

# Relationship Between Panel Stiffness and Mid-span Deflection in Profiled Steel Sheeting Dry Board with Geopolymer Concrete Infill

MOHD ISA JAFFAR<sup>1</sup>, WAN HAMIDON WAN BADARUZZAMAN<sup>1</sup>, MOHD MUSTAFA AL BAKRI ABDULLAH<sup>2,3\*</sup>, SHAHRIZAN BAHAROM<sup>1</sup>, LIGIA MIHAELA MOGA<sup>4</sup>, ANDREI VICTOR SANDU<sup>2,5\*</sup>

<sup>1</sup> Department of Civil and Structural Engineering, National University of Malaysia (UKM), 43600 Bangi, Selangor, Malaysia,

<sup>2</sup> Center of Excellence Geopolymer & Green Technology (CEGeoGTech), School of Materials Engineering, Universiti Malaysia Perlis (UniMAP) 01000, P.O. Box 77, D/A Pejabat Pos Besar, Kangar, Perlis Malaysia

<sup>3</sup> Faculty of Engineering Technology, Universiti Malaysia Perlis (UniMAP) 01000, P.O. Box 77, D/A Pejabat Pos Besar, Kangar, Perlis Malaysia

<sup>4</sup> Technical University of Cluj Napoca, Faculty of Civil Engineering, 15 C. Daicoviciu Str., 400020, Cluj-Napoca, Romania

<sup>5</sup> "Gheorghe Asachi" Technical University of Iasi, Faculty of Materials Science and Engineering, 41 D. Mangeron Blv, Iasi, 700050, Romania

*Profiled steel sheeting dry board (PSSDB) consists of steel sheeting that are connected to a dry board using self-drilling and self-tapping screw to form a light composite structure. This study focuses on PSSDB that uses 12 M geopolymer concrete infill with half-sized dry-board infill (GPCHB). The detected weakness of the profiled steel sheeting on this PSSDB system is due to the relatively easy occurrence of local buckling on its structure as it reaches an ultimate load, especially on the top flange. This study aims to analyze the relationship between stiffness and deflection at the mid-span of PSSDB systems using different parameters. Results show that the panel with 12 M GPCHB has 107% and 40% increase in rigidity compared with those of the control (without infill) and full board normal concrete panels, respectively. Mid-span deflection is also reduced to 52%. In conclusion, stiffness increases and deflection decreases when 12 M GPCHB is used in the panel.*

*Keywords: composite structure, geopolymer concrete, weakness, local buckling, stiffness*

Profiled steel sheeting concrete is a composite floor system that replaces steel reinforcement bars in conventional concrete floor systems. Using profiled steel sheeting concrete composite floor system, the concrete at the bottom of concrete floor can be reduced based on the profiled steel sheeting [1].

Continuous research has been conducted to identify infill materials that can improve the compressive strength and connection stiffness of the system. Profiled steel sheeting-dry board (PSSDB) composite system is a prefabricated structure of lightweight composite system [2]. This system is derived from a combination of profiled steel sheet and dry board via mechanical connectors.

Evans and Wright [3] suggested the use of dry board as concrete replacement in composite floor system technology. A study on the behaviour of PSSDB panel showed that the stiffness of the profiled steel sheeting increased by approximately 14% to 70% when subject to out-of-plane bending along the main axis, considering that the dry board is connected to the profiled steel sheeting at a distance of 100 mm to 300 mm [3].

The presence of dry board was also found to contribute to the delay of local buckling mode. A study showed that the steel sheeting used in composite floor structure can withstand loads from wet concrete, labor, and construction equipment, which can reach up to 4 kN/m<sup>2</sup> [4].

The profiled steel sheeting used in PSSDB system are cold-formed steel with 350 MPa to 550 MPa yield stress and 275 g/m<sup>2</sup>-thick with zinc-aluminium coating [5]. The various types of steel sheet present in the market can be

generally categorized into two types, namely, trapezium and dovetail shapes. In this study, a Peva 50 profiled steel sheeting was used, as shown in the diagram in figure 1.

