International Journal of GEOMATE, April., 2021, Vol.20, Issue 80, pp. 9-16
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2021.80.6126
Geotechnique, Construction Materials and Environment

EFFECT OF CEMENT REPLACEMENT BY FLY ASH AND FGD GYPSUM ON STRENGTH OF SUBBASE

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ABSTRACT: The using of Portland cement as an admixture to improve the strength of poor subbase induce a high cost for road construction. The replacement of cement with by-product materials from Mae Moh power plant in the admixture is a good alternative to reduce the amount of cement and cost for subbase improvement. Therefore, this study focused on fly ash and FGD gypsum replaced cement in the admixture. The soil samples mixed with the admixture at 3% were conducted on unconfined compressive strength test to determine the strength of soil improvement. The results demonstrated that the replacement of cement by fly ash at 1.5% and FGD gypsum at 0.5% is the optimum content to replace cement in the admixture. This mixture can develop the strength more than the requirements recommended by the Thailand Department of Highways. Moreover, soil mixed with cement at 2% and FGD gypsum at 1% can develop the strength near the soil mixed with cement at 3%. Soil mixed with cement at 2% and fly ash at 1% can increase the strength 29% from soil mixed with cement at 3%. The results illustrated that the strength of soil improvement tended to increase with the increase of fly ash. However, the strength of soil improvement decreased with the increase of FGD gypsum in the admixture. In conclusion, the partial replacement of cement by fly ash and FGD gypsum can develop the strength of soils and reduce the amount of cement in the admixture.

Keywords: Fly ash, FGD gypsum, Soil improvement, Compressive strength, Subbase

1. INTRODUCTION

The lateritic soil has been used in the road construction of Thailand and widespread in the rural area. Subbase of the road in Thailand was constructed by lateritic soil. However, it becomes the realize problem because of the low compressive strength of the poor lateritic soil and poor durability. The bearing capacity of poor subbase was lower than the minimum requirement for the road construction. Moreover, the rain infiltration or the water inundates of the subbase can be causing road damage [1].

The most commonly used additive for soil stabilization is ordinary Portland cement. To build a subbase with cement stabilized ash alone is not yet common, but this is one of the high volume ash applications being promoted by ash producers [2]. The use of ash or the pozzolanic materials combined with cement to improve the strength of soil can reduce the cost of soil stabilization. Therefore, this study investigated on the replacement of cement with fly ash and FGD gypsum to improve the strength of poor subbase.

Mae Moh power plant produces three types of lignite by-products from the lignite-fired power generation include fly ash, bottom ash, and FGD gypsum. Fly ash is the most widely used pozzolanic material all over the world. In recent times, the importance and use of fly ash in concrete have grown so much that it has almost become a common ingredient in concrete, particularly for making high strength and high-performance concrete. ASTM broadly classifies fly ash two classes, Class F and Class C. Class F fly ash is normally produced by burning anthracite or bituminous coal and has pozzolanic properties only. While Class C fly ash is normally produced by burning lignite or sub-bituminous coal and can possess pozzolanic as well as cementitious properties [3]. Mae Moh lignite fly ash is a Class C type. The chemical composition of fly ash includes 30.1% CaO, 20.6% SiO_2, 16.1% Al_2O_3, 6.1% SO_3, 12.0% Fe_2O_3, 1.9% MgO, 1.7% Na_2O, 2.2% k_2O, 1.0% TiO_2, 8.3% etc. Fly ash has all the quality of being a pozzolan material [4]. In the cement hydration development, the calcium silicate hydrate (C-S-H) and calcium hydroxide (Ca $(OH)_2$, or CH) are released within the hydration of two main components of cement namely tricalcium silicate (C_3S) and dicalcium silicate (C_2S) where C, S represent CaO and SiO_2. The C-S-H gel is generated by the hydration of C_3S and C_2S. This is the main strengthening constituent [5]. It is known that by adding pozzolanic material to the mortar of concrete mix, the pozzolanic reaction will only start when CH is released/CH interaction exit. In the pozzolan-lime reaction, OH^- and Ca^{2+} react with the SiO_2 or Al_2O_3-SiO_2 framework to form calcium silicate hydrate (C-S-H), calcium aluminate hydrate (C-A-H) and calcium aluminate ferrite hydrate [6].

