite prism. The design of the normal concrete grade 30 was based on the Dobrowolski (1998) concrete construction handbook. The density value of the concrete was to be 2400 kg/m^3. Figure 4 shows the cross section of PEVA50 profiled steel sheeting.

Table 2 Material properties

Materials	Thickness /diameter (mm)	Width and Length (mm)	Modulus of Elasticity E, (N/mm2)	Poisson Ratio ν	Ultimate Strength (N/mm2)	Weight of covered area (N/m2)
Profiled Steel Sheeting (Peva 50)	1.0	1000 × 2600	210 × 103	0.3	350	100
Self-drilling and self-tapping screws (DS-FH 432)	4.2	30.0	_	_	_	_
Dry board (PRIMAflex)	12.0	1000 ×2600	8030	0.25	22	172
Concrete grade 30	Infill	Infill	26 x 103	0.2	30	606.4

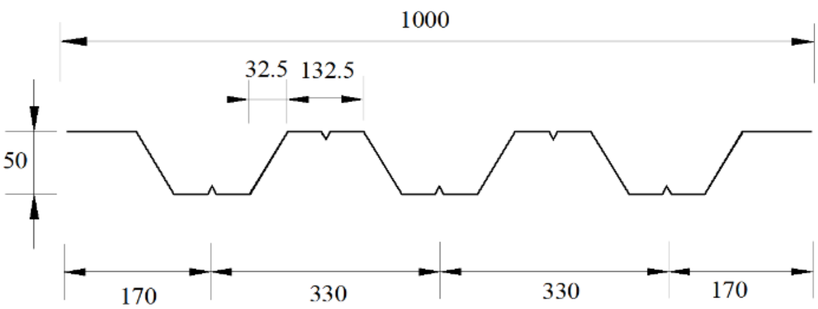
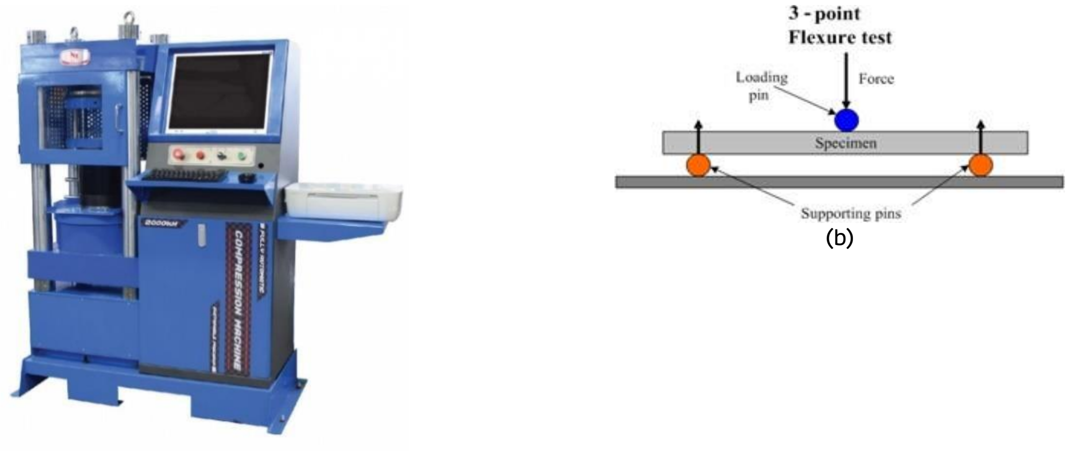


Figure 7 Profiled steel sheeting PEVA 50 (all dimensions in mm)

3.3 Experimental Testing

Tests on composite prism samples using Computerized Compression Machine 2000kN (model NL 4000 X / 034N), as shown in Figure 8 (a). The concept of 3 point flexural of specimen test is applied according to BS Standard EN-2390-5-2009 Part 5 as shown in Figure 8 (b).



(b)

(a)

Figure 8 (a) Computerized Compression Machine 2000kN (model NL 4000 X / 034N) (b) 3-point Flexure test method

Table 3 Sample preparation

Composite Prism	Code of Sample	Cement Board	Concrete Infill	Total of Sample
Group 1 (TrapeziumCross Section)	P1	✓	-	3
	P2	✓	✓	3
	P3	-	✓	3
Group 2 (RectangleCross Section)	P4	✓	-	3
	P5	✓	✓	3
	P6	-	✓	3


Figure 9 The process of forming a rectangle cross-section.


Figure 10 Profile steel sheetingtrapezium cross section.


Figure 11 Profile steel sheeting rectangle cross section.