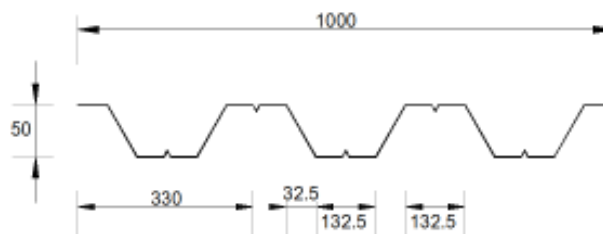


Fig. 1. Profiled steel sheeting Peva 50 (all dimensions are in mm)

Dry board is an important component of PSSDB floor system because of its high flexural strength and ability to withstand load. It is connected to the steel sheet with a self-drilling and self-tapping screw. A dry board in the PSSDB system serves as replacement for concrete. The advantages of using a dry board are due to its ability to reduce local buckling on profiled steel sheeting and to improve the stiffness of the composite system. The use of dry board can increase panel stiffness by 25% compared with the use a profiled steel sheeting alone [6]. Various types of dry board have been studied for their stiffness, namely, plywood, Cemboard, fiber board, and PRIMAflex. In this study, a locally acquired PRIMAflex type was used as dry board. It has a high elasticity modulus (8000 N/mm<sup>2</sup>) compared with that of Cemboard (4500 N/mm<sup>2</sup>) [7].

\* email: mustafa\_albakri@unimap.edu.my; sav@tuiasi.ro

Concrete	Panel Sample	Sample Code
Normal Concrete	NCFB (Full Board with Normal Concrete)	NCFB S1 NCFB S2 NCFB S3
	NCHB (Half Board with Normal Concrete)	NCHB S1 NCHB S2 NCHB S3
	GPCFB (Full Board with Geopolymer Concrete)	GPCFB S1 GPCFB S2 GPCFB S3
Geopolymer Concrete	GPCHB (Half Board with Geopolymer Concrete)	GPCHB S1 GPCHB S2 GPCHB S3

**Table 1**  
LIST OF CUBE SAMPLE

A screw is a shear connector used in PSSDB systems, which is similar to the studs used in conventional composites. The strength of the screw is influenced by the strength of the material used to build it, its size, and its distances. In addition, the screw's shear strength is affected by its diameter, length, head type, and the tools used to install it [8].

Various connectors, such as nails, bolt and nut, as well as threaded and self-drilling screws, have been examined. From their studies, the drilling and threading screws were found to have many advantages compared with other connector materials used in PSSDB system [9]. The screw used in this study is a DS-FH 432 self-drilling and self-tapping type with a 4.2 mm diameter and 30.0 mm length; the screws were installed at distances of 200 mm.

A concrete is an ideal material used as infill in PSSDB system because of its high compressive strength; however, it has low tensile strength [10]. A concrete is a mixture of sand materials, aggregate, cement (Ordinary Portland Cement, OPC), and water. However, worldwide OPC cement production contributes around 1.35 B tons of greenhouse gas emissions each year or approximately 7% of the total emission of greenhouse gases into the earth's atmosphere [11]. Geopolymer technology uses geopolymerbinder solutions that can reduce CO<sub>2</sub> emissions by 80% compared with the use of OPC [12]. Total CO<sub>2</sub> emissions from geopolymer binders include CO<sub>2</sub> emissions from dissolved solids of the alkaline activator (Na<sub>2</sub>O + SiO<sub>2</sub>) [13]. Geopolymer concrete is an alternative material for cement-based mixture. It is produced from the reaction of fly ash with alkaline activator (Na<sub>2</sub>SiO<sub>3</sub> and NaOH solution), which is an alternative to OPC in construction industries [14-18].

This study aims to analyze the relationship between panel stiffness and mid-span deflection in profiled steel sheeting dry board with geopolymer concrete infill compared with normal concrete infill in full- and half-board panels. The experimental results were compared with panels without any infill materials (control). In addition, mid-span deflection values were also compared.

