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Bolstering Sandy Soil Stability: Evaluating Fly Ash Integration for Enhanced Shear Strength

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***Abstract*— Sand soil, inherently lacking cohesion and exhibiting poor gradation, is susceptible to soil shear stress. Congot Beach typifies such sand attributes, with small, rounded grains unevenly distributed, leading to diminished shear strength and land failure. To improve these properties, fly ash additives are utilized. This study investigates the stabilization of sand soil samples with varying fly ash proportions 10%, 12%, and 14% by weight—over curing periods of 3, 7, and 14 days. The aim is to assess the impact of fly ash on enhancing shear strength, measured through cohesion values and friction angles. Results demonstrate increased shear strength, particularly with 12% fly ash, supported by X-ray fluorescence (XRF) and scanning electron microscopy (SEM) analyses. This highlights fly ash's effectiveness in stabilizing sandy soils, reducing soil instability and erosion risks.**

***Index Terms*— Fly Ash, Sandy Soil, Shear Strength, Stablility.**

I. INTRODUCTION

Sand with favorable characteristics typically comprises a diverse grain composition, encompassing grains of varying sizes capable of filling pore voids effectively to confer robust shear resistance. Conversely, sand exhibiting inferior attributes often manifests in large grain arrangements laden with excessive fine grains, rendering them rounded and lacking in grain surface roughness, thereby impeding soil shear strength against external stresses (Lata & Kumar, 2022).

Congot Beach sand epitomizes such suboptimal quality, characterized by rounded grains devoid of intergranular roughness and an overabundance of fine grains, thereby disrupting uniform grain size distribution and culminating in diminished shear strength. This deficiency not only compromises soil stability but also engenders heightened susceptibility to shear failure under increased soil shear stress. The research location can be seen in Figure 1.

The research was conducted in the vicinity south of Yogyakarta International Airport (YIA), a critical infrastructure hub in the region. The selection of this site is paramount due to the pivotal role of YIA Airport in Yogyakarta's infrastructure landscape. Consequently, investigating the stabilization of coastal land in proximity to the airport becomes imperative, particularly in anticipation of the forthcoming development surge following the operationalization of YIA Airport. Envisioned infrastructure projects, including accommodations, resorts, and beachfront attractions, underscore the exigency of preemptive coastal land stabilization measures to facilitate seamless integration with the burgeoning infrastructure ecosystem in the airport vicinity (Nur, 2021)(Dewi &

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Jaya, 2021)(Kesharwani et al., 2017).
Addressing these challenges necessitates soil improvement interventions, prominently through stabilization techniques. Critical parameters governing soil shear strength, namely cohesion (c) and internal friction angle (ø), underscore the imperative of enhancing soil stability and durability through proactive interventions (Adefemi et al., 2014). Notably, sand, classified as non-cohesive soil, exhibits loose intergranular properties, characterized by grain separation upon desiccation and limited inter-grain adhesion reliant on surface tension upon wetting (Antoni et al., 2021; Lata & Kumar, 2023).

Figure 1. Research Location (-7.902643,110.039759)

In such circumstances, chemical soil stabilization emerges as a viable recourse, as underscored by previous studies. Fly ash, a residual byproduct of coal combustion, emerges as a promising stabilizing agent owing to its akin chemical composition to cement. While lacking inherent binding capacity akin to cement, fly ash, upon interaction with water, undergoes chemical reactions resulting in the formation of substances conducive to interlocking sand particles and sealing soil pores, thereby bolstering shear strength (Kelechi et al., 2022)(Antoni et al., 2021).
Notably, projections indicate a substantial increase in fly ash and bottom ash (FABA) production, accentuating the urgency of addressing associated environmental and health concerns. Leveraging fly ash for land stabilization emerges as a pragmatic approach to mitigate its adverse environmental impact and capitalize on its potential as a stabilizing agent (Alterary & Marei, 2021)(Kholishoh, 2014).
This study embarks on laboratory-based examinations and testing endeavors to devise effective solutions for sand soil characterized by disparate grain sizes, a phenomenon deleterious to shear strength. Through the incorporation of fly ash additives, the research endeavors to augment both the physical and mechanical properties of sandy soil, thereby addressing environmental imperatives while concurrently ameliorating soil stability concerns associated with fly ash waste (Alterary & Marei, 2021)(Pangestuti et al., 2018).

