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EVALUATION OF THE STRENGTH CHARACTERISTIC OF SOIL STABILIZED WITH FLY ASH

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Abstract

High domestic consumption of coal, especially in energy sector, has raised concerns on several environmental issues in Indonesia. Large amount of coal combustion product in the form of solid waste, such as fly ash resulting from coal power plant production causes problems in its disposal since its necessity of land occupancy. Over the last decade, many researchers have put effort to solve this disposal concerns by utilizing these materials for various purposes, such as construction materials as part of circular economy. This paper presents the utilization of fly ash for soil stabilization in Surabaya. Firstly, the index properties of soil samples were determined through a series of laboratory soil test including specific gravity, unit weight, moisture content, sieve analysis and Atterberg's limit tests. Subsequently, standard proctor test was conducted to obtain the maximum dry density and optimum moisture content of the soil samples. Using those parameters, four types of soil stabilized with fly ash samples were prepared with fly ash content based on weight of soil as follows: 0%, 5%, 10%, and 15%. Finally, unconfined compression tests were performed with cylindrical soil samples to assess the unconfined compressive strength of those samples. The results indicate that soil with fly ash content of 10% showing the highest unconfined compressive strength compared to the other variations of 0.90 kg/cm^2.

Keywords: Solid Waste, Fly Ash, Soil Stabilization, Standard Proctor Test, Unconfined Compressive Strength

Introduction

Concerns about environmental issues have significantly risen in Indonesia due to high domestic coal usage, particularly in energy industry. Due to the requirement of land occupancy, the large volume of coal combustion product in the form of solid waste such as fly ash produced from coal power plant production poses challenges in its disposal (Besari et al., 2022; Bhajantri et al., 2018). Many researchers have worked over the last decade to address the disposal difficulties of fly ash by utilizing these materials for multiple purposes such as construction materials as part of the circular economy (Mathapati et al., 2021; Saldarriaga et al., 2022).

Basically, fly ash is a smooth, ill-defined structure made of the unburned mineral fraction of the coal that remains after combustion. Fly ash particles are spherical and range in size from 0.5 to 200 microns (C. Verma et al., 2016; Xie & Ozbakkaloglu, 2015). Moreover, fly ash has a low to medium bulk density of 0.54–0.86 g/cm^3, and due to the small speres of fly ash make fly ash has a high surface area of 300–500m^2/kg (Ambikakumari Sanalkumar et al., 2019). The porosity of fly ash is about 40-50%, moisture is about 3.14 %, and specific gravity is 2.288 (Adjei & Elkatatny, 2020; Bhajantri et al., 2018). Generally, the spesific gravity of fly ash lies around 2.0 but varies from 1.6 to 3.1(Bhatt et al., 2019a). In addition, a study also reviews fly ash's chemical and Mineralogical properties (Alterary & Marei, 2021; Xu & Shi, 2018; Zimar et al., 2022). Furthermore, some researchers have put effort into studying the physical and chemical properties of fly ash globally (Bhatt et al., 2019b; Ram & Mohanty, 2022) and produced particularly in Indonesia (Petrus et al., 2020; Risdanareni et al., 2017; Robbani et al., 2023; Tri et al., 2022).

The chemical properties of fly ash are the basis for identifying the main group of fly ash. The American Society for Testing and Materials (ASTM) and the American Association of State Highway Traffic Officials (AASHTO) have divided fly ash into two classes: C and F. Numerous studies have worked to understand the chemical properties of both classes of fly ash (Adjei & Elkatatny, 2020; Mathapati et al., 2021; Yavuz et al., 2022). Class C of fly ash often comes from coals that have the potential to generally produce ash with greater lime concentration, more than 10-15%, which could demonstrate self-hardening tendencies since there is more CaO present. In other words, class F is more widely available and often has a low lime percentage (less than 10-15%) and a higher level of alumina, silica, and iron (Alterary & Marei, 2021; Bhajantri et al., 2018). In addition, Class C of fly ash has pozzolanic and cementitious (due to the high concentration of CaO) properties, whereas Class F purely has pozzolanic properties (Alterary & Marei, 2021; Hou et al., 2013).

Soils with inadequate load-bearing capacity, excessive settlement problems, liquefaction potential, slope instability, swelling and shrinkage potential are termed problematic soils. This problematic soil is usually identical with soft soil. The distribution of soft soils in Indonesia is generally found in coastal plains, including the East Coast of Sumatra, the North Coast of Java, the West – South Coast of Kalimantan Island and the South Coast of Papua Island. The area is estimated to be around 20 million hectares or about 10 percent of Indonesia's total land area (Badan geologi, 2019). Several studies have researched the characteristics of soil in Indonesia (Permana & Rahardjo, 2022; Zaika et al., 2019). The accepted solutions for problematic soil are the use of appropriate soil or changing the site construction. However, these solutions are technically economically unacceptable. For this reason, according to the treatment method, the ground improvement technique can be divided into three groups: mechanical, biological and chemical stabilization (H. Verma et al., 2021).

