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Compressive Strength Characteristics of Trass Stabilized Dredged Soil

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ABSTRACT Landslides from Mount Bawakaraeng caldera in 2004 have caused high dam sedimentation at the lower reaches of the Jeneberang River. The availability of this large sedimentary material makes this material need to be considered as an alternative to new materials in the geotechnical field. However, the results of laboratory tests applied to sedimentary materials show that these materials' mechanical characteristics are insufficient for construction materials. Therefore, it is essential to study how to improve the quality of dredged soil by adding Trass as a stabilizing agent to improve the quality of the mechanical properties of the dredged soil. This study analyzes the mechanical characteristics of the dredged soil stabilized with Trass. The research was conducted by adding Trass with compositions of 3%, 6%, 9%, and 12%, respectively, to the dredged soil's dry weight. The curing time was applied for 3, 7, and 14 days to analyze the significant binding of Trass to the stabilized dredged soil. Laboratory tests were conducted on the density test and unconfined compression test. The results showed an increase in the maximum dry density of the dredged soil between 1.41% - 3.56% due to the addition of Trass and a decrease in the optimum water content between 0.8% - 2.7%. In addition, there was an increase in the value of unconfined compressive strength from 47.76% to 388.89% in the Trass stabilized dredged soil during the curing period of 3, 7, and 14 days. Using dredged soil and Trass as stabilizing agents can be an alternative option in soil improvement efforts based on the utilization of waste material and local content potential.

KEYWORDS Dredged Soil; Soil Stabilization; Trass; Compressive Strength; Waste Material.

1 INTRODUCTION

The Mount Bawakaraeng caldera landslides are known to cause high dam sedimentation downstream of Jeneberang River in 2004, leading to a great challenge that is associated with the reservoir capacity. This shows that sediment and other depositions at the upstream dam have caused great economic losses of water supply, as well as affected environmental and ecological problems. To maintain the maximum function of the dam, annual dredging activities have been applied at the Bilibili reservoir. From these activities, the geotechnical characteristics of dredged materials have become another important issue for consideration (Mohammad *et al.*, 2018), which needs to be deeply investigated to determine the conditions and prospects for its application. Several laboratory tests on this material indicated that its mechanical properties were insufficient for use in construction fields. However, the utilization of dredged soil as an embankment is one of the solutions consistent with eco-friendly activities in geotechnical engineering. The dredged soil has poor geotechnical properties and is often treated as waste (Huang *et al.*, 2010; Park *et al.*, 2016), although its use as a road embankment requires a high-density subgrade property (Selvam *et al.*, 2016). This explains the necessity to improve the geotechnical properties of the material until its appropriate use in the civil construction field. In this process, several reports emphasized stabilization for dredged soil, to determine a suitable improvement formula, specifically in the subgrade or subbase layer of road pavement or building foundation.

This stabilization often emphasizes physical (dynamic compaction) and chemical (cement, FA, lime, and hydrated lime) processes during different analysis (Murthy *et al.*, 2016), with all the available methods used to improve soil properties. Based on various studies, several satisfactory results were produced through the performance of soil stabilization with cement, lime, gypsum, class-F fly ash, fibre, etc. These results exhibited an increase in soil geotechnical properties, such as (1) unconfined compressive strength (UCS), (2) California Bearing Ratio (CBR), (3) direct shear strength, (4) ductility, and (5) soil workability