Normally, fly ash is used as a pozzolanic material in the concrete industry. The partial replacement of Portland cement with fly ash reduces the heat of hydration and improves the strength and durability of concrete [7], [8].

SO_2 is one of the major environmental contaminations generated from coal-burning power stations and heating plants. It is very important to develop flue gas desulphurization (FGD) technologies to remove SO_2 for FGD clean coal combustion. Although FGD technology is successful in reducing SO_2 discharge, it generates a large quantity of FGD gypsum at the same time. FGD gypsum from Mae Moh power plant is shown in Fig. 1. The chemical composition of FGD gypsum includes 37.7% CaO, 4.0% SiO_2, 2.0% Al_2O_3, 54.1% SO_3, 0.5% FeO_3, 1.6% MgO, 0% Na_2O, 0.1% k_2O, 0% TiO_2 [9]. Normally, FGD gypsum contains in the mixture of mortar can increase the durability and compressive strength [10], [11]. FGD gypsum is effective in providing the additional calcium and sulfate required to activate the clinker to form ettringite. The compressive strength produces high early strength than ordinary Portland cement. Additional long-term strength is possible provided by hydration of dicalcium silicate (C_2S) within the clinker [12]. However, the excessive amount of FGD gypsum can decrease the workability and the strength of mortar [13].

Fig. 1 FGD gypsum obtained from Mae Moh power plant.

Therefore, the objective of this study is to investigate the utilization of fly ash and FGD gypsum to improve the strength of lateritic soil and reduce the cost of soil improvement. The target strength of the soil improvement is 689 kPa. This target strength is recommended by the Thailand Department of Highways.

2. MATERIALS PREPARATION AND MIXTURE OF SOIL IMPROVEMENT

The poor quality of lateritic soil was used in this experiment. The strength of the soil samples was less than the requirement of the Thailand Department of Highways. The soil samples were conducted on Atterberg limits test and sieve analysis test to determine the properties and classify the soil samples. Portland cement type 1, fly ash, and FGD gypsum were used as an admixture to improve the strength of soil. Fly ash and FGD gypsum were obtained from Mae Moh power plant. All admixtures stored in plastic bags to maintain their dry condition. The soil samples were mixed with cement, fly ash, and FGD gypsum in the ratio according to Table 1. The amount of admixture mixed with the soil samples was 3% by weight. Table 1 shows the mixture code of C, D, E, and F is fly ash and FGD gypsum replace cement in the admixture.

Table 1 The mixture ratio of the admixture for stabilized soil

Mixture code	Cement (%)	Fly Ash (%)	FGD Gypsum (%)
A	-	-	-
B1	1.5	-	-
B2	3.0	-	-
C1	0.5	-	2.5
C2	0.5	0.5	2.0
C3	0.5	1.0	1.5
C4	0.5	1.5	1.0
C5	0.5	2.0	0.5
D1	1.0	-	2.0
D2	1.0	0.5	1.5
D3	1.0	1.0	1.0
D4	1.0	1.5	0.5
E1	1.5	-	1.5
E2	1.5	0.5	1.0
E3	1.5	1.0	0.5
F1	2.0	-	1.0
F2	2.0	0.5	0.5
F3	2.0	1.0	-

This study investigated on the partial replacement of cement with fly ash and FGD gypsum to develop the strength of poor subbase. The mixture code in group A presents the non-improvement soil samples. The mixture code in group B presents soil mixed with cement at 1.5-3.0%. Whereas, the mixture in group C represents the soil samples mixed with cement at 0.5%, fly ash 0-2.0%, and FGD gypsum 0.5-2.5%. The mixture code in group D presents the soil samples mixed with cement at 1.0%, fly ash 0-1.5%, and FGD gypsum 0.5-2.0%. The mixture code in group E presents the soil samples mixed with cement at 1.5%, fly ash 0-1.0%, and FGD gypsum 0.5-1.5%. The mixture code in group F presents the soil samples mixed with cement at 2.0%, fly ash 0-1.0%, and FGD gypsum 0-1.0%. The combination of cement, fly ash, and FGD gypsum of the admixture in groups C, D, E, and F is 3%.