In term of chemical stabilization, most of researches on the use of waste materials for soil treatment have proven that composite material made of soil and other substances, such as fly ash, bottom ash, gypsum, and lime might improve the mechanical qualities of the soil (Andavan & Pagadala, 2020a, 2020b; Ghosh & Subbarao, 2007; Grace et al., 2016; Islam et al., 2018; Karami et al., 2021; Sharma & Singh, 2019). Some studies even specifically compared the effect of adding C class and F class of fly ash on soil. The results showed that with the increasing percentages of fly ash content for both classes of fly ash, the unconfined compressive strength increases (Nath et al., 2017; Seyrek, 2018; Shirkhanloo et al., 2021). Furthermore, The effectiveness of fly ash for subgrade treatment which is shown by the CBR value has been reported by some researchers recently (Kumar & Harika, 2020; Ozdemir, 2016; Renjith et al., 2021; Singh et al., 2021; Zimar et al., 2022). A recent study shows the potential benefits of using biofuel fly ash for the circular economy and effective resource use since the increased bearing capacity on the road stabilized by the fly ash after 11 years (Nordmark et al., 2022).

Over the last decade, many researchers have put effort to study the effect of fly ash for soil stabilization for various applications. A study demonstrated that the unconfined compressive strength (UCS) of the clayey soil reaches the maximum value when the soil is treated with the 6% (Kalita et al., 2017) and 5% (Islam et al., 2018) of fly ash without curing. Moreover, a low shear strength of soil has the maximum shear strength when it mixed with 10% of fly ash (Ahmad et al., 2015). For organic soil, the UCS value increases by adding fly ash content from 5% to 15% (Nath et al., 2017). However, for an expansive soil which is improved by mixed with fly ash has been reported that the UCS value increased and reached the maximum value when the fly ash content is 10% (Kumar & Harika, 2020). In addition, fly ash is also used for expansive soil mixed with nano-SiO_2 (Munda et al., 2022).

This paper presents laboratory tests for evaluating strength characteristic of soil in Surabaya stabilized with fly ash. The influence of various fly ash content to the weight of soil was investigated in this study. The obtained information can be useful as reference to design soil stabilization using fly ash for various purposes such as embankment, pavement, etc.

Research Methodology

The effect of fly ash addition on the strength characteristic of soil was evaluated by conducting laboratory soil tests. At first, the soil sample was collected from Gunung Anyar sub-district, Surabaya, Indonesia at the depth of 0.6 – 1.2 m. This depth was chosen to avoid the influence of plant roots which usually grow to the depth up to 50 cm below the soil surface. The index properties of soil samples were determined by a series of laboratory soil tests. Sieve analysis was carried out to determine the grain size distribution (SNI 03-1968-1990). Moreover, the moisture content (SNI 1965:2008), specific gravity (SNI 1964:2008), unit weight test (SNI 03-3637-1994) and Atterberg limits tests (SNI 1966:2008 and SNI 1967:2008) were also conducted to the soil samples.

Standard proctor test was performed according to SNI 1742:2008. The compaction parameters including optimum moisture content (OMC) and maximum dry unit weight (γ_{dmax}) of the soil samples were obtained from the test.

The unconfined compression test (UCT) was used to assess the unconfined compressive strength (UCS) of soil stabilized with fly ash. There are four types of soil stabilized with fly ash samples were prepared with fly ash content based on weight of soil as follows: 0%, 5%, 10% and 15%. The variation of fly ash content was determined based on the results of prior studies mentioned previously which show that the optimum fly ash content is around 5 – 15%. The soil samples used in UCT tests are in cylindrical shape. The fly ash used in this study was C class fly ash. Each sample for UCT was compacted at 95% of optimum moisture content based on the prior standard proctor test. In this study, the soil samples for UCT were prepared without curing as referring to the method used by prior researchers mention previously.

Research Results and Discussion

Index properties of soil samples obtained from laboratory tests are presented in Table 1. According to the particle size distribution curve obtained from sieve analysis, as shown in Figure 1, the soil sample contains 69.76% of sand and 30.24% of fine particles. The results of Atterberg limits test indicate that the soil sample has liquid limit (LL) and plastic limit (PL) of 75% and 39%, respectively. Therefore, the plasticity index (PI) = LL – PL = 36%.

Table 1. Index properties of soil sample

Property	
Particle size	
< 4.75 mm (%)	100
< 0.075 mm (%)	38.6
Atterberg limits	
Liquid Limit, LL (%)	75
Plastic Limit, PL (%)	39
Shrinkage Limit, SL (%)	31.37
Soil Classification (USCS)	SM
Specific Gravity, G_s	2.27
Unit weight, γ (g/cm³)	1.47

Based on the Unified Soil Classification System (USCS) according to ASTM D 2487-00, the soil sample is classified as high plasticity silty sand (SM). Moreover, the specific gravity test result according to ASTM D 854-83 shows that the soil has a specific gravity of 2.27.

