Exploring Mechanical Behavior of Soil Stabilized by Fly Ash

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Abstract. Fly ash as a residual waste from coal combustion has been used widely for soil stabilization. In order to apply coal ash as alternative additive material to substitute other fine aggregate partially or fully in stabilization process, the mechanical properties of soil admixture and its analysis must be explored. This study is laboratory experimental basis where standard compaction test and uncofined compressive stress were carried out on soil sample to investigate the engineering properties. The findings indicate that the addition of fly ash at different percentage ranged from 2,5% to 15% can be used as stabilization material. However, the high percentage beyond the optimum content might lead to decrease in soil strength. This study is briefly discussed the mechanical properties of soil due to the utilization of fly ash in soil stabilization.

Keywords: Fly ash, coal combustion, residual waste, compaction, comprresive strength

1 Introduction

A continuous coal combustion from the thermal power plant could lead a huge mass of coal ash production. In industry scale, coal ash production is a residu that is considered to be waste material. This waste can be in the form of solid particle and gas including fly ash (FA), bottom ash (BA), and slag. For several years, the waste management is being a big deal to industry due to high public awareness to prevent environment from harmness. Therefore, a circular business model has been developed to manage the utilization of waste material through 3R approach before it finally dispose. Through 3R (Reduce, Reuse, and Recycle) approach, the waste is re-processed into economically viability. It might not only break the waste chain but also increase the operational income for maximum benefit.

Fly ash (FA), as a fine residu, has been used potentially in construction material. FA has subtituted or replaced cement and fine aggregare partially or fully in some construction works. The massive utilization of FA is due to pozzolanic characteristics that can be activated by stabilization process. Its pozzolanic is highly dependent upon the calcium content. High calcium content in FA shows that it posses cementious value level and good reactivity with water. Without stabilization process, it can be used directly by nature. This classify into class C FA. In contrast, class F FA contains less calcium. Stabilizers like cement and lime must be added for it to have cementious value.

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Several studies have been conducted to classify FA in Indonesia [1]. The study shows that the majority of Indonesia FA produces by thermal power plant is classified into class F. Generally, this type of FA is used as concrete mix ingredient [2] [3]. The low calcium content present in FA will enhace the probability to change the microstructure of fresh concrete.

Furthermore, the use of FA is not only limited to geopolymer concrete. Some researchers have focused on increasing soil bearing capacity utilising FA. Through stabilization process where soil and additive materials such as FA are added on admixture, various engineering properties like shear strength, stability and bearing capacity can be improved [4] [5]. By using FA, the soil volumetric can be controlled. The relative fine particle in fly ash is tend to fill the small void. It allows soil particle and FA to bind together more densely. As a result, a plasticity and swelling decreased.

FA can be used with other additive materials from nature to chemical. Rice husk can be an alternative to replace additives derived from chemical compounds. Because of its pozzolanic qualities, this substance can partially replace cement in the stabilization process. It was shown that adding both rice husk and FA at levels of 5% to 20% might lessen excessive edema and shrinking [6]. Ions in clay minerals can be replaced by the silica in rice husk ash and the sticky qualities of fly ash.

Utilizing the chemical and its derivatives in soil stabilization showed better result. However, the cost required are highly [7] [8]. Therefore, waste materials like FA as additive in soil stabilization is more economical. Moreover, the source of raw material is in high volume and can be developed for other civil works. The present study is aim to investigate the utilization of FA for road pavement layer. The mechanical properties of clay soil treated by different percentage of fly ash addition is studied. Then the result of this study is a laboratory based using Unconfined Compression Stress (UCS).

2. Literature Review

The distribution of soft soil that stretches almost 10% of the total land area of Indonesia opens up opportunities for changes in land use as construction areas. These changes cannot be separated from the direction of government policy which is carrying out massive development in the infrastructure sector. In the last decade, road construction as a civil construction has experienced rapid progress. Connectivity between regions connected by roads increases the flow of goods and people.