The soil samples mixed with the admixture in the ratio according to Table 1 were compacted by the modified compaction test method. The moisture used in the compaction method was the optimum moisture content (OMC) of soil. The samples were manually compacted in five equal layers using the modified compaction effort. After completing the compaction process, each sample was extruded from the compaction mold and then cured in the plastic bag for 3, 5, and 7 days. Following the curing process, the samples were soaked in water for 2 hours, and then compressed the samples by the compression machine, as shown in Fig.2. The compressive strength values for each mixture are the average of three specimens.

Fig. 2 The specimens conducted on unconfined compressive strength tests.

The results can represent the possibility to use by-product materials replace cement in the admixture. However, the Thailand Department of highways suggested that the unconfined compressive strength of subbase improvement should be more than 689 kPa at the curing time of 7 days. Therefore, the optimum content of fly ash and FGD gypsum replaced cement in the admixture to improve the strength of soil can be determined.

3. RESULTS AND DISCUSSION

3.1 Engineering Properties of Lateritic Soil

The soil samples were conducted on Atterberg limits test, sieve analysis test, and modified compaction test to determine the engineering properties of the soil samples. The results demonstrated that the liquid limit, plastic limit, and plasticity index of the soil samples was 27%, 17%, and 10%, respectively. Fig. 3 shows the particle size distribution of the soil samples in this study. According to the AASHTO classification system, the soil samples were A-2-4. The gradation of the soil sample is excellent or good for subgrade materials when considered on the general subgrade rating of AASHTO. Moreover, the results of modified compaction tests are shown in Fig.4. The results demonstrated that the maximum dry density of the soil samples was approximately 1,978 kg/m^3, and optimum moisture content was 10.9%. The soil samples used in this test has low durability. The non-improvement samples break down after soaked in the water, as shown in Fig. 5.

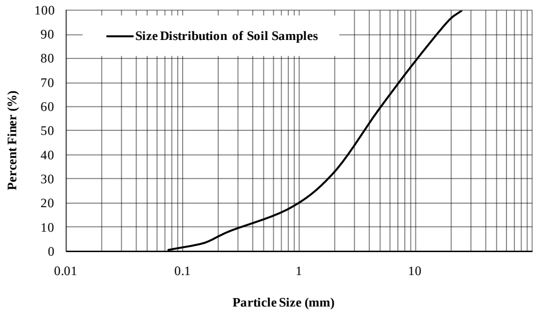

Fig. 3 Particle size distribution of the soil samples.

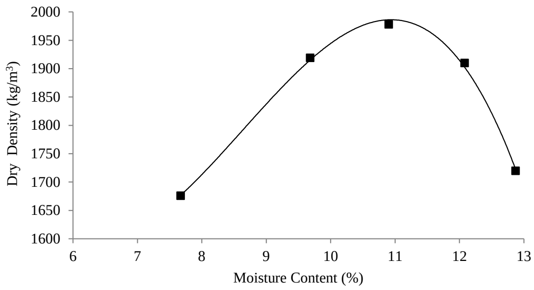

Fig. 4 The relation between dry density and moisture content of the soil samples.

Fig. 5 Non-improvement soil samples after soaked in the water.

3.2 Unconfined Compressive Strength of Soil Improvement

The unconfined compressive strength of the non-improvement soil (A) was 318 kPa. The results illustrated that the strength of the soil samples increased when the soil mixed with an admixture. The unconfined compressive strength of the soil mixed with the admixture in group C is shown in Fig 6. The results demonstrated that the strength of C5 was higher than the soil mixed with cement at 1.5% and gave the highest strength in group C. The compressive strength of C5 was 471 kPa, while the compressive strength of B1 was 456 kPa at the curing time of 7 days. The compressive strength of C5 increased by 3% from B1. However, by-product materials can develop the compressive strength of C5 by approximately 10% from B1 at the curing time of 3 days. Moreover, the compressive strength of C4 was near the samples B1 at the curing time of 5 days and 7 days. Nevertheless, the compressive strength of C4 increased by 5% from B1 at the curing time of 3 days. Therefore, this result represented that the replacement of cement with fly ash and FGD gypsum efficient to develop the strength of soil, especially at 3 days. Nevertheless, the compressive strength of soil improvement with the admixture in group C was lower than the suggestion of the Thailand Department of highways.