### Experimental part

The experiment was divided into two stages. Raw materials for 12M geopolymer and grade 30 normal concretes were prepared in the first stage. The compressive strengths of the cubes were tested. The PSSDB panels were prepared in stage two for bending tests. Table 1 shows the concrete cube that should be prepared; each PSSDB panel represents three concrete cubes. Results from the compression tests of each cube are presented as average for each panel.

#### Geopolymer Concrete 12M NaOH Concentration

The strength of the geopolymer concrete is determined using NaOH concentrations and fly ash/alkaline activator

to Na<sub>2</sub>SiO<sub>3</sub>/NaOH ratios. Many methods can be used to determine the geopolymer concrete mixture ratio. A study conducted by [19] found that different NaOH concentrations resulted in geopolymer concretes with different compressive strengths. In the said study, the highest compressive strength (68.48 MPa) was obtained after seven days using 12 M NaOH at 60°C [20]. Studies [21] also reported that samples with 12 M NaOH exhibited better compressive strengths compared with those with 18 M NaOH. For this experiment, geopolymer concrete infills were prepared using 12 M NaOH.

#### Fly ash/alkaline activator and Na<sub>2</sub>SiO<sub>3</sub>/NaOH ratios

Based on a report on alkaline solution usage [21], the type of alkaline activator is very important in geopolymerization. High reaction rate was observed using dissolved silica compared with the use of basic hydroxide. The reaction between dissolved materials increased when sodium silicate was added with NaOH [22].

Moreover, NaOH was found to be a better choice of alkaline activator compared with KOH because of its higher dissolution rate. Hardjito [23] suggested a 2.5 Na<sub>2</sub>SiO<sub>3</sub>/NaOH ratio. In addition, 2.0 and 2.5 ratios between fly ash/alkaline activator and Na<sub>2</sub>SiO<sub>3</sub>/NaOH have been suggested by [19] for higher compressive strength, seven days after curing. Thus, these ratios were used in preparing geopolymer concrete for PSSDB panels. Generally, compressive strength increases when alkaline activator/fly ash ratio changes from 0.3 to 0.35, which provides the highest geopolymerization rate and is suitable for production of geopolymers with high compressive strength [20].

Fly ash is the main geopolymer material for geopolymer production because it contains 40 to 60% reactivated silicate, 80 to 90% of less than 45µm particulate size, low CaO content, less than 10% Fe<sub>2</sub>O<sub>3</sub> content, and 5% inflammable materials, as proven by [24]. In this study, class F low-calcium dried fly ash (ASTM C618-84) was obtained from the silo of Sultan Salahuddin Abdul Aziz Power Plant in Kapar, Selangor, Malaysia.

According to [25], fly ash addition and activator solution concentration increase the compressive strength of geopolymer material. A study on geopolymer concrete using low calcium fly ash was conducted by [26], which focused on the engineering properties and application of the structure.

#### Coarse and Fine Aggregates

The density of the geopolymer concrete that was prepared as infill for the PSSDB panel is similar to that of a normal concrete (2262 kg/m<sup>3</sup>) [20]. Aggregate grading, which uses a dry sieving method based on BS 812-103.1:1985 was applied to produce a geopolymer concrete that is similar to that of a normal concrete, with coarse and fine aggregate sizes of 20 mm and 600µm, respectively [27]. The percentage distributions of coarse and fine aggregates are set to 30% and 70%, respectively. The

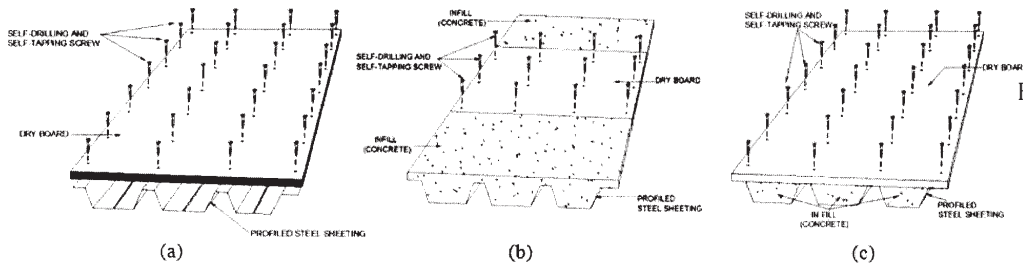


Fig. 2. Profiled steel sheeting-dry board (PSSDB) with: (a) out infill, (b) half board with infill (c) full Board with infill

