Lowland Technology International 2018; 20 (2): 161-168
International Association of Lowland Technology (IALT): ISSN 1344-9656
Special Issue on: Green Technology for Sustainable Infrastructure Development

Research Paper

Load test of pre-cast geopolymer concrete slabs

C. Ridtirud [1], V. Lam [2] and C. Sapsin [3]

ARTICLE INFORMATION

Article history:

Received: 11 December, 2016
Received in revised form: 03 June, 2018
Accepted: 21 July 2018
Publish on: 07 September 2018

Keywords:

Pre-cast Geopolymer concrete
Slab
Deflection
Fly ash
Geopolymer

ABSTRACT

This research aims to study load testing of pre-cast geopolymer concrete slab. Fly ash, a by-product of generation process of electricity was used in mixture as alternative to ordinary Portland cements in this research. To design and produce pre-cast geopolymer concrete slab, the compressive strength of geopolymer concrete was tested by using fly ash: fine aggregate: coarse aggregate ratio of 1:0.95:1.76 by weight, and the ratio of sodium silicate to sodium hydroxide of 1:1 by weight. The pre-cast geopolymer concrete slab of 0.35x2.40x0.05 m. was designed with live load of 150 kg/ sq. m, five PC-wire of 4 mm. with ultimate strength not less than 17,500 kg/ sq. cm, and was pulled by forced of 13,329 kg/ sq. cm. In this research, pre-cast geopolymer concrete slab was casted and tested by following to Thai Industrial Standards Institute 577-2531. The result of testing pre-cast geopolymer concrete slab was showed that, the value of deflection was exceeded and rebound was less than allowable by the Thai Industrial Standards Institute 577-2531. However, in this research the pre-cast geopolymer concrete slab might be stronger and increase load bearing capacity if the processing of temperature was raised.

1. Introduction and objective

Pre-cast concrete slabs were used to alternate the concrete slabs which cast in placed in many kinds of structure. Pre-cast concrete elements have been extensively used in construction over the past decades due to its time and cost effectiveness and higher quality of the products.

Concrete has become one of the largest production materials with an annual global production of about one cubic meter for every person on earth. Concrete is a composite mixture containing cement paste and aggregates as its main components. Portland cement is conventionally used as primary binder to produce concrete. The production of cement is increasing about 7% annually. Portland cement is manufactured using limestone and clay mixed in definite proportions to produce chemical reaction burnt at very high temperature. To produce one ton of Portland cement, 1.6 tons of raw materials are needed and the extraction of raw materials from the earth is 20% faster than the earth replenishing it, so raw materials consumed in 12 months will take 14.4 months to be filled back. Hence, the production of cement is becoming the source of environmental degradation.

On the other hand, in the last decades the climate change due to global warming has become a major concern. The global warming is caused by the emission of greenhouse gases to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming. The cement industry is held responsible for some of the CO_2 emissions because

[1] Lecturer of Civil Engineering, Rajamangala University of Technology Isan Khon Kaen campus, THAILAND, +66 89-516-4594, charoenchai.ri@rmuti.ac.th
[2] Master degree student of Civil Engineering, Rajamangala University of Technology Isan Khon Kaen campus, THAILAND, lamveasna@gmail.com
[3] Master degree student of Civil Engineering, Rajamangala University of Technology Isan Khon Kaen campus, THAILAND
Note: Discussion on this paper is open until March 2019

the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere. Approximately, the contribution of cement industry to the CO_2 emissions is about 5–7% of the global CO_2 emissions.

Geopolymers are the product of alkali activation of an aluminosilicate source by product such as fly ash, slag, silica fume, metakaolin, rice husk ash, silica fume and volcanic ashes. Geopolymers are cement-free eco-friendly construction materials with much lower of carbon dioxide release high early strength gain, durability against chemical attack, high surface hardness, and higher fire resistance, they have a great potential to be used in construction as an alternative to than traditional ordinary Portland cement (OPC).

Fly ash is considered one of pozzolanic material which is widely available worldwide also possesses pozzolanic properties, and it is rich with alumina and silicate and yet its usage to date is very limited. Fly ash is a by-product of burning anthracite or bituminous coal. Geopolymer concrete is a type of polymer concrete which is made without Portland cement. Inorganic polymer which is used in production of geopolymer is aluminum-silicate polymer. Fly ash and other mineral admixture are considered rich sources of aluminum and silicate. Geopolymer concrete reduce the CO_2 emissions by the cement industries, and it also utilizes the waste materials such as fly ash. Hence, the development of geopolymer concrete is an important vision towards the production of environmentally friendly concretes.