In terms of soil characteristics, most of these construction areas are located in soft clay to swampy areas and construction on land with these conditions is certainly not ideal. The physical properties of the soil which tend to have high organic minerals and low bearing capacity and a fairly large level of potential development (swelling) can cause obstacles in each phase of construction work Generally, geotechnical obstacles faced with potentially medium to high risks such as land subsidence. If the condition of the base soil is not handled immediately, it will affect the condition of the infrastructure's feasibility. Therefore, the method of soil improvement as part of the construction planning aspect needs to be considered so that risk mitigation can be mapped.

To evaluate the possibility of these conditions, soil stabilization is carried out. In the stabilization process, the additive materials are added as a mixture to the soil. The addition of these additives aims to improve the physical and mechanical properties of the soil. Consequently,the soil quality increases and reduces the potential for damage to structures built on it. The application of soil stabilization methods in geotechnical engineering can be used in various construction projects including road construction.

2.1. Soil Stabilization

One type of ground improvement for troublesome soil is soil stabilization. This method is used to alter or enhance the mechanical and physical characteristics of soil. This procedure can raise the soil's bearing capacity. Chemical additives can be used to stabilize soil, which is often done on fine-grained soil. Studies related to soil stabilization have been widely conducted by researchers before. Beginning with the addition of different additives to different types of soil, such as fly ash, cement, lime, and bottom ash.

[9] In this study, stabilization was carried out on soft clay soil using a combination of waste materials in the form of fly ash (FA) and expanded polystyrene (EPS). The purpose of the study was to determine the behavior of soft clay soil as a base layer of road pavement through CBR testing in the laboratory. The variables studied were the composition of EPS and the length of curing time with the FA composition set at 16%. The composition of the EPS addition was planned at 0%; 0.25%; 0.5%; and 0.75% with curing times varying for 3, 7, 14, and 21 days. From the results of the CBR test, the addition of EPS at a percentage of 0.75% together with the addition of 16% FA with a curing time of 14 days showed the optimum composition of the CBR value. The addition of this material showed the performance of increasing the CBR value when compared to the original condition of the soil before being stabilized.

[10] A number of laboratory tests led to the conclusion that adding fly ash and lime enhances the soil's mechanical and physical qualities, including lowering the likelihood of expansion and shrinkage brought on by variations in water content. Nevertheless, there isn't always a straight line between the two variables and the soil's mechanical performance. In fact, adding fly ash at greater levels actually lessens soil expansion at optimal composition.

From the results of the literature review, it shows that fly ash has the potential as a construction material that can be used for various civil engineering purposes. Fly ash as coal waste in relatively large quantities has an impact on environmental pollution. One alternative solution to the problem is to use this material for soil stabilization.

2.2. Fly Ash

One byproduct of burning coal is fly ash, a pozzolanic residue with a high cement concentration. This pozzolanic contains chemical element such silica and alumina. So far, fly ash is still categorized as Hazardous and Toxic Waste (B3) which can pollute the environment. Environmental damage due to fly ash pollution must be avoided and handled. Therefore, proper fly ash handling efforts are needed, such as utilizing fly ash to improve soil quality, texture and pH.

3. Materials and Methods

3.1. Material

The materials used in this study are consist of soil and fly ash. Fly ash as additive material in soil mixture was collected from Bukit Asam Power Plant which is located in Tanjung Enim, Indonesia. To separate fine aggregates, the FA was sieved. The passing FA through a No. 200 sieve then will be used. A review literature to determine a predominant chemical composition is considered to classify the FA category. From the analysis, the sum of predominant of Al_2O_3, SiO_2, and Fe_2O_3 is $\geq$ 50% and high CaO presence in FA > 10% were enough to establish the class C fly ash. The analysis of Bukit Asam FA is given in Table 1.

Meanwhile, a soil used in the study was clay soil that were taken from Sungai Pinang, OKI District, Sumatera Selatan. To determine the index properties of soil, the preliminary test was conducted in laboratory. From the preliminary result of laboratory testing, it can be seen that the soil used as the main material for this study is classified as CH according to USCS Classification System. It indicated that soil has high plasticity with potential in swelling and shrinkage.The properties are presented in Table 2.

