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THE INFLUENCE OF FLY ASH AND FOSROC CEBEX-100 ON THE MECHANICAL PROPERTIES OF STABILISED SOFT SOIL

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Abstract

The problem of soft soil in infrastructure, specifically in road construction, will cause ongoing issues due to the nature of soft soil, which often undergoes shrinkage and swelling, potentially leading to failure in the structures above it. The solution of stabilizing the soil using chemical methods while also utilizing waste that is harmful to the environment has become very common, such as the use of fly ash material. This research focuses on the stabilization of soft soil using two stabilizing materials, namely fly ash and fosoc cebex-100, to improve the strength of problematic soil so that it can support the load of the construction above it. Fly ash was added at 20%, 25%, and 30% of soil weight, and Cebex-100 at 0,45% of fly ash weight. The sample variations were subjected to physical tests, including Unconfined Compression Tests and shear strength tests, to determine the changes in physical and mechanical properties that occurred after the addition of the additives. The research results obtained from the unconfined compressive strength and elastic modulus parameters showed an improvement as the fly ash composition increased. The soil shear strength test identified 25% fly ash as the optimum variation, resulting in a cohesion value of 34.49 kN/m² and a friction angle of 7.66°. It can be concluded that the addition of fly ash and cebex-100 to problematic soil conditions can improve the physical and mechanical properties of the soil.

Keywords: Soil Stabilization, Fly Ash, Fosroc Cebex-100, Unconfined Compression Test, Direct Shear Test

Introduction

Soft soil is typically found in areas with saturated soil conditions or where water is present, such as in wetlands, shrimp ponds, and peatlands. In these areas, the soil tends to be soft. The distribution of soft soil in Indonesia covers about 10 percent of the 20 million hectares of land in Indonesia (Badan Geologi, 2019). This study examines one location, specifically the North Lamongan Ring Road Project, which crosses through wetland areas.

Figure 1. Research Location of the JLU Lamongan Project

Soft soil has a high water content, high plasticity, and low bearing capacity (Irvan et al., 2021). If infrastructure such as roads or other buildings are placed on it, they will experience several problems such as significant settlement and collapse. The issues of infrastructure development due to standing on problematic soil have been extensively analyzed (Arianto, 2020; Fakhrudin et al., 2021; Kuswanda, 2015). The characteristics of soft soil easily undergo changes in moisture, where the soil expands when wet and shrinks when dry, resulting in cracks and uplifted soil (Alam & Alselami, 2024). With such soft soil properties, construction is also very disadvantageous due to the high costs of rehabilitation and reconstruction (Nugroho et al., 2022a). Considering the important role of soil as a support and receiver of structural loads (Duque-Acevedo et al., 2022), ground reinforcement is carried out in accordance with technical requirements.

Soil stabilization can be achieved through various methods, including reinforcement with geotextiles (Vimal et al., 2023), planting vegetation or using root reinforcement (Hutama & Farichah, 2024), and applying chemical agents to improve strength and permeability (Fitrian et al., 2023; Kusuma et al., 2015; Syahril et al., 2022). Soil stabilization with chemical materials requires a binder to enhance the strength and permeability of weak soils (Ahmad et al., 2024; Rai et al., 2021). This study focuses on soil stabilization using two stabilizing materials, namely fly ash and fosroc cebex-100. Fosroc is typically mixed with concrete to improve its quality (Meutia et al., 2022). When used as a stabilizing agent, this material has proven effective in soil stabilization. The reaction between the two materials can influence the structure of the soil mixture, as confirmed by the chemical properties of the soil and fly ash mixture (Wu et al., 2023). Recent research also examines the chemical properties that occur during stabilization with fly ash and fosroc cebex-100 (Farichah et al., 2024).

Fosroc Cebex-100 is a chemical material in the form of fine powder, commonly used as an additive in concrete grouting processes and for soil structure repair. Fosroc is said to be usable for soil stabilization due to its property as an injection like cement, which can fill the voids in the pores and can increase the compressive strength (Gaudel et al., 2021). From the perspective of several researchers discussing the success of Cebex in terms of stabilization, the percentage of Cebex dosage usage has also been studied with the water-to-cement ratio (Fosroc, 2011; Gaudel et al., 2022). Here are the percentages of the compound content found in the Fosroc Cebex-100 material (Fosroc, 2010): Silica Sand (SiO_2) 60 – 100%, Calcium Lignosulfonate ($C_{20}H_{24}CaO_{10}S_2$) 10 – 30%, and Aluminum Powder (Al) <1%.