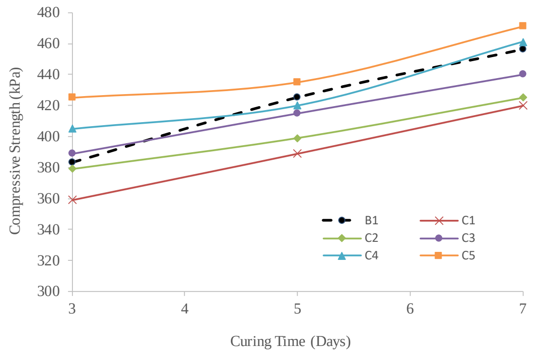

Fig. 6 Unconfined compressive strength of the soil mixed with an admixture in group C.

The results of the soil samples mixed with admixture in group D are shown in Fig. 7. Cement content of the admixture in group D was 1%. Fig.7 shows the strength of the soil samples mixed with the admixture in group D can reach 70-92% and 66-78% of the samples B2 at 5 days and 7 days, respectively. The compressive strength of D1, D2, D3, and D4 at the curing time of 7 days was 589 kPa, 599 kPa, 625 kPa, and 702 kPa, respectively. D4 has the highest compressive strength of the mixture in this group. Moreover, the results demonstrated that the compressive strength of soil mixed with admixture D4 was higher than B1, approximately 51-54% while the samples D4 used cement less than B1 at 0.5%. Therefore, this result can verify the replacement of by-product materials in the admixture to develop the compressive strength of soils. Moreover, the strength of D4 was near B2 at 3 days. The compressive strength of D4 at 3 days was 579 kPa. However, the compressive strength of D4 less than B2 at 5 days and 7 days.

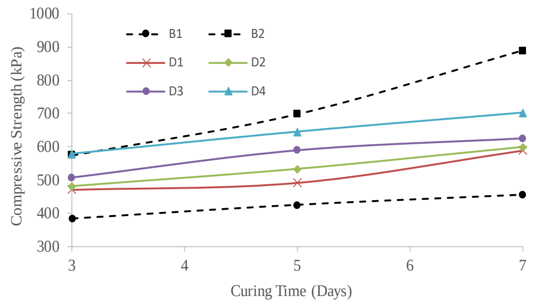

Fig. 7 Unconfined compressive strength of the soil mixed with an admixture in group D.

Fig. 8 shows the compressive strength of the samples mixed with the admixture in group E. The results demonstrated that the strength of soil mixed with the admixture in group E was higher than B2, approximately 5-17% at the curing time of 3 days. Moreover, the samples mixed with the admixture in this group can develop the strength of 2-6% from B2 at the curing time of 5 days. However, the compressive strength of the soil mixed with the admixture in group E was less than B2, approximately 10-15% at the curing time of 7 days. Therefore, the results demonstrated that the replacement of cement with fly ash and FGD gypsum can develop early strength. FGD gypsum consists of SO_3 approximately 54.1%. SO_3 seems to be responsible for the higher early compressive strength. However, the later strength is controlled mainly by calcium silicate hydrate [14]. Fly ash affects the early strength gain probably due to the free lime that is still reacting during the curing process [3].

Moreover, the samples in group E can develop compressive strength higher than the samples B1 while the mixture in group E and B1 used a similar amount of cement at 1.5%. However, the admixture in group E added fly ash at 0-1.0% and FGD gypsum at 0.5-1.5%. The results illustrated the strength of the samples in group E was higher than the samples in group B1 approximately, 58-77%, 67-74%, and 64-76% at the curing time of 3 days, 5 days, and 7 days, respectively. Therefore, the results verified the addition of fly ash and FGD gypsum in the admixture can develop the strength of soil.

Consideration of the compressive strength of soil improvement at the curing time of 7 days, the results demonstrated that the strength in this group was higher than the requirement at 689 kPa. The compressive strength of E1, E2, and E3 at the curing time of 7 days was 748 kPa, 768 kPa, and 804 kPa, respectively.