Table 1. Analysis of Fly Ash

Chemical Parameter	Chemical Analysis
SiO_2	34,29
Al_2O_3	16,62
Fe_2O_3	15,38
TiO_2	0,73
CaO	18,18
MgO	7,52
K_2O	1,35
Na_2O	2,97
SO_3	1,63
MnO_2	0,17
P_2O_5	0,25
LOI	0,36

Table 2. Geotechnical properties of clay soil

Parameter	Index Properties
Spesific Gravity (Gs)	2,68
Passing Sieve No 200 (%)	91,40
Liquid Limit (%)	50,68
Plastic Limit (%)	28,52
Index Plasticity (%)	22,16
Maximum Dry Unit Weight, γ_{dmax} (kN/m^3)	1,45
Optimum Moisture Content, w_{opt}(%)	32,68

3.2. Method

The soil sample obtained from the location are first air dried. Then the soil sample is grinded into small particles and sieved using a set of sieve No 10, No 40, and No 200. After the sample is prepared, some laboratory tests are determined following the American Society of Testing Materials (ASTM) Standard. In this study, physical characteristic on soil is obtained from Atterberg Limit Test. The mechanical properties on soil were carried out using Proctor Standar Test and Unified Compression Test (UCS). This test are tested both on original soil and soil – fly ash treated. This study is conducted under the non-cured and unsoaked soil condition.

The Atterberg Limit Test is determined following ASTM D854-58. Five samples on diferrent blow number obtained from Cassagrande tool for each soil admixture are calculated. The data recorded is used to adjust the Liquid Limit. Meanwhile, two samples of each soil admixture were carried out to determine the plastic limit. From the Atterberg Limit Test, the water content and plasticity index are calculated.

The Standard Compaction Test is performed in accordance with ASTM D698-12. The samples on original soil and soil admixture are compacted in three layers. Each layer is compacted with 25 blows for the 4-in mold. After compaction completed and mass specimen recorded, the specimen water content is obtained using representative portion. In this compaction test, the samples are tested with various water content to produce different dry densities. By conducting Standard Compaction Test, the maximum dry unit weight and OMC are obtained.

Then **the UCS Test** is performed following ASTM D2166-00. This test method covers the determination of shear strength for cohesive soil. To know the shear strength of original soil before stabilized using fly ash, the undisturbed sample of original soil is prepared. The soil sample is prepared by molding in cylindrical tube of 100 m x 200 m. Once the sample is ready, it places in the loading device. Apply the axial load at a rate of 1/2 to 2%/min then record the load and deformation of the specimen to shape the stress-strain curve.

For UCS test on soil-fly ash admixture, the soil sample is first mixed with fly ash. This mixture is conformed to sample variation design. After the soil mixed, the sample is remolded using the same tube. Then the procedures are repeated following the previous specimen.

In this study, clay soil and fly ash are combined in different portions. The percentage of FA added to soil is 2,5%, 5%, 7,5%, 12,5% dan 15%. Therefore, the ratio of soil – fly ash is designed 97,5/2,5; 95/5; 92,5/7,5; 87,5/12,5; 85/15 by weight. The mixing process itself is conducted by adding fly ash gradually until it mixed well. Then the amount of water is added to the mixture following the test. The code of the sample variation is presented in Table 3.

Table 3. Soil sample variation

Sample variation	% of soil	% of FA
100% clay	100	-
S97,5FA2,5	97,5	2,5
S95FA5	95	5
S92,5FA7,5	92,5	7,5

S90FA10	90	10
S87,5FA12,5	87,5	12,5
S85FA15	85	15

4. Result and Conclusion

4.1. Atterberg Limit Test

As afforementioned, this study conducted the Atterberg Limit Test for both native soil and soil admixture. This two different samples were used to observe the soil behavior upon its consistency with water. The soil consistency was tested through the liquid limit and plastic limit. Meanwhile for soil admixture, the liquid limit and plastic limit were conducted after mixing the soil with the addition of FA in different portion. Then, the plasticity index could be determined by substracting the value of liquid limit and plastic limit. The results of the Atterberg Limit Test can be seen in Table 4.