Figures 9 to 11 show the process of forming profiled steel sheeting to a rectangle cross section. The position of the sample is placed on both parts of the support as shown in Figure 12 to 14 and a point load will be applied to the middle part of the sample.

Figure 12 Flexural strength test on composite prisms


Figure 13 Failure one of the composite prism samples.


Figure 14 Cylinder bar position for point load

Figure 15 shows the failure of the composite prism sample after being tested. From the observations made, the failure was caused by cracking on the dry board and also concrete on the sample.

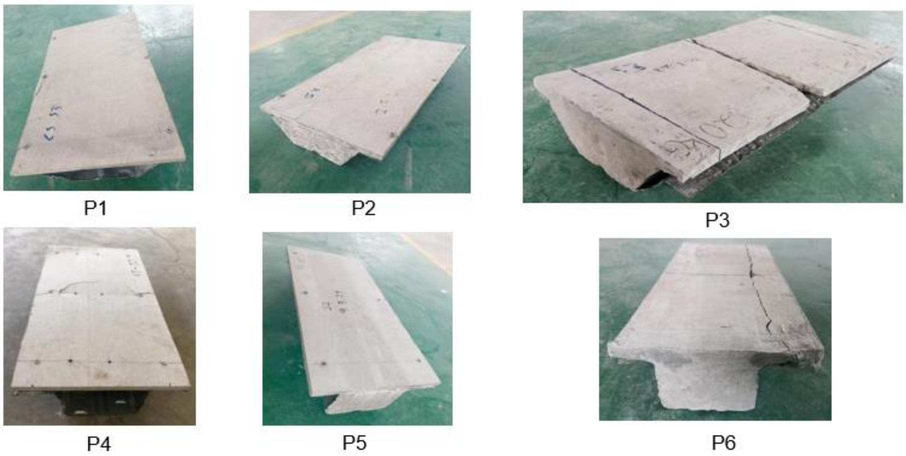


Figure 15 Failure of the prism composite

4.0 Discussion of analysis and findings

Refer to Figure 16 (a) Sample P6 (rectangle) shows higher performance which is 69% compared to P1 (control sample) whereas Sample P3 (trapezium) increases only 57% when compared with P1. Figure 16 (b) shows that the Flexural Strength value also increases for sample P6 which is as high as 37% compared to sample P3. When the change in the cross-section, the inertia moment value for the rectangle is higher which is 6.14×10^6 compared to the trapezium which is 4.48×10^6 the cross-section change to the rectangle has increased the inertia moment value by 27%. Figure 16 (d) exhibits that the presence of the dry board does not give any significant impact on the sample where the sample without dry board shows higher performance which is 23%. Although the total volume of the concrete for sample P6 is less than 10% compared to P3, the performance of the rectangle's composite prism remains high.

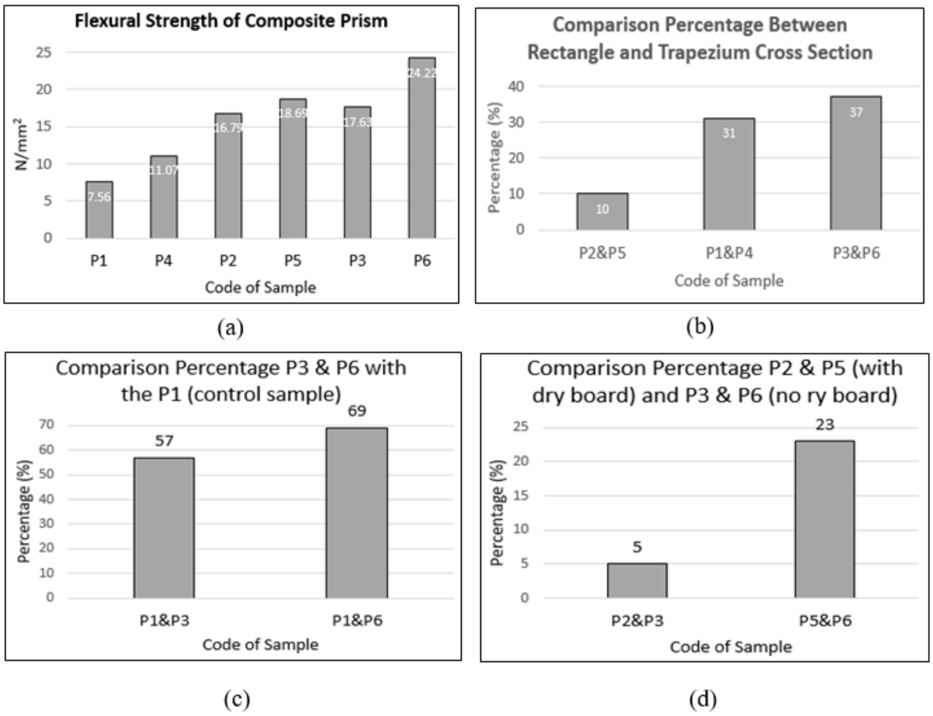
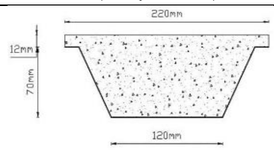
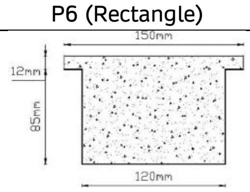