For the materials used in this research, fly ash from Mae Moh, Lampang, Thailand, natural sand with fineness modulus of 2.0 – 2.4, coarse aggregate with nominal maximum size of 25 mm, the concentration of sodium hydroxide (NaOH) solution of 15M, sodium silicate, and the prestressed steel 4 mm. with ultimate strength not less than 17,500 kg/ sq.cm were used.

The purposes of this research, testing compressive strength of cylinder specimen of 10x20 cm. of geopolymer concrete, and load test of pre-cast geopolymer concrete slab of 0.35x2.4x0.05 m. was investigated to study feasibility and value of deflection of precast geopolymer concrete slab compared to the value deflection which is provided by the Thai Industrial Standard Institute 577-2531.

2. Methodology and experimental

2.1 Materials properties and mixing proportion

In this study, high calcium fly ash (ASTM C618, Class C) was used as the main source material for alumino-silicates of geopolymer binder with specific gravity of 2.2 and 95% was passing through the 45 µm sieve. The natural sand with fineness modulus of 2.13, specific gravity (SSD) of 2.67, and absorption of 0.41% was used as fine aggregate, coarse aggregate with specific gravity of 2.69, and absorption of 0.26%.

A mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions were used as the activator solution. The concentration of sodium hydroxide (NaOH) solution of 15M was used for all mixtures. Sodium silicate solution contained sodium oxide (Na_20_3) of 9.50%, silicon dioxide of 9.00%, and water of 61.5% by weight, and the prestressed steel of 4 mm. with ultimate strength not less than 17,500 kg/sq.cm were used. The basic properties of all materials are also shown in table 1.

All specimens were mixed with the ratio of fly ash: fine aggregate: coarse aggregate and sodium silicate to sodium hydroxide of 1:0.95:1.76 and 1:1 by weight respectively. For mixing procedure, mixed fly ash with sodium hydroxide for 5 minutes before fine aggregate was added and mixed for 2 more minutes. Then coarse aggregate was continued mixing to the proportion for 3 minutes before sodium silicate was mixed for another 4 minutes, after that casted in the mold and waited for testing.

Table 1. The basic properties of material used in this research.

Materials	Properties	Value
Fine Aggregate	Specific Gravity (SSD)	2.67
	Absorption (%)	0.41
	Fineness Modulus	2.13
Coarse Aggregate	Specific Gravity (SSD)	2.69
	Absorption (%)	0.26
	Maximum size (mm)	10
Sodium Hydroxide	Concentration (M)	15
Prestressed Strand	Ultimate Strength (ksc)	17,500
	Diameter (mm)	4
Low Calcium Fly Ash	Specific Gravity	2.2
	% passed sieve 45 µm	95

2.2 Methodology of testing

2.2.1 Testing compressive strength of geopolymer concrete

The compressive strength of geopolymer concrete of cylinder specimens of 10x20 cm. were tested according to ASTM C39 by using the ratio of fly ash: fine aggregate:

coarse aggregate of 1.0:0.95:1.76 by weight. The tests were considered the effect on compressive strength of geopolymer concrete by variation of curing time of 2, 3, 4, and 5 days at site curing temperature, the variation of curing temperature of 40, 60, and 80^{o}C at age of 2 days, and variation of curing time of 3, 6, 12, 24, and 48h at curing temperature of 60^{o}C and 80^{o}C.

mm. with ultimate strength not less than 17,500 kg/ sq. cm, and was pulled by forced of 13,329 kg/ sq. cm. by following to the Thai Industrial Standards institute 577-2531. The processing of preparation and casting precast geopolymer concrete is presented in figure 1a - 1d.

(a) (b) (c) (d)

Fig. 1a-1d. The processing of preparation and casting precast geopolymer concrete.