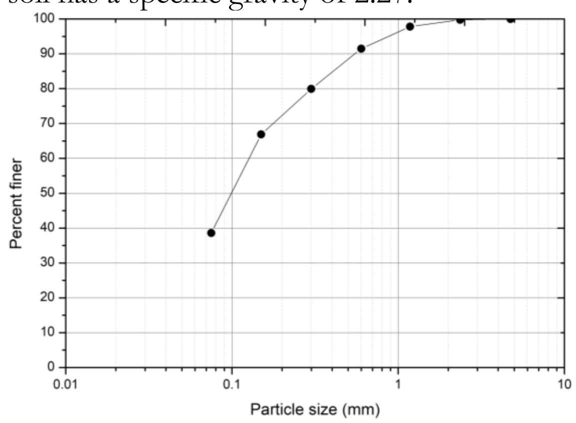

Figure 1. Particle size distribution curve

Figure 2 shows the compaction curve and zero air void line obtained from standard proctor test. The results indicate that the soil sample has OMC and γ_{dmax} of 27% and 1.09 g/cm^3, respectively. The zero air void line plotted in the Figure 2 is line showing the dry density as a function of water content for soil containing no air voids. The compaction parameters obtained in this test were used to prepare samples for UCT.

UCT tests were conducted to obtain unconfined compressive strength (UCS) of soil stabilized with fly ash. Table 2 presents the unconfined compressive strength (UCS) of samples with different fly ash content. The fly ash content of 0% refers to soil sample without fly ash addition. The UCS of 0.75 kg/cm^2 was obtained for this sample. The addition of fly ash content to 5% decreases the UCS to 0.53 kg/cm^2. However, the UCS increases to 0.90 kg/cm^2 for fly ash content of 10% which is the highest value of UCS compared to other samples in this study. It is also observed that the UCS decreases significantly to 0.39 kg/cm^2 when the fly ash content reaches 15%.

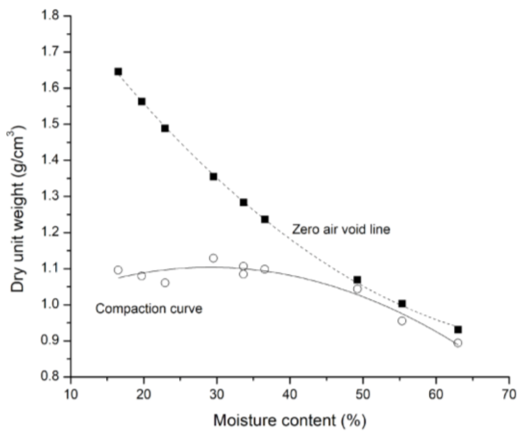

Figure 2. Compaction curve and zero air void line

Table 2. Effects of fly ash content on UCS

Fly Ash Content (%)	**UCS (kg/cm²)**
0	0.75
5	0.53
10	0.90
15	0.39

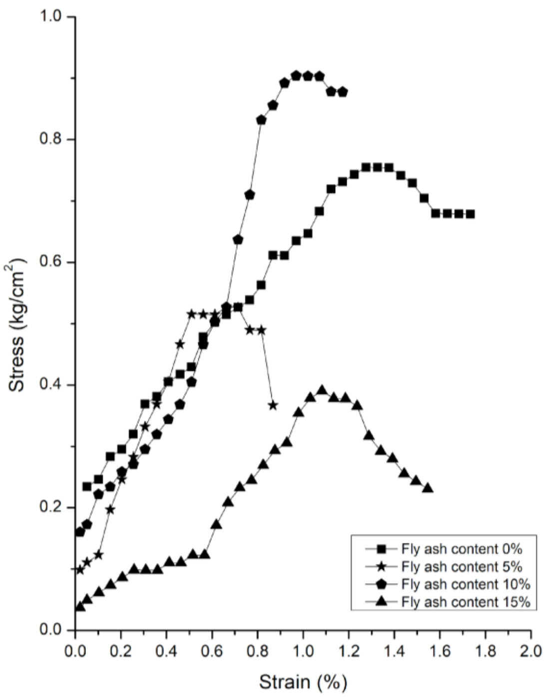

Figure 3. Stress-strain relationship obtained from UCT

Figure 3 shows the stress-strain relationship obtained from UCT. It can be observed that the soil with fly ash content of 10% reaches UCS of 0.90 kg/cm^2 at the strain of 0.97%. Furthermore, it can be seen that the soil sample with 0% of fly ash content behaves as ductile material. On the contrary, it can be observed that the soil sample with 10% of fly ash content tends to be more brittle. It is indicated that the material characteristics are having high UCS and less deformation after its elastic limit at the time of failure. Therefore, the optimum result is obtained for fly ash content of 10% since it can provide high UCS at low strain compared to the other samples.

Conclusion

The strength characteristic of soil stabilized with fly ash has been evaluated in this study. The following conclusions can be made on the basis of the obtained results:

1. Soil sample can be classified as high plasticity silty sand (SM) with OMC and γ_{dmax} obtained from standard proctor test are 27% and 1.09 g/cm^3, respectively.
2. The addition of fly ash affects the unconfined compressive strength of soil.
3. The optimum result is obtained for soil with 10% fly content since it shows the highest unconfined compressive strength of 0.90 kg/cm^2 compared to other samples.
4. Material behavior of soil with 10% of fly ash content is more brittle compared to soil with 0% of fly ash content.

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