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Comparative Study of Soil Stabilization Using Ceramic Waste Powder and Glass Waster Powder as Additive

Nanda[1,*], Rafki Imani[1], Muhammad Mursyid[1], Ade Pratama[1]
Jurusan Teknik Sipil, Universitas Putra Indonesia YPTK, Padang[1]
Koresponden*, Email: *nanda_nanda@upiyptk.ac.id*

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Abstract

Clay soil is aproblematic soil that high swelling-shrinking properties, expands when given water, and shrinks when dry. One method to improve the clay soil that can be used is soil stabilization using additives or added materials. In this research, the additional materials used are ceramic waste powder (CWP) and glass waste powder (GWP) which will be mixed into clay soil at the location of Koto Baru Nan XX, Padang. From laboratory testing, it was found that the soil had an LL value of 73.75 and PI 19.98. Based on AASHTO, the soil is classified as A-7-5 (clay) with very poor GI value. The quantities of CWP and GWP used for each added ingredient are 10%, 15%, 20%, and 25%. The method used is an observation method which aims to analyze the physical and mechanical parameters of the soil before and after adding additional materials. The results of the test show that the plasticity index value using CWP and GWP additives decreased by 85% and 59%, respectively. The increase in UCS value when adding CWP and GWP is almost the same when adding 20%. The OMC value decreased by an average of 40% each with the addition of CWP and GWP. Meanwhile, the increase in MDD value in GWP is greater than the addition of CWP.

1. Introduction

*Soil stabilization is a technique used in civil engineering to improve and increase the mechanical strength, permeability, compressibility, durability, and plasticity of soils. Clay or silty soil has the geotechnical characteristics of swelling, becoming plastic when exposed to water, and shrinking when dry. Many studies have demonstrated that the mechanical characteristics of soil are significantly improved when various waste materials are added to clay soil. Reducing the amount of waste materials in landfill is made possible by using waster materials for soil stabilization [1]. The use of replacement materials offer cost reduction, energy savings, arguably superior products, and fewer hazards in the evironment [2]. Using locally available resources and waste materials should be supported for sustainable development in order to preserve natural resources for future generations. These waste products carriages a serious enviromental problem if it is not disposed properly [3]. The aproximate chemical composition of glass powder and ceramic powder can be seen in **Tables 1** and **2**.*

Rathore and Tiwari observed that a decreasing pattern in swelling pressure was obtained in clay-ceramic composites with increased ceramic waste content [4]. Experiment by Dewi [5] showed that the substitution of 15% ceramic powder in the soil makes a dominant contribution to changing the physical properties of the soil. The stress value increases after mixing ceramic waste are related to mechanical properties, and the longer incubation day, the higher the swelling volume and the highest swelling volume in a mixture of 5% ceramic waste or minimum percentage [6]. The optimum moisture content of the clayey soil decreases as the percentage of ceramic waste increases, and MMD is obtained at a certain optimum content of ceramic waste and decreases beyond this optimum content of ceramic waste [7].
Nifana [8] found that at a 70:30 mix of soil and ceramic powder, the liquid limit reduces from 33% to 42%, sub-grade soil is reduced from CH to CL, and the CBR increases from 1.7% to 2.2%.

Percent glass powder that finer than 75 µm exhibited better results than those exhibit by particle between 425 µm and 75 µm in terms of increase of strength and decrease in volume change susceptibility of modified subgrade soils [9]. A study by Salih et al., [1] the mix of 7.5% glass powder and 5% lime provided the best improvement for the soil strength, as the strength increased by 166.06%, according to the findings of UCS, which were considered to be the primary indicator used to evaluate the performance of glass powder as a stabilizer. Based on experiment by Niyomukiza et al. [10] it was noted that gradation and consistency limits improved greatly, which in turn improved the strength properties of the soil. The UCS revealed that 7% glass powder greatly improved the strength properties in the study area. A comprehensive review by Sherwany et al. [11] the content of *waste glass for soil stabilization range from 2% to 25%. When an appropriate amount of waste glass is mixed with soil, it makes particles more easily rearrange to a dense state thus increasing the MDD and soil strength, such as UCS and CBR. However, when an excessive amount of waste glass is used, it may reduce soil strength. Blayi et al. studied that the free swelling of untreated and treated expansive soil decreased by 83.3% due to an increase in the percentages of GWP up to 25%. The thickness of the sub-base layer of the road was decreased by 37.5% with an increase in the percentages of GWP up to 15% [12]. The percent of glass powder such used must be constrained, high percent makes soil similar to sand; the reduction in soil cohesion with increasing of friction angle will occurs and fail in shear, while low percent may noticeably effect on improvement [13].*