(Bowers *et al.,* 2013; Peddaiah and Suresh, 2017; Nguyen *et al.,* 2018; Harianto *et al.,* 2008). However, the performance of chemical stabilization through cement and lime was considered an environmental issue because of the production process (Das, 1995). This indicates the necessity for additional stabilization performances, using natural material derivatives such as Trass, which has been previously utilized by many reports as a pozzolana. Based on the results, the dredged sludge was successfully stabilized by combining natural pozzolana and lime (Zoubir *et al.,* 2013). Trass (natural pozzolan) is a derivative from the weathering of volcanic rocks and a mineral included in Group-C EM (Excavated Materials), as stated in Government Regulation 27/1980 concerning Classification of Excavated Materials (Indonesia, 1980). This is an excavated material with many feldspar and silica, including andesite breccia, granite, and rhyolite, which have undergone a weathering process. In this case, feldspar often turns into clay/kaolin and amorphous silica compounds. The main chemical contents of Trass include SiO_2 (silica oxide), Al_2O_3 (aluminium oxide), Fe_2O_3 (iron oxide), CaO (calcium oxide/quicklime), and other compounds, in relatively low levels (ASTM-C-618-92a 1998). This confirms that the stabilization of soil with fine pozzolanic matters commonly leads to particle binding and water-absorption reduction by its clayey components (Hossain and Mol, 2011). Therefore, this study aims to analyze the mechanical characteristics of Trass stabilized dredged soil, with tests conducted on both untreated and treated materials to determine density and UCS.

2 METHODS

This study was conducted using dredged soil and Trass as the original stabilized material and stabilization agent, respectively.

2.1 Dredged Soil

Dredged soil was obtained from Bilibili Dam in Gowa Province, South Sulawesi, Indonesia. The location of the collection quarry was at coordinates 5° 16′35.70″ S and 119° 34′50.09″ E. This soil is the waste material from the annual dam dredging activity, which was conducted to maintain the reservoir capacity. It is also treated as an unusable waste material, which sample colour is light brown with fine particle size, as shown in Figure 1.

Figure 1. (a) Dredged soil location; (b) Visual detail of dredged soil material on location (Source: Google Earth, 2020)

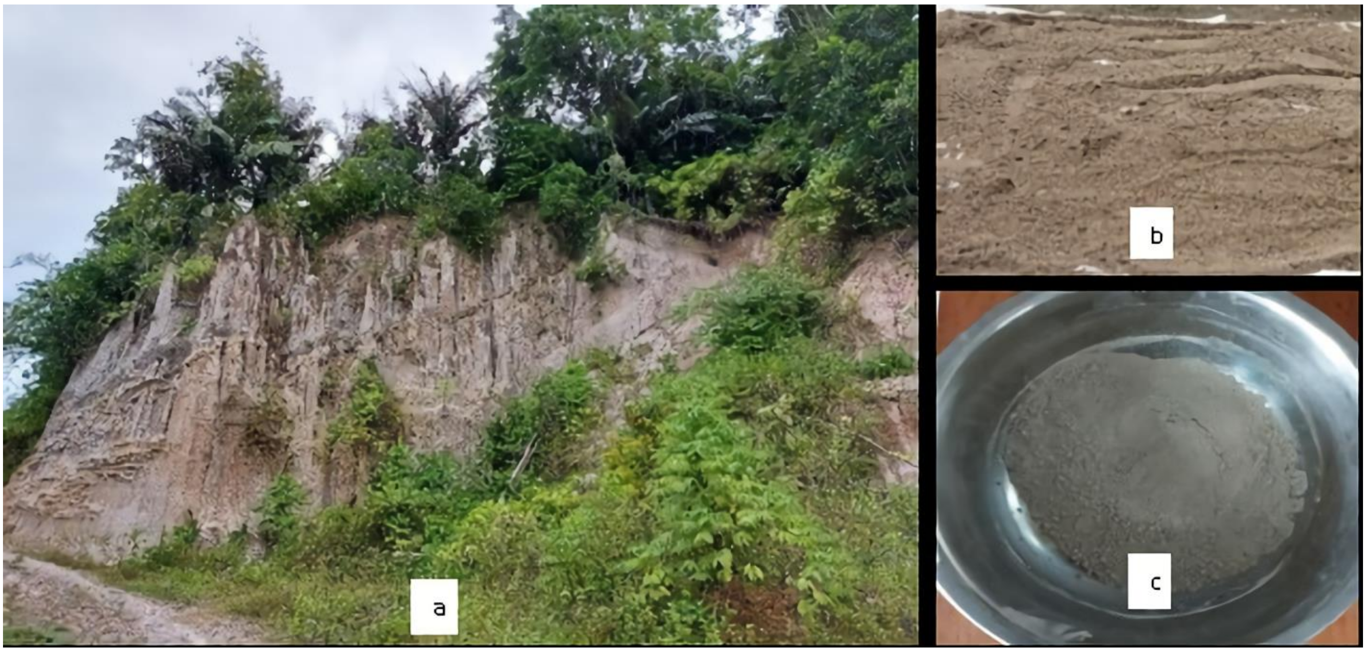


Figure 2. (a) Trass quarry; (b) Row material of Trass; c) Trass passing over sieve #200

