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Investigation on Structural Behaviors of Precast Lightweight Foamed Concrete Sandwich Panel (PLFP) Using Finite Element Method

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Abstract: Development of Precast Lightweight Foamed Concrete Sandwich Panel (PLFP) has achieved global with Industrial Building System (IBS). PLFP assists reduction in multiple loads and longer spans. Recently, focused on reduced concrete thickness and prioritize textile reinforced concrete. This study has objectives to design different PLFP models with different polystyrene thickness to overall thickness in 500 mm width and 1000 mm length. The study also analyses structural behaviors in term of maximum equivalent elastic strain, maximum equivalent stress, total deformation and maximum deformation. The results include evaluation of steel reinforcement ratio, body mass, and presence of fatigue and fracture of different PLFP. Finite element method (FEM) using ANSYS software with Explicit Dynamics to investigate structural behavior of PLFP under compression test, 3- point bending test, and tensile test. PLFP constructed in 1:3 scale with two pre-mixed 35 MPa concrete wythes and polystyrene insulation layer with thickness from 20 mm to 30 mm wythes. Reinforcement such as continuous shear truss, continuous trapezoidal-shaped, honeycomb and no reinforcement with AISI 4340 steels are applied. Results analysis found that steel reinforcement ratios of reinforced PLFP models from 1.9935% to 3.2284%. Based results, as the stress increases, the strain will increase. The PLFP with continuous shear truss reinforcement shows the least presence of fatigue and fractures compared to other designs. Therefore, it is concluded that PLFP with continuous shear truss reinforcement is the most suitable model, and can be applicable and safe for construction. A full-scale and different mechanical testing also recommended for further work.

Keywords: Precast Lightweight Foamed Concrete Sandwich Panel (PLFP), Structural Behavior, Finite Element Method (FEM)

1. Introduction

The development of Precast Lightweight Foamed Concrete Sandwich Panel (PLFP) has achieved acceptance global in conjunction with the Industrial Building System (IBS) [1]. PLFP was classified as a cellular concrete that mostly 16% to 35% lighter than the ordinary concrete with comparable strengths [2]. It assists reduction in multiple loads, improved cyclic structural reaction, enabled to forma longer

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spans and low construction costs [2]. The current scenario of this research, focused on reduced concrete section thickness and prioritize the use of textile reinforced concrete which new manufacturing method and specialist equipment [3].

1.1 Problem statements

The problem of housing among urban dwellers towards the affordability of housing and home ownership are common around the world [4]. One of the best alternatives to solve these common issues in construction industries is to study the new metal reinforcement, manufacturing method and materials used in PLFP to seek new, viable product lines, and architects and engineers are pleased with the energy performance and aesthetics of the panels [5].

1.2 Objectives

The objectives of this study are to is to investigate the structural behaviors of different types of PLFP design in term of maximum equivalent elastic strain, maximum equivalent stress, total deformation and maximum deformation under different mechanical testing using finite element method by designing different types of PLFP models with different aspect ratio of polystyrene thickness to overall thickness in same width and length. The study also evaluates the steel reinforcement ratio, body mass, and presence of fatigue and fracture of different types of PLFP models.

1.3 Scope of study and significance of research

The scope of study involves a review and analysis of the load tracing and structural behaviors of different types of PLFP by simulation work on design of reinforcement and polystyrene thickness to overall thickness of PLFP. The expected outcomes of this study are that the suitable design PLFP reinforcement and the aspect ratio of polystyrene and concrete to achieve the desirable construction quality.

2. Materials and Methods

The Finite Element Method (FEM), Analysis System (ANSYS) modelling and simulation are used to predict and investigate the structural behaviors of PLFP. The modelling, simulation and theoretical calculation are capable of predicting the maximum equivalent stress, maximum equivalent strain, total deformation, maximum total deformation, steel reinforcement ratio and presence of fatigue and fracture of PLFP under mechanical testing such as compression test, 3-point bending test and tensile test.

2.1 Materials

The materials subjected into the simulation design model are pre-mixed 35 MPa concrete, polystyrene and AISI 4340 steel which from the engineering explicit materials data sources in ANSYS. The properties of materials in ANSYS simulation are important in order to obtain exact results. Table 1 shows the material properties that use in the simulation of PLFP model.

Table 1: Material properties used in PLFP

Material	Density, ρ (kg/m^3)	Shear Modulus, G (Pa)	Compression strength (Pa)	Specific Heat Constant Pressure, C_p (J/kg. ℃)	Tensile strength, (Pa)
35 MPa Concrete	2314	1.67e+10	3.5e+6	654	3e+6
Polystyrene	1044	7e+8	4.14e+5	1300 - 1500	3.4e+7
AISI 4340 Steel	7830	4.27+8	0.35	477	7.45e+8

2.2 Parameter used and its unit

The test simulation details of PLFP are specified composed design of two concrete panels, separated by a layer of polystyrene as insulation and connected with steel reinforcement. The statically load panels were designed in a scale ratio of 1:3 to the real-life measure. The PLFPs are created as tall as 1000 mm, as width as 500 mm and overall total thickness of 100 mm. The different thickness of polystyrene (20 mm, 22.5 mm, 25 mm, 27.5 mm, and 30 mm) is applied to separate the different thickness of concrete wythes (80 mm, 77.5 mm, 75 mm, 72.5 mm, and 70 mm). Then, the concrete wythes and polystyrene layer enhanced by steel reinforcement rod with a radius of 2.17 mm. Each PLFP designed with different steel reinforcement with continuous shear truss, continuous trapezoidal-shaped, honeycomb and none. Standard for PLFP (PCI and ASTM). The insulated sandwich wall panels can be strictly structural and architectural where it follows the Precast/Prestressed Concrete Institute (PCI) standards. The typical sandwich wall widths from 4 to 15 foots, typical heights from 8 to 50 foots and typical thicknesses from 5 to 12 inches including from 1 to 4 inches of insulation. The criteria used to evaluate maximum equivalent stresses, maximum equivalent plastic strains, total deformation, maximum deformation, steel reinforcement ratio and presence of fatigue and fracture of PLPFP are in accordance with the current version of ACI 318, Building Code Requirements for Structural Concrete. The panels are addressed in nationally recognized ASTM standards for material production.

2.3 Testing configuration

Compression test, 3-point bending test and tensile test are the mechanical testing will be carried out in this research using ANSYS software. All of the simulation analysis settings preference for the step's controls remained 2 number of steps with an end time of 0.01 seconds, whereas, for the erosion controls, the material failure is enabled, and the remaining controls will be program controlled. The imprint faces with a dimension of (100 mm heights and 500 mm widths) also constructed in the 3-point bending test and tensile test.

2.3.1 Compression test

For the compression test, the bottom concrete face of the specimen geometry will be the fixed support and a compressive load was in -2000 kN in Y-axis on the top concrete face.