Table 1. *Chemical composition of waste ceramic powder [14]*

Constituent	%
Silicon dioxide (SiO_2)	66.57
Aluminium Oxide (Al_2O_3)	21.60
Sodium Oxide (Na_2O)	1.41
Iron Oxide (Fe_2O_3)	1.41
Calcium Oxide (CaO)	2.41
Potassium Oxide (K_2O)	2.79
Zirconium Oxide (ZrO_2)	1.49

Table 2. *Chemical composition waste of glass powder [15]*

Constituent	%
Silicon dioxide (SiO_2)	71.09
Aluminium Oxide (Al_2O_3)	3.52
Sodium Oxide (Na2O)	10.46
Iron Oxide (Fe_2O_3)	1.77
Calcium Oxide (CaO)	10.59
Magnesium Oxide (MgO)	1.56
Potassium Oxide (K_2O)	0.89
Loss of Ignition (LOI)	0.60
Sulfur trioxide (SO_3)	0.03

Solid materials can be used for soil stabilization in place of conventional stabilizer like lime [7]. Stabilization using ceramic waste and glass waste materials, which can applied to enhance clayey soil characteristics. It is relatively easy to get CWP and GWP at numerous manufacturing sites and construction sites. In order to reduce the amount of these waste materials ans consequently the environmental impact of disposal into landfills, the current study compares ceramic waste powder (CWP) and glass waste powder (GWP) in geotechnical applications, particularly strength improvement and road subgrade design.

2. Method

The clay soil was collected from Padang City's Kelurahan Koto Baru Nan XX. A series of laboratory tests were carried out to determine its consistency limit, optimum moisture content (OMC), maximum dry density (MDD), and unconfined strength test (UCS). The mixture used is ceramic waste powder (CWP) and glass waste powder (GWP). Based on previous research, the use of CWP and GWP additives in clay soils is usually above 15%, while in sandy soil, additions of less than 10% can be used. The content of water glass utilized for soil stabilization ranged from 2% to 25% [11], while the addition of ceramic waste is in the range 2% to 30% [4]. Therefore, this research uses the proportions of each mixture is 10%, 15%, 20%, and 25% added to the soil to find out the test value that have been mentioned or can be seen in ***Table 3****.*

Table 3. *Scenario of soil stabilizations*

Scenario	Admixture
Scenario 1	Clay soil + 10% CWP
Scenario 2	Clay soil + 15% CWP
Scenario 3	Clay soil + 20% CWP
Scenario 4	Clay soil + 25% CWP
Scenario 5	Clay Soil + 10% GWP
Scenario 6	Clay Soil + 15% GWP
Scenario 7	Clay Soil + 20% GWP
Scenario 8	Clay Soil + 25% GWP

Consistency limits

*One of the basic measure of characterisrics of fine-grained soil is the Atterberg's limits (****Table 4, 5****). The soil can appear in four different states: solid, semi-solid, plastic, and liquid, depending on the amount of water in the soil.*

Table 4. *Typical values of LL and PL [16]*

Soil Type	LL	PL
Silts	24 – 27	16 – 20
Clays	80 – 100	45 – 54
Kaolinite	35 – 100	15 – 60
Illite	55 – 120	20 – 70
Montmorillonite	100 – 800	50 – 700

Table 5. *Typical values for degree of expansion [17]*

PI	Degree of Expansion
>35%	Very high
25 – 41	High
15 – 28	Medium
<18	Low

Unconfined Compressive Strength

*Unconfined compressive strength test is an experiment that aims to determine the free compressive strength (without any horizontal pressure), q_u in undisturbed or remoulded soil and also to determine the degree of soil sensitivity [18] (**Table 6**). With the addition of CWP and GWP mixtures, it is expected that the strength of the soil will increase, the soil will become better, and the test will be conducted based on ASTM D2166/D2166M-13 [19].*

Table 6. *Unconfined compression strength values [16]*

Soil Consistency	q_u (kPa)	q_u (kg/cm^2)
Very soft	<25	<0.25
Soft	25 – 50	0.25 – 0.50
Medium	50 – 100	0.50 – 1.00
Stiff	100 – 200	1.00 – 2.00
Hard	200 – 400	2.00 – 4.00
Very hard	>400	>4.00

Compaction Test

The process of mechanically compacting soil grains results in air evading from the soil pore space, which increases the density of the soil. The purpose of compaction experiments is to determine the optimum dry density (γ_{dry}) and optimum moisture content (W_{opt}) of soil samples with a given energy. The optimal dry density of the soil can be used to calculated the level of soil density. Compaction testing follows ASTM D1557-12 guidelines [20].

