International Journal of GEOMATE, May, 2018 Vol.14, Issue 46, pp.82-88
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2018.46.mat61
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

COMPRESSIVE STRENGTH OF SOIL CEMENT BASE MIXED WITH FLY ASH – BASED GEOPOLYMER

*Charoenchai Ridtirud[1], Somporn Leekongbub[2] and Prinya Chindaprasirt[3]

[1,2]Faculty of Engineering, Rajamangala University of Technology Isan, Thailand
[3]Department of Civil Engineering, Khon Kaen University, Thailand

*Corresponding Author, Received: 20 Dec.. 2017, Revised: 20 Jan. 2018, Accepted: 20 Feb. 2018

ABSTRACT: At present, the improvement of compressive strength of soil using the Portland cement is widely used for roads and embankments, however, it has an enormous impact on the environment. Geopolymer cement is a material that can replace Portland cement and has less impact on the environment. Therefore, this research aims to study lateritic soil improvement by using Fly ash-based geopolymer materials. Percentage of fly ash was 1.5, 3, 5, 7, 10, 15 and 20 % by weight. Specimens were prepared by the method of modified Proctor compaction test. Curing was done at 40^{o}C for 24 hours and immerse in water for 2 hours before the tests. Unconfined compressive strength tests at 7, 14 and 28 days were performed. The results showed that the 5% fly ash by weight and $NaOH/Na_2SiO_3$ ratio of 1/1 was leading to the improvement of compressive strength above 17.5 ksc which is higher than the standard No. DH-S. 204/2533 - Soil cement base.

Keywords: Geopolymer, Fly ash, Soil cement base, Unconfined compressive strength, Lateritic soil.

1. INTRODUCTION

Soil Stabilization is a method to improve the natural soil to increase its engineering quality, for example, compressive strength, shear strength, swelling durability and degradation in water [1-3]. There are multiple ways to stabilize soil depending on the purpose of soil application. Also, the users need to be aware of the worthiness of soil stabilization budget as the lateritic soil is one of the most used soils as a base in road construction [4], [5]. The lateritic soil has high engineering quality, which is suitable for road construction. However, the traffic format and traffic quantity changed a lot: vehicle characteristics and weight load, therefore, quality of lateritic soil needs to be improved to increase for engineering purpose. In general, cement shall be mixed into the soil to improve its quality, which is call soil cement and used as sub-base and base [6]. Nevertheless, Portland cement application tends to make road construction cost high, and moreover, Portland cement production seriously affects the environment as it consumes a lot of energy and emits Carbon Dioxide [7]. In other words, the production of a ton of Portland cement shall emit a ton of the carbon dioxide [8]. Therefore, new binder called geopolymer is developed as the replacement of Portland cement because. Both materials have similar quality. However, a by-product of the products mainly containing silica and alumina is used as a material in geopolymer synthesis and fly ash is the most used material since waste of fly ash is left over a lot in each year. Many pieces of research affirm that fly ash can be synthesized to be a binder and used instead of the Portland cement [9]-[14]. Also, fly ash is better because it endures chemical erosion and fire resistance [15] and it is faster setting than ordinary Portland cement [16], [17].

From other experiments, geopolymer can be applied to improve quality of many kinds of soil; Silty clay, Colombian soil [19] and Soft marine clay [20]. It shows that the engineering quality of all the soil gain s higher, therefore, the researcher would like to improve the lateritic soil with geopolymer instead of Portland cement on the base layer of road construction according to the standard No. DH-S. 204/2533 - Soil cement base, which is used to compare to the research. In the experiment, the percentage of fly ash is added as follows: 1.5, 3, 5, 7, 10, 15 and 20 by weight and the curing temperature is controlled and maintained at 40 degrees Celsius, equal to the temperature at a field. The curing time is specified at 24 hours in order to observe the compressive strength of the specimens of 6, 14 and 28 days. However, before the samples were tested, they must be soaked in water for 2 hours.