Materials	Thickness /diameter (mm)	Width and Length (mm)	Modulus of Elasticity E, N/mm <sup>2</sup>	Ultimate strength N/mm <sup>2</sup>	Weight of covered area N/m <sup>2</sup>
Profiled Steel Sheeting (Peva 50)	1.0	1000 x 2600	275 x 10 <sup>3</sup>	350	100.00
Self-drilling and self-tapping screw (DS-FH 432)	4.2	30.0	-	-	-
Dry board (PRIMAflex)	12.0	1000 x 1300	8030	22	172
Concrete grade 30	Infill	Infill	25000	30	598
Geopolymer Concrete (12M)	Infill	Infill	29000	68.48	575

**Table 2**  
PROPERTIES OF THE MATERIALS USED FOR THE PSSDB PANEL

geopolymer concrete was mixed and poured into a cube mold measuring 150 mm × 150 mm × 150 mm. Three cubic geopolymer concrete samples were prepared for each PSSDB panel.

#### Normal Concrete Grade 30

The strength of the normal concrete is obtained by the type and composition of the material component used for the concrete. Generally, higher concrete grade requires more cement and less water. A number of methods have been used in determining the mixture rate from the respective material components. In this study the procedure from the Concrete Construction Handbook [28] was followed in the design of the mixture method.

The concrete used as infill in this study was a grade 30 with 2262 kg/m<sup>3</sup> concrete density. A 0.4 cement-water ratio was used for the concrete mixture. The standard deviation value was assumed to be 5 N/mm<sup>2</sup>; thus, the proposed design have a 30 N/mm<sup>2</sup> strength, which is added with 5 N/mm<sup>2</sup> and becomes 35 N/mm<sup>2</sup>. A grade 30 concrete was then mixed, stirred, and placed into 150 × 150 × 150 mm cubic mold. Three normal concrete cube samples were prepared for each PSSDB panel.

#### Cube Testing

The compressive strengths of the concrete cubes were tested based on the BS 1881-116:1983 standard method using a Compression Testing Machine with a 100 kN capacity and 5 mm/min loading rate. The obtained ultimate load readings from the three concrete cube samples were averaged for each PSSDB panel.

#### PSSDB Sample Preparation

Laboratory experiment is one of the methods adopted to identify the behaviour of every structure being examined. Moreover, it enables researchers to compare the panels using various parameters. Thus, a full-scale experiment

was conducted to determine the bending behaviour of PSSDB floor system using the concrete infill and different dry-board sizes (fig. 2).

Table 2 shows the properties of the materials used for the PSSDB panel. Table 3 shows the different PSSDB panels tested including the Control sample with no infill.

The bending behaviour of the PSSDB floor system can be determined by imposing some bending load on the system in which the load value and the deflection produced can be recorded. The failure mode can also be identified in the experiment. Generally, the floor is required to accommodate uniformly distributed load outside the plane. The floor is safe when the limiting deflection for non-brittle partitions is equal to  $L/350$ , where  $L$  is the span distance based on [29].

For the above requirement, five types of samples were prepared as listed in table 3. The control sample is prepared without the use of infill. For the next sample, the trenches of the profiled steel sheeting were filled with the infill and the panel was added with the half-board infill up to the dry board level. With this, the influence of the infill on the bending behaviour of PSSDB floor system can be identified. The distance between the screw installed on the dry board and the profiled steel sheeting is 200 mm [5].