2.2 Trass

Trass was used as a stabilizing material obtained from a quarry in Bone Bolango, Gorontalo Province, Indonesia, which collection location is at coordinates 0° 31.34'08" N and 123° 11' 37.47" E. The availability of this material is very abundant as slightly coarse and non-cohesive sand grains. Trass from the quarry will be dried to enhance easier processing and then crushed to obtain desired grain sizes. Using a 20-sized sieve, Trass was used to obtain very fine particles in providing an optimal surface area impact as a stabilizer for untreated soil. This proved that greater grain surface area led to higher expected effectiveness of the Trass as a stabilizing agent.

2.3 Test Method

Microstructural testing was applied on both dredged soil and Trass through X-RF and X-RD analyses, to determine the content of elements and the structure of the material providing crystallinity, respectively. In this process, the utilized soil was filtered and passed through sieve #10, with the extracted samples being in air-dry conditions or under optimum moisture content. Before mixing, the original water content was 5% below the OMC (optimum moisture content), which was then provided with an increment of approximately 2% until the derivation of the maximum dry density (MDD). Standard Proctor compaction procedures and apparatus were also used to compact the soil samples at several water contents. In addition, the energy of compaction was consistent with the data stated in ASTM Standard Proctor compaction tests, i.e., 600 kN/m^3 (ASTM-D698-07, 2007).

Figure 3. Compaction apparatus with Proctor Standard

Based on the provision of additives, subsequent analyses were conducted to increase the UCS value of the stabilized soil. Meanwhile, the elements test of these soil samples was conducted by adding Trass at the composition of 3, 6, 9 and 12%, respectively. To analyze the binding rate of the soil's stabilizing agent, curing periods of 3, 7, and 14 days were also applied. The element sample was then produced in a mould with a diameter and height of 5.5 and 11 cm, respectively. In this analysis, both untreated and treated soil was compacted with a cylindrical mould, at 25 blows for every three layers. This was in line with the standard proctor procedure for compaction.

The test specimens were then placed in the loading device, with the load applied to set an axial strain at 2 mm/min. This UCS machine provided the load, deformation, and time values at sufficient intervals. It also obtained the UCS value of untreated and treated soil samples, as well as the shape of the stress-strain curve.

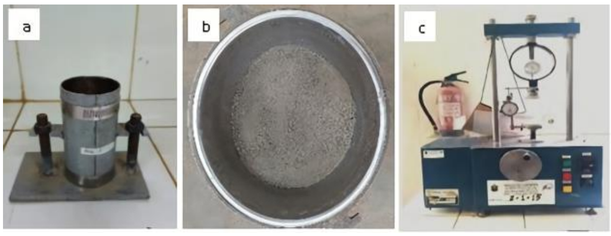


Figure 4. a) UCS mold; b) Specimen mixing bowl; c) UCS testing machine

3 RESULTS

3.1 Basic and Microstructural Properties of Dredged Soil

Based on the basic properties test, the dredged soil material contained 85% of silt, as well as a Specific Gravity and Plasticity Index (PI) values of 2.664 and 6.54, respectively. This indicated that the material was classified in the soft inorganic group with low plasticity (ML), according to the USCS classification system. Meanwhile, it was included in groups A-4 based to the AASHTO system. The basic properties of the dredged soil are presented in Table 1.