Table 4. The Result of Atterberg Limit

Sample	LL (%)	PL (%)	PI (%)
100% clay	50,68	28,52	22,16
S97,5FA2,5	49,84	26,25	23,59
S95FA5	49,56	29,02	20,54
S92,5FA7,5	49,17	27,69	21,48
S90FA10	48,92	27,75	21,17
S87,5FA12,5	48,51	27,87	20,64
S85FA15	48,35	27,11	21,24

For the native soil, the liquid limit and plastic limit were obtained 50,68% and 28,52% respectively. From this value, the soil is classified into CH. It is high plasticity clay with complex characteristics. CH soil has high strength in dry condition but significantly low in strength when immersed by water. It causes the soil instability [11]. To improve the interlocking between grain particles, the additive material is added to soil. In this study, the soil sample was mixed with FA.

From the Atterberg Limit Test for soil admixture, the addition of FA in high percentage is prove to decrease plasticity index. This phenomenon might occur due to cementation process. The FA cementation could affect the enlargement pore of soil. It leads the water to be easily absorped. Furthermore, it causes the intermolecular force between soil particle to decrease. This finding is consistent with the previous research [12] [13].

4.2. Standard Compaction Test

In this study, the Standard Compaction Test was conducted in accordance to following ASTM D698-12. The test is carried out for both native soil and soil admixture. After the soil sieved by No 4 and mixed using various water content, the sample is cured for ± 24h. Then it compacted in three layers and a small portion of soil specimen is taken to test further. After all compaction process are completed, dry unit weight and water content are recorded. Then it plotted in the chart. From the chart, the maximum dry unit weight and optimum water content could be determined. The result of standar compaction test can be seen in Figure 1.

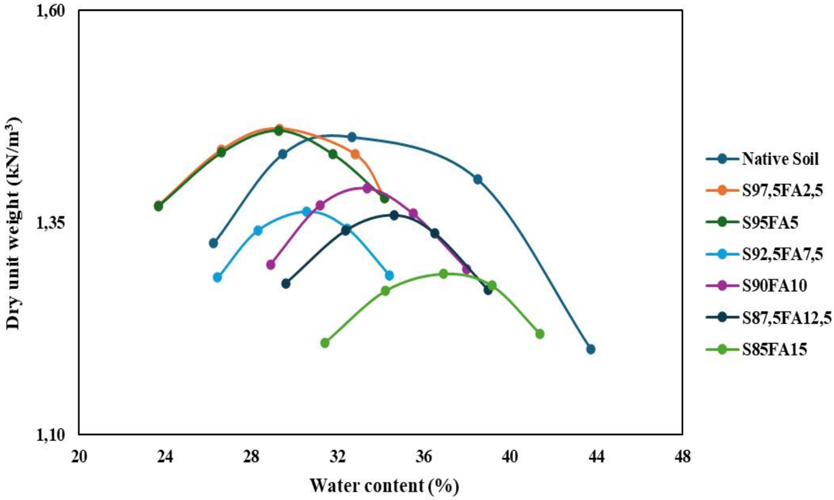

Fig 1. Compaction curves for the native soil and fly ash-stabilised soil samples

From Figure 1, it can be seen that the native soil tends to have higher MDD and lower OMC compared to soil stabilized by fly ash. This trend were similar to research reported by [14] [15]. While the addition of FA in soil admixture with percentage up to 15% show a decrease in MDD and increase in OMC. However, the addition of FA up to 5% can increase MDD and decrease OMC than the native soil. This could be attributed to FA grain size particle that slightly coarser than clay particle. It will cause the particle of FA has a larger surface area and porous. For that reason, soil mixed with fly ash requires more water to reach higher density. Consequently, it results in higher mass loss during drying.

Furthermore, FA also has lower specific gravity than clay. Generally, the spesific gravity is used to calculate the multiphase system of soil, such as void ratio. The spesific gravity is also often related to soil density. Low spesific gravity indicates low density. Those factors lead to MDD decrease following the increasing of fly ash in mixture.