#### Bending test on PSSDB panel

In this experiment, a rig that was designed with a pinned and roller supporter was used to place the samples. The samples were simply supported by a boundary condition. The load imposed on the sample is the line load that is close to the uniformly distributed load method. A 100 mm × 100 mm, 4 mm-thick hollow steel beam was arranged using the Whiffle tree method, in which the load was distributed symmetrically from the load cell to the sample using four convergent line loads, as illustrated in figures 3 and 4. The load was generated using the hydraulic jack from the load cell that has a 1000 kN capacity. Data were

Model	Description	Dimensions of Peva 50 (mm)	Dimensions of PRIMAflex (mm)	
			Full Board	Half Board
CS	Control Sample	2600 x 1000	2600 x 1000	1300 x 1000
NCFB	Full Board With Normal Concrete Infill	2600 x 1000	2600 x 1000	1300 x 1000
NCHB	Half Board With Normal Concrete Infill	2600 x 1000	2600 x 1000	1300 x 1000
GPCFB	Full Board With Geopolymer Concrete Infill	2600 x 1000	2600 x 1000	1300 x 1000
GPCHB	Full Board With Geopolymer Concrete Infill	2600 x 1000	2600 x 1000	1300 x 1000

**Table 3**  
PSSDB PANEL FOR TESTING

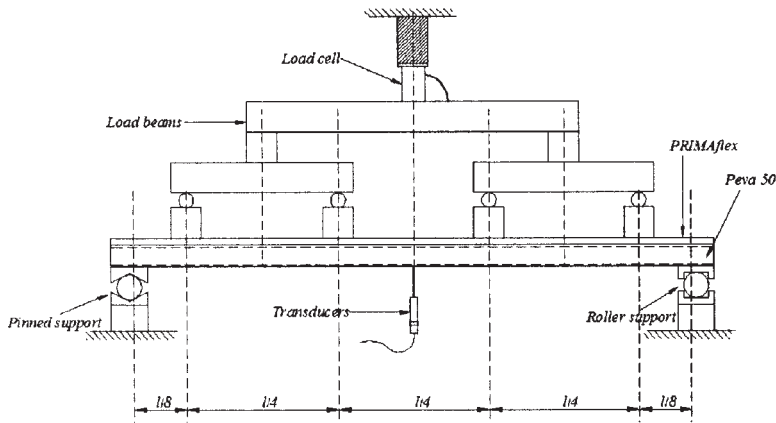


Fig. 4. Image of test set-up details and testing of a PSSDB floor panel

Fig. 3. Scheme of test set-up details and testing of a PSSDB panel

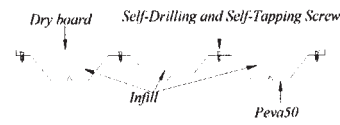


Fig. 5. Local buckling at the top flange of the profiled steel sheeting (experiment)

recorded using a computer software package. A transducer is a normal tool that measures the deflection either vertically or horizontally. In this study, transducers were installed at the mid-span under the PSSDB panel. The transducers were used to measure the deflection of the panel at the mid-span.

Loading must be carefully conducted to avoid a drastic load input into the sample. The average value of every loading was  $0.075 \text{ kN/m}^2$ . Loads were imposed continuously until a maximum reading was obtained and when the sample has failed, that is, load value decreases although deflection reading increases. Results show that local buckling occurred at the bottom of the mid-span of the steel sheeting as showed in figure 4. In the absence of infill, local buckling was observed to occur in the plane and at the top flange. Conversely, local buckling in samples with infill occurred outside the plane of the profiled steel sheeting web.

## Results and discussion

### Compressive cube test

The results from the compressive strength test on the 12 cube samples are shown in figure 6. A comparison of the compressive strengths of both types of concrete shows that the geopolymer concrete demonstrates a 43% higher average compressive strength compared with that of the normal concrete. This result provides evidence that compressive strength increases as fly ash content and activator solution concentration increase [19].