Generally, fly ash material has a size of 0.5 to 200 microns (Muhaimin & Simatupang, 2020). Fly ash also has pozzolanic properties, which means it can react and form binding compounds when mixed with water at normal temperatures (Narmluk & Nawa, 2014). Fly ash has two types, namely type C and type F, both of which have their respective chemical composition limits (Suseno & Farady, 2020). Type C fly ash contains more than 10% CaO, which can reduce shrinkage and cracking, while type F fly ash contains less than 10% CaO (Jafer et al., 2015; Muhaimin & Simatupang, 2020). Type C fly ash is also widely used due to its cementitious properties, which are effective in soil stabilization (Amal, 2023; H. N et al., 2024; Li et al., 2018). The mixture of fly ash with soil will undergo a cementation bonding process, influenced by pozzolanic substances, which have natural properties that allow them to harden in the presence of water. Fly ash consists of silica (SiO_2) with a composition between 35% and 65%, alumina (Al_2O_3) between 10% and 30%, iron oxide (Fe_2O_3) between 4% and 20%, and lime (CaO) between 1% and 35% (Chandra et al., 2019).

Because the use of fly ash material also succeeds in utilizing industrial coal waste that causes environmental pollution (Asof et al., 2022; Firda et al., 2021). It has been agreed that fly ash provides significant results in improving the mechanical properties of soil in various types of soil such as sandy soil (Simatupang, 2021), expansive soil (Simatupang, 2021), and clay (Auli et al., 2021; Srijan et al., 2023). Several researchers have studied the success of the influence of fly ash on unconfined compressive strength (Farichah et al., 2023; Indera et al., 2016), shear strength (Amania et al., 2021; Karwi & Yunus, 2018), and california bearing ratio (Hangge et al., 2021; Rai et al., 2021). Various percentages of fly ash used range from 0%-30% of the fly ash mixture to the nature soil weight (Kodicherla & Nandyala, 2019; Leliana & Andajani, 2015; Yuniati Pratiwi et al., 2022). They confirmed that the addition of fly ash can convincingly improve the soil properties.

As explained previously, the improvement of the physical and mechanical properties of the soil will affect the soil strength, especially for soil that will serve as the foundation for a construction (Andajani & Risdianto, 2022). This research was conducted with the aim of determining the effect of fly ash and fosroc cebex-100 on the mechanical properties of the soil. From previous researchers, it can be explained that stabilization additives such as fly ash also increase the cohesion value, permeability, and improve the soil strength value (Fitriyana & Satrio, 2022; Nugroho, Zulnasari, et al., 2022). Therefore, mechanical soil tests were conducted, namely unconfined compressive strength and direct shear strength tests on soil samples with fly ash variations of 0%, 20%, 25%, and 30%, mixed with 0.45% cebex-100 by the weight of fly ash. This research also offers insights into the performance of fly ash and Fosroc Cebex-100 materials, which can improve the stability of soft soil.

Research Methods

Materials and Research Location

Soil samples for this research were taken from the JLU project site in Lamongan, East Java at a depth of 1-2 meters from the ground surface. The fly ash used in this research is Type C fly ash collected from the Paiton Power Plant in Probolinggo, while the cebex-100 material is produced by PT. Fosroc Indonesia. Four samples are tested for their physical and mechanical properties: natural soil (without additives) and three variations of fly ash mixed with natural soil at 20%, 25%, and 30% of the soil weight, with a constant addition of 0.45% cebex-100 based on the weight of the fly ash.

Laboratory Tests

The tests conducted on all samples include physical tests such as moisture content (Wc), specific gravity (Gs), unit weight (γ), and Atterberg limits tests (PL, LL, and IP). This is followed by mechanical soil tests, specifically the Proctor test, which uses only the nature soil samples to determine the optimum moisture content (OMC) that will be used in subsequent mechanical tests.

Unconfined Compression Test is conducted to determine the soil strength when the test specimen collapses or reaches 20% of the axial strain. This test is performed on all soil samples after the Proctor test, using elongated cylindrical samples. The target was to obtain the unconfined compressive strength (UCS) value and subsequently determining the elastic modulus (E) value derived from the ratio of strain and stress changes.