2.3.2 3-point bending test

For the 3-point bending test, the imprint face at the left side of the bottom concrete face of the specimen geometry will be fixed support, whereas, the displacement support with free movement in Z-axis and constant 0 m (ramped) in X-axis and Y-axis will be applied on the imprint face at the right side of the concrete face. A center load -100 kN also applied on the imprint face at the center of the top concrete face.

2.3.3 Tensile test

For the tensile test, the imprint face at the left side of the top and bottom concrete faces of the specimen geometry will act as a clamp for fixed support, whereas the tensile displacement of -0.001 m in Z-axis will be applied on the imprint faces at the right side of the concrete faces act a clamp for tensile force.

2.3 Steel reinforcement ratio

The steel reinforcement ratio is one of the methods to identify the amount of steel reinforcement used in PLFP. The formula for steel reinforcement ratio is as shown in Eq. 1.

$$\frac{Total\ Mass\ of\ Steel\ Reinforcement}{Percentage\ \times Mass\ of\ Steel\ 4340\ (7830\ kg/m^3) \times Volume\ of\ Concrete\ Used} \quad \text{Eq. 1}$$

2.4 Presence of fatigue and fracture

After the simulation has been analyzed, based on the results, the presence of fatigue and fracture of PLFP will be observed in order to know whether the PLFP achieve to overcome the mechanical testing.

3. Results and Discussion

The ANSYS simulation and formula equation result on the structural behaviors and effect of different thickness of polystyrene thickness of all PLFP designs under mechanical test using application of Explicit Dynamics. The analysis of data is a process where the data is being analyzed according to the study objectives. The results obtained were discussed accordingly.

3.1 Effect of different polystyrene thickness of all PLFP designs under compression test

Figure 1 illustrates the maximum equivalent stress (Pa) against maximum equivalent elastic strain (m/m) of 30 mm thick polystyrene of all PLFP designs under compression load of -2000 kN in Y-axis under compression test. As described by [6], shear truss wall is designed and constructed to transfer in-plane horizontal and lateral forces from one elevation to another. Hence, the PLFP with honeycomb reinforcement stress and strain are the greatest, whereas, the PLFP with continuous trapezoidal-shaped stress and strain are the least compared to other designs respectively. The result was supported from the studied by [7], the author found that the stress development in the transverse reinforcement is initiated after the occurrence of cracking in the concrete.

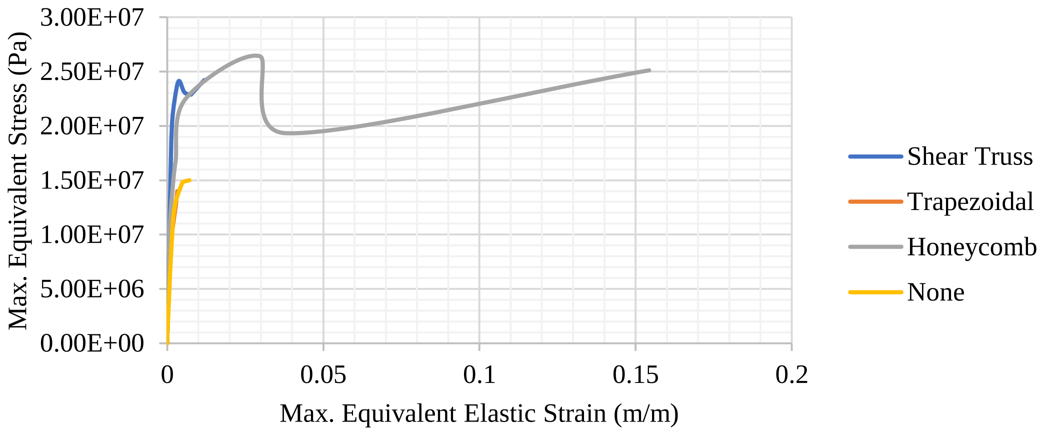

Figure 1: Graphs of maximum equivalent stress (Pa) against maximum equivalent elastic strain (m/m) of all PLFP for 30 mm thick polystyrene under compression load of -2000 kN in Y-axis under compression test

Figure 2 illustrates the maximum total deformation of 25 mm thick polystyrene of all PLFP designs under compression load of -2000 kN in Y-axis under compression test. According to [7], the shear strength degradation and the contribution of the transverse reinforcement to the shear resistance is insignificant and the whole shear force is resisted by the concrete mechanism. Hence, the failure mechanism will be controlled by the amount of transverse reinforcement. The PLFP with honeycomb reinforcement deformed greatest, whereas, the PLFP with continuous trapezoidal-shaped shear truss deformed least compared to other designs respectively.

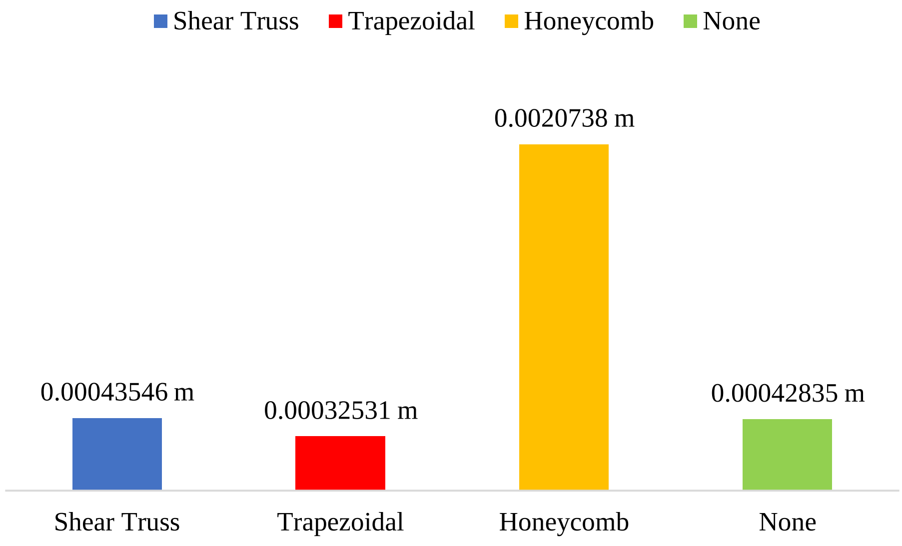

Figure 2: Maximum total deformation (m) of 25 mm thick polystyrene of all PLFP under compression load of -2000 kN in Y-axis under compression test

3.2 Effect of different polystyrene thickness of all PLFP designs under 3-point bending test

Figure 3 illustrates the maximum equivalent stress (Pa) against maximum equivalent elastic strain (m/m) of 30 mm thick polystyrene of all PLFP designs under center load of -100 kN in Y-axis under 3-point bending test. The PLFP with no reinforcement stress and strain are the greatest, whereas, the PLFP with continuous shear truss stress and strain are the least compared to other designs respectively.