### Bending Test

In the experiment conducted on PSSDB panel, failure was found to occur on the sample because of local buckling, especially on the top flange of the profiled steel sheeting in the mid-span. The loading imposed on the sample caused the PRIMAflex to bend and the steel sheeting to experience high tension, which further caused local buckling on the web of steel sheeting. The web part

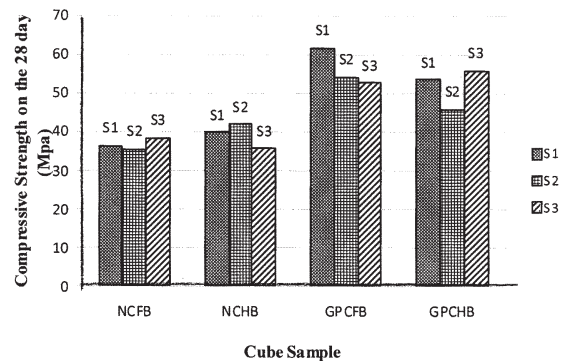


Fig. 6. Compressive strength of the cube testing

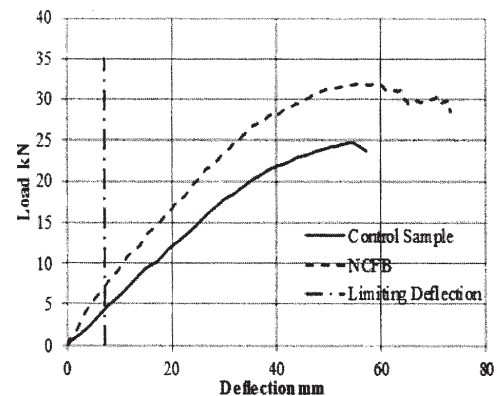


Fig. 7. Load-deflection curve for NCFB

of the steel sheeting exhibited a remarkable deformation because of local buckling, which resulted in a non-linear relationship in the plastic range of the load-deflection graph. The curve relationships observed in all the PSSDB panels tested were almost linear initially and subsequently became non-linear as load was added continuously. All the experimental results from the panel were compared with that of the control samples. Based on [29], the

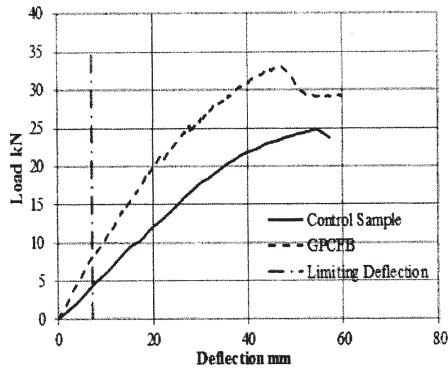


Fig. 8. Load-deflection curve for GPCCFB

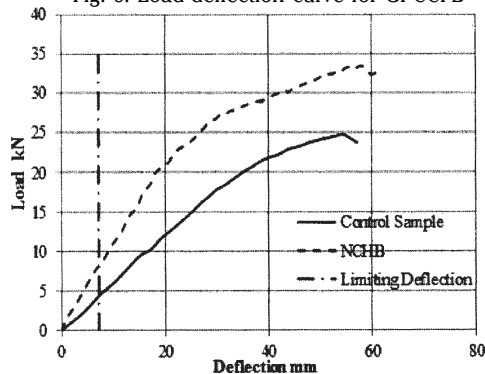


Fig. 9 Load-deflection curve for NCHB

serviceability deflection limit for non-brittle partitions is  $L/350$ , which resulted in a serviceability deflection limit of 7.14 mm.

Figures 6 and 7 present the linearity of the curve relationship during the early loading stage on both NCFB and GPCFB panels. From that figure shows the increased serviceability limited the deflection on NCFB and GPCFB panels by 66% (fig. 7) and 77% (fig. 8), respectively, compared with that of the control sample. The 17% increase is attributed to the use of the geopolymer concrete infill in the PSSDB panel with full board. The deflection mid-span was also reduced by 22%.