Direct Shear Test is conducted to determine the soil's shear strength, which is the force of the soil against the shear stress that arises within the soil. The testing is performed on all soil samples with the aim of obtaining the values of cohesion (c) and friction angle (φ) of the soil. The determination of cohesion and friction angle values uses Mohr's theory (1910), where the failure condition of a sample or material occurs due to a combination of critical states of normal stress and shear stress, as seen in Equation 1.

$\tau\ (kN/m^2) = c + \sigma \tan \varphi$ ....(1.)

Description:

τ = Maximum Shear Strength (kN/m^2)

c = Cohesion (kN/m^2)

σ = Normal Stress (kN/m^2)

φ = Friction Angle (^{0})

Research Results and Discussion

The results of the laboratory testing on the physical properties of the natural soil include a water content (Wc) value of 52.66%, a specific gravity (Gs) value of 2.72, and a bulk density (γ) value of 16.61 kN/m^2. The Atterberg limit values are as follows: liquid limit (LL) of 71.75%, plastic limit (PL) of 54%, and plasticity index (PI) of 17.75%. Additionally, the sieve analysis results classify the natural soil as A-7-5 according to AASHTO and as SM (silty sand) according to USCS. Based on the physical test results, it can be concluded that the natural soil has the characteristics of silt-clay soil. The natural soil test also yielded an OMC value of 31.6%, with a water capacity of 400 ml and a maximum dry gamma value of 1.21 g/cm^3 from the Proctor test.

Unconfined Compression Test Results

The results of the Unconfined Compressive Test (UCT) provided the UCS and elastic modulus (E) values for all sample variations, can be seen in Table 1. For the nature soil sample, a UCS value of 26.75 kN/m^2 was obtained. For Variation 1, the UCS value was 77.43 kN/m^2; for Variation 2, it was 44.08 kN/m^2; and for Variation 3, it was 46.21 kN/m^2. After determining the UCS values, the elastic modulus values were obtained as follows: for the nature soil, 1007 kN/m^2; for Variation 1, 4765 kN/m^2; for Variation 2, 5718 kN/m^2; and for Variation 3, 6002 kN/m^2.

Table 1. The UCS Values and Elastic Modulus of All Variations

No	Samples	UCS (kN/m^2)	E (kN/m^2)
1	Nature Soil (0%FA+0%Cb)	26.75	1007
2	Variation 1 (Nature Soil+20%FA+0,45%Cb)	77.43	4765
3	Variation 2 (Nature Soil+25%FA+0,45%Cb)	88.15	5718

4	Variation 3 (Nature Soil+30%FA+0,45%Cb)	92.42	6002

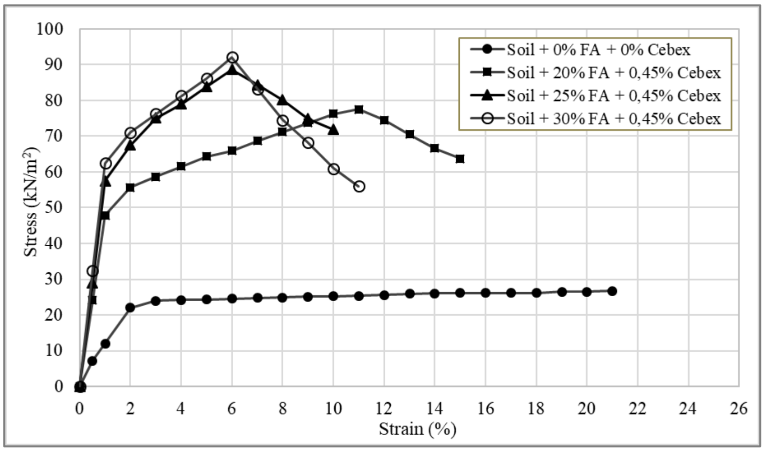

Figure 2. Relationship Between Strain and Stress From UCT

It can be observed from Figure 2. There is an increase in the UCS results of the soft soil + FA + Cebex-100 mixture. The higher the fly ash precentage, the higher the UCS value will be. The minimum UCS value is obtained from the UCS value of the nature soil sample, in the condition of unstabilized soft soil with a UCS value of 26.75 kN/m^2. The highest UCS value is obtained from a 30% FA percentage, amounting to 92.42 kN/m^2. From the pattern of this increase, it can be explained that the higher the percentage of fly ash, the more brittle the material becomes, as the UCS value is directly proportional to the percentage of fly ash.