2. MATERIALS AND METHODS

2.1 Materials and properties

The material used in this research is fly ash from Mae Mah, Lumpang, which is investigated in order to find out its chemical compositions by the method of X-ray fluorescence (XRF), as shown in table 1. CaO has 23.3%, which is considered high calcium fly ash, it is classified into Class C in accordance with ASTM C618 standard and has specific gravity equal to 2.4, mean size of 2.4 and particle size distribution as shown in Fig.1.

Table 1 Fly ash chemical compositions

Chemical composition	% by weight
SiO_2	35.855
CaO	23.312
Al_2O_3	16.273
Fe_2O_3	14.06
SO_3	8.004
K_2O	1.624
TiO_2	0.439
MnO_2	0.158
SrO	0.136
As_2O_5	0.046
Rb_2O	0.024
ZrO_2	0.028

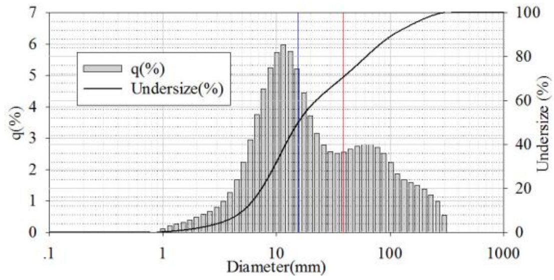

Fig.1 Particle size distribution of Fly Ash

The lateritic soil used in this research is from Kantarawichai, Sarakam, THAILAND its properties and particle size distribution is showed in Table 2 and Fig. 2. Alkaline and sodium silicate solutions (Na_2SiO_3) have a chemical element as follows: Na_2O 8.9%, SiO_3 28.7% and H_2O 62.5% and another solution is Sodium hydroxide solution with a concentrate of 8 Molar, prepared from Sodium hydroxide flake, diluted with distilled water and left 24 hours to cool it down before use.

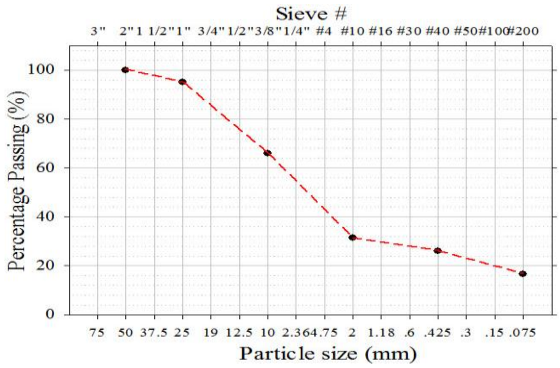

Fig.2 Particle size distribution of lateritic soil

Table 2 Laterite soil properties

Properties	Values
Specific gravity	2.8
Liquid limit, %	30
Plasticity Index, %	4.8
Color	Reddish brown
Pass sieve #10	31.50%
Pass sieve #40	26
Pass sieve #200	16.7
AASHTO Classification	A-2-4
USCS Classification	GM-SM (Silty Clayey Gravel with sand)
Maximum dry Density, g/cm³	2.265
Optimum moisture content, %	7.4
Unconfined Compressive Strength, ksc.	20.2

Specimens and Mixing Proportion Preparation starts from finding out Optimum Moisture Content (OMC) using modified Proctor test according to ASTM D1557 standard. It is found that the OMC is equal to 7.4% as shown in Fig. 3. This value is used to determine the quantity of water used in soil-cement base mixing and the amount of solution used in soil geopolymer base mixing.