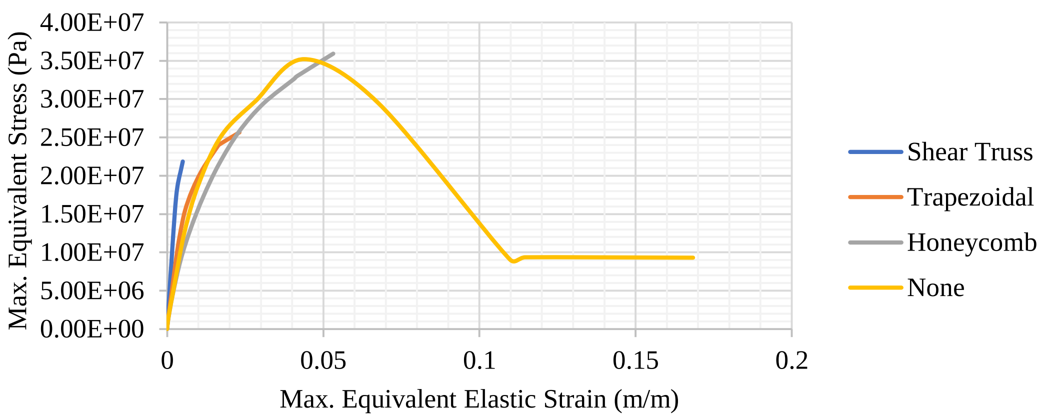

Figure 3: Graphs of maximum equivalent stress (Pa) against maximum equivalent elastic strain (m/m) of all PLFP for 30 mm thick polystyrene under center load of -100 kN in Y-axis under 3-point bending test

Figure 4 illustrates the maximum total deformation of 25 mm thick polystyrene of all PLFP designs under center load of -100 kN in Y-axis under 3-point bending test. The PLFP with honeycomb reinforcement deformed greatest, whereas, the PLFP with continuous shear truss deformed least compared to other designs respectively. These results supported by [8], the author mentioned that a continuous steel truss-shaped shear connector is the most effect that able to achieve high composite action and allows the full transfer of shear forces by bending between wythes.

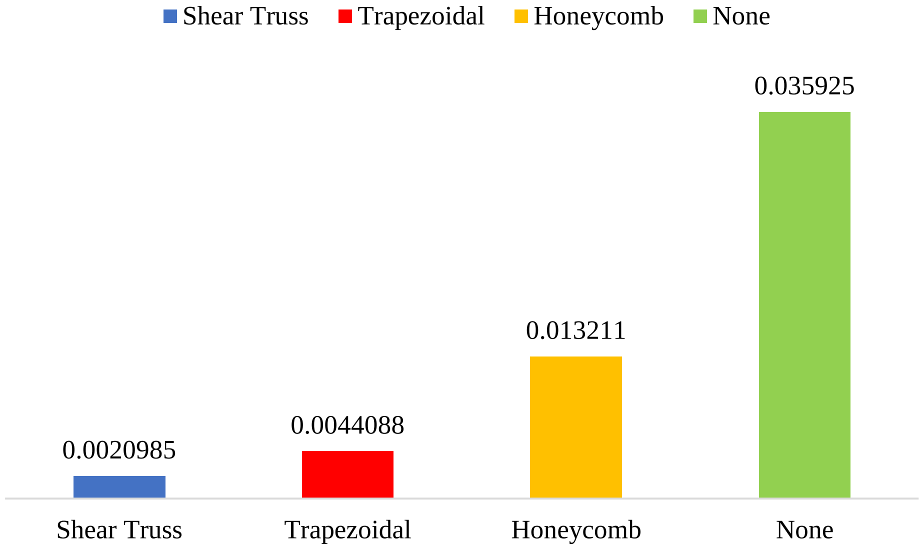

Figure 4: Maximum total deformation (m) of 25 mm thick polystyrene of all PLFP under center load of -100 kN in Y-axis under 3-point bending test

3.3 Effect of different polystyrene thickness of all PLFP designs under tensile test

Figure 5 illustrates the maximum equivalent stress (Pa) against maximum equivalent elastic strain (m/m) of 30 mm thick polystyrene of all PLFP designs under tensile displacement of -0.001 m in Z-axis under tensile test. The PLFP with continuous shear truss stress and strain are the greatest, whereas, the PLFP with continuous trapezoidal-shaped stress and strain are the least compared to other designs respectively. The stress-strain curve of PLFP with honeycomb reinforcement curved backward due to the fracture of concrete but not the steel reinforcement. The simulation showed the stress-strain of the steel reinforcement after the fracture of concrete.

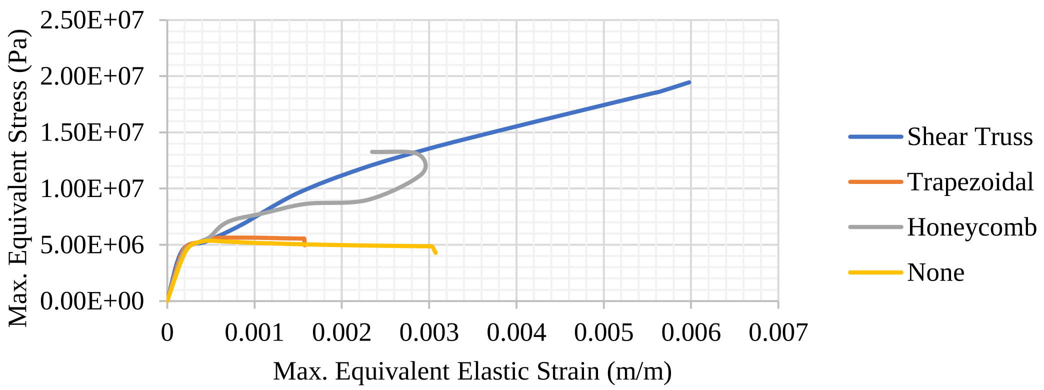

Figure 5: Graphs of maximum equivalent stress (Pa) against maximum equivalent elastic strain (m/m) of all PLFP for 30 mm thick polystyrene under tensile displacement of -0.001 m in Z-axis under tensile test

Figure 6 illustrates the maximum total deformation of 25 mm thick polystyrene of all PLFP designs under center load of -100 kN in Y-axis under 3-point bending test. The PLFP with honeycomb reinforcement deformed greatest, whereas, the PLFP with continuous trapezoidal-shaped shear truss deformed least compared to other designs respectively.