3. Result and Discussion

***Table** 7 shows the original soil sample properties at Padang City's Kelurahan Koto Baru Nan XX Baru.*

***Table** 7. Soil properties of sample [18]*

Properties	Value	Standard
Water content (%)	61.17	ASTM D2216
Specific gravity	2.61	ASTM D854
Sieve analysis:		
Passing #200 (%)	97.15	ASTM D422
Retained #200 (%)	2.85	ASTM D422
Liquid limit (%)	73.75	ASTM D4318
Plastic limit (%)	53.77	ASTM D4318
Plasticity index (%)	19.98	ASTM D4318
Sensitivity	2.14	ASTM D2166
Optimum Moisture Content (%)	48.06	ASTM D698
Maximum Dry Density (g/cm^3)	1.28	ASTM D698
California Bearing Ratio	2.65	ASTM D1883

Based on AASHTO, the soil is classified as A-7-5 (clay) with very poor GI value. This soil samples have low strength and are unsuitable for subgrade materials. However, the USCS classifies the soil as sandy elastic silt. Changes in soil properties due to the inclusion of added materials are presented and discussed appropriately.

Consistency Limit

*The Atterberg limit test was carried out to compare the effect of CWP and GWP mixtures on the consistensy limit of clay soil. With the addition of CWP and GWP, the PI of clay soil reduces [10], [21]. The outcome of the plasticity index are shown in **Table 8**. **Figure 1** shows the effect of each mixture at a percentage of 10%, 15%, 20%, and 25% on the plasticity index. A decrease in soil plasticity indicates a reduction in the modified of swelling characteristics, which in turn leads to an improvement in its physical properties. The value of PI falls sharply by 73% with addition 10% CWP and keep falling until 20% of CPW is added. When 25% of CWP is added, the value of PI increases to 2.19. The value of PI drops by 52% when 10% GWP is added, and it keeps going down until 20% of GWP is added. When 25% GWP is added, the value of PI increases slightly to 7.52. It can be seen that the addition of CWP produces a greater decrease in the PI value than GWP.*

Table 8. *Effect of addition of CWP and GWP on plastisity index (PI)*

%	Plasticity Index	
	CWP	GWP
0	19.98	19.98
10	5.34	9.68
15	3.3	8.03
20	1.14	7.17
25	2.19	7.52

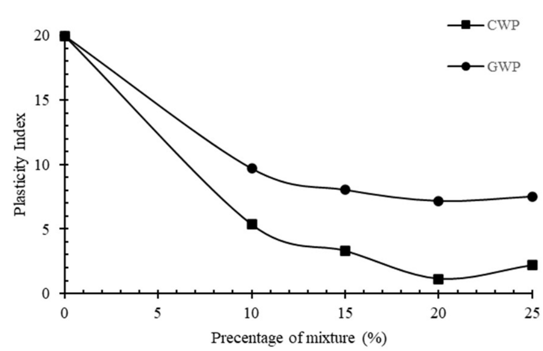

Figure 1. *Effect of mixtures on plasticity index*

Unconfined Compressive Strength

Based on laboratory tests, the sensitivity value (ST) of the original soil sample was found to be 2.14, when the q_u (unconfined compressive strength) value of the sample was 0.29. The effect of CWP and GWP on the unconfined *compressive strength for the stabilized soil samples is shown in **Table 9**. The addition of 10% CWP, the q_u value in soil sample increased considerably to 0.67, and continued to increase until the addition of 20% was 0.83. When 25% of CWP added, the q_u value slumped to 0.74. In the same case, when GWP was added by 10%, the q_u value in the soil sampel rose to 0.40, and continued to increase until the addition of 20% to 0.61. From **Figure 2** it can be seen that the maxium q_u occurs at an addition of 20%. On addition of more that 20% the value of q_u decreases again. These results are comparable to those that [12], [22], [23] reported.*

