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Engineering Properties of Soil Stabilized with Cement and Fly Ash for Sustainable Road Construction

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ABSTRACT

This study presents an experimental study of engineering properties of soil stabilized with cement and fly ash for layers in roadway construction. The fly ash was used in this study satisfies the requirement according to ASTM C618. Five proportion mixes were used in this work with varying quantities of ordinary Portland cement amounts of 8, 10% cement and combination of 8% cement with fly ash content of 2%, 4%, and 6%. Specified curing periods of 7, 14, 28 days were applied for all types of specimens. Some engineering tests were carried out, such as unconfined compressive strength (UCS), splitting tensile strength, stiffness of stabilized soil, SEM, and XRD techniques. SEM images, magnified 3000 times, showed that compacted soil structure was found as small and odd particles arranged without gel bound, while cement-fly ash stabilized soil was covered foam formation due to cement-fly ash crystal, and small particles cannot be observed. The peak intensity of silicon oxide was seen in the region 26-28° with an angle of 2θ. In addition, cement and fly ash significantly improved the mechanical properties of stabilized soils. Finally, the specimen containing 8% cement and 2% fly ash at 14-day curing had a splitting tensile strength greater than 0.45 MPa, satisfying the base layer of road construction requirement according to current Vietnamese standards. The obtained results provided a shred of evidence for capable of using fly ash for road construction in the context of an increase in the fly ash generated in thermal power plants.

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1. INTRODUCTION

Vietnam significantly developed and constructed infrastructures such as roads, dams, and industrial zones in recent years. Among them, road construction was more paid attention because of the soft soil layers underneath that caused unexpected collapses and failure. For three past decades, the employments of ordinary cement and blended cement have been developing significantly. Ordinary Portland Cement (OPC) and Portland concrete are prevalent materials in civil engineering due to their strong, durable, and cheap characteristics; however, they have significantly affected environmental drawbacks. Cement manufacture releases significantly CO_2 emissions during the limestone combustion and calcination processes [1].

The properties of clayey soils are usually characterized by compression, low shear strength, low shear capacity, and highly swelling potential [2], resulted in not be capable of using in subbase and subgrade of road construction. Significantly, volume changes due to shrinkage and swelling cause road surface deformation and bearing capacity reduction [3].

Several methods have been considered and employed regarding the soil improvement techniques, including mechanical stabilization, stabilization using soft aggregates, bituminous stabilization, lime stabilization, cement stabilization, thermal stabilization, chemical and electric stabilizations. Various admixtures, such as cement, fly ash, lime, blast-furnace slag cement, enzyme, and calcium chloride, were used in different areas in the world [4-10].

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Recently, pozzolans from waste materials, such as fly ash, rice husk ash, and slag, are considered eco-friendly cementitious materials to replace traditional materials. Literature reviews indicated that using fly ash and cement on soil stabilization materials from local materials can remarkably reduce the cost of construction, especially for road construction [11-18]. For instance, Phan [8] indicated that the unconfined compressive strength, shear strength parameters on consolidated-undrained and unconsolidated-undrained triaxial tests improved with various cement contents of 4-8% OPC; furthermore, results also indicated that Portland cement of 4% was the economical ratio for treated mudstone. Mahedi et al. [19] treated expansive soil with cement, lime, and fly ash and revealed that the Atterberg limits, pH, unconfined compressive strength, and volumetric swell were best with 10% -10% calcium oxide in stabilizers for expansive soils. Simatupang et al. [20] conducted fly-ash-stabilized sands and concluded that UCS and direct shear strength values increased by increasing fly ash content and curing time in the specimen. In Vietnam, although available studies have been conducted to understand the behavior and engineering properties of soil stabilization using cement and lime; there were no apparent reports on engineering properties of using fly ash-cement soil stabilization in the laboratory and practice.

This study investigates the engineering properties of soil stabilized with various concentrations of cement and fly ash contents. Specific engineering properties, such as unconfined compressive strength, splitting tensile strength, elastic modulus, SEM, and XRD methods, were determined with the curing periods of 7, 14, 28 days. The obtained results were expected to consume a high quantity of waste fly ash every year and create a sustainable material for layers in road construction.