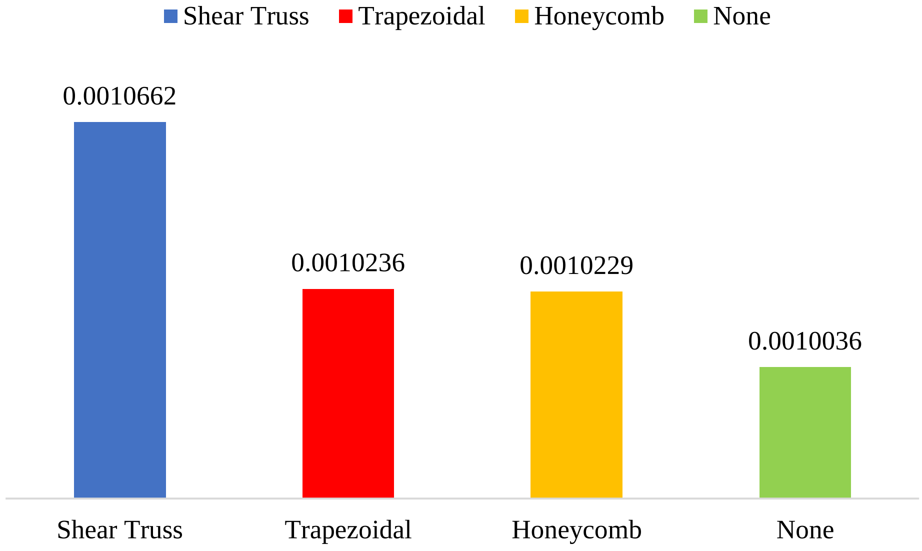

Figure 6: Maximum total deformation (m) of 25 mm thick polystyrene of all PLFP under tensile displacement of -0.001 m in Z-axis under tensile test

3.4 The steel reinforcement ratio and mass of different concrete thickness of all PLFP

The steel reinforcement ratio of different thicknesses of concrete (70 mm, 72.5 mm, 75 mm, 77.5 mm, and 80 mm) of PLFP with all reinforced models (continuous shear truss, continuous trapezoidal-shaped, and honeycomb) were calculated using the formula. Table 2 indicates the steel reinforcement ratio in all type of PLFP for all specimen polystyrene thickness using formula.

According to [9], the steel reinforcement ratio will affect the flexural performance of reinforced concrete. The ideal steel reinforcement ratio is said to be around 1% to 2% to avoid under reinforced or over-reinforced. For every mechanical testing, if a PLFP with right steel reinforcement ratio, it will deform gradually, however, if a PLFP exceed the ideal steel reinforcement ratio, it will deform explosively and has brittle behavior.

Table 2: Maximum total deformation (m) of 25 mm thick polystyrene of all PLFP under tensile displacement of -0.001 m in Z-axis under tensile test.

Thickness of Polystyrene	Volume of Concrete Used	$\frac{\textbf{Steel Reinforcement Ratio}, \textbf{Total Mass of Steel Reinforcement}}{\textbf{Percentage} \times \textbf{Mass of Steel 4340} \times \textbf{Volume of Concrete}}$, where mass of steel 4340 is $7830 kg/m^3$			
		Type of Reinforcement			
		Continuous Shear Truss	**Continuous Trapezoidal-Shaped**	**Honeycomb**	**None**
$20mm$	$0.04\ m^3$	1.9935%	1.8381%	2.8249%	N/A
$22.5mm$	$0.03875\ m^3$	2.0578%	1.8974%	2.9160%	N/A
$25mm$	$0.0375\ m^3$	2.1264%	1.9607%	3.0132%	N/A
$27.5mm$	$0.03625\ m^3$	2.1997%	2.0283%	3.1171%	N/A
$30mm$	$0.035\ m^3$	2.2782%	2.1007%	3.2284%	N/A

Besides, Table 3 indicates the mass of all PLFP models. The mass value of the PLFP models were extracted from the simulations. The mass of each model decreased as the overall polystyrene thickness decreased. This is because concrete has higher density than the polystyrene. According to [3], the steel reinforcement is low weight in design and good in construction support. Based the comparison of the mass PLFP with reinforcement and no reinforcement, the statement is correct where the increment of low mass by adding steel reinforcement in the PLFP structure.

Table 3: The mass of all PLFP models

Thickness of Polystyrene	Volume of Concrete Used	Mass			
		Type of Reinforcement			
		Continuous Shear Truss	Continuous Trapezoidal-Shaped	Honeycomb	None
$20mm$	$0.04\ m^3$	$109.24\ kg$	$108.76\ kg$	$111.85\ kg$	$103.00\ kg$
$22.5mm$	$0.03875\ m^3$	$107.66\ kg$	$107.17\ kg$	$110.26\ kg$	$101.41\ kg$
$25mm$	$0.0375\ m^3$	$106.07\ kg$	$105.58\ kg$	$108.67\ kg$	$99.825\ kg$
$27.5mm$	$0.03625\ m^3$	$104.48\ kg$	$103.99\ kg$	$107.08\ kg$	$98.238\ kg$
$30mm$	$0.035\ m^3$	$102.89\ kg$	$102.41\ kg$	$105.50\ kg$	$96.65\ kg$

3.5 The presence of fatigue and fracture of different polystyrene thickness of all PLFP

The presence of fatigue and fracture of all PLFP models for all mechanical testing were fully evaluated from the simulations.

3.5.1 Effect under compression test

Figure 7 (a) shows the maximum and minimum total deformation of PLFP solid bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under compression load of -2000 kN in Y-axis under compression test. The result showed that the fatigue embedded mainly on the edges of the PLFP solid bodies, whereas, the minimum fatigue located mainly on the top center surface and bottom surface. Figure 7 (b) shows the maximum and minimum total deformation of PLFP line bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under compression load of -2000 kN in Y-axis under compression test.

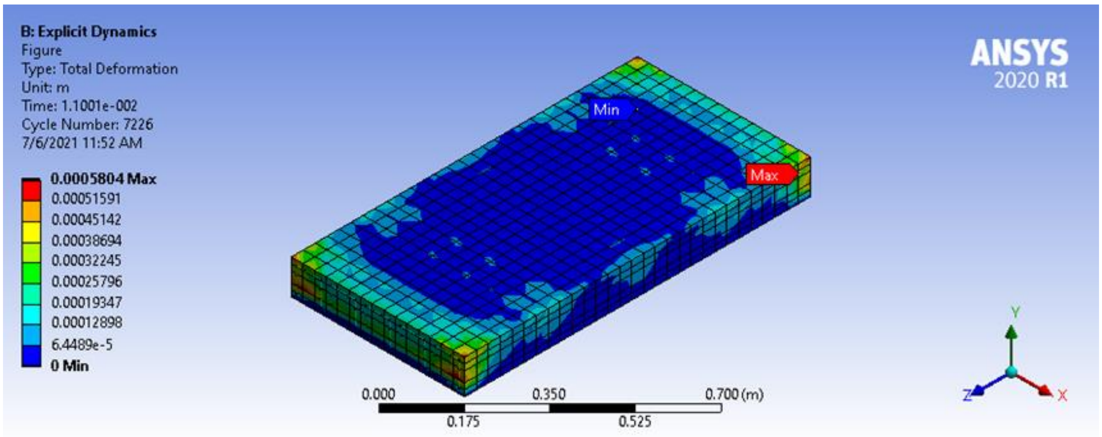

Figure 7 (a): The maximum and minimum total deformation of PLFP solid bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under compression load of -2000 kN in Y-axis under compression test