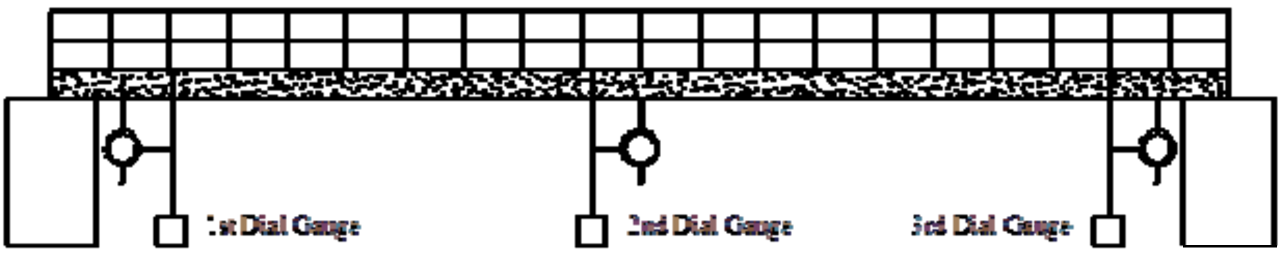

Fig. 2. The procedure of load testing pre-cast geopolymer concrete slab.

2.2.2 Load testing of pre-cast geopolymer concrete slab

Geopolymer concrete slab of 0.35x2.4x0.05 m. was designed with live load of 150 kg/ sq. m, five PC-wire of 4 The procedure of test was progressed as described and showed in the figure 1 below.

Preparation of a sample on the platform by offset both ends of pre-cast geopolymer slab on the platform for 10 cm. Measuring the length of pre-cast geopolymer slab at least two positions, the width and thickness of both ends and the center. Installing dial gauges at the center and both ends, by offset 10 cm from the ends of pre-cast geopolymer concrete slab. Then, distributing the uniform load on pre-cast geopolymer slab by increasing load of 25%, 50%, 75%, 100%, 125%, and 150% of design load. After giving load distribution of 25% of design load, read and record values of immediately deflection and after applied load at 15 minutes of all dial gauges. Adding distribution load by increasing load of 25% to reach 150% of design load, after that read and record values of immediately deflection and after applied load at 15 minutes of each step of all dial gauges. For each step, removing load distribution then reads and records the values of immediately rebound and after removed load at 15 minutes of all dial gauges. After applied uniform load of 150% of design load, leave precast geopolymer slab for 24h then read and record the values of deflection of all dial gauges, and the value of rebound after remove all loads from pre-cast geopolymer concrete at 24h. Finally, removed all dial gauges, then applied uniform load by increasing load of 25% of design load again until pre-cast peopolymer slab failed or cracked more than 1.0 cm. after 15 minutes then record the load.

3 Results and Discussions

Fly ash based geopolymer concrete was investigate to study the effect of curing temperature and curing time on the compressive strength, and load testing of pre-cast geopolymer concrete slab. The following sections reveal in details the results and discussion of the considered parameters.

2.3 The effect of curing temperature and time on compressive strength of geopolymer

The ration of fly ash: fine aggregate: coarse aggregate 1.0:0.95:1.76 by weight was used to consider the compressive strength of cylinder specimen of 10x20 cm. The average value of three samples of each section was used to consider.

2.3.1 The effect of curing time on compressive strength

Compressive strength of geopolymer concrete at curing times of 2, 3, 4, and 5 days at the site curing temperature are shown in the figure 3.

The average values of three specimens of compressive strength was 217.14 kg/ sq.cm, 261.81 kg/ sq.cm, 278.72 kg/ sq.cm, and 295.33 kg/ sq.cm, respectively. From the results, rising curing period even with low curing temperature improved compressive strength. The compressive strength of all of the geopolymer samples increased with curing age. This finding supports that curing time promotes the development of compressive strength.

Compressive strength increased with the curing age of the samples and resulted in a chemical reaction between silica and alumina in the presence of alkali ions.

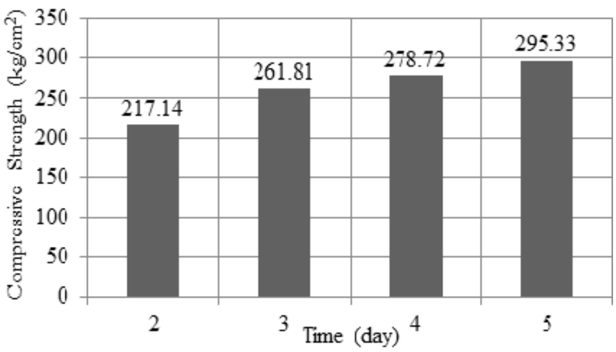

Fig. 3. The effect curing time at site temperature on compressive strength of geopolymer.