2. EXPERIMENTAL PROGRAM

The materials used in this study composed of excavated soil, ordinary Portland cement (OPC), and fly ash (FA).

2. 1. Materials Used

Excavated soil The soil sample for the laboratory test was taken from Cu Chi province, Southern Vietnam. The disturbed soil sample was excavated with a depth of 1m from the surface. The basic physical properties of undisturbed samples are listed in Table 1. The grain size distribution is plotted in Figure 1.

FA Fly ash used in this study was collected from Formosa power station, Dong Nai Province, Vietnam. The engineering properties of fly ash are satisfied with the requirement in ASTM C618 [21]. The distribution of grain size smaller than 45µm is 71.9 %, the loss on ignition with the temperature is 3.2%, calcium oxide content is 3.3%.

OPC OPC, grade 40, used in this work was purchased from a local company. The compressive strength, setting time, fineness, specify gravity, and standard consistency gravity of OPC were determined. The test results of fundamental properties are listed in Table 2.

2. 2. Mix Proportions, Sample Preparation, and Testing Methods

Mix proportions Based on TCVN 10379-2014, soils stabilized with inorganic adhesive substances, chemical agent or reinforced composite for road construction, construction and quality control, the additive used is in range of 5-12% by dry soil weight. Thus, to reduce the cement consumption and make use of the fly ash; this

TABLE 1. Basic physical properties of undisturbed soil

Basic properties	Test value
Specific gravity, Gs	2.65
Liquid limit, (%)	27.66
Plastic limit, (%)	15.48
Plastic index, (%	12.18
Maximum dry unit weight (g/cm^3)	2.057
Optimum water content (%)	9.90

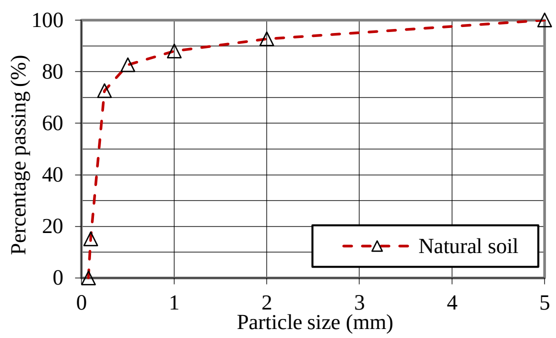


Figure 1. Grain size distribution curve of natural soil

TABLE 2. Properties of OPC 40

Properties	Tested result
Compressive strength	
28 days	43.5
Setting time, min.	
Initial	133
Final	172
Fineness, cm^2/g	3850
Specific gravity	3.09
Standard consistency, C/W, %	31.5

study used 8, 10% cement, and a combination of 8% cement with 2% FA, 4% FA, and 6% FA which is expected to have enough strength of stabilized soil for subbase and base layers in road construction. A total of 5 sets of mixed proportions was carried out for this experimental program. Natural soil was mixed with five cement and fly ash ratios, including 8%C, 10%C, 8%C+2%FA, 8%C+4%FA, 8%C+6%FA, by dry weight. The specimens were conducted on five mix groups, namely M.8.0, M.10.0, M.8.2, M.8.4, M.8.6, respectively, as presented in Table 3.

Sample preparation This paper concentrates on investigating the optimum amount of fly ash and cement for evaluating the engineering properties of cement-fly ash stabilized soil (CFSS). The specimens were prepared by proctor method, conditioned at room temperature and above 80% relative humidity, then tested with soaked conditions at 7, 14, 28 days. Unconfined compressive strength, splitting tensile strength, the elastic modulus of CFSS specimens were obtained in this study. Furthermore, SEM and XRD techniques were also investigated on the compacted soil and CFSS specimens. This work presents one case as a component of a broader research effort on the properties of locally available soils for construction in Cu Chi province, located in southern Vietnam. The experimental data provide a quantitative basis for further road construction in this area.

Compaction test Standard Proctor compaction tests were performed by AASHTO T99-95, using method A. The specimens were of 101.6 mm diameter and 116 mm height. To conduct tests, the soil, cement, and FA were manually prepared in dry material and different moisture contents. A metal rammer was used with a mass of 2.50 kg and having a flat circular face of 50.8 mm. The rammer was dropped freely from the height of 305 mm. The specimen was prepared in three layers, and 25 blows compacted each layer. Finally, maximum dry unit weight and optimum moisture content were obtained through this test.