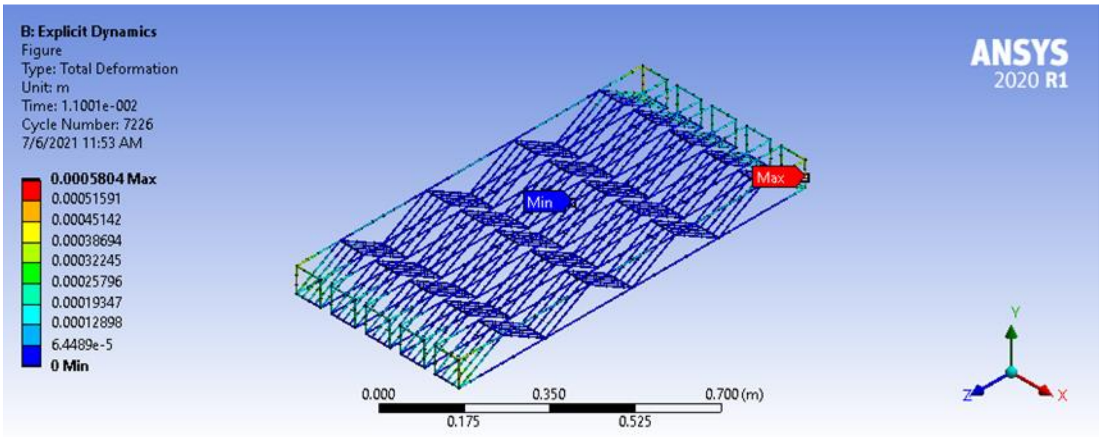

Figure 7 (b): The maximum and minimum total deformation of PLFP line bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under compression load of -2000 kN in Y-axis under compression test

Besides, the PLFP with honeycomb reinforcement were differently in term of presence of fatigue and fracture as compared to the other PLFP designs. Figure 8 (a) shows the maximum and minimum total deformation of PLFP solid bodies with honeycomb reinforcement for 30 mm thick polystyrene under compression of -2000 kN in Y-axis under compression test. The result showed that the fatigue embedded mainly on the edges of the PLFP solid bodies, whereas, the minimum fatigue located mainly on the top center surface and bottom surface. Figure 8 (b) shows the maximum and minimum total deformation of PLFP line bodies with honeycomb reinforcement for 30 mm thick polystyrene under compression load of -2000 kN in Y-axis under compression test. The results showed that the fatigue embedded mainly on the edges of the PLFP line bodies, whereas, the minimum fatigue located mainly on the top center surface and bottom surface. This PLFP model with 25 mm and 27.5 mm thick polystyrene also experienced fracture at the concrete edges.

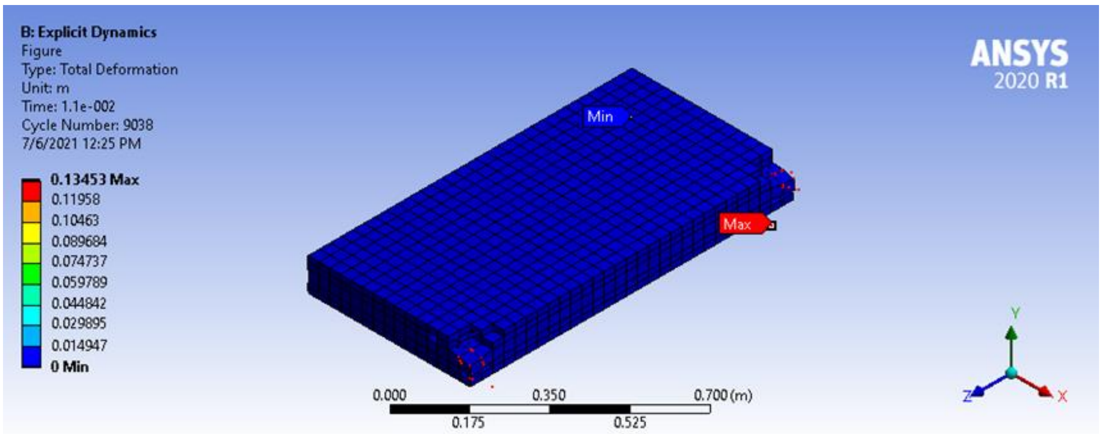

Figure 8 (a): The maximum and minimum total deformation of PLFP solid bodies with honeycomb reinforcement for 30 mm thick polystyrene under compression load of -2000 kN in Y-axis under compression test

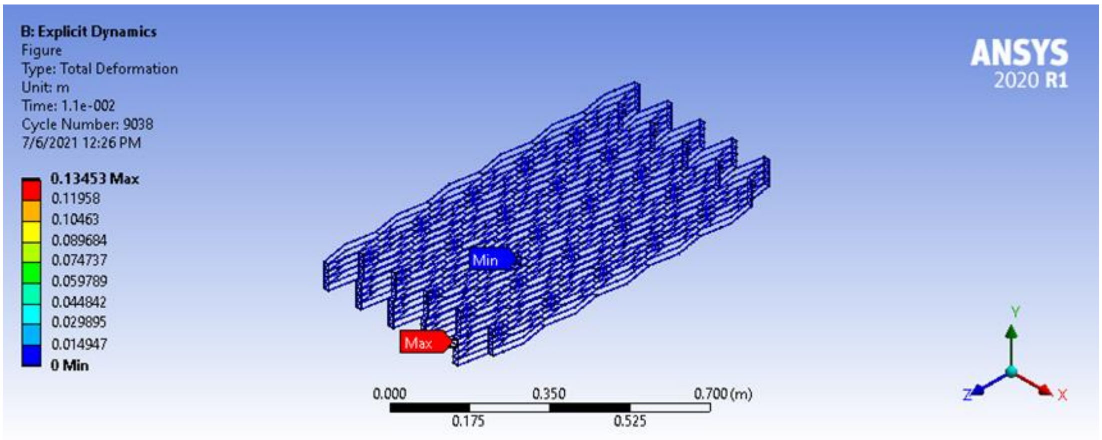

Figure 8 (b): The maximum and minimum total deformation of PLFP line bodies with honeycomb reinforcement for 30 mm thick polystyrene under compression load of -2000 kN in Y-axis under compression test

Moreover, Table 4 indicates the presence of fracture and area of fracture in all type of PLFP for all specimen polystyrene thickness under compression load of -2000kN in Y-axis. As compared the different types of PLFP models, the PLFP with continuous shear truss and trapezoidal-shaped reinforcement could be considered optimal for achieving maximum tensile test as they were not fracture.

Table 4: The presence of fracture and area of fracture in all type of PLFP for all specimen polystyrene thickness under compression load of -2000kN in Y-axis under compression test

Thickness of Polystyre-ne	Volume of Concrete Used	Presence of Fracture (List the Area Affected if Any)			
		Type of Reinforcement			
		Shear Truss	Trapezoidal	Honeycomb	None
$20\ mm$	$0.04\ m^3$	No	No	No	No
$22.5\ mm$	$0.03875\ m^3$	No	No	No	No
$25\ mm$	$0.0375\ m^3$	No	No	Concrete Edges	No
$27.5\ mm$	$0.03625\ m^3$	No	No	Concrete Edges	No
$30\ mm$	$0.035\ m^3$	No	No	Concrete Edges	No

3.5.2 Effect under 3-point bending test

Figure 9 (a) shows the maximum and minimum total deformation of PLFP solid bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under center load of -100 kN in Y-axis under 3-point bending test. The result showed that the fatigue embedded mainly on the center and edges of the PLFP solid bodies, whereas, the minimum fatigue located mainly on the end surface and bottom surface. Figure 9 (b) shows the maximum and minimum total deformation of PLFP line bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under center load of -100 kN in Y-axis under 3-point bending test.