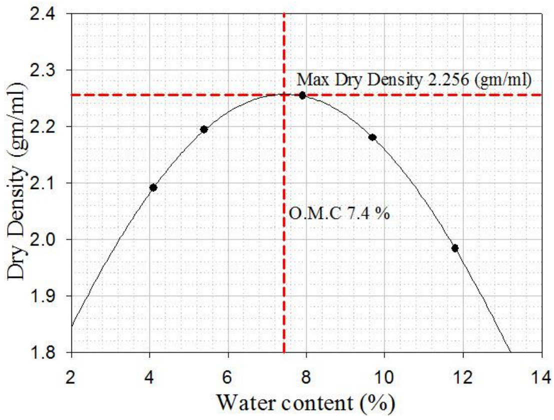

Fig.3 Optimum Moisture Content of lateritic soil

The specimen of soil cement base preparation by mixing the mixture of lateritic soil and 2-8% of cement by weight with water according to the Optimum Moisture Content values. The mixture of lateritic soil and cement is mixed with water thoroughly and put into a mold by mean of the modified proctor. Next, the specimen is taken from the mold, and its physical characteristic is showed in Fig. 4(a). After that, it is cured in a plastic bag for 7 days before being unpacked and soaked in water for 2 hours and investigated for compressive strength in accordance with Unconfined Compressive Strength investigation.

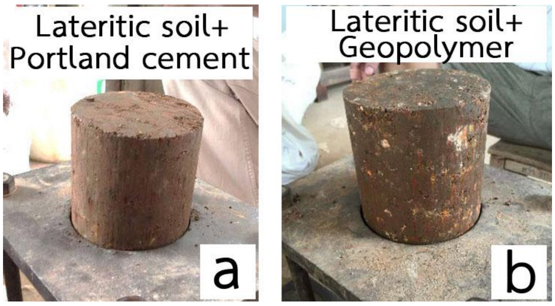

Fig.4 Physical characteristic of lateritic soil mixed with Portland cement (a) and of lateritic soil mixed with Fly ash – based geopolymer (b)

The soil geopolymer base specimen is prepared by using 1.5, 3, 5, 7, 10, 15, 20 and 25% of fly ash adding in soil geopolymer by weight. The preparation starts with measuring materials and alkaline solution. The ratio of $NaOH/Na_2SiO_3$ is equal to 1/1, and these two solutions together are equivalent to OMC value by weight. The combination NaOH and Na_2SiO_3 of 7.4% by weight. Fly ash and NaOH are mixed for 5 minutes, and lateritic soil is added and mixed for 5 more minutes. Then Na_2SiO_3 is added and mixed for 3 minutes. After that, the process is the same to Soil Cement Base preparation. After all these steps, the specimen's physical characteristic is as shown in Figure 4(b). Also, the investigation of change in the ratio of $NaOH/Na_2SiO_3$, curing temperature and specimen age is done by curing the specimen at room temperature and 40 degrees Celsius for 24 hours. The ratios of NaOH/ Na_2SiO_3 are 3/1, 3/2, 3/2, 2/3 and 1/3 and test the specimen at the age of 7, 14 and 28 days, the process of specimen preparation is done as same as the change in the percentage of fly ash.

3. RESULTS

3.1 The result of Soil-Cement Base test

The result of a change in the percentage of cement is shown in Figure 5. The linear graph can be created from the data, and the deviation value is equal to 0.95. Also, it is found that the use of cement of 3.6% results in compressive strength of more than 17.5 ksc, which passes the standard No. DH-S. 204/2533 - Soil cement base. If the compressive strength of 115% or 20.2 ksc. is needed in case that it is used for mixing capability in the field, the cement of 5.4% shall be used.

3.2 The result of Soil Geopolymer Base

After the age of the sample was 7 days at room temperature. The characteristic of the graph is slightly different from the cement test. The trend of the graph is not in a straight line as shown in Figure 6. However, the strength of specimen developing rapidly when the geopolymer of 3% is used. However, the compressive strength will not gain higher if fly ash is added more than 7%. The compressive strength is higher than 17.5 ksc when fly ash of 3% is used to make a specimen. The compressive strength that is chosen to mix in the field is at 115% or 20.2 ksc when fly ash of more 7% is added.