4.3. Unconfined Compression (UCS) Test

The optimum water content for each soil admixture added by fly ash including native soil will be used as basis data to prepare UCS specimen. The water added to soil is considered by weight. From UCS test, the maximum compressive strength (qu) of native soil and soil mixed by fly ash will be evaluated. The result of UCS Test is presented in Figure 2.

Through Figure 2, the addition of fly ash in different percentage increased the compressive strength up to an optimum value. From the sample variation, it can be seen that the optimum value of soil admixture is at 10% of FA. Beyond this percentage, the addition of fly ash showed a reduction of compressive strength. According to previous studies, the compressive strength obtained by UCS test increased as the increment ratio of fly ash applied to design. However, the UCS decreased when the activation of pozzolanic properties exceeded the optimum dosage. This finding is similar with the results of the present study. As explained by [5] in reviewing of fly ash on geotechnical properties, higher percentage of fly ash could attribute to the cementitious production. When fly ash mixed with water, the hydration would occur. The presence of SiO_2 and Al_2O3 causes the fly ash has amorphous or non-crystalline state. Though fly ash do not have solid shape but it has high strength, stiffness, and hardness. It posess the gel properties that attribute to cementation after mixing with clay soil. Thereby, the high mineral content in clay can exchange the ion. The negative aluminosilicate covering the soil surface can result in high cation exchange. When the FA content increases gradually, the negative surface in soil admixture will decrease. This way lead to increase the strength.

However, when percentage of fly ash exceeded the optimum, the soil strength decreased. It could be possible due to changes in soil structure. As the fly ash increases, amount of water added. The higher water content causes the porosity and water absorption decrease. In this way, the flow of water slide the contact area between soil particles. It causes the rising of pore volume. This present study indicates that the increase of strength can not be fully reached with very high fly ash.

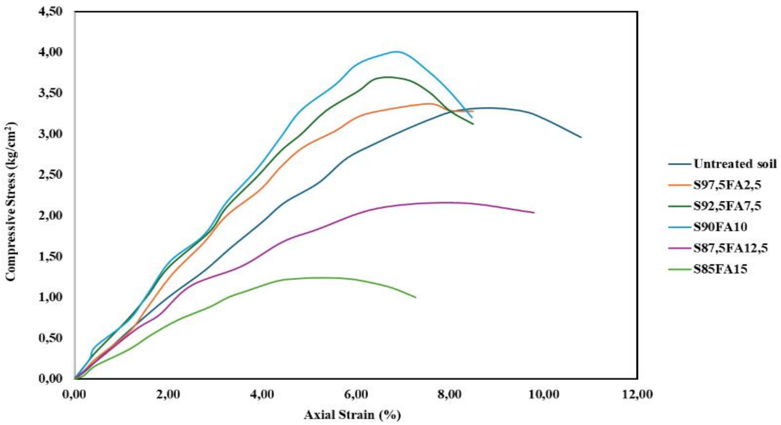

Fig 2. Analysis UCS Test

Figure 3 demonstrates the qu value for each variation. The higher FA, the higher qu. The addition of fly ash 2,5%, 5%, and 10% in example increased the qu. The qu is respectively 3,29 kg/cm^2 to 3,35 kg/cm^2 and last 3,67 kg/cm^2. The soil sample used in this study is uncured and unsoaked. Therefore, the behaviour of soil stabilized by fly ash in accordance with different curing and soaking can not be seen. However, some research has reported that the cured and soaked condition can significantly improve the compressive strength (Fig 4) [13]. The significant value improvement is affected by type of FA whether C or F. For class F fly ash, the low calcium content is found to be insignificant even the period of curing is quite long. It might be due to the lack reaction of chemical compound between soil and fly ash.