II. METHODOLOGY

Research methods are a way to obtain data to answer problems that have been explained through systematic stages. On This research uses trial and error methods in the laboratory. Test Objects This research will be carried out with a variety of test objects as follows:

- Initial soil,
- Initial soil + fly ash 10%,
- Initial soil + fly ash 12%, and
- Initial soil + fly ash 14%, with curing variations of 3 days, 7 days and 14 days respectively. The test materials used in this research are as follows following:

A. Sandy Soil (Initial soil)

Soil samples in the form of sandy soil with salinity originating from Congot Beach sand soil in Jangkaran, Temon District, Kulon Progo Regency, Special Region of Yogyakarta.

(a) (b)

Figure 2. (a) Soil sample, and (b) Sampling location

B. Fly ash

According to ASTM C 618-03, fly ash is divided into 3 classes, namely class C, class F, and class N. The fly ash in this research used is class C coal burning waste from Pacitan, East Java.

TABLE I. ASTM C-618, POZZOLAN

Summary – ASTM C-618, Pozzolan

Chemical		F	C	N
$SiO_2 + Al_2O_3 + Fe_2O_3$	min %	70	50	70
SO_3	max %	5	5	4
Moisture Content	max %	3	3	3
Loss on Ignition	max %	6	6	10

Figure 3 is fly ash class C from Pacitan, the containing CaO above 10% is produced from burning lignite or sub-bituminous coal (light coal or sub-bitumminous). Content (SiO_2 + Al_2O_3 + Fe_2O_3) > 50%. CaO levels > 10% (ASTM 20%, CSA sets the figure at 8-20% for CI type and above 20% for CH), Carbon content (C) is around 2%. Class C fly ash, colloquially referred to as high-calcium fly ash, is distinguished by its elevated CaO content, endowing it with both cementitious and pozzolanic properties. Given its substantial CaO composition and inherent cementitious characteristics, Class C fly ash demonstrates the propensity to undergo hydration and subsequently harden within approximately 45 minutes when exposed to water or humidity (Ondova et al., 2012).

Figure 3. Fly ash

Research that has been carried out includes testing the physical properties of the soil, namely regarding water content, specific gravity, grain size analysis, and mechanical properties of the soil which includes the Direct Shear Test on the initial soil and the effect of adding fly ash.

C. SEM and XRF Tests

The SEM and XRF test for the stabilization of sandy soil with fly ash offer valuable insights into both the microstructural and elemental alterations induced by the incorporation of fly ash additives. The SEM analysis provides a detailed examination of the soil's microstructure, revealing any changes in particle morphology, size distribution, and inter-particle interactions following the addition of fly ash. This analysis allows for the observation of improvements in particle packing, increased cohesion, and enhanced interlocking between soil particles and fly ash particles, all of which contribute to the stabilization of the soil matrix. In parallel, the XRF analysis elucidates the elemental composition of the stabilized soil, providing quantitative data on the presence and concentration of various elements. By comparing the elemental composition of the stabilized soil with that of the initial soil and the fly ash additive, XRF analysis enables the identification of elemental transformations and chemical reactions occurring during the stabilization process. This analysis can reveal the incorporation of fly ash constituents into the soil matrix and the formation of new compounds or phases as a result of chemical interactions (Diana et al., 2024).

III. Results And Discussion

The outcomes of the research conducted at the Janabadra University Soil Mechanics Laboratory, involving the utilization of a fly ash mixture as a key stabilizing agent, are delineated within this chapter.

A. Water Content Testing

The water content is the ratio between the weight of water and the weight of solid particles, expressed as a percentage. To ascertain the moisture content value contained within the soil under field conditions. Based on the results of the initial soil moisture content testing, the average moisture content value of Congot Beach sand soil in Jangkaran, Temon District, Kulon Progo Regency, Special Region of Yogyakarta, is determined to be 6.16%.

B. Specific Gravity Testing

Soil specific gravity testing entails comparing the weight of a solid soil volume to the weight of an equal volume of water at a specific temperature. Based on the calculations from the table above, the average specific gravity (Gs) value of Congot Beach sand soil in Jangkaran, Temon District, Kulon Progo Regency, Special Region of Yogyakarta, is determined to be 3.31 gram/cm3.