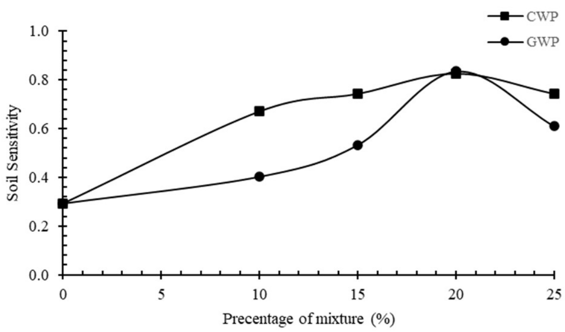

***Figure 2.** Soil sensitivity of at various percentages of CWP and GWP*

***Table 9.** Soil sensitivity of various percentages*

%	Soil Sensitivity	
	CWP	GWP
0	0.29	0.29
10	0.67	0.40
15	0.74	0.53
20	0.83	0.84
25	0.74	0.61

Compaction

*The MDD and OMC values of the original soil sample were 1.29 and 48.06, respectively. The MDD and OMC at various persentation of CWP and GWP can be seen in **Table 10**. A 10% increase in CWP resulted in a 5% increase in MDD to 1.35 and a 40% decrease in OMC value to 28.93. When GWP added to soil 10%, MDD increased as well. The MDD value increased by 2% reaching 1.31, while the OMC value reduced by 41% reaching 28.40. CWP and GWP mixtures both increased up to 25% additions, while the OMC values continued to decrease up to 25% additions. The observation of increasing MDD and decreasing OMC (**Figure 3, 4**) is in line with the outcomes reported by a few other studies [4], [7], [10], [22].*

***Table 10.** MDD and OMC at various persentation of CWP and GWP*

Admixture	MDD	OMC
Clay Soil	1.28	48.06
Clay Soil + 10% CWP	1.35	28.93
Clay Soil + 15% CWP	1.36	27.65
Clay Soil + 20% CWP	1.37	27.02
Clay Soil + 25% CWP	1.38	26.51
Clay Soil + 10% GWP	1.31	28.40
Clay Soil + 15% GWP	1.34	26.94
Clay Soil + 20% GWP	1.43	26.40
Clay Soil + 25% GWP	1.44	25.40

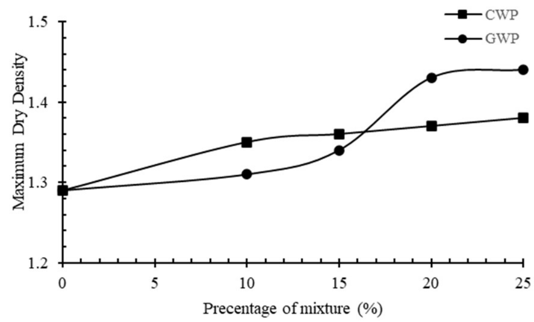

***Figure 3.** MDD at various percentages of CWP and GWP*

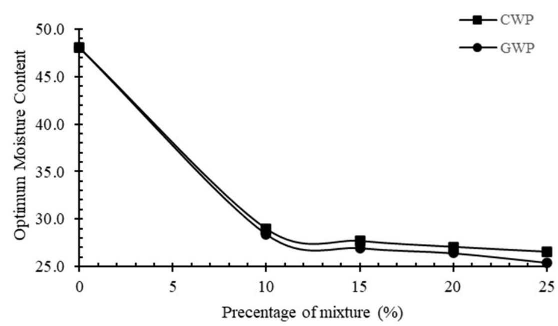

***Figure 4.** OMC at various percentages of CWP and GWP*

4. Conclusion

We use laboratory testing is used to analyze the physical and mechanical properties of clay soil added with CWP and GWP soil materials. From the Atterberg limit test, it was found that the maximum decrease in the PI value was obtained with the addition of 20% CWP and GWP. With the addition of 20% CWP, the UCS value increased to 94%, whereas with the addition of 20% GWP, it increased to 64%.

From the UCS test, with the addition of 20% CWP and GWP, the soil strength increased 182% and 185% respectively. In compaction testing, the OMC value decreases to 40% and MDD increases to 6 to 7%.

This explanation makes it clear that 20% is the appropriate amount for soil stability. If we consider the *increase in the percentage of added materials, it can be conclude that the addition of CWP is more significant than the addition of GWP.*

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