2.3.2 The effect of curing temperature at 24h on compressive strength of geopolymer

The compressive strength of specimens with curing temperatures of 40, 60, and 80^{o}C at the curing time of 24h are shown in the figure 4. The average values of three specimens of compressive strength were 102.92 kg/sq.cm, 213.97 kg/sq.cm, and 470 kg/sq.cm, respectively. Increasing heat curing temperature improved compressive strength of geopolymer. The effects of curing temperature suggested higher temperatures are beneficial to improving densification and mechanical properties. In fact, curing temperature mainly affects condensation and re-solidification during geopolymerization, which plays a decisive role in development of microstructure and mechanical properties [12]. It seems that the high temperature curing provided a higher degree of reaction compared to that of curing at room temperature.

2.3.3 The effect of curing time at 60^{o}C and 80^{o}C on compressive strength

The value of compressive strength with curing times of 3, 6, 12, 24, and 48h at curing temperature of 60^{o}C are shown in figure 5. The average values of each curing time were 67.37 kg/ sq.cm, 99.62 kg/ sq.cm, 154.41 kg/ sq.cm, 213.97 kg/ sq.cm, and 449.87 kg/ sq.cm, respectively.

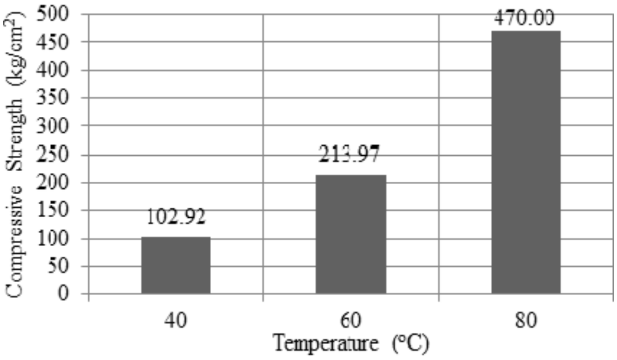

Fig. 4. The effect of curing temperature at 24h on compressive strength of geopolymer.

And compressive strength of specimens with curing times of 3, 6, 12, 24, and 48h at curing temperature of 80^{o}C of geopolymer concrete at age of 2 days are shown in the figure 6. The average values were 133.83 kg/ sq.cm, 241.39 kg/sq.cm, 294.44 kg/sq.cm, 356.65 kg/sq.cm and 470.01 kg/sq.cm, respectively. Increasing heat curing temperature improved compressive strength of geopolymer concrete due to increasing curing time. The curing temperature accelerates both extent and rate of dehydroxylation, contributing to rearranging of atomic structure. More free water evaporates at higher curing time. At early ages, the pores are slightly larger, but gel continued to grow after being cured for a period. Therefore, the larger voids are gradually fills with the reaction products, and longer chains and branches are formed as the polymerization proceeding. Precisely becaused of this, the microstructure of the resulting geopolymer densilfies, corresponding to the excellent mechanical properties.

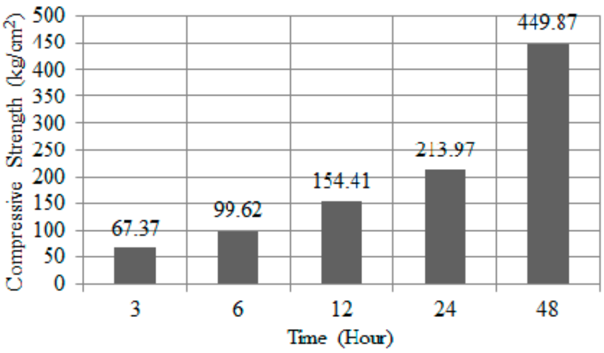

Fig. 5. The effect of curing time at 60^{o}C on compressive strength of geopolymer.