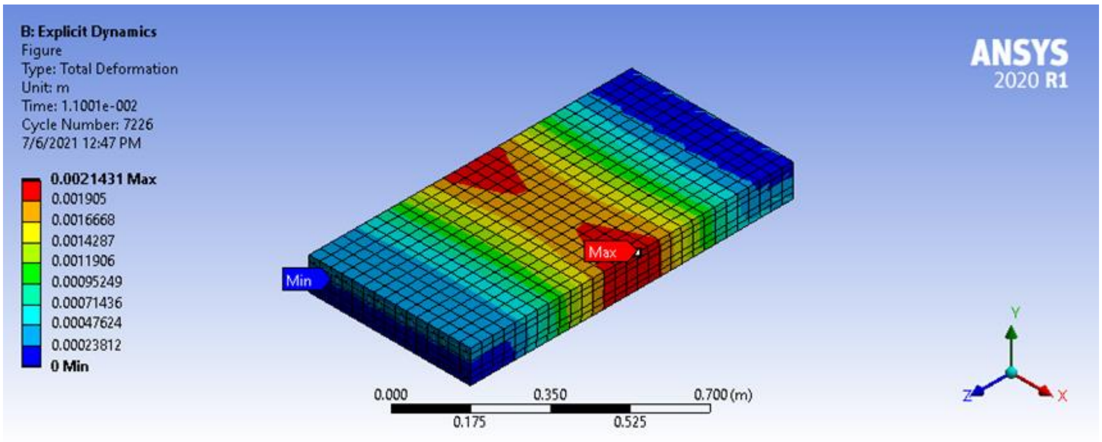

Figure 9 (a): The maximum and minimum total deformation of PLFP solid bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under center load of -100 kN in Y-axis under 3-point bending test

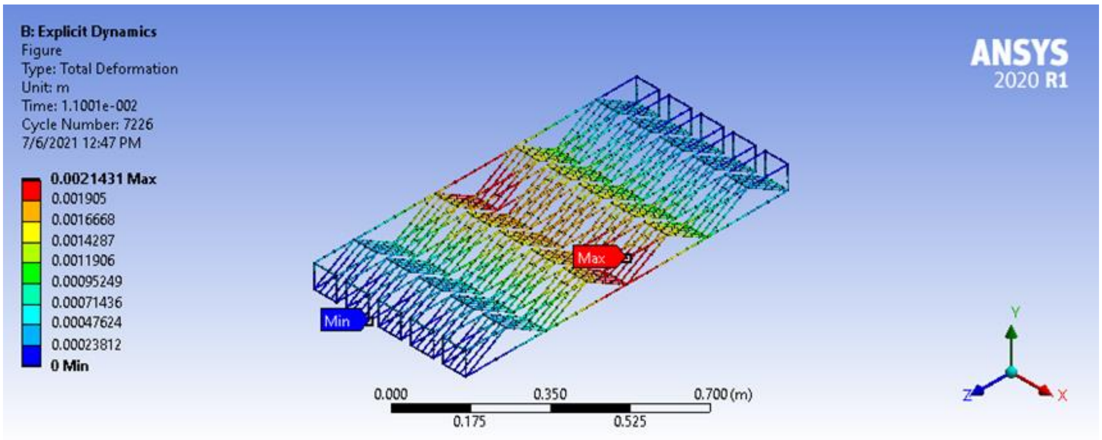

Figure 9 (b): The maximum and minimum total deformation of PLFP line bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under center load of -100 kN in Y-axis under 3-point bending test

Besides, the PLFP with honeycomb reinforcement were differently in term of presence of fatigue and fracture as compared to the other PLFP designs. Figure 10 (a) shows the maximum and minimum total deformation of PLFP solid bodies with honeycomb reinforcement for 30 mm thick polystyrene under center load of -100 kN in Y-axis under 3-point bending test. The result showed that the fatigue embedded mainly on the center, edges and end of the PLFP solid bodies, whereas, the minimum fatigue located mainly on the end surface and bottom surface. Figure 10 (b) shows the maximum and minimum total deformation of PLFP line bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under center load of -100 kN in Y-axis under 3-point bending test. The crack pattern and mode of failure always happened at the concrete and indicate signs of buckling at bending test. The result showed that the fatigue embedded mainly on the center and edges of the PLFP solid bodies, whereas, the minimum fatigue located mainly on the end surface and bottom surface. These effects were exactly same with the PLFP with continuous trapezoidal-shaped (except for the 25 mm and 27.5 mm thick polystyrene) and no reinforcement.

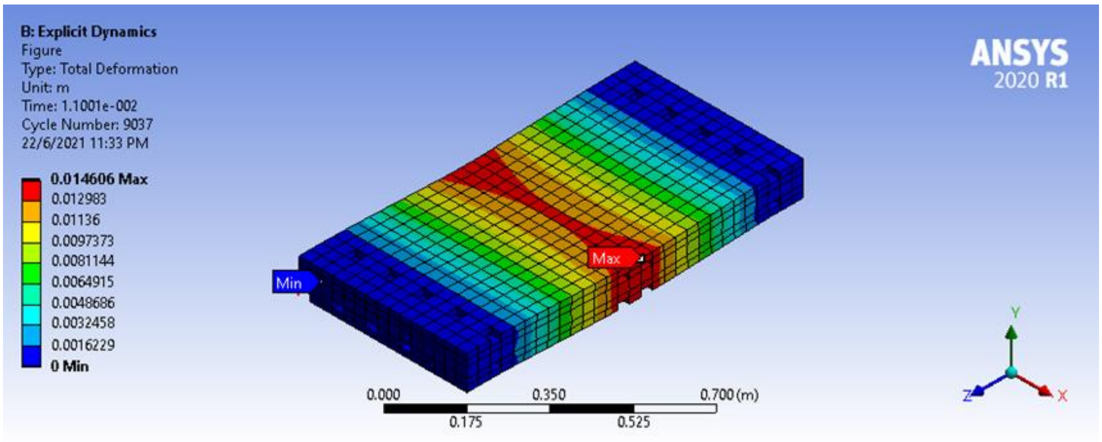

Figure 10 (a): The maximum and minimum total deformation of PLFP solid bodies with honeycomb reinforcement for 30 mm thick polystyrene under compression load of -2000 kN in Y-axis under 3-point bending test