Figures 9 and 10 show the results of the panel experiment in which geopolymer and normal concretes infill were used with half dry board. An almost linear relationship is observed at the initial phase of the curve load, which is followed by a non-linear relationship up until the panel reached failure. Based on the graphs in figures 8 and 9, NCHB and GPCHB show a 100% and 144% increase in rigidities compared with that of the control sample. Moreover, the GPCHB panel, which used a half dry board, showed a 44% increase compared with that of the NCHB panel, which used a normal concrete infill. Mid-span deflection was also reduced by as much as 37%. Collectively, the experiment clearly showed that infill's, such as geopolymer concrete, influence the rigidity and mid-span deflection of PSSDB panel structure.

## Conclusions

The PSSDB floor system uses a 1 mm-thick profiled steel sheeting owing to the fact that local buckling can easily occur on the top flange. The slim cross-section of the PSSDB floor system and without the use of any infill is not capable of carrying a maximum ultimate load. This study analyzed the different parameters of a PSSDB floor system using a geopolymer concrete infill and half-sized dry board. The PSSDB system was modified and differs from the system that has been previously studied. Results show that the GPCHB exhibited a 40% increased rigidity

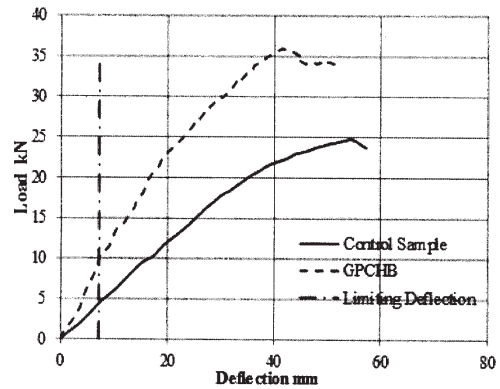


Fig. 10. Load-deflection curve for GPCHB

compared with that of the PSSDB system with NCFB. Mid-span deflection was also reduced to 52%. The increased stiffness is associated with the stiffness between the geopolymer concrete infill and the profiled steel sheeting. Infill volume also increased to 68% when a half dry board was used in GPCHB panel. Compared with the study conducted by [30], the GPCHB panel also demonstrated a 25% increase in rigidity. Collectively, the results clearly demonstrate that GPCHB panel stiffness increases as rigidity increases, whereas mid-span deflection of the PSSDB system decreases under the bending load.

*Acknowledgements: The research work support provided by Ministry of Education Malaysia, Universiti Kebangsaan Malaysia (UKM) and Universiti Malaysia Perlis (UniMAP). The authors would like to express sincere gratitude for all the support provided.*

## References

1. WRIGHT, H.D., HOSSAIN, K.M.A., Thin-Walled Structures, **29**, no. 1-4, 1997, p. 79.
2. SHODIQ, H.M., WAN BADARUZZAMAN, W.H., KHALIM, A., Proceeding of the World Engineering Congress & Exhibition WEC 2002, Kuching, 2003, p. 245.
3. WRIGHT, H.D., EVANS, H.R., BURT, C.A., The Structural Engineer, **67**, no. 7, 1989, p. 114.
4. WRIGHT, H.D., EVANS, H.R., SERC Grant GR/D/76875, 1986, United Kingdom.
5. AKHAND, A.M., WAN BADARUZZAMAN, W.H., WRIGHT, H.D., Thin-Walled Structures, **42**, no. 7, 2004, p. 1067.
6. WAN BADARUZZAMAN, W.H., ZAIN, M.F.M., AKHAND, A.M., AHMED, E., Construction and Building Materials, **17**, no. 4, 2003, p. 289.
7. AWANG, H., WAN BADARUZZAMAN, W.H., Journal of Construction in Developing Countries, **14**, no. 2, 2009, p. 21.
8. AHMED, E., WAN BADARUZZAMAN, W.H., Construction and Building Materials, **19**, no. 4, 2005, p. 285.
9. AHMED, E., WAN BADARUZZAMAN, W.H., WRIGHT, H.D., Thin-Walled Structures, **38**, 2000, p. 125.
10. SHODIQ, H.M., WAN BADARUZZAMAN, W.H., KHALIM, A., Proceeding of the World Engineering Congress & Exhibition WEC 2002, Kuching, 2003, p. 245.
11. MALHOTRA, V.M., ACI Concrete International, **21**, no. 5, 2000, p. 61.
12. DAVIDOVITS, P.J., Geopolymer Conference, October 28-29, 2002, Saint-Quentin, France. p.1.
13. MIRANDA, J.M., FERNA, A., PALOMO, A., Cement and Concrete Research, **35**, 2005, p. 1210.
14. ABDULLAH, A.M.M., KAMARUDIN, H., NIZAR, I.K., SANDU, A.V., BINHUSSAIN, M., ZARINA, Y., RAFIZA, A.R., Rev. Chim. (Bucharest), **64**, no. 4, 2013, p. 382.
15. RAZAK, R.A., ABDULLAH, M.M.A., HUSSIN, K., ISMAIL, K.N., SANDU, I.G., HARDJITO, D., YAHYA, Z., SANDU, A.V., Rev Chim (Bucharest), **65**, no. 7, 2014, p. 828.