Unconfined compressive strength UCS tests of stabilized soil with different cement and FA contents for various curing ages were conducted under AASHTO T208. A metal mold prepared cylindrical specimens with 5 cm in diameter and 10 cm in height at the maximum dry unit weight and optimum moisture content obtained in the standard Proctor compaction test. After that, the specimens were immediately packed in a plastic bag and stored in a chamber at room temperature, as shown in Figure 2. In addition, all specimens were conditioned by moisture curing and tested after soaking 2 days for a 7-day test and 7 days for 14- and 28-day test.

TABLE 3. Proportion mixes

No.	Mix	Mix proportion (%)		
		Soil	C	FA
1	M.8.0	100	8	0
2	M.10.0	100	10	0
3	M.8.2	100	8	2
4	M.8.4	100	8	4
5	M.8.6	100	8	6

Splitting tensile strength (STS) ASTM C496-96 was used to test the splitting tensile strength of stabilized soil. The diameter and height of the specimen were 101.6 mm and 116 mm, respectively. Three specimens have been tested for each stabilized soil sample, and the average value of the result has been used for evaluation. The splitting tensile strength is calculated by Eq. [1], as follows:

$$T = 2P/(\pi HD) \quad (1)$$

where T is splitting tensile strength; P is maximum applied load; H and D are the length and diameter of the specimen, respectively.

Stiffness of soil Elastic modulus of stabilized materials is an important parameter required in layered elastic analysis of pavement structure. To determine the elastic modulus, the specimen with the diameter and height is 101.6 mm and 116 mm, respectively, as shown in Figure 3. The elastic modulus test conformed to TCVN 9843-2013 [22] was used in this study.

3. TEST RESULTS AND DISCUSSIONS

A series of tests have investigated the mechanical engineering properties of CFSS specimens. The UCS, STS, and the elastic modulus results are presented, respectively, as below.

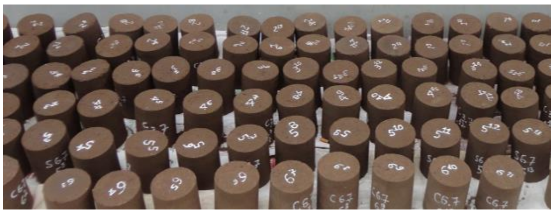


Figure 2. Prepared samples

Figure 3. Elastic modulus test

3. 1. Unconfined Compressive Strength Unconfined compressive strength is a common property to evaluate the strength of CFSS specimens. Figure 4 plots the variation of UCS at 7-, 14-, and 28-day curing ages of stabilized soil with various percentages of cement and fly ash %. It can be seen in Figure 4 that the UCS of 7-, 14- day, and 28-day give the value of 4.12-4.99 MPa, 5.26-6.11 MPa, and 7.31-8.03 MPa, respectively. The UCS increased as the curing period increased due to the time-dependent pozzolanic reactions. As shown in Figure 4, the compressive strength of cement stabilized soil increases with a percentage of cement increases in the range of 8-10%. Adding 2% FA yields the greatest compressive strength compared to two other contents at the same cement content. The phenomenon can be attributed to the combination of 2% FA and 8% cement causing the best continuation of the cementitious-hydrated process in the mixture.

3. 2. Splitting Tensile Strength The STS values of CFSS specimens with various percentages of cement and FA contents are presented in Figure 5. Regarding the effects of cement content on STS, it is depicted from this figure that the STS increased with an increase in cement content up to 10%. On the other hand, an increase in FA content up to 6% caused a decrease in STS, irrespective of curing day. The specimen with 8% C and 2% FA at 14-day curing has an STS greater than 0.45 MPa that satisfies the strength requirement of the base layer for road construction according to TCVN 8858-2011.