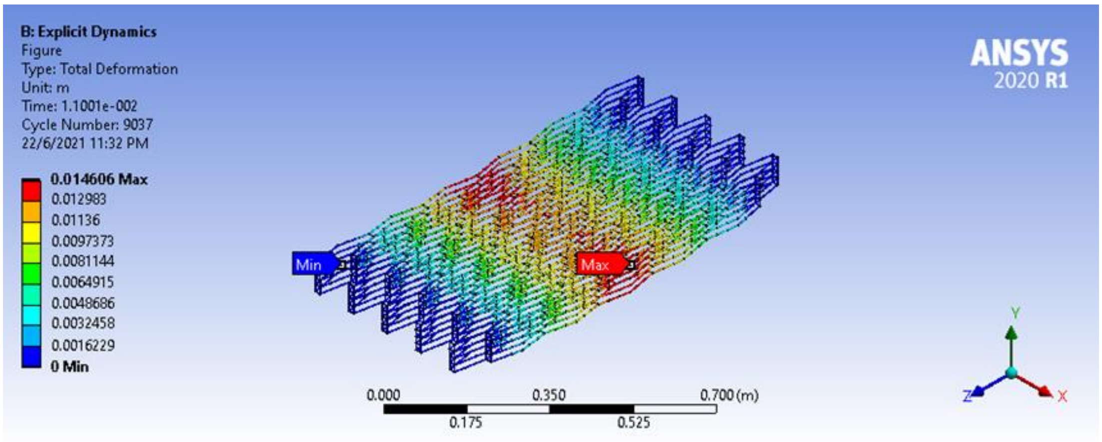

Figure 10 (b): The maximum and minimum total deformation of PLFP line bodies with honeycomb reinforcement for 30 mm thick polystyrene under center load of -100 kN in Y-axis under 3-point bending test

Moreover, Table 5 indicates the presence of fracture and area of fracture in all type of PLFP for all specimen polystyrene thickness under center load of -100kN in Y-axis. As compared the different types of PLFP models, the PLFP with continuous shear truss reinforcement could be considered optimal for achieving maximum tensile test as it was not fracture.

Table 5: The presence of fracture and area of fracture in all type of PLFP for all specimen polystyrene thickness under center load of -100kN in Y-axis under 3-point bending test

Thickness of Polystyre-ne	Volume of Concrete Used	Presence of Fracture (List the Area Affected if Any)			
		Type of Reinforcement			
		Shear Truss	Trapezoidal	Honeycomb	None
20 mm	0.04 m^3	No	Concrete Surfaces	Concrete Surfaces	Concrete Surfaces
22.5 mm	0.03875 m^3	No	Concrete Surfaces	Concrete Surfaces	Concrete Surfaces

Table 5: (continued)

Thickness of Polystyre-ne	Volume of Concrete Used	Presence of Fracture (List the Area Affected if Any)			
		Type of Reinforcement			
		Shear Truss	Trapezoidal	Honeycomb	None
$25\ mm$	$0.0375\ m^3$	No	No	Concrete Surfaces	Concrete Surfaces
$27.5\ mm$	$0.03625\ m^3$	No	No	Concrete Surfaces	Concrete Surfaces
$30\ mm$	$0.035\ m^3$	No	Concrete Surfaces	Concrete Surfaces	Concrete Surfaces

3.5.3 Effect under tensile test

Figure 11 (a) shows the maximum and minimum total deformation of PLFP solid bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under tensile displacement of -0.001 m in Z-axis under tensile test. The result showed that the fatigue embedded mainly on the end surface and bottom of the PLFP solid bodies where the tensile displacement applied, whereas, the minimum fatigue located mainly on the end surface and bottom surface where the fixed support applied. Figure 11 (b) shows the maximum and minimum total deformation of PLFP line bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under tensile displacement of -0.001 m in Z-axis under tensile test.

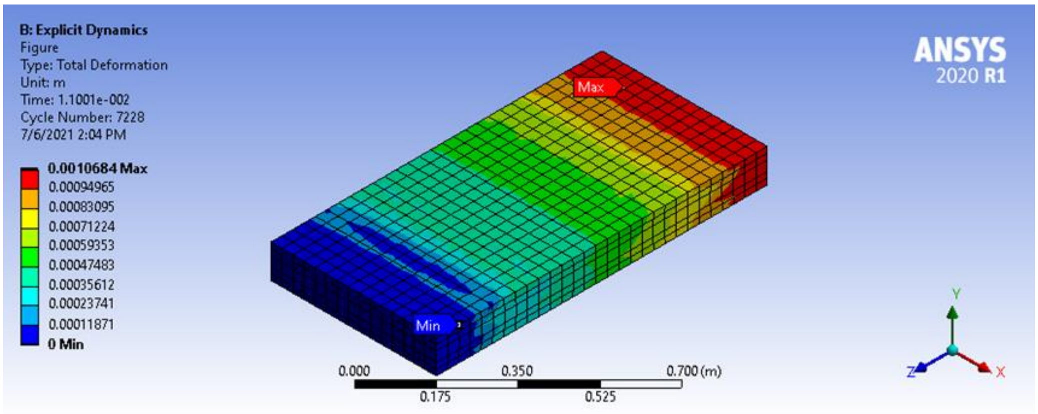

Figure 11 (a): The maximum and minimum total deformation of PLFP solid bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under tensile displacement of -0.001 m in Z-axis under tensile test

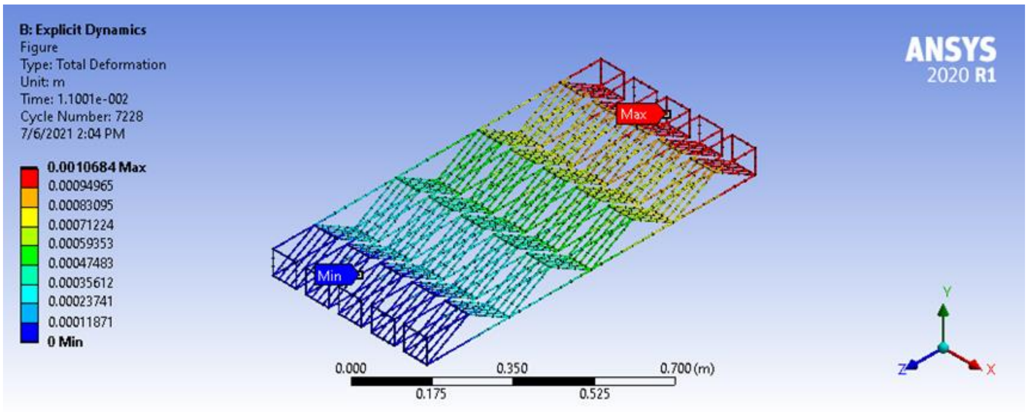

Figure 11 (b): The maximum and minimum total deformation of PLFP line bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under tensile displacement of -0.001 m in Z-axis under tensile test

Besides, the PLFP with honeycomb reinforcement were differently in term of presence of fatigue and fracture as compared to the other PLFP designs. Figure 12 (a) shows the maximum and minimum total deformation of PLFP solid bodies with honeycomb reinforcement for 30 mm thick polystyrene under tensile displacement of -0.001 m in Z-axis under tensile test. The result showed that the fatigue embedded mainly on the end of the PLFP solid bodies where the tensile displacement applied, whereas, the minimum fatigue located mainly on the end surface and bottom surface where the fixed applied. There were some of the concrete bodies at the end of fixed support fracture. Figure 12 (b) shows the maximum and minimum total deformation of PLFP line bodies with continuous shear truss reinforcement for 30 mm thick polystyrene under tensile displacement of -0.001 m in Z-axis under tensile test. The result showed that the fatigue embedded mainly on the end surface and bottom of the PLFP line bodies where the tensile displacement applied, whereas, the minimum fatigue located mainly on the end surface and bottom surface where the fixed support applied.