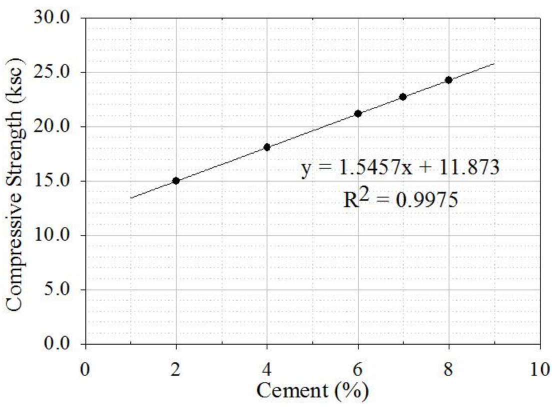

Fig.5 Effect of percent of cement content on compressive strength

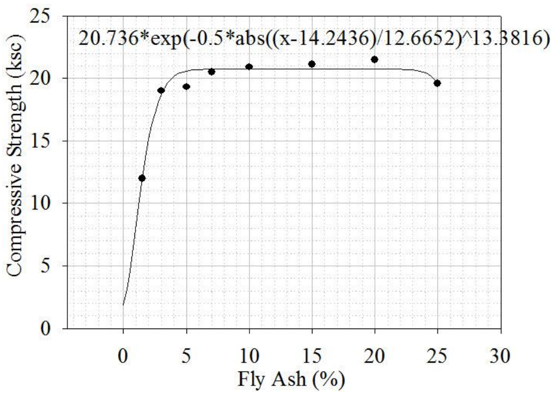

Fig.6 Effect of percent of Fly ash content on compressive strength

The result of the change in curing temperature and ratio of $NaOH/Na_2SiO_3$ is shown in Figure 7. It is found that the temperature of 40 degrees Celsius or the temperature that is higher than room temperature gives higher compressive strength. The ratio of $NaOH/Na_2SiO_3$ that is highly effective at room temperature is 1/1, and the ratio of NaOH/ Na_2SiO_3 at 40 degrees Celsius that is highly effective is 2/3. Moreover, the compressive strength is continuously improved when the age of specimen gains more as showed in Figure 7 and the tendency of compressive strength affecting by $NaOH/Na_2SiO_3$ ratio indicates that the compressive strength of 40 degrees Celsius is higher than the room temperature in all age of the specimen.

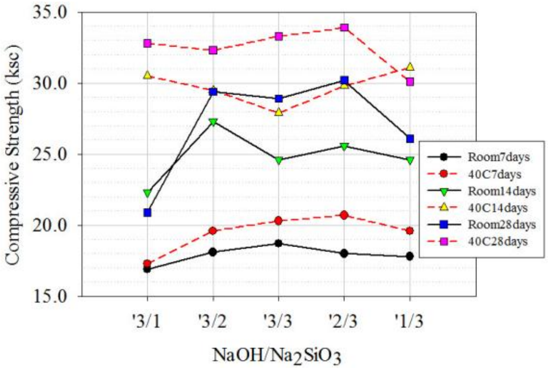

Fig.7 Effect of $NaOH/Na_2SiO_3$ ratio, curing temperature and age of sample on compressive strength

4. DISCUSSION

The comparison between the use of cement and geopolymer shows that the cement that is directly proportional to the increase compressive strength in cement volume increased. On the other hand, the appropriate percentage of geopolymer is at 7%, and it does not make any better compressive strength if the quantity of fly ash is more than 7% as the quantity of water or alkali activator is fixed in this research according to the OMC. Therefore, when the water/cement ratio is decreased, the free water will be reduced, the compressive strength of specimen gains normally higher [21]. However, it is different from geopolymer system which the compressive strength is not increased when fly ash is added more than 7% because there is not enough solution to make reaction [22]. There is possible to enhance the compressive strength with increase liquid solution at appropriate quantity when added fly ash more than 7% due to increase more binder.