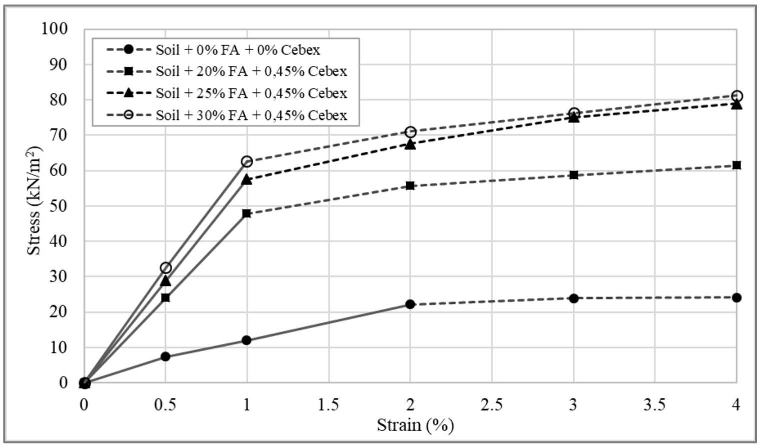

Figure 3. Graph of Elastic Modulus for All Samples

In the Figure 2. the relationship between strain and stress obtained that the modulus of the nature soil is 1007 kN/m^2, the value at 20% FA is 4765 kN/m^2, at 25% FA is 5718 kN/m^2, and at 30% FA is 6002 kN/m^2. And it can be observed that the lowest modulus value is found in the nature soil sample, as the strain that occurs in the nature soil takes longer compared to the fly ash and cebex-100 variation samples. The elastic modulus values in the 20%, 25%, and 30% fly ash samples have strain values that are ½ of the strain value of the nature soil sample. This is because in the fly ash and cebex-100 mixture variation samples, the strain occurs more quickly but with higher stress.

Direct Shear Test Results

The soil shear test obtained the soil shear strength values with parameters of cohesion (c) and friction angle (φ), can be seen in Table 2. The results for the nature soil sample showed a shear stress of 29.32 kN/m², for variation 1 it was 34.59 kN/m², for variation 2 it was 38.35 kN/m², and for variation 3 it was 30.83 kN/m². After obtaining the shear stress values, the cohesion and friction angle values can be determined using the Mohr-Coulomb equation. For example, the equation for the variation of the natural soil is shown in Figure 4: the linear equation $y = 0.4107x + 16.792$, where (y) is the shear stress value and (x) is the normal stress. The obtained cohesion value is 16.79 kN/m². The friction angle is then determined by substituting into the equation, resulting in a friction angle of 22.33°.

Table 2. The UCS Values and Elastic Modulus of All Variations

No	Samples	Shear Stress (kN/m²)	Cohesion (kN/m²)	Friction Angle (°)
1	Nature Soil (0%FA+0%Cb)	29.32	16.79	22.33
2	Variation 1 (Nature Soil+20%FA+0,45%Cb)	34.59	25.56	16.63
3	Variation 2 (Nature Soil+25%FA+0,45%Cb)	38.35	34.49	7.66
4	Variation 3 (Nature Soil+30%FA+0,45%Cb)	30.83	25.31	10.57

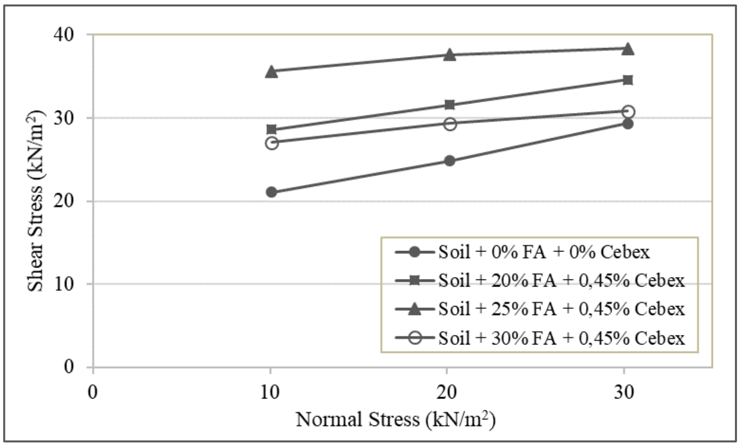

Figure 4. Graph of Normal Stress and Shear Stress from Direct Shear Test

It can be observed in Figure 4, the graph of normal stress and shear stress from the direct shear test, the shear stress value increases for the nature soil sample, 20% FA percentage, and 25% FA percentage. However, there is a decrease in the shear stress value for the 30% FA percentage sample. The maximum shear stress value occurs in the 25% FA percentage sample.