16. STANESCU, M.M., BOLCU, D., CIUCA, I., MIRITOIU, C.M., BACIU, F., *Mat. Plast.*, **50**, no. 3, 2013, p. 179.
17. MIRITOIU, C.M., BOLCU, D., STANESCU, M.M., CIUCA, I., CORMOS, R., *Mat. Plast.*, **49**, no. 2, 2012, p. 118.
18. CRIADO M, FERNANDEZ-JIMANEZ, A., DE LA TORRE, A.G., ARANDA, M.A.G., PALOMO, A., *Cement and Concrete Research*, **37**, no. 5, 2007, p. 671.
19. ABDULLAH, M.M.A., KAMARUDIN, H., KHAIRUL NIZAR, I., BNHUSSAIN, M., ZARINA, Y., RAFIZA, A.R., *Advanced Materials Research*, **341-342**, 2012, p. 189-193.
20. ABDULLAH, M.M.A., KAMARUDIN, H., MOHAMMED, H., KHAIRUL NIZAR, I., RAFIZA, A.R., ZARINA, Y., *Advanced Materials Research*, **328-330**, 2011, p. 1475.
21. PALOMO, A., BLANCO-VARELA, M.T, GRANIZO, M.L, PUERTAS, F., VAZQUEZ, T., GRUTZECK, M.W., *Cement and Concrete Research*, **29**, 1999, p. 997.
22. XU, H., *Int. J. Miner. Process.* **59**, no. 3, 2000, p. 247.
23. HARDJITO, D., Ph.D. Thesis, Curtin University, Australia, 2005.
24. FERNÁNDEZ-JIMÉNEZ, A.M, PALOMO, A., *Microporous and Mesoporous Materials*, **91**, no. 1-3, 2006, p. 111.
25. HARDJITO, D., WALLAH, S.E., SUMAJOUW, D.M.J., RANGAN, B.V., *ACI Materials Journal*, **101**, no. 6, 2004, p. 467.
26. HARDJITO, D., WALLAH, S.E., RANGAN, B.V., *Journal of the Australasian Ceramic Society*, **38**, no. 1, 2002, p. 44.
27. HARDJITO, D., WALLAH, S.E., SUMAJOUW, D.M.J., RANGAN, B.V., *Proceedings of the International Conference Our World in Concrete*, Singapore, 2005.
28. DOBROWOLSKI, J.A.,. *Concrete construction handbook*, Ed. 4., Mc. Graw-Hill, New York, 1998.
29. \*\*, BS 8110 Part 1. 1997. Code for practice for design and construction. Structural use of concrete, British Standards Institution.
30. SERAJI, M., WAN BADARUZZAMAN, W.H., OSMAN, S.A., *Journal of Engineering Science and Technology*, **8**, no. 1, 2013, p. 57

---

Manuscript received: 7.12.2014