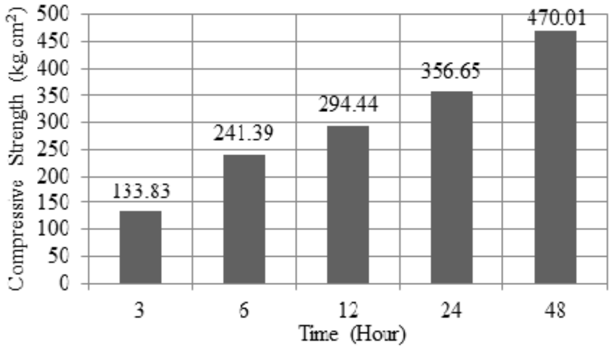

Fig. 6. The effect of curing time at 80^{o}C on compressive strength of geopolymer.

2.4 Load testing of pre-cast geopolymer concrete slab

The test of pre-cast geopolymer concrete slab was tested as normal pre-cast concrete. The test was considered on the value of deflection and rebound compared to the Thai Industrial Standard Institute 577-2531. The test was considered as following below.

2.4.1 The deflection and rebound of pre-cast geopolymer concrete slab

The pre-cast geopolymer concrete slabs of 0.35x2.40x0.05 m. were designed with five PC-wire of 4 mm. with ultimate strength not less than 17,500 kg/ sq. cm, and were pulled by forced of 13,329 kg/ sq. cm to carry the uniform live load designed of 150 kg/ sq. m. The area of pre-cast geopolymer concrete slab was 2.44x0.35 = 0.87 sq. m. The various values of immediately deflection and rebound and after applied load at 15 minutes of 1st dial gauge of each increasing load of 25% of design load are shown in the figure 7 and 8, 2nd dial gauge are shown in the figure 9 and figure 10. For both dial gauges after applied load of 150% of design loaded at 24 hours of 1st and 2nd dial gauge are shown in the figure 11.

Figure 7 shows relationship between immediately deflection and rebound and various load applied at the end of precast geopolymer concrete slab. The value of immediately deflection and rebound of precast geopolymer concrete slab at design load were 0.48 mm. and 0.19 mm, respectively.

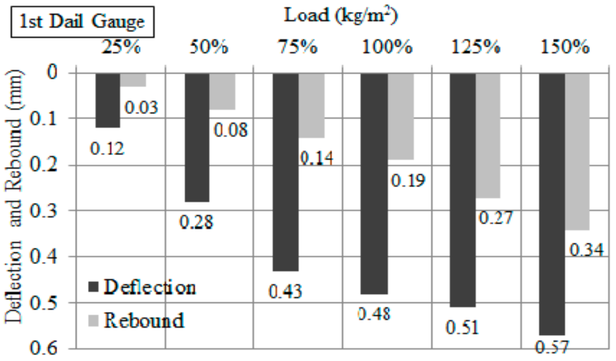

Fig. 7. The immediately deflection and rebound of 1st dial gauge.

The relationship deflection and rebound and percentage of design load after applied load at the end of precast geopolymer concrete slab is shown in the figure 8. From the figure, increasing percentages of load design increased deflection and rebound of precast geopolymer concrete slab. And the value deflection and rebound after applied 100% of design load at 15 minutes were 0.5 mm. and 0.21 mm. respectively.

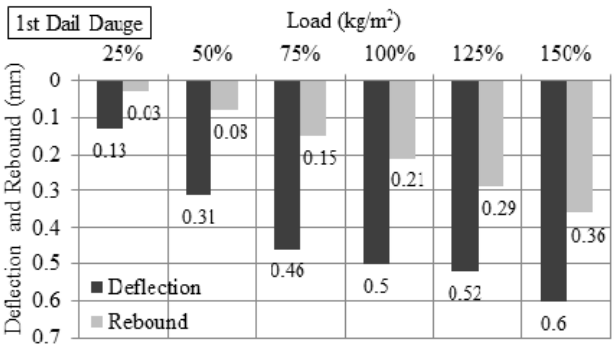

Fig. 8. The deflection and rebound of 1st dial gauge after 15 minutes load applied.

For results of immediately deflection and rebound at the center of precast geopolymer concrete slab are shown in the figure 9. The value of deflection and rebound increased with increasing percentages of design load. After applied 100% of design load, the value of immediately deflection and rebound at the center of precast geopolymer concrete slab were 5.48 mm. and 4.95 mm, respectively.