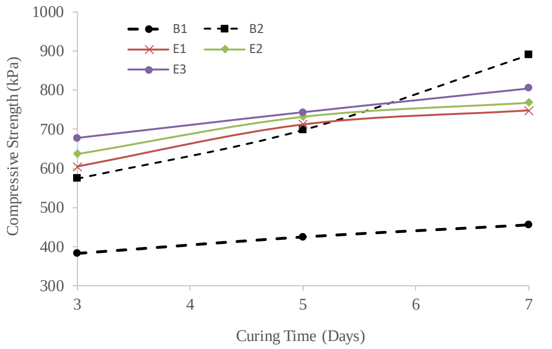

Fig. 8 Unconfined compressive strength of the soil mixed with an admixture in group E.

Fig. 9 shows the compressive strength of the soil samples mixed with the admixture in group F. The results demonstrated that soil mixed with admixture in group F can develop the compressive strength higher than B2 while the mixture in group F used cement content of only 2%.

The compressive strength of the samples in group F was higher than B2 approximately, 37-67%, 22-52%, and 1-29% at the curing time of 3 days, 5 days, and 7 days, respectively. The results illustrated that the contrast of compressive strength between admixture in group F and B2 tended to decrease with time increment. This is due to the cement content of B2 is higher than admixture group F and the later strength is controlled mainly by calcium silicate hydrate [14]. The compressive strength of F1, F2, and F3 at the curing time of 7 days was 896 kPa, 983 kPa, and 1147 kPa, respectively.

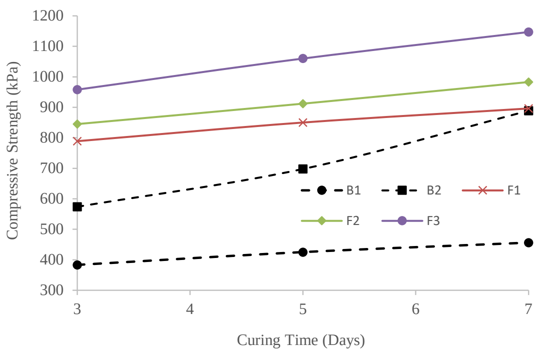

Fig. 9 Unconfined compressive strength of the soil mixed with an admixture in group F.

Moreover, the addition of admixtures in the soil can increase the durability of the subbase. Fig. 10 shows the comparison between the durability of non-improvement soil and soil mixed with the admixture. The results demonstrated that non-improvement soil occurred erosion after soaked in the water for 2 hours. However, the soil mixed with an admixture can maintain the characteristics after soaked in the water.

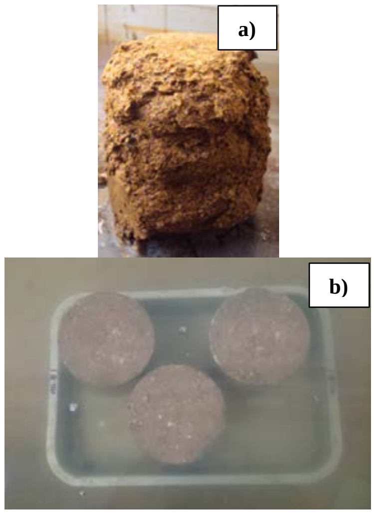

Fig. 10 a) Non-improvement soil after soaked in the water, b) Soil improvement soaked in the water.

3.3 Effect of Fly Ash and FGD Gypsum on Strength of Soil Improvement

The effect of fly ash and FGD gypsum on the compressive strength of soil improvement is shown in Fig. 11, Fig. 12, Fig. 13, and Fig. 14. The results demonstrated that the strength of soil improvement tended to increase with fly ash increment. However, the compressive strength of soil improvement was decreased by the increasing of FGD gypsum in the admixture.

Fig. 11 shows the relation between the compressive strength, amount of fly ash, and FGD gypsum in the admixture of group C. The results demonstrated that the strength increased by approximately 12-18% when fly ash increased from 0% to 2.0% and FGD gypsum reduced from 2.5% remaining to 0.5%.