C. Grain Size Analysis Testing

This testing is intended to determine the percentage of soil grain sizes based on the classification boundaries of soil types. Grain size analysis testing is conducted through sieve analysis on test specimens retained by a No. 200 sieve to ascertain fine and coarse aggregate grains. Based on the results of the sieve analysis testing the distribution graph of soil grain sizes can be depicted, as shown in Figure 4 below.

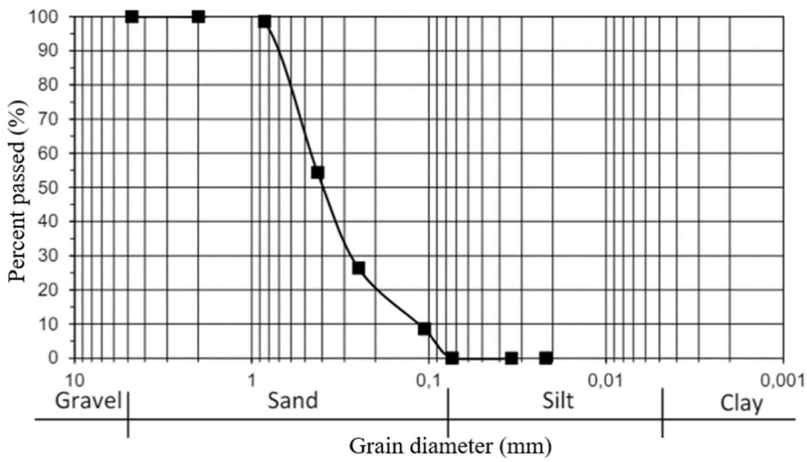


Figure 4. Distribution graph of soil grain sizes

Based on the graph above, the values of the initial soil grain fractions are as follows.

TABLE II. INITIAL SOIL GRAIN FRACTIONS

Description	*Fly Ash*
Gravel	0 %
Sand	54.39 %
Clay and Silt	0.12 %
Pass 200	0.1 %
D_{60}	0.47 mm
D_{30}	0.28 mm
D_{10}	0.14 mm
Cc	1.19 %
Cu	3.36 %

i. Soil Classification Based on the Unified Soils Classification System (USCS): Soil classification based on the USCS indicates that, according to the initial soil classification results from Congot Beach, Jangkaran, Temon District, Kulon Progo Regency, Special Region of Yogyakarta, it falls under the SP group. This classification denotes that the soil predominantly consists of coarse grains, characteristic of poorly graded sand, with minimal or no presence of fine particles.

ii. Soil Classification Based on the American Association of State Highway and Transportation Classification (AASHTO): Soil classification according to AASHTO can utilize Table 2 by utilizing the parameter of the percentage passing sieve No. 200. Based on the results of sieve analysis testing, the initial soil classification from Congot Beach, Jangkaran, Temon District, Kulon Progo Regency, Special Region of Yogyakarta, falls under the A-3 group, indicating fine sand soil type.

D. Direct Shear Testing

The purpose of this direct shear testing is to determine the shear strength parameters of the soil, namely cohesion (c) and internal friction angle (ø). This study comprises direct shear testing on initial soil samples and direct shear testing on initial soil samples stabilized with fly ash additives. The variations include fly ash addition percentages of 10%, 12%, and 14%, followed by curing periods of 3 days, 7 days, and 14 days. Each percentage variation involves testing with three sample specimens subjected to different loads: 0.25 kg, 0.5 kg, and 1 kg.