The curing temperature also affects, and the result complies with other research. That is to say that the higher curing temperature [23], the greater compressive strength will gain. 40 degrees Celsius is applied in this research as it is close to the temperature of the realistic construction site. Moreover, 40 degrees Celsius is not the highest temperature that can improve the strength of geopolymer [24], [25]. It can be continuously enhanced, and the best ratio of the solution is at 1/1 - 2/3 which makes the highest compressive strength according to the experiment. The ratio of NaOH is analyzed and found that the excessively high ratio of NaOH leaves NaOH in the system so that the white stain can be noticed. The 28 days specimens have the lower compressive strength and the alkaline solution can be washed out which affect the environment in harmful ways. On the other hands, to use a lot of Na2SiO3 produce high viscosity and the specimen will be well compressed. However, if there is too much Na2SiO3, which is a solution that helps to complete geopolymer synthesis, it is not good to raise compressive strength [26].

5. CONCLUSION

The result of experiment indicates that the geopolymer in the ratio of NaOH/ Na_2SiO_3 equal to 1/1 can be used as the replacement of general cement. At compressive strength of 17.5 ksc, fly-ash base geopolymer shall be added to soil only 3% of all the mixture but 3.4% for general cement and at the compressive strength of 20.2ksc in order to meet construction requirement, fly-ash base geopolymer and general cement shall be added to soil only 7% and 5.2% of all the mixture, respectively. However, the system of geopolymer is that if it is applied to the realistic road construction and temperature at the construction site is more than 40 degrees Celsius, its compressive strength will gain higher. In consequence, the geopolymer proportion can be decreased to at least 5% of all the mixture and the compressive strength will be improved consecutively. Therefore, it can be concluded that fly ash – base geopolymer can be applied to stabilize the lateritic soil in term of compressive strength and it can replace the use of cement which is expensive and concerned environment issues.

6. ACKNOWLEDGEMENTS

The research for this paper was financially supported by the Rajamangala University of Technology Isan.

7. REFERENCES

[1] Hossain, M. Z., Narioka H., and Sakai, T. 2006. Effect of ordinary Portland-cement on properties of clayey soil in Mie Prefecture. Journal Japan Society Soil Physics. 103: 31-38.
[2] Hossain, M. Z. and Sakai, T. 2008. The Effectiveness of Nominal Dosage of Ordinary Cement on Strength and Permeability of Clayey Soil. Journal Japan Society Soil Physics. 110:25-35.
[3] Rica H.C., Saussaye L., Boutouil M., Leleyter L. and Baraud F. "Stabilization of a silty soil: Effects of disruptive salts," Engineering Geology, vol. 208, 2016, pp. 191-197.
[4] Biswal D.R., Sahoo U.C. and Dash S.R.

"Characterization of granular lateritic soils as pavement material, Transportation Geotechnics, vol. 6, 2016, pp. 108-122.

[5] Onana V.L., Ngo'o Ze A., Eko R.M., Ntouala R F.D., Nanga Bineli M.T. and Owoudou B.N. "Geological identification, geotechnical and mechanical characterization of charnockite-derived lateritic gravels from Southern Cameroon for road construction purposes," Transportation Geotechnics, vol. 10, 2017, pp. 35-46.

[6] Ribeiro D., Néri R. and Cardoso R. "Influence of Water Content in the UCS of Soil-Cement Mixtures for Different Cement Dosages," Procedia Engineering, vol. 143, 2016, pp. 59-66.

[7] Li Y., Liu Y., Gong X., Nie Z., Cui S., Wang Z., "Environmental impact analysis of blast furnace slag applied to ordinary Portland cement production," Journal of Cleaner Production, vol. 120, 2016, pp. 221-230.

[8] Gao T., Shen L., Shen M., Chen F., Liu L. and Gao L., "Analysis on differences of carbon dioxide emission from cement production and their major determinants," Journal of Cleaner Production, vol. 103, 2015, pp. 160-170.

[9] Hosan A., Haque S., and Shaikh F. "Compressive behavior of sodium and potassium activators synthetized fly ash geopolymer at elevated temperatures: A comparative study," Journal of Building Engineering, vol. 8, 2016, pp. 123-130.

[10] Nath P. and Sarker P.K. "Flexural strength and elastic modulus of ambient-cured blended low-calcium fly ash geopolymer concrete," Construction and Building Materials, vol. 130, 2017, pp. 22-31.