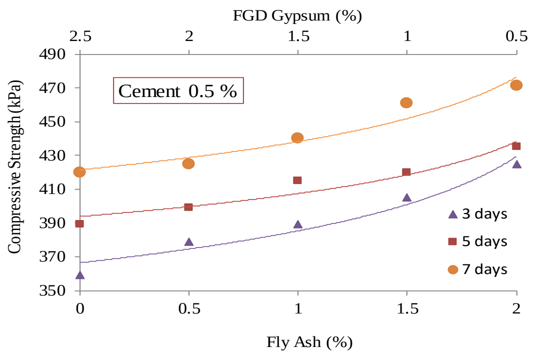

Fig. 11 Relation between the compressive strength, fly ash, and FGD gypsum in the admixture group C.

Fig. 12 shows the relation between the compressive strength, amount of fly ash, and FGD gypsum in the admixture of group D. The results demonstrated that the compressive strength increased 20-31% when fly ash increased from 0% to 1.5%, and FGD gypsum reduced from 2.0% remaining to 0.5%. The strength rapidly increased when fly ash increased from 1.0% to 1.5%, and FGD gypsum decreased from 1.0% remaining to 0.5%.

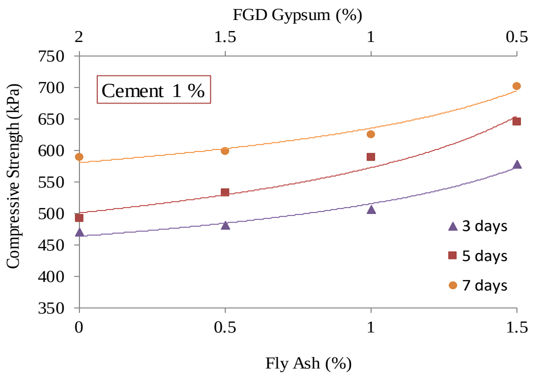

Fig. 12 Relation between the compressive strength, fly ash, and FGD gypsum in the admixture group D.

Fig. 13 shows the relationship between the compressive strength, amount of fly ash, and FGD gypsum in the admixture of group E. The results demonstrated that the compressive strength increased 5-12% when fly ash increased from 0% to 1.0%, and FGD gypsum decreased from 1.5% remaining to 0.5%.

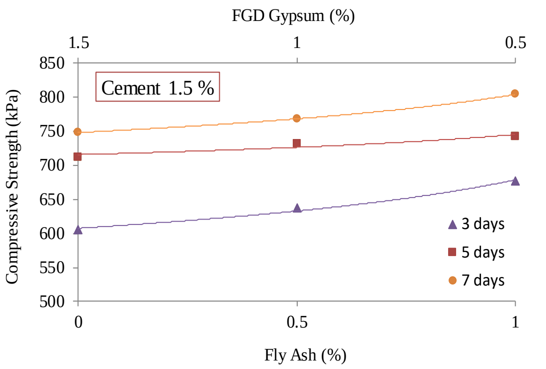

Fig. 13 Relation between the compressive strength, fly ash, and FGD gypsum in the admixture group E.

Fig. 14 shows the relationship between the compressive strength, amount of fly ash, and FGD gypsum in the admixture of group F. The results demonstrated that the compressive strength increased 21-28% when fly ash increased from 0% to 1.0%, and FGD gypsum decreased from 1.0% remaining to 0%. The results presented that the strength of soil samples mixed with admixture groups C, D, E, and F tended to increase with fly ash increment and the reduction of FGD gypsum.

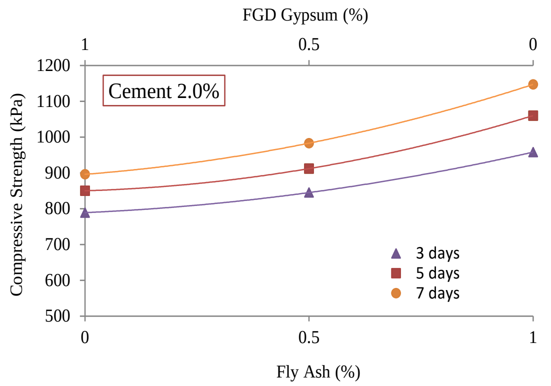

Fig. 14 Relation between the compressive strength, fly ash, and FGD gypsum in the admixture group F.