Figure 10 shown about the result of value of deflection and rebound after applied load at 15 minutes at the center of precast geopolymer concrete slab. The value of deflection and rebound at the center of precast geopolymer concrete slab after applied design load (100%) at 15 minutes were 5.84 mm. and 4.98 mm, respectively.

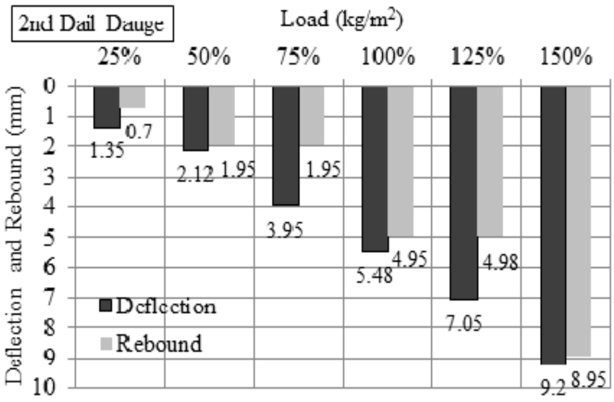

Fig. 9. The immediately deflections and rebound of 2nd dial gauge.

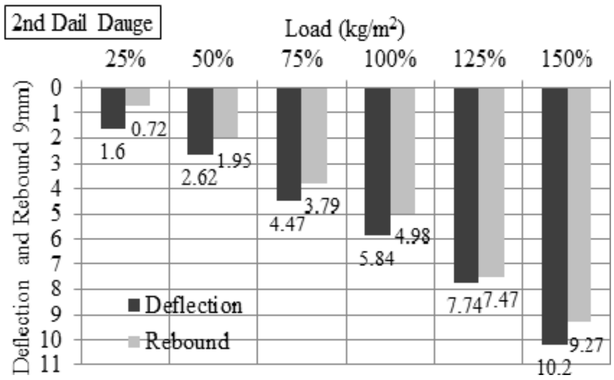

Fig. 10. The deflection and rebound of 2nd dial gauge after 15 minutes load applied.

The value of deflection and rebound at the end and center of precast geopolymer concrete slab after applied 150% of design load at 24 h. are shown in the figure 11. At the end of precast geopolymer concrete slab, the value of deflection and rebound were 0.93 mm. and 0.39 mm. respectively, and 19.84 mm. and 11.47 mm. respectively for the value of deflection and rebound at the center of precast geopolymer concrete slab.

The result of load testing, when the distribution uniform load of 100% of design load was applied on the pre-cast geopolymer concrete slab, the values of deflection immediately at center and the end were 0.48 mm. and 5.48 mm, respectively, and at 15 minutes after applied load were 0.50 mm. and 5.48 mm, respectively. The allowable value of deflection providing by the Thai Industrial Standards Institute 577-2531 is 5.25 mm. The result of testing was shown that, the value deflection of pre-cast geopolymer concrete slab at the center of 5.48 mm. was exceeded the value deflection of 5.25 mm. which is provided by the Thai Industrial Standards Institute 577-2531. This exceeding is due to slow reaction of geopolymerization of geopolymer concrete slab. To solve this problem, precast geopolymer concrete slab need to heat curing with high temperature to enhance geopolymerization reaction of geopolymer material and improve mechanics properties of geopolymer.

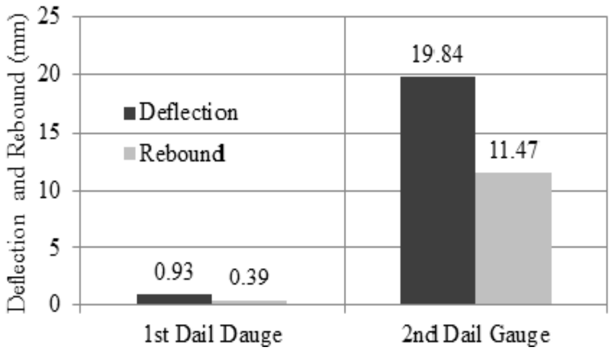

Fig. 11. The deflection and rebound of 1st and 2nd dial gauge after 24 h load applied.

3. Conclusion

Based on our experimental results, the conclusion was draw as below:

- Rising curing time at the same curing temperature increased the compressive strength of geopolymer concrete.

- Increasing curing temperature with the same curing time increased the compressive strength of geopolymer concrete.

