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Mechanical properties of dredged soil reinforced with natural pozzolan and shredded tires

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Abstract. The utilization of waste materials is still an interesting subject to investigate. The dredged soil (DS) was classified as a waste material that requires more effort to improve its mechanical properties. Adding natural pozzolan (NP) material and shredded tires (ST) can be an exciting field to investigate and quite friendly to the environment. This research objective investigates the mechanical properties of the dredged soil stabilized with natural pozzolan material and shredded tires as a new way of green engineering. This research involved trass as a natural pozzolan and shredded tires as car-used tires waste retreading factory. Basic and mechanical properties tests were investigated, including standard proctor, unconfined compressive strength (UCS), and direct shear of the stabilized dredged soil. The proportions of involved trass were 3%, 6%, 9%, and 12%, while the proportions of shredded tires were 2% and 3% to the maximum dry weight of the material sample. These mechanical properties tests were conducted in a curing period of 7, 14, and 28 days. This recent research shows an increase in the maximum dry weight of the stabilizing soil to the untreated soil by 0.5% - 1.7%. While for the compressive strength value, an increase in the UCS value by 175% - 324% was revealed. Furthermore, there was an increased shear strength value, and it was found that the increase in cohesion value (c) was 6% - 83%, and the increase in internal friction angle value (ϕ) was 31% - 98%.

Keywords: dredged soil, shredded tires, natural pozzolan.

1. Introduction

As a result of the landslide at the caldera of Mount Bawakaraeng in 2004, it increased the sedimentation rate in the Bilibili Dam. It is necessary to dredge sediment soil to provide an efficient river channel, construct an effective dam's storage, and maintain the downstream area of the river reach [1]. Dredged soil refers to any soil excavated or dredged from the water regime, pond, or dam's bottom. This dredged soil offers a vast and sustainable resource for various practical applications, including fill material, sub-grade construction, reclamation, landscaping, etc. However, many researchers report that the dredged soil cannot be used directly due to its poor geotechnical characteristics. [2] [3] [4] [5] [6]. Some of these properties are bearing capacity (qu) and shear strength (ϕ). Furthermore, it is necessary to investigate and find the solutions to the dredged soil problem.

There are many ways to stabilize the dredged soil. One of them is by adding cement. However, cement has stepped forward as a stabilizing agent with environmental consequences. CO2 emissions from cement production come from two sources: combustion (38%) and calcination (62%). CO2 emissions from combustion are related to fuel use, whereas emissions from calcination are produced when raw materials (mainly limestone and clay) are heated and CO2 is liberated from the decomposed limestone. Therefore, it is necessary to propose other stabilization efforts using natural pozzolan minerals. Adding a stabilizing agent like this is considered to be included in the stabilization effort that is friendly to the environment [7].

On the other hand, the growth of rubber waste as an impact of the waste tires automobile industry is increasing annually across the country. It poses the problem of disposal and adds to environmental contamination and health risks, utilization of such refuse, and industrial wastes [8]. Therefore, it takes an innovative effort to reuse this kind of waste. A relatively progressive thought will be involved in this research by combining the used shredded tires into dredged soil to produce a new alternative geo-material of the embankment that can be utilized. This research deals with the dredged soil from dredging activities at the Bilibili Dam and deals with waste materials from cars used tires factory activities.

Blending natural pozzolan minerals with shredded tires has been shown to provide benefits, specifically in terms of improving soil mechanical properties on the one hand and reducing environmental damage on the other. These properties can be enhanced by controlled compaction using mechanical equipment or by adding appropriate admixtures such as cement, fly ash, lime, or by reinforcing the soil with shredded tires, crumb rubber, plastic waste, etc [9] [10].

2. Materials

This research provides dredged soil, trass as a natural pozzolan, and shredded tires as the materials research. The following is an explanation of these three materials:

2.1. Dredged soil (DS)

The dredged soil used was obtained through dredging activities at the Bilibili Dam. This dredged soil has a specific gravity (Gs) of 2.66 and is mostly silt in grain size (85.3%). It has a plasticity index (PI) of 7% and a light cream color. According to the USCS soil classification system, this soil is classified as ML or silt with low plasticity. The basic properties of the dredged soil used are listed in the table below:

Table 1. Soil characteristic

Basic properties	Value	Unit
Gs	2.66	-
Sieve analysis		
Sand	11.8	%
Silt	85.3	%
Clay	2.9	%
Atterberg's limits		
PI	7	%
LL	39	%
PL	32	%
SL	30	%
USCS Classification	ML	-