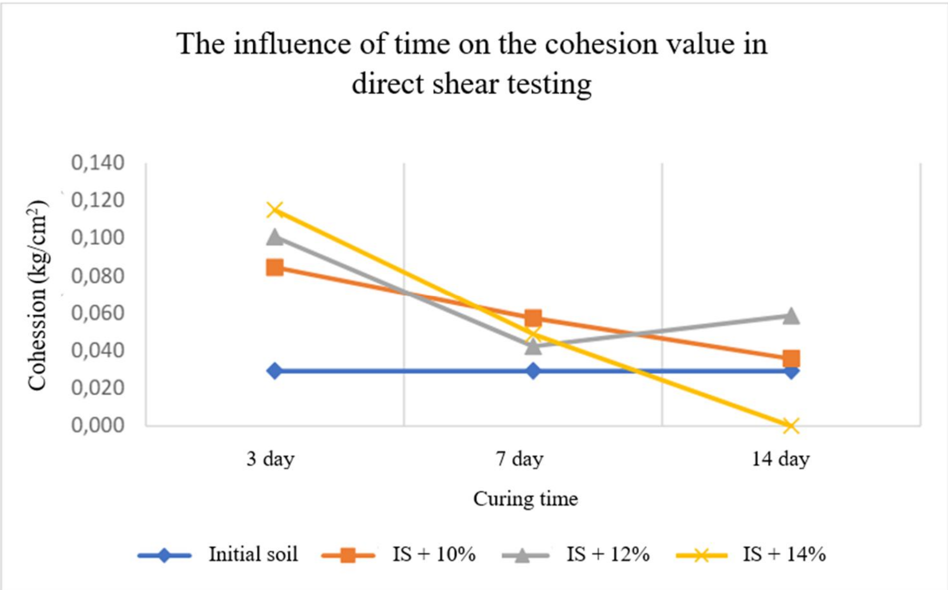


Figure 5. Cohesion values over curing time

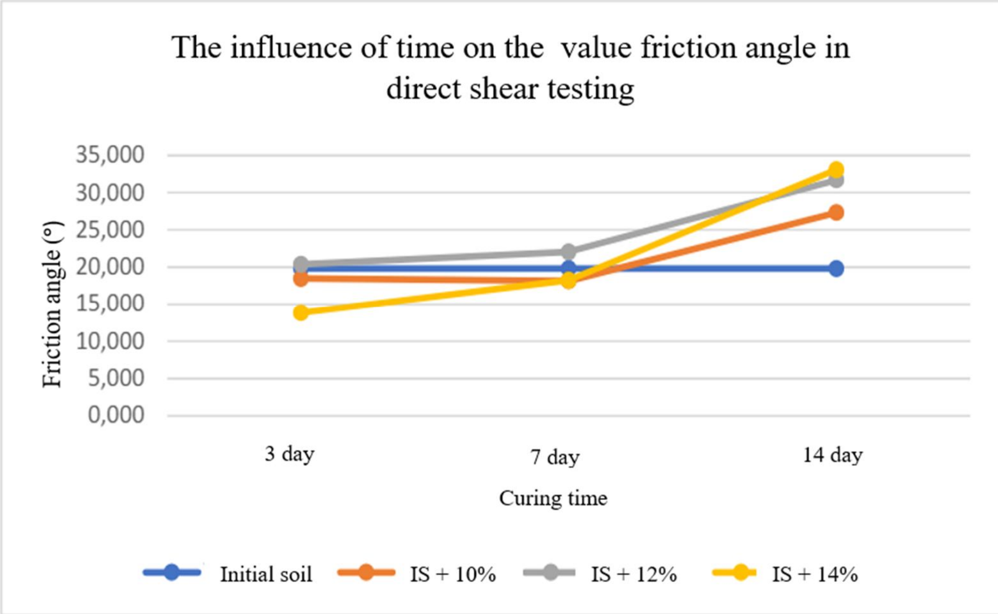


Figure 6. Direct shear values over curing time

Based on the graph figure 5 and figure 6, it is evident that the curing duration tends to increase the internal friction angle values of the soil. On the 3rd day, there is a decrease in the internal friction angle value at the 10% and 14% percentages, while an increase is observed at the 12% percentage compared to the 0% initial soil percentage. On the 7th day, an increase in the internal friction angle value occurs at the 10% percentage, while a decrease is observed at the 12% and 14% percentages compared to the internal friction angle value on the 3rd day. Subsequently, on the 14th day, there is an increase in the internal friction angle value at the 10%, 12%, and 14% percentages compared to the 7th day. Thus, the optimal curing duration is 3 days, as there is a decrease on the 3rd day at the 10% and 14% percentages, while a slight increase is observed at the 12% percentage compared to the initial soil, the cohesion value obtained is 0.115 kg/cm² with an internal friction angle of 13.880. Consequently, the curing duration significantly influences the increase in the internal friction angle value and is inversely proportional to the cohesion value