- Increasing heat curing temperature up to 80^{o}C improved compressive strength of geopolymer concrete.

- The value of deflection of pre-cast geopolymer concrete slab was exceeding the value deflection provided by the Thai Industrial Standard Institute 577-2531, so the pre-cast geopolymer concrete slab was failed for the curing temperature at the site in this research. By the way, to improve the capacity of pre-cast geopolymer concrete slab, the curing temperature should increase in the high temperature up to 80^{o}C.

Acknowledgements

Authors acknowledge the department of Civil Engineering, faculty Engineering of Rajamangala University of Technology Isan, Khon Kaen campus for providing the materials and laboratory.

References

Davidovits, J., 2008. Geopolymer Chemistry and Applications. Institut Geopolymere,Saint-Quentin, France.

Duxson, P., Fernández-Jiménez, A., Provis, J.L., Lukey, G.C., Palomo, A. and Van Deventer, J.S., 2007. Geopolymer technology: the current state of the art. Materials & Sciences, **42**: 2917–2933.

Ranjbar, N., Mehrali, M., Behnia, A., Alengaram, U.J. and Jumaat, M.Z., 2014. Compressive strength and microstructural analysis of fly ash/palm oil fuel ash based geopolymer mortar. Materials & Design, **59**: 532–539.

Bakharev, T., 2005. Geopolymeric materials prepared using Class F fly ash and elevated temperature curing. Cement & Concrete Composites, **35**: 1224–1232.

Sakulich, A.R., 2011. Reinforced geopolymer composites for enhanced material greenness and durability. Sustainable Cities and Society, **1**: 195–210.

Tchadjié, L.N., Djobo, J.N.Y., Ranjbar, N., Tchakouté, H.K., Kenne, B.B.D., Elimbi, A. and Njopwouo, D., 2016. Potential of using granite waste as raw material for geopolymer synthesis. Ceramics International, **42**: 3046–3055.

Roberts, T, 1985. Finite difference analysis of composite beams with partial interaction. Computers and Structures, **21**: 469–473.

Service UUSG, 2007. Minerals commodity summary – cement.

Ali, A., Aliabdo, AEMAE, 2016. Effect of cement addition, solution resting time and curing characteristics on fly ash based geopolymer concrete performance. Construction and Building Materials.

Thakur, R.N.Z.W.,2000. Development of High-Performance Blended Cements. College of Engineering and Applied Science (Ph.D. thesis): pp 177.

McCAFFREY, R, 2002. Climate change and the cement industry. Global cement and lime magazine (environmental special issue):15–19.

Davidovits, J, 1994. Global warming impact on the cement and aggregates industries. World Resource Review, **6** (2): 263-278.

Benhelal, E., Zahedi, G., Shamsaei, E. and Bahadori, A., 2013. Global strategies and potentials to curb CO_2 emissions in cement industry. Journal of Cleaner Production:142–161.

Davidovits, J.,1998. Geopolymer properties and chemistry. 1st European Conference on Soft Minerallurgy, Geopolymer, Compiegne, France: 25–48.

Material ASfT, 1996. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. Designation: ASTM C 136.

Standard Test Method for Loading Capacity Pre-cast Concrete slabs and Concrete Floor Systems, 1998. Thai Industrial Standards institute: 577-2531.

Materials ASfT, 1999. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete. Designation: ASTM C 618.

Materials ASfT, 1997. Standard Test Method for Specific Gravity and Absorption of Fine Aggregate. Designation: ASTM C 128.

Materials ASfT,1988. Specific Gravity and Absorption of Coarse Aggregate. Designation: ASTM C 127.

Materials ASfT, 1999. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Designation: C 39/C 39M.

Rangan DHaBV, 2005. Development and properties of low-calcium fly ash-based geopolymer concrete. Research Report GC 1 Faculty of Engineering Curtin University of Technology Perth, Australia.

Huseien, G.F., Mirza, J., Ismail, M. and Hussin, M.W., 2016. Influence of different curing temperatures and alkali activators on properties of GBFS geopolymer mortars containing fly ash and palm-oil fuel ash. Construction and Building Materials, 125: 1229-1240.

Van Chanh, N., Trung, B.D. and Van Tuan, D., 2008. Recent research geopolymer concrete. The 3rd ACF International Conference-ACF/VCA, Vietnam 2008:11–13.