[11] Shaikh F.U.A. "Mechanical and durability properties of fly ash geopolymer concrete containing recycled coarse aggregates," International Journal of Sustainable Built Environment, vol. 5, 2016, pp. 277-287.

[12] Shehab H.K., Eisa A.S. and Wahba A.M. "Mechanical properties of fly ash based geopolymer concrete with full and partial cement replacement," Construction and Building Materials, vol. 126, 2016, pp. 560-565.

[13] Adak D., Sarkar M., and Mandal S. "Structural performance of nano-silica modified fly-ash based geopolymer concrete," Construction and Building Materials, vol. 135, 2017, pp. 430-439.

[14] Khan M.Z.N., Shaikh F.U.A, Hao Y. and Hao H., "Synthesis of high strength ambient cured geopolymer composite by using low calcium fly ash," Construction and Building Materials, vol. 125, 2016, pp. 809-820.

[15] Sarker P.K. and McBeath S. "Fire endurance of steel reinforced fly ash geopolymer concrete elements," Construction and Building Materials, vol. 90, 2015, pp. 91-98.

[16] Phoo-Ngernkham T., Sata V., Hanjitsuwan S. Ridtirud C., Hatanaka S. and Chindaprasirt P., "High calcium fly ash geopolymer mortar containing Portland cement for use as repair material," Construction and Building Materials, vol. 98, 2015, pp. 482-488.

[17] Dave N., Misra A.K., Srivastava A., and Kaushik S.K., "Setting time and standard consistency of quaternary binders: The influence of cementitious material addition and mixing," International Journal of Sustainable Built Environment. Vol 6, Issue 1, 2017, pp. 30-36.

[18] Horpibulsuk S., Rachan S.R., Chinkulkijniwat A., Raksachon Y. and Suddeepong A., "Analysis of strength development in cement-stabilized silty clay from microstructural considerations," Construction and Building Materials, vol. 24, 2010, pp. 2011-2021.

[19] Rios S., Ramos C., Fonseca A.V.D., N. Cruz N. and Rodrigues C., "Colombian Soil Stabilized with Geopolymers for Low Cost Roads," Procedia Engineering, vol. 143, 2016, pp. 1392-1400.

[20] Phetchuay C., Horpibulsuk S., Arulrajah A., Suksiripattanapong C., and Udomchai A. "Strength development in soft marine clay stabilized by fly ash and calcium carbide residue based geopolymer," Applied Clay Science, vol. 127–128, 2016, pp. 134-142.

[21] Yaman I.O., Hearn N., and Aktan H.M., "Active and non-active porosity in concrete Part I: Experimental evidence," Materials and Structures, vol. 35, 2002, p. 102-109.

[22] Bakria A.M.M.A., Kamarudin H., BinHussain M., Nizar I.K., Zarina Y. and Rafiza A.R., "The Effect of Curing Temperature on Physical and Chemical Properties of Geopolymers," Physics Procedia, vol. 22, 2011, pp. 286-291.

[23] Zhou W., Yan C., Duan P., Liu Y., Zhang Z., and Qiu X. "A comparative study of high- and low-Al2O3 fly ash based-geopolymers: The role of mix proportion factors and curing

temperature," Materials & Design, vol. 95, 2016, pp. 63-74.

[24] Ridtirud C., Chindaprasirt P., and Pimraksa K. "Factors affecting the shrinkage of fly ash geopolymers," International Journal of Minerals, Metallurgy, and Materials, vol. 18, 2011, pp. 100-104.

[25] Atiş C.D., Görür E.B., Karahan O., Bilim C., İlkentapar S. and Luga E., "Very high strength (120 MPa) class F fly ash geopolymer mortar activated at different NaOH amount, heat curing temperature and heat curing duration," Construction and Building Materials, vol. 96, 2015, pp. 673-678.

[26] Leong H.Y., Ong D.E.L., Sanjayan J.G. and Nazari A., "The effect of different Na2O and K2O ratios of alkali activator on compressive strength of fly ash based-geopolymer," Construction and Building Materials, vol. 106, 2016, pp. 500-511.