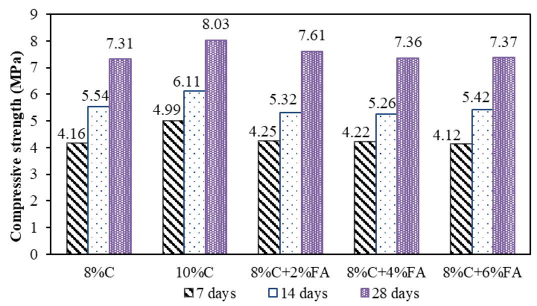


Figure 4. The UCS of cement/cement-FA stabilized soils

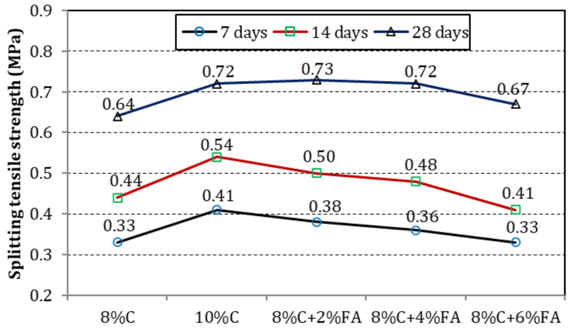


Figure 5. The STS of cement/ cement-FA stabilized soil

Furthermore, it is depicted in Figure 5 that the specimens with the FA contents of 4% and 6% FA are not applicable in a base layer for road construction.

3. 3. Elastic Modulus (E) The elastic modulus of soil treated with different FA and cement percentages is plotted in Figure 6. The elastic modulus results were in a range of 976-111 MPa, 1033-1305 MPa, 1033-1305 MPa, and 1195-1329 MPa for 7, 14, and 28 days, respectively. Without using FA, a general tendency to increase elastic modulus was found to increase in cement content of 8-10%. More remarkably, using cement and FA improved the elastic modulus with the cement content of 8% and FA content of 2%; after that, the elastic modulus decreased value with a further increase in FA content. The obtained data provided some specific values of elastic modulus, which are very helpful and valuable for designers and site practice for future design and construction, especially for low-cost road construction.

3. 4. SEM and XRD Results The Scanning Electron Microscope (SEM) technique was employed to investigate the surface of compacted soil and CFSS specimen, magnified by 3000 times, as shown in Figure 7. Figure 7a shows that compacted soil structure was found as small and odd particles arranged without gel bound. On the other hand, Figure 7b shows the foam formation due to the surrounding adhesive, and small particles cannot be observed. The phenomenon was likely attributed to cement, FA, and soil chemical reactions that established cementitious and pozzolanic gels consisting of calcium silicate hydrate (CSH) gel and calcium aluminate hydrate (CAH) gel. Based on the obtained images and the chemical reaction, it can be concluded that the CFSS significantly improved the strength compared to that of compacted soil.

X-ray Diffraction (XRD) is a technique to determine the crystallographic structure of a material. Figure 8 presents the comparison of XRD patterns between compacted soil and cement-FA treated soil specimens. In

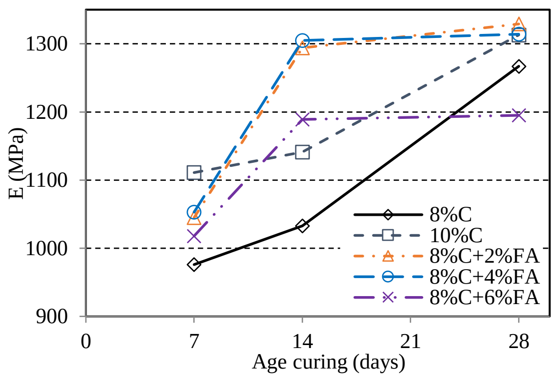
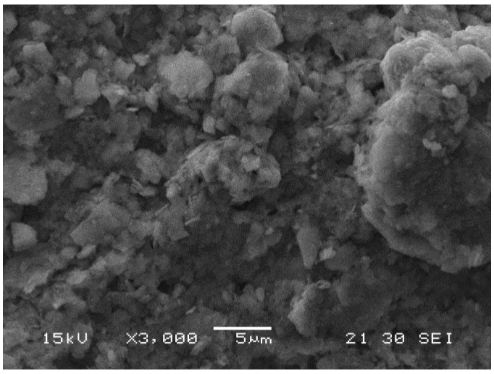
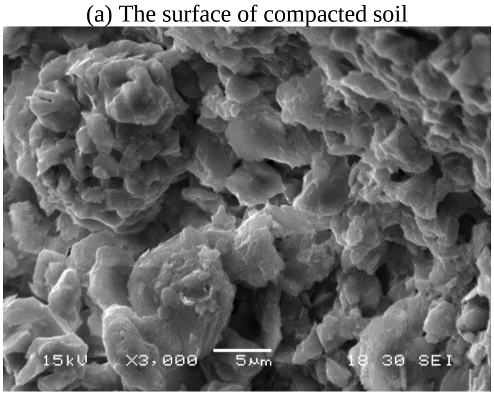