Figure 16 Comparison graph of flexural strength composite prism test results with various parameters.

This result is supported by Shodiq 2004, where the depth of the groove for the profiled steel sheeting will influence the inertia moment. This is because the deeper depth of the profiled steel sheets, the higher the inertia moment of the steel sheets. The higher the inertia moment, the stronger the structure of the steel sheets. Apart from that, the concrete infill material volume also can increase the stiffness of lightweight composite floor structure parallel to the study carried out by Wan Badaruzzaman et. al 2002 and Seraji 2013. Table 4 shows the comparison of the experiment results between Trapezium (P3) and Rectangle (P6) samples.

Table 4 Comparison of test results between sample P3 (Trapezium) and P6 (Rectangle)

Technical	P3 (Trapezium)	P6 (Rectangle)
Cross section		
Volume (m^3)	0.0056	0.0051 m^3
Centroid	37.6	42.5
Moment inertia (mm^4)	4.48×10^6	6.14×10^6
Force (kN)	21.6	35.4
Flexural Strength (N/mm^2)	17.6	24.4
Moment resistance (kNm)	2.1	3.5
Performance comparison with control sample (%)	57%	69%

From the findings, it is found that the change in the cross section from trapezium to rectangle leaves an impact to the increased performance of the composite prism's flexural strength value, where this is indirectly able to increase the performance of the recommended Hybrid Green-Tech Lightweight (HGT) Floor Panel. The HGT Lightweight Floor Panel as the light floor structure can be used for domestic buildings. The combination of the concrete and the profiled steel sheeting creates a hybrid reaction between one another which is able to improve the performance of the panel. Due to the fact that this system does not use any formwork like the conventional method, the emphasis is more on the green technology element. The HGT Lightweight panel is expected to be able to lend support to the IBS system, as this panel fulfils the criteria as established in the industry with controlled quality, low cost, easy instalment, time- saving nature and that it uses minimum labour. Figure 16 shows that the HGT Lightweight Floor Panel has high performance.

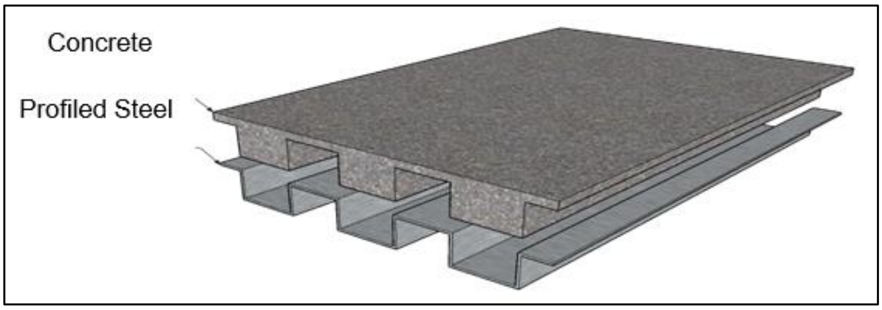


Figure 16 A Hybrid Green-tech Lightweight Composite Floor Panel.

5.0 Conclusion and future research

The rectangle cross-section composite prism with concrete infill gives a very obvious impact with the increased flexural strength value. The cross-section change to rectangle can reduce the concrete volume to 10%, but the increased performance of the composite prism can still be enhanced. A very positive impact for the light composite structure is named Hybrid Green-tech Lightweight Composite Prism Floor Panel, where the strength lies in the improved performance and strength of the lightweight composite panel structure. With the improved performance for the composite floor system, the span distance can be added and this means less span use. The Hybrid Green- tech Lightweight Composite Prism Floor Panel is applied in the Industrialised Building System (IBS) as the lightweight composite floor panel. It is suitable for small buildings like homestay, chalet, or resort house built on high areas as it uses a light composite prefabricated floor system.

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