Table 1. Basic properties of dredged soil

Properties	Value
Specific Gravity, Gs	2.664
Water Content, (%)	11.26
Consistency limit	
Plasticity Index, PI (%)	6.54
Liquid Limit, LL (%)	38.53
Plasticity Limit, PL (%)	31.99
Shrinkage Limit, (%)	30.11
Grain size proportion	
Sand (%)	11.80
Silt (%)	85.30
Clay (%)	2.90
Soil Classification	
USCS	ML
AASHTO	A-4

The results of the microstructural analysis were also applied with X-RF (X-Ray Fluorescence) and X-RD (X-Ray Diffraction) tests. From the X-RF output, the dominant sediment elements contained Quartz (SiO_2) and Aluminium Oxide (Al_2O_3). Meanwhile, the dominance of Albite compounds (58.4%) with a crystalline phase was observed for the X-RD test. The complete results of these sedimentary analyses are presented in Table 2 and Figure 5.

Table 2. The constituent elements of dredged soil

Element	Value (%)
Quartz (SiO_2)	50.322
Aluminium Oxide (Al_2O_3)	36.175
Ferric Oxide (Fe_2O_3)	5.108
Calcium Oxide (CaO)	3.653
Potassium Oxide (K_2O)	3.268
Others	1.474

According to Table 2, the dredged soil contained several materials from the weathering of volcanic rocks. These materials had good bonding strength potential when combined with appropriate stabilization agents.

3.2 Microstructural Properties of Trass

The microstructural properties of Trass are presented in Table 3 and Figure 6.

Table 3. The constituent elements of Trass Lompoto'o

Element	Value (%)
Quartz (SiO_2)	60.928
Aluminium Oxide (Al_2O_3)	31.834
Calcium Oxide (CaO)	2.526
Ferric Oxide (Fe_2O_3)	2.443
Potassium Oxide (K_2O)	1.652
Others	0.617

The results showed that a 200-sized sieve was used to produce finer Trass particles with specific gravity (Gs) and water content of 2.687 and 0.74%, respectively. This was used during the X-RF tests, to observe the variation of the elemental contents, as shown in Table 3.

According to ASTM C618-92a, the natural/artificial Pozzolan categories containing a total content of $SiO_2 + Al_2O_3 + Fe_2O_3$ were more than 70%.