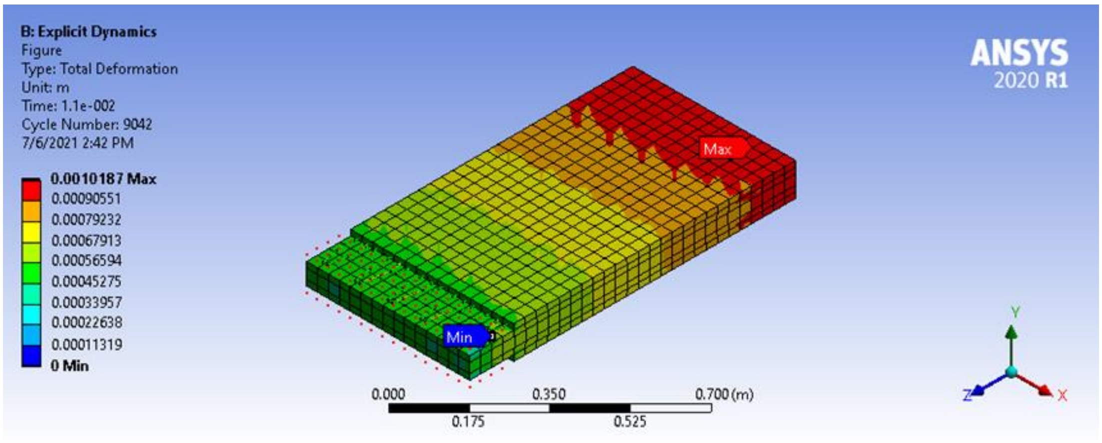

Figure 12 (a): The maximum and minimum total deformation of PLFP solid bodies with honeycomb reinforcement for 30 mm thick polystyrene under tensile displacement of -0.001 m in Z-axis under tensile test

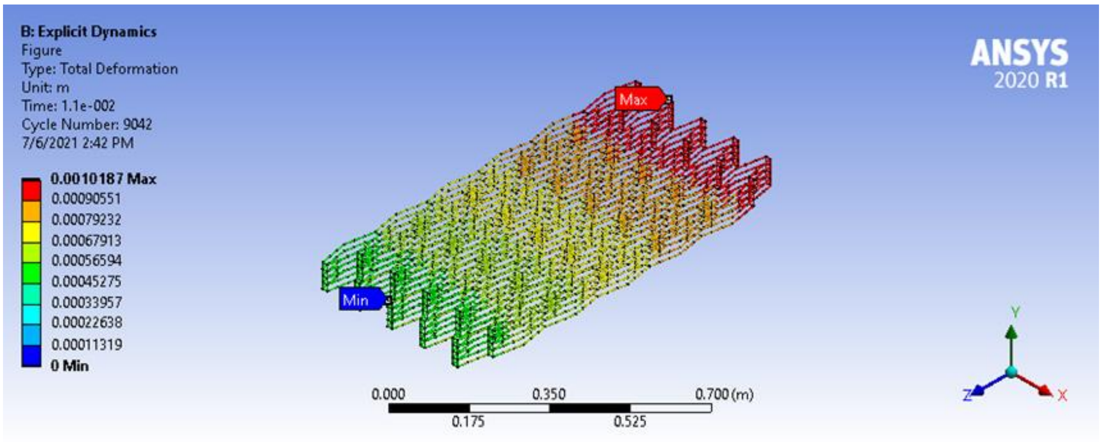

Figure 12 (b): The maximum and minimum total deformation of PLFP line bodies with honeycomb reinforcement for 30 mm thick polystyrene under tensile displacement of -0.001 m in Z-axis under tensile test

Moreover, Table 6 indicates the presence of fracture and area of fracture in all type of PLFP for all specimen polystyrene thickness under tensile displacement of -0.001 m in Z-axis. As compared the different types of PLFP models, the PLFP with continuous shear truss and trapezoidal-shaped reinforcement could be considered optimal for achieving maximum tensile test as they were not fracture.

Table 6: The presence of fracture and area of fracture in all type of PLFP for all specimen polystyrene thickness under tensile displacement of -0.001m in Z-axis under tensile test

Thickness of Polystyre-ne	Volume of Concrete Used	Presence of Fracture (List the Area Affected if Any)			
		Type of Reinforcement			
		Shear Truss	Trapezoidal	Honeycomb	None
$20\ mm$	$0.04\ m^3$	No	No	End of Concrete	No
$22.5\ mm$	$0.03875\ m^3$	No	No	End of Concrete	No
$25\ mm$	$0.0375\ m^3$	No	No	End of Concrete	No
$27.5\ mm$	$0.03625\ m^3$	No	No	End of Concrete	No
$30\ mm$	$0.035\ m^3$	No	No	End of Concrete	No

4. Conclusion

The designs of PLFP with different type of reinforcement (continuous shear truss, continuous trapezoidal-shaped, honeycomb and none) with different aspect ratio of polystyrene thickness to overall thickness in same width and length for 1:3 scale was successfully constructed using ANSYS Geometry Design Modeler. The structural behaviors of PLFP also fully defined. A good PLFP design should deflects gradually when force or displacement applied, where the concrete will crack and after cracking has occurred after the load or displacement have been removed will return to its original position and the cracks will close.

Results analysis found that steel reinforcement ratios of reinforced PLFP models are from 1.9935% to 3.2284%. Based results, as the stress increases, the strain will increase. The PLFP with continuous shear truss has the smoothest stress-strain curve, lowest stress and strain value, lowest deformation value, lowest steel reinforcement ratio and no presence of fracture for each mechanical testing. An over-reinforced PLFP such as honeycomb reinforcement also cannot be used because it will cause explosive brittle behavior. The polystyrene thickness which not follow the ASTM standards (20 mm and 22.5 mm) will create unstable simulation data. Hence, it is not encouraged to use this parameter. PLFP with continuous shear truss reinforcement requires a smaller number of raw materials, lightweight, easy to be constructed and strong in compressive strength and tension strength. Therefore, it is concluded that PLFP with continuous shear truss reinforcement is the most suitable model, and can be applicable and safe for construction. Lastly, for the recommendations, a full-scale model and different mechanical testing are recommended to apply in the simulation to obtain the real and actual reading for all simulation data.

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