Figure 6. Elastic modulus of cement/ cement-FA stabilized soil

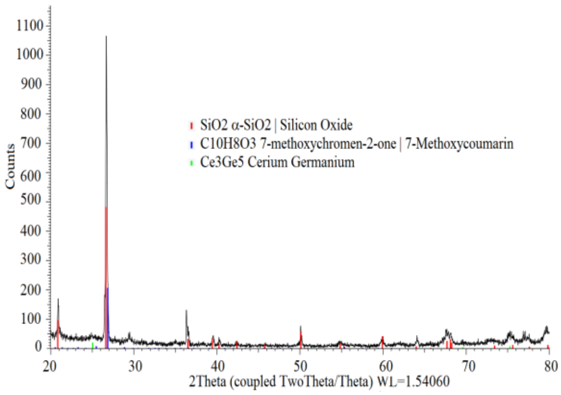


(a) The surface of compacted soil

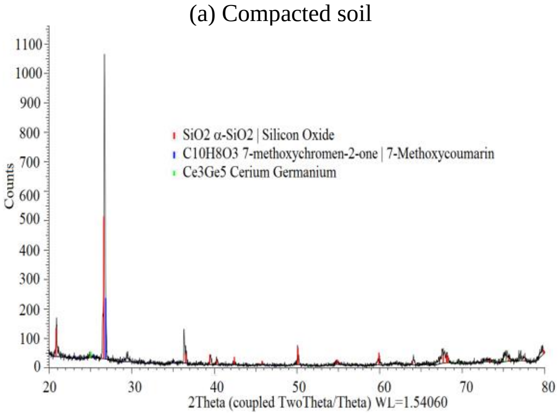


(b) The surface of CFSS specimens

Figure 7. SEM images, magnified by 3000 times



(a) Compacted soil



(b) CFSS specimen at 14 days

Figure 8. XRD patterns of specimens

this study, the cement-FA treated soil was made with 8%C and 2%FA and cured at room temperature until 28 days. In general, the peak intensity of Silicon Oxide is seen in the region 26-28° 2θ. In addition, Methoxycoumarin and Cerium Germanium were also obtained in two specimens.

3. 5. Effect of Different Size Samples on Compressive and Splitting Tensile Strength

As determined in the previous section, the optimum content containing 6% cement and 2% FA can be used for the base layer in road construction. In addition, to understand the effects of size specimen on the compressive strength and tensile strength of CFSS specimens, this study used two sizes of specimens such as D × H = 15.24 × 11.7 cm and D × H = 10.16 × 11.7 cm to test the compressive and tensile strengths.

Tables 4 and 5 indicated that a smaller specimen has a smaller compressive and greater splitting tensile strength with a conversion ratio of 0.74 and 1.09, respectively. This result may be used as a suitable ratio in practical and laboratory situations when using a standard proctor to prepare the specimen.

TABLE 4. UCS of CFSS specimens

No.	Sample	Size (cm)			Curing age (days)	Tested values	Average Tested values
		D	×	H		(MPa)	(MPa)
1		15.24	×	11.7	28	8.0	
2		15.24	×	11.7	28	7.5	
3	8%C+ 2%FA	15.24	×	11.7	28	8.1	**8.02**
4		15.24	×	11.7	28	8.3	
5		15.24	×	11.7	28	8.2	
6		10.16	×	11.7	28	5.8	
7		10.16	×	11.7	28	5.4	
8	8%C+ 2%FA	10.16	×	11.7	28	6.4	**5.95**
9		10.16	×	11.7	28	6.2	
10		10.16	×	11.7	28	5.9	