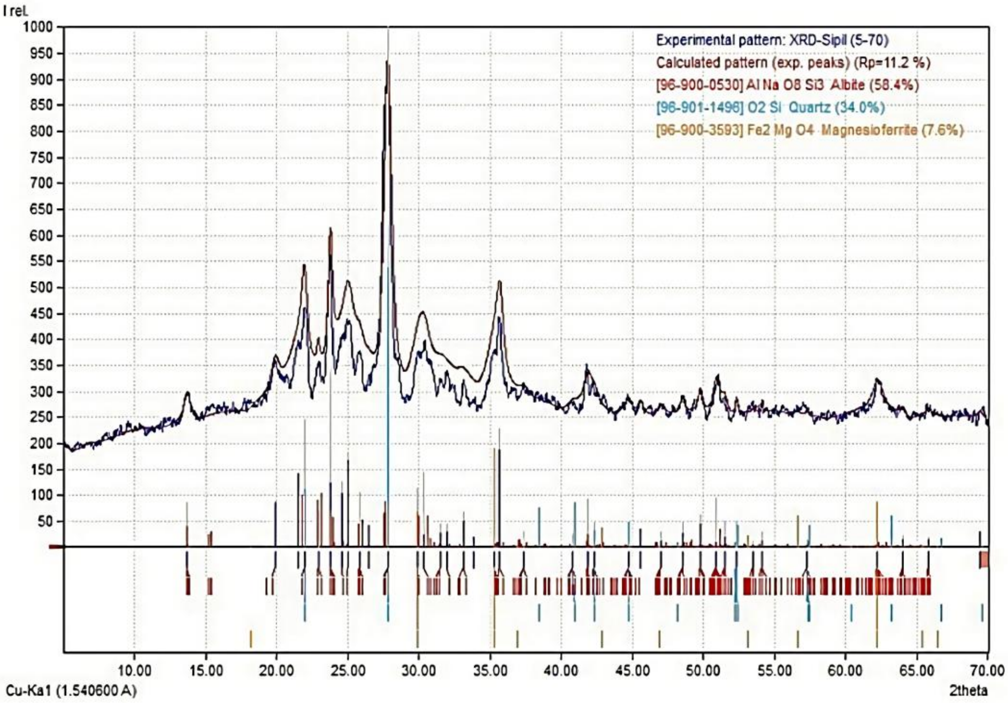


Figure 5. X-RD result of dredged soil

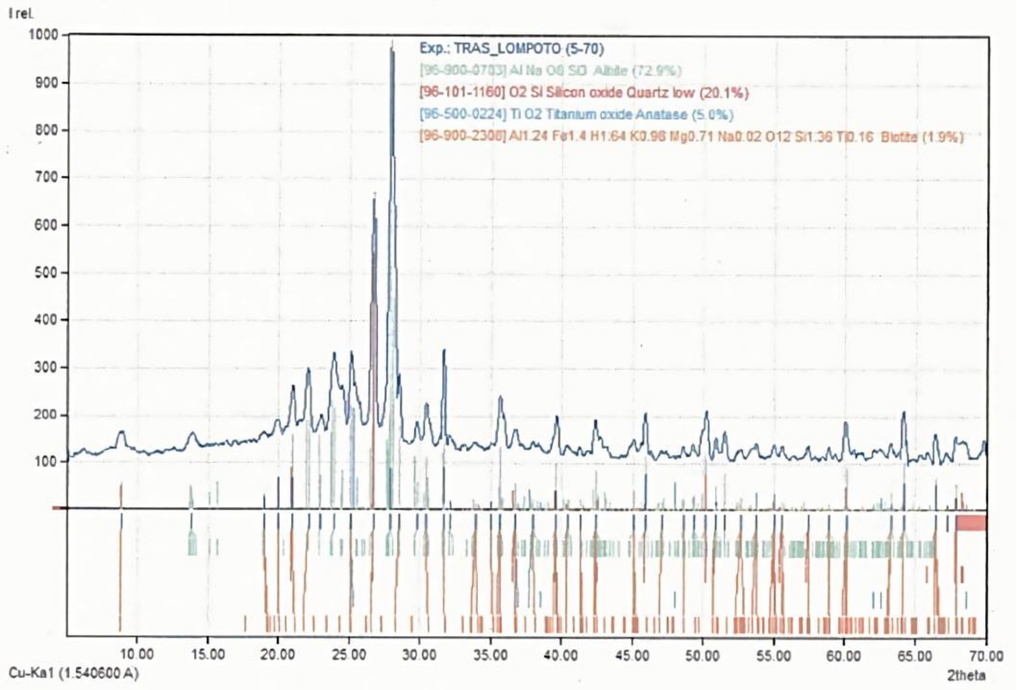


Figure 6. X-RD result of Trass Lompoto'o

This was not in line with the analysis of the basic properties, where several elemental compositions were consistent with the criteria of a natural agent. Therefore, Trass Lompoto'o was appropriately considered an additive and a stabilizing agent. For the X-RD test, the dominance of Trass was observed to be in form of Albite compounds (72.9%) with a crystalline phase, as shown in Figure 6.

3.3 Relationship of Dry Density-Moisture Content

A compaction test was used to determine the dry density-moisture content relationship of the soil, with the result shown in Figure 7. In this process, the maximum dry density of the treated soil was higher than the untreated. This proved that the maximum dry unit weight gradually increased with the elevation of the Trass content (Figure 8).