2.2. Natural pozzolan (NP)

The natural pozzolan used in this study is trass. The trass was taken from a quarry in the Gorontalo Province district of Bone Bolango. The used trass has a specific gravity (Gs) of 2.69 and a grain size that passes through the #200 sieve. The dominant mineralogy content in this trass is silicon dioxide (SiO_2) at 61%, aluminium trioxide (Al_2O_3) at 32%, calcium oxide (CaO) at 3%, and iron trioxide (Fe_2O_3) at 2%, and the remaining minerals at 2%. According to ASTM C-618, this material is classified as a pozzolan material class-N if the percentage of SiO2 + Al2O3 + Fe2O3 is greater than 70%. The characteristics of the materials used in this study are presented below:

Table 2. Mineralogy of materials used

Mineral	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	Others %	G_s -	Grain size pass #200 %
Dredged soil	50	36	5	4	5	2.66	88
Natural Pozzolon (Trass)	61	32	2	3	2	2.69	100

2.3. Shredded tires (ST)

The shredded tires used in this study are from the shred of used tires in the vehicle tire retreading industry. It is black and contains only 0.80% moisture. The shredded tires retained at the #10 sieve are 29.72% of the volume of this waste material. The length of these shred materials is 20-30 mm, the thickness is 1-2 mm, and the width is 0.5-1 mm. The percentage of shredded tires used in this study was 2% and 3% by weight of the sample's dry weight.

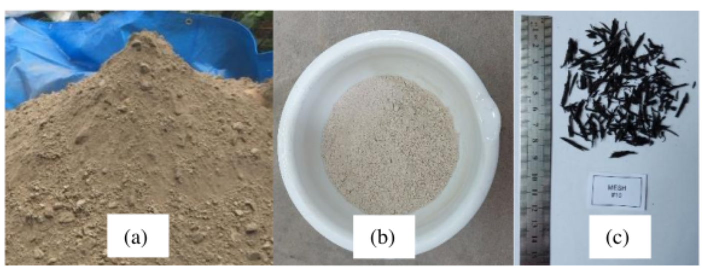

Figure 1. Material used, (a) Dreddeg soil; (b) Trass; and (c) Shredded tires

Experimental Methods and Test

A comprehensive series of laboratory tests on dredged soil was conducted to investigate the potential uses of treated dredged soil as fill material in transportation-related projects. The dredged soil was mixed with trass, a natural pozzolan material (3%, 6%, 9%, and 12% by dry weight), as well as shredded tires (2% and 3%). Index properties, compaction characteristics, unconfined compressive strength, and shear stress were tested on trass-rubber treated dredged soil.

The mechanical properties of the dredged soil mixed with trass and shredded tires will be determined. The maximum dry density and optimum moisture content of soil stabilized with trass and shredded tires were investigated using a standard proctor test (ASTM: D698-07). Unconfined compressive strength tests were also performed to determine the effect of this stabilizing effort (ASTM: D2166-06). A testing machine with a 2 mm/minute compression speed is used to evaluate the unconfined compressive strength sample. The element test samples were made by remoulding and compacted in three layers, with compaction energy is 600 kN/m^3.

Meanwhile, a simple direct shear strength test (ASTM: D3080-04) was performed by remoulding the sample at the maximum density of each predetermined composition to determine the shear strength parameter. A sample size of 6 cm in diameter and 2 cm in height was created. The sample was tested with three axial load variations with a shear load speed of 1.25 mm/minute. All element samples were cured for 7, 14, and 28 days, respectively.

4. Result and Discussion

4.1. Compaction with a standard proctor apparatus

The compaction value results from the standard proctor experiment of trass stabilization soil and shredded tires revealed that the value of maximum dry density of the soil increased by 0.5% - 1.7%, and the optimum moisture content increased by 3.8% - 4.7% as well. The following table shows the value of the density and moisture content of stabilized dredged soil:

Table 3. Maximum dry density (MDD) dan Optimum moisture content (OMC) of the stabilized soil