TABLE 5. STS of CFSS specimens

No.	Sample	Size (cm)			Curing age (days)	Tested values	Average Tested values
		D	×	H		(MPa)	(MPa)
1		15.24	×	11.7	28	0.78	
2		15.24	×	11.7	28	0.82	
3	8%C +2%FA	15.24	×	11.7	28	0.72	**0.76**
4		15.24	×	11.7	28	0.78	
5		15.24	×	11.7	28	0.69	

6	8%C +2%FA	10.16	×	11.7	28	0.83	**0.83**
7		10.16	×	11.7	28	0.87	
8		10.16	×	11.7	28	0.80	
9		10.16	×	11.7	28	0.80	
10		10.16	×	11.7	28	0.82	

4. CONCLUSIONS

An experimental study was performed to investigate the engineering properties of soil stabilized with cement and FA. Some specific conclusions can be made:

• Without using FA, the compressive strength, splitting tensile strength, and elastic modulus of stabilized soils significantly increased with the cement content in a range of 8-10 percent.

• An economical mixture was found of 8% cement and 2% FA, which simultaneously yielded the best performance in UCS, STS, and elastic modulus; furthermore, this also satisfied the requirement for the base layer in road construction according to the current Vietnamese standard.

• SEM images indicated that the compacted soil structure was found as small and odd particles arranged without gel bound, while the CFSS specimen showed foam formation due to the surrounding adhesive, and small particles cannot be observed. The XRD pattern showed that the peak intensity of Silicon Oxide was seen in the region 26-28° 2θ. Methoxycoumarin and Cerium Germanium crystals were also obtained in two specimens.

• Two sizes of specimens such as D×H= 15.24× 11.7 cm, and D×H= 10.16× 11.7 cm used to test the compressive and splitting tensile strengths with a conversion coefficient of 0.74 and 1.09, respectively.

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Persian Abstract

چکیده

این مطالعه یک مطالعه تجربی از ویژگی های مهندسی خاک تثبیت شده با سیمان و خاکستر کوره برای لایه ها در ساخت جاده ارائه می دهد. خاکستر کوره در این مطالعه مورد استفاده قرار گرفته است و مطابق ASTM C618 نیاز را برآورده می کند. پنج مخلوط نسبت در این کار با مقادیر مختلف مقادیر مختلف سیمان پرتلند ۸ ، ۱۰ و ۸ درصد سیمان همراه با محتوای خاکستر کوره ۲ درصد ، ۴ درصد و ۶ درصد استفاده شد. دوره های سخت شدن نمونه مشخص ۷ ، ۱۴ ، ۲۸ روز برای همه نوع نمونه اعمال شد. برخی از آزمایشات مهندسی مانند مقاومت فشاری نامحدود (UCS) ، مقاومت کششی تقسیم ، سفتی خاک تثبیت شده ، تکنیک های SEM و XRD انجام شد. تصاویر SEM ، که ۳۰۰۰ بار بزرگ شده اند ، نشان داد که ساختار خاک فشرده به عنوان ذرات کوچک و عجیب بدون چسباندن ژل یافت شده است ، در حالی که خاک تثبیت شده با خاکستر سیمان به دلیل کریستال خاکستر سیمان کوره پوشانده شده است و ذرات کوچک قابل مشاهده نیستند. اوج شدت اکسید سیلیکون در منطقه ۲۶–۲۸ درجه با زاویه ۲ درجه مشاهده شد. علاوه بر این ، سیمان و خاکستر کوره به طور قابل توجهی خواص مکانیکی خاکهای تثبیت شده را بهبود بخشید. سرانجام ، نمونه حاوی ۸٪ سیمان و ۲٪ خاکستر بادی در زمان سخت شدن ۱۴ روزه دارای مقاومت کششی بیشتر از ۰.۴۵ مگاپاسکال بود ، که طبق استانداردهای ویتنامی فعلی ، نیاز اساسی راهسازی را برآورده می کرد. نتایج بدست آمده شواهدی را برای استفاده از خاکستر بکوره برای ساخت جاده در زمینه افزایش خاکستر کوره تولید شده در نیروگاه های حرارتی ارائه می دهد.