3.4 Strength Requirement for Subbase Improvement

The unconfined compressive strength of subbase improvement suggested by the Thailand Department of Highways was 689 kPa. Fig. 15 shows the strength of soil mixed with an admixture at the curing time of 7 days. The results demonstrated that the samples passed the requirement include B2, D4, E1, E2, E3, F1, F2, and F3. The unconfined compressive strength of B2, D4, E1, E2, E3, F1, F2, and F3 was 889 kPa, 702 kPa, 748 kPa, 768 kPa, 804 kPa, 896 kPa, 983 kPa, and 1147 kPa, respectively.

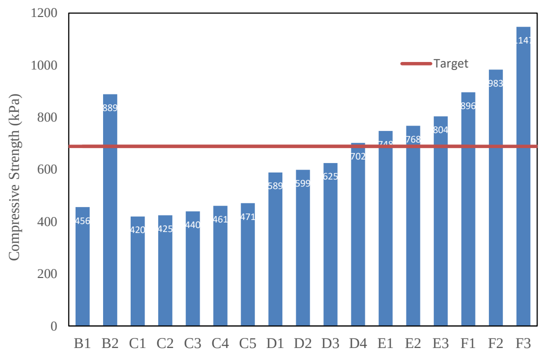

Fig. 15 Unconfined compressive strength of the soil improvement at the curing time of 7 days.

Fig. 16 shows the relation between the compressive strength and cement content in the admixture. The results demonstrated that the strength of soil tended to increase with cement increment. The mixture D4 can develop the strength higher than the requirement. Whereas the cement content of D4 less than B2 and the admixture group E at 2% and 0.5%, respectively. Moreover, the strength of D4 can reach 79% of B2, while D4 used cement only 33% of B2. The results presented that E3 used cement content, only 50% of B2. However, the compressive strength of E3 can reach 90% of B2. Admixture in the group of F1 can develop the compressive strength near B2 and F3 can develop the strength higher than B2, approximately 29%. However, cement content in the admixture of group F is less than B2 at 1%. Therefore, the use of admixture in group D, E, and F to improve the strength of soil can reduce the cement content for subbase improvement, approximately 67% and 50%, 33%, respectively.

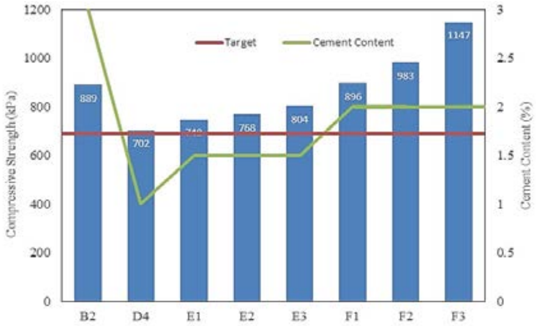

Fig. 16 Relation between compressive strength and cement content.

4. CONCLUSION

Based on the results obtained from this study, the following conclusion was made:

1. The replacement of cement with fly ash and FGD gypsum can increase the strength of poor subbase, increase the durability, and reduce cement content in the admixture.

2. The strength of subbase improvement by cement at 1.5%, fly ash 1.0%, and FGD gypsum 0.5% can reach 90% of the soil mixed with cement at 3%. This result shows the replacement of cement with fly ash and FGD gypsum can develop the strength of subbase.

3. The strength of soil improvement tended to increase with the increase of fly ash in the admixture. However, the compressive strength of soil improvement tended to decrease with the increase of FGD gypsum.

4. The replacement of cement with fly ash at 1.5% and FGD gypsum at 0.5% was the optimum content to replace cement in the admixture. This mixture can develop the strength of soil more than the requirement of the Thailand Department of Highways, and it can reduce costs by approximately 67%.

5. Soil mixed with cement at 2% and FGD gypsum at 1% can develop the compressive strength near the soil mixed with cement at 3%. Moreover, soil mixed with cement at 2% and fly ash at 1% can develop the compressive strength higher than soil mixed with cement at 3%, approximately 29%. Thus, these results illustrated that the replacement of cement by fly ash and FGD gypsum can develop strength of soil and reduce cost of soil improvement.

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