From the graph of normal stress and shear stress in Figure 4, the cohesion and friction angle values can be determined. It can be seen in Figure 5, the cohesion and friction angle values follow a fluctuating pattern. The addition of fly ash (FA) increases the cohesion value, with the nature soil having a cohesion value of 16.79 kN/m², which increases to 25.56 kN/m² at 20% FA, and 34.49 kN/m² at 25% FA. However, at 30% FA, there is a decrease, with the cohesion value dropping to 25.31 kN/m². The friction angle values presented in Figure 5(b) show that the maximum value is found in the nature soil sample at 22.33°. With the addition of 20% FA, the friction angle decreases to 16.63°, then further drops to 7.66° at 25% FA, before increasing again to 10.57° at 30% FA.

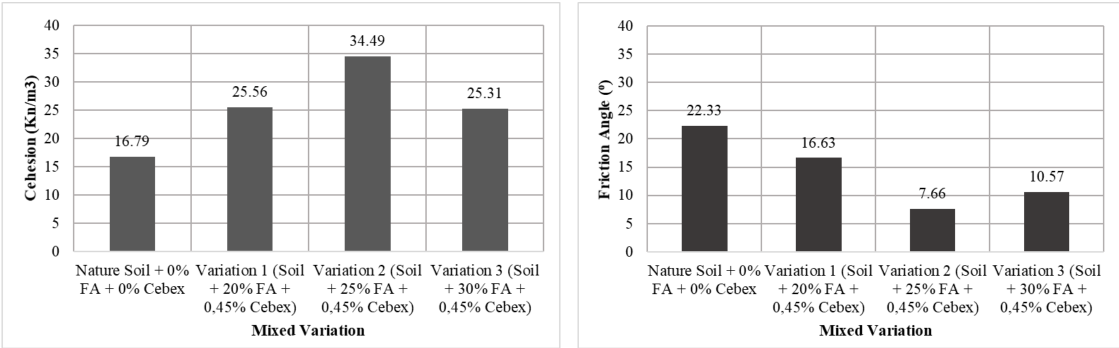

Figure 5. (a) Cohesion of All Samples and (b) Friction Angle of All Samples

The increase in cohesion value in stabilized soil is significantly influenced by the use of fly ash and the additive Cebex-100, which play a role in enhancing the density and cohesion between soil particles. Cebex-100 acts as a binding agent that reacts with fly ash and soil particles, strengthening the soil matrix by filling the spaces between grains and reducing voids. This process increases the compactness and interparticle bonding, contributing to the overall improvement in soil strength. The highest cohesion value is achieved with a composition of 25% fly ash, where the interparticle attraction is strongest, and the soil's density and compactness reach their peak compared to other samples. However, in the mixture containing 30% fly ash, the cohesion value decreases due to the separation of soil particles, which is caused by excess water filling the soil pores, thereby weakening the interparticle bonds.

In contrast, the internal friction angle shows a decreasing trend, with the highest value observed in the natural soil sample. This decline is attributed to the weakening of interparticle forces, resulting in reduced shear strength and the formation of a smaller failure angle, particularly in the 25% fly ash mixture.

In addition to material composition, environmental factors such as humidity also play an important role in influencing soil strength. Excessive moisture can cause the soil pores to become filled with water, which hinders the formation of bonds between particles, as seen in the decrease in cohesion and shear strength in the sample with 30% fly ash

Conclusion

This research states that the mechanical properties of soft soil can be modified through stabilization using fly ash and Fosroc Cebex-100. Based on the results obtained, it can be concluded that the natural soil sample from the JLU Lamongan project has characteristics that classify it as soft soil. The addition of variations of fly ash and Cebex-100 significantly impacts the soil's mechanical properties, including the UCS value, elastic modulus (E), cohesion (c), and friction angle (φ).

Based on the results of the UCS and elastic modulus values, there is a proportional increase in the soil's mechanical properties with the rise in fly ash percentage. The maximum cohesion value of 34.49 kN/m^2 was obtained from the soil sample with 25% fly ash and 0.45% Cebex-100. Although the friction angle decreases, the stabilization overall improves the soil's mechanical properties, making it suitable for construction on soft soil.

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