The proportion of Dredged Soil (DS) + Natural Pozzolan (NP) + Shredded Tires (ST)	Max. Dry Density (MDD) (γ)	Opt. Moisture Content (OMC) (ω)	Enhancement Percentage (%)	
	kN/m^3	%	γ	ω
0%	14.06	25.04	-	-
DS + 3% NP + 2% ST	14.15	26.22	0.6	4.7
DS + 6% NP + 2% ST	14.16	26.20	0.7	4.6
DS + 9% NP + 2% ST	14.25	26.10	1.3	4.2
DS + 12% NP + 2% ST	14.30	25.98	1.7	3.8
DS + 3% NP + 3% ST	14.12	26.17	0.4	4.5
DS + 6% NP + 3% ST	14.13	26.15	0.5	4.5
DS + 9% NP + 3% ST	14.22	26.05	1.1	4.1
DS + 12% NP + 3% ST	14.27	25.93	1.5	3.6

According to Table 3 above, the maximum dry density of all sediment dredged soil stabilized with natural pozzolan and shredded tires is greater than that of the original soil. The increase in the maximum dry density value can be an initial indicator of improved soil geotechnical properties due to mechanical effort.

4.2. Unconfined Compression Strength

The stabilized soil's compressive strength showed an increase in the value of the UCS. Adding 2% and 3% shredded tires increased 175% to 324% for acquiring 3%, 6%, 9%, and 12% natural pozzolans, respectively. The increase is depicted in the graphic below:

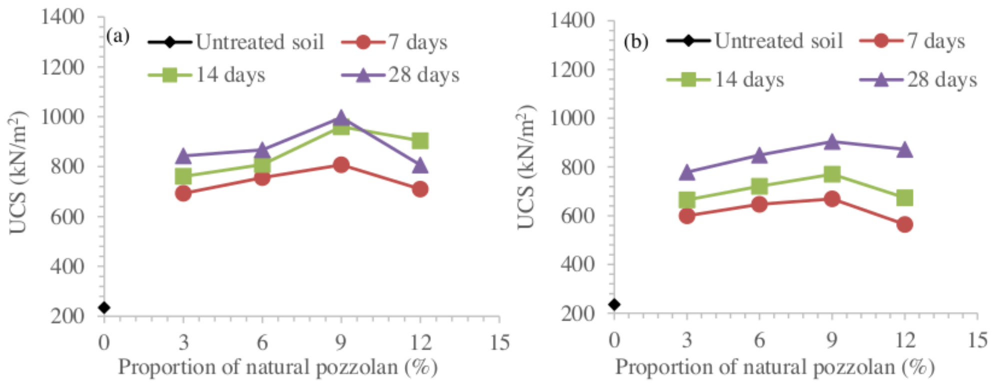

Figure 2. Increased UCS value, (a) soil with 2% shredded tires, (b) soil with 3% shredded tires

According to Figure 2, there is an increase in the UCS value in the stabilized soil. This increase occurred gradually and reached its peak with the addition of 9% natural pozzolan, both for 2% and 3% shredded tires. This condition indicates that the maximum amount of natural pozzolan added to the mixture of dredged soil and shredded rubber is 9%. The following table summarizes the normalized value of compressive strength test results on sediment dredged soil samples stabilized with natural pozzolan and shredded tires:

Table 4. The normalized value of the UCS increasing

Proportion	Normalized value (q_u/q_{uo}) of UCS					
	Adding 2% shredded tires			Adding 3% shredded tires		
	7 days	14 days	28 days	7 days	14 days	28 days
3%	2.9	3.2	3.6	2.5	2.8	3.3
6%	3.2	3.4	3.7	2.8	3.1	3.6
9%	3.4	4.1	4.2	2.8	3.3	3.8
12%	3.0	3.8	3.4	2.4	2.9	3.7

According to Table 4, all the compositions of shredded tires and natural pozzolan increased by 2.5 to 4.2 times at various curing times of 7, 14, and 28 days. This value demonstrates that the value of the unconfined compressive strength, which is related to the bearing capacity of this material, is of high quality and should be considered for use as embankment material. The increase in the value of the unconfined compressive strength of the stabilizing soil indicates that the incorporation of natural pozzolan and shredded tires significantly influences the improvement of its geotechnical properties, particularly for determining the bearing capacity of the embankment soil. It can be used to justify the decision to use this material as an alternative to a new soil embankment type.