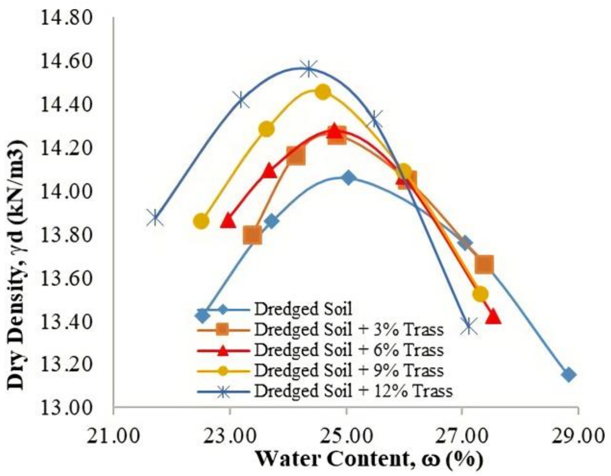


Figure 7. Dry density-moisture content relationships of the treated and untreated Dredged Soil

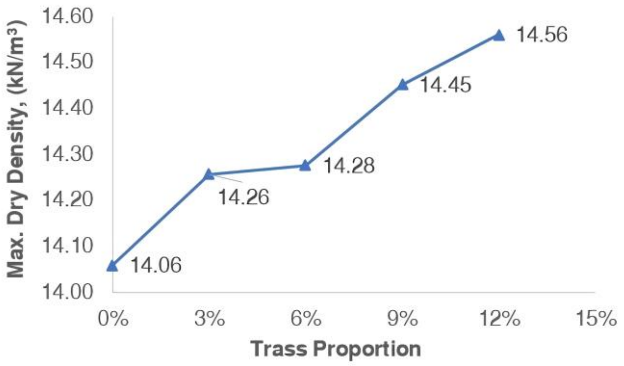


Figure 8. Increase of treated soil density due to addition of Trass

Based on Figure 8 and Table 4, the addition of Trass affected the increase of the maximum dry density value for the treated soil. This indicated that the stabilized soil density increase and optimum moisture content decrease were observed at 1.41-3.56% and 0.8-2.7%, respectively.Unconfined Compressive Strength of Trass Stabilized Dredged Soil

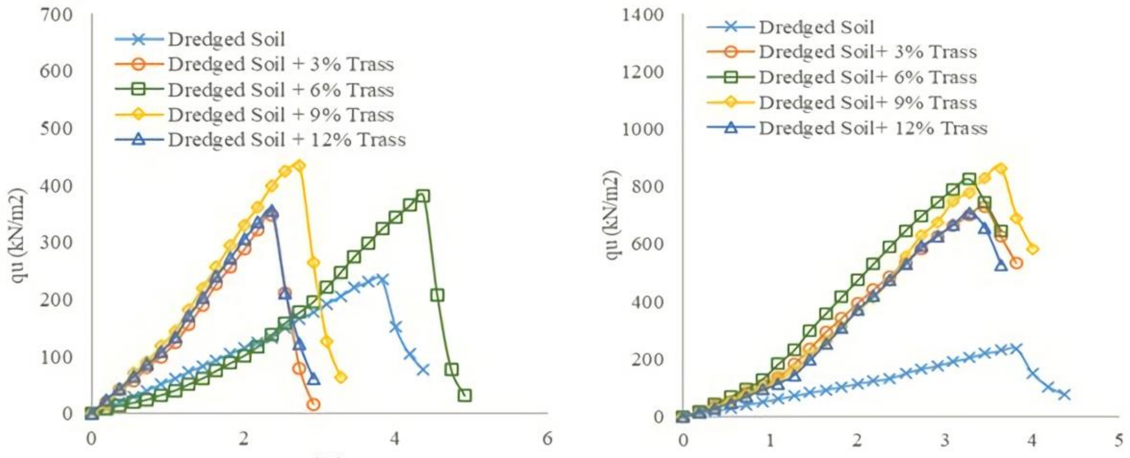
UCS tests were conducted on treated and untreated dredged soil. In this analysis, preparations were conducted by mixing the soil samples with Trass in varying proportions and predetermined optimum moisture content. These samples were compacted according to the standard compaction procedure and confined at room temperature for curing. Each proportion was tested on two identical samples, with load and deformation readings also recorded. As a stress-strain curve at several curing periods, the results of the UCS test are shown in Figure 9. According to Figure 9, the sample failure generally occurred at the strain values between 2.25-3.75%. In addition, the UCS values of the untreated and treated samples are presented in Table 5.