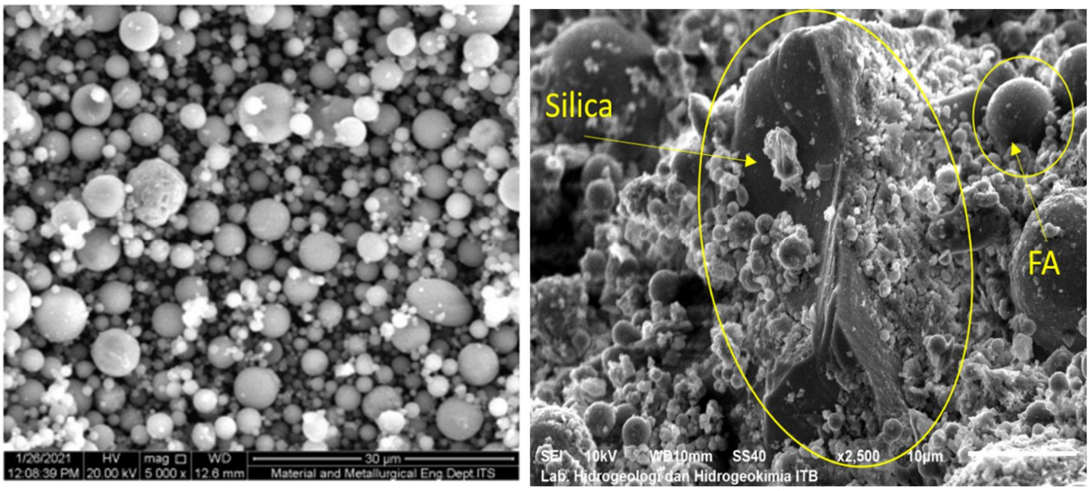
E. XRF and SEM test result

Together, XRF and SEM analyses offer a comprehensive understanding of the physical and chemical mechanisms underlying soil stabilization with fly ash. These insights are crucial for optimizing stabilization procedures, assessing the long-term stability and durability of stabilized soils, and informing the development of sustainable geotechnical engineering practices.

TABLE III. XRF FLY ASH TEST RESULT

Oxides	*Fly Ash*
SiO_2	19.5 %
Al_2O_3	7.5 %
Fe_2O_3	29.4 %
CaO	34.7 %
Na_2O	1.2 %
TiO_2	0.081 %
$SiO_2 + Al_2O_3 + Fe_2O_3$	56.4%
Other	6.5%

The table 3 indicates that the XRF results for fly ash show a calcium oxide (CaO) content of 34.7% and a combined content of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3) totaling 56.4%. This signifies that the fly ash content falls within the category of Type C fly ash, capable of enhancing inter-particle binding among sand soil particles to achieve greater strength and expedited stabilization. The SEM testing results of fly ash reveal that the particles exhibit a fine, spherical, and uniform shape, with varying sizes and a smooth surface texture, as depicted in Figure 7a.



(a) (b)

Figure 7. (a) SEM Fly ash test result (Zoom x5000), (b) SEM test result of soil stabilization (Zoom x2500)

At the optimal condition resulting from the shear strength test of soil with 12% fly ash addition and 14 days of curing, SEM analysis was conducted to observe how the bonding between sand grains occurred, solidifying the sample, thus increasing the soil's shear strength and bearing capacity. This is attributed to chemical reactions between the fly ash content and the grains, forming silica, as depicted in Figure 7b.

IV. Conclusion

The soil sample is classified as group A-3 according to the AASHTO classification method and as group SP according to the USCS classification method. Based on the Direct Shear test, the cohesion value obtained is 0.115 kg/cm² with an internal friction angle of 13.880°. The addition of fly ash to the tested sand soil has an impact on increasing the soil's shear strength parameter values. The increase in soil shear strength is influenced by the curing duration. The optimal value of the internal friction angle is achieved with a 12% fly ash addition. Chemical compounds form between fly ash and sand soil, resulting in silica that enhances particle bonding, thus solidifying the sand soil and increasing its bearing capacity and shear strength. A suggestion for further research is to increase the variations in percentage and curing time to determine the most optimal duration for the curing process in stabilization using fly ash on sandy soil. Additionally, additional testing can be conducted using triaxial testing to observe the increase in soil strength under three different loadings in unconsolidated undrain condition.

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