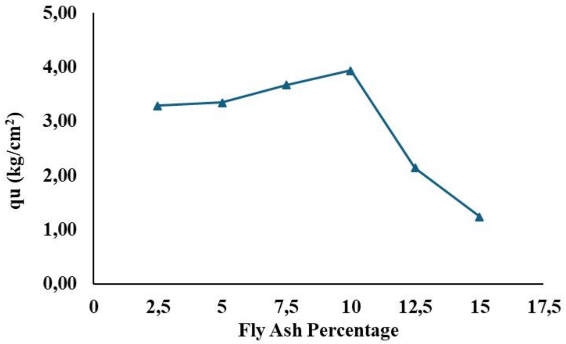

Fig 3. Qu value to fly ash percentage

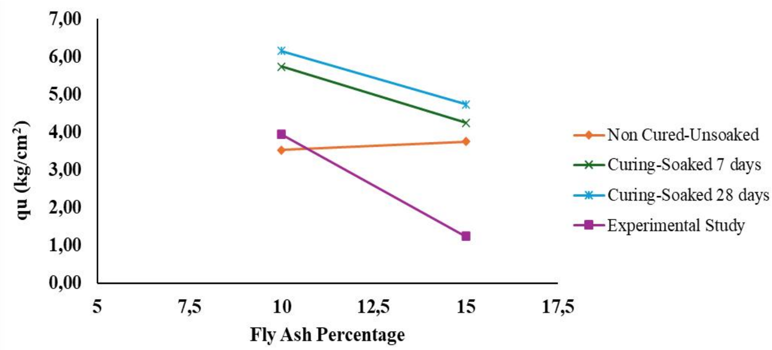

Fig 4. Effect of curing and soaked

To describe the microstructure of untreated soil and treated soil – flyash, Scanning Electron Microscopy (SEM) was conducted. The results of SEM presented in Fig 5 were conducted by other researchers. The presence of void on untreated soil will diminish as fly ash added. The more fly ash added to soil, the further reduced of void. This could be attributed to pozzolanic process that causes cementitious. At last, it results in higher quantity of water. Thereby, the soil structure will disperse randomly since water acts like lubricant. The micrograph describes more about the finding in this study.

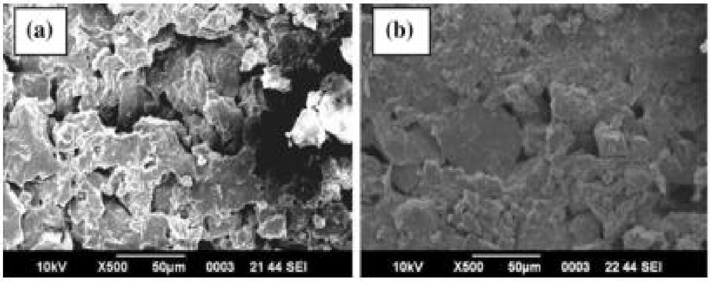

Fig 5. Micrograph of (a) untreated soil; (b) soil + 20% fly ash [16]

4.4. Future Scope of Work

From the afforementioned study, a type of class fly ash will give different engineering properties as well as the effect to soil admixture. Considering the use of different fly ash either in class F or sources are needed to study futher. Moreover, examining the effect of 100% bottom ash and partially mixed fly ash-bottom ash should be figured out. Hence, this composition needs to be well investigated to provide more information on the utilization of coal ash combustion.

5. Conclusion

The present study investigated the effect of fly ash as stabilisation additives on the compaction and strength at different portion of addition. The following conclusions can be drawn from the results obtained in this study.

1. The findings indicate that the addition of fly ash at different percentage on clay soil can be used as stabilization additive. However at high percentage of fly ash, the addition of fly ash is trend to lower the strength both in maximum unit weight and compressive strength.
2. The native soil in this study had higher MDD and lower OMC so does the soil admixture with fly ash at percentage up to 5%. Adding fly ash at high percentage > 5% decrease MDD and increase OMC. This could be explained that the soil mix with fly ash absorp more water to reach higher density.
3. The UCS of the soil increased with the addition of fly ash. The highest UCS result was found at 10% fly ash content. Beyond this percentage, the addition of fly ash has shown a reduction of compressive strength

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