Table 4. Maximum dry density and moisture content value of each soil mixture with Trass

Soil	**γ_d (max)**	**ω**
	kN/m^3	%
Dredged Soil (Untreated)	14.06	25.04
Dredged Soil + 3% Trass	14.26	24.84
Dredged Soil + 6% Trass	14.28	24.80
Dredged Soil + 9% Trass	14.45	24.60
Dredged Soil + 12% Trass	14.56	24.36

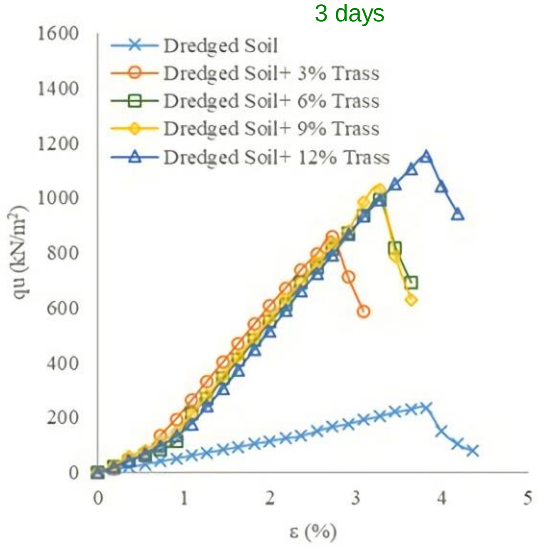
Table 5. UCS values of the untreated and treated at several curing time

Sample	Unconfined Compressive Strength (kN/m^2)			
	0 day	3-days	7-days	14-days
Untreated dredged soil	235.19	-	-	-
Dredged soil + 3% trass	-	347.51	729.22	856.28
Dredged soil + 6% trass	-	381.96	825.20	993.39
Dredged soil + 9% trass	-	433.43	863.99	1030.18
Dredged soil + 12% trass	-	355.46	709.57	1149.81



3 days

7 days



14 days

Figure 9. Stress-strain curves of Trass Stabilized Dredged Soil at 3, 7, and 14 days of curing time

In Table 5, the addition of Trass in various proportions increased the UCS value of the dredged soil for several curing times. This proved that the lowest and highest increases were 47.76 and 388.89% at 3 and 14-days curing, respectively.

4 DISCUSSION

The inclusion of Trass as a stabilization agent for dredged soil emphasized the performance of eco-engineering in the geotechnical field. This showed that Trass did not undergo an environmental pollution process during the provision of a stabilizing agent, compared to the cement and lime processing at the plant.

In this study, an increase was found in the treated soil density value than the untreated condition, indicating that the fine particles of the 200-sieve Trass were filled into the dredged soil voids during the compaction processes. This was in line with the UCS value of the treated soil, regarding the chemical bonding properties of the stabilizing agent. Ranging from 2 to 5 times, the UCS value increase for untreated soil had the potential to mechanically improve the geotechnical properties of the dredged soil.

Furthermore, the improvement of the stabilized material brittleness was observed, showing that Trass affected the brittle behaviour of the soil and provided a higher stress value. The curing time also proved that the Trass influenced the compressive strength elevation of the dredged soil sample.

5 CONCLUSION

A satisfactory result was obtained for the Trass-stabilized dredged soil analysis, as observed through the value increase of the density and

UCS of the treated material. The increased density and decreased optimum moisture content of the stabilized soil were also found at 1.41-3.56% and 0.8-2.7%, respectively. According to the stress-strain graph, the sample failure generally occurred between 2.25-3.75%, with the increase in UCS value ranging from 47.76 to 388.89%. These results have become the new insights related to soil stabilization in the geotechnical field. With the analytical processes still in the early stages of using Trass as a stabilizing agent, more aspects of the dredged soil's mechanical properties need to be futuristically investigated for further study.

DISCLAIMER

The authors declare no conflict of interest.

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