4.3. Shear strength parameter

The direct shear strength test results indicated that the value of cohesion (c) increased by 6 % to 83%, and the value of the internal shear angle (ϕ) increased by 30% to 98%. This increase is substantial in enhancing the soil's shear strength. The increased parameters of the shear strength of the stabilized material also indicate an improvement in the mechanical properties of the stabilized soil. The following figures are the results of the direct shear strength test of the dredged soil stabilized with shredded tires and natural pozzolan:

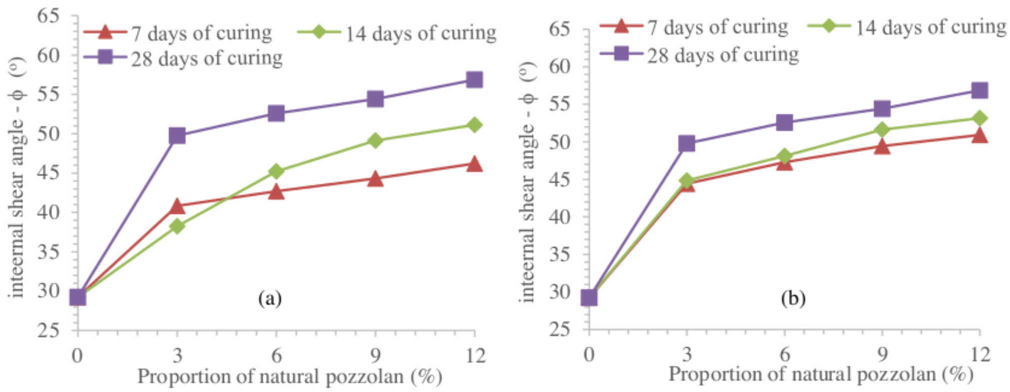

Figure 3. Increased of internal shear angle value, (a) soil with 2% shredded tires, (b) soil with 3% shredded tires

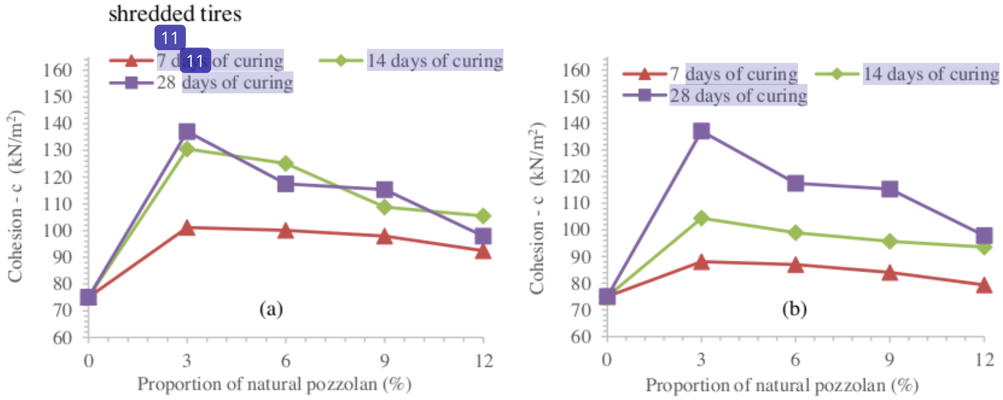

Figure 4. Cohesion value, (a) soil with 2% shredded tires, (b) soil with 3% shredded tires

Figure 3 demonstrates that the internal shear angle of the stabilized dredged soil, regardless of the proportion of natural pozzolan and shredded tires added, increased significantly compared to the untreated dredged soil. This increase is linearly proportional to the length of the curing period. It indicates that the stabilized dredged soil is improving over time. The increasing value of the internal shear angle demonstrates that the geotechnical conditions are improving, making it more suitable for use as a steep-sloped embankment.

Meanwhile, as shown in Figure 4, the cohesion value of the stabilized dredged soil increased when compared to the cohesion value of the untreated dredged soil. This higher cohesion value than the previous one contributed to the geotechnical properties of the dredged soil.

5. Conclusion

This study investigated the basic and mechanical properties of dredged soil stabilized with natural pozzolan and shredded tires using compaction, unconfined compression strength, and direct shear tests. Based on the results of these tests, it found that dredged soil of the Bilibili dam in the Gowa District, South Sulawesi, is typical of silt soil with a low plasticity index. Furthermore, there was an increase in the maximum dry density of the stabilized soil to the untreated soil by 0.5% - 1.7%, and the optimum moisture content increased by 3.8% - 4.7%. It also revealed that the compressive strength test of the stabilized soil had shown an increase of UCS value by 175% - 324%. Finally, there was an increased shear strength value, and it was found that the increase in cohesion value (c) was 6% - 83%, and the increase in internal friction angle value (ϕ) was 31% - 98%.

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