International Journal of GEOMATE, March., 2024 Vol.26, Issue 115, pp.124-133
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2024.115.4215
Geotechnique, Construction Materials and Environment

DETERMINATION OF OPTIMUM CEMENT CONTENT FOR SILTY SAND SOIL STABILIZATION AS THE BASE COURSE

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*Corresponding Author, Received: 09 Nov. 2023, Revised: 29 Jan. 2024, Accepted: 30 Jan. 2024

ABSTRACT: The aggregate base course is important in the flexible pavement structure, requiring quality materials. In areas where quality material is difficult to find, local soil stabilization using cement is needed to obtain material to replace the aggregate base course. This study aimed to determine the optimum cement content in stabilizing sand-silty soil that meets the requirements specified in the General Specification of Highways 2018 for Road and Bridge Works and to find the effect of pH-soaking water. The research was conducted in the laboratory by testing the Unconfined Compressive Strength of soil cement using variations in cement content of 3%, 5%, 8%, and 10% of the dry weight of soil, soaking time of 3, 7, 14, and 28 days; and pH of soaking water (tap water with a pH value of 8, water with pH value of 4 (containing H_2SO_4), water with pH value of 9 (containing NaOH)). Cement content of 8% and 10% meets the minimum UCS value according to road specifications. The optimum cement content (which produces the UCS target specification value of 2353.60 kPa) is 9% on the seventh day. Soaking water with pH 4 and 9 decreased the UCS of soaking water with a pH value of 8. A soil cement base course can substitute an aggregate base course in areas with inadequate aggregate material with an 80% CBR value.

Keywords: Soil stabilization, Cement, Base course, Unconfined compressive strength

1. INTRODUCTION

The base course is important for flexible pavement structures because it provides a stable and solid foundation for the upper layer and avoids inevitable cracks or settling over time [1]. So, the base course materials must be sturdy and quality and meet multiple requirements. One of the requirements for base course material, according to AASHTO 1993 [2], is to have a CBR value ≥ 80%. Materials with a CBR of more than 80% can be used as road-based course materials. Materials that can meet this CBR value are aggregates. In addition to aggregate, the soil cement base course can be used as a base course for flexible pavement. This base course is usually used for areas that lack aggregate material [3].

The soil-cement base course is made of soil stabilized with cement to increase soil strength [4]. Cement is a binder often chosen from several types of binders in soil stabilization, either used alone or combined with other substances such as lime [5], volcanic ash [6], and others. Cement is often used for local soil improvement in highway works such as subgrade, subbase, and base course because cement is easy to obtain and economical [7]. Cement stabilization will be effective for cohesionless soils until adequately cohesive to produce increased compressive strength but not adequate for highly plastic soils [8]. Based on [9], non-cohesive soil can be stabilized with cement if the plasticity index is ≥12. Meanwhile, stabilization for cohesive soil with high plasticity (Plasticity Index ≥ 35) uses materials such as lime, lime-cement mixture, lime-fly ash, or lime-fume silica [10,11].

The strength of soil stabilized with cement can increase due to the strong bonds between soil particles and the reaction between cement and water. The reaction between cement and soil is called a hydration reaction. It produces hydrated compounds that have cementing properties, namely calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which play a significant role in increasing soil stabilization strength with cement [12]. The water needed for hydration is only around 0.25 percent of the weight of cement required [13].

Several studies have been conducted on soil cement as a road base course. Research [14] found that MH (A-7-5) soil with high plasticity requires 6% Portland cement (CEM II) to obtain CBR and UCS values of 201.5% and 3.07 MPa, respectively. This value meets the standards as a base course pavement based on the CEBTP (Experimental Center for Research and Studies in Building and Public Works) pavement design manual for tropical countries. The research conducted by [15] used three types of soil from Thailand, namely clay/CL (A-7-5) low plasticity, laterite-sand soil poorly graded/SP (A-1-b) non-plastic, and sand soil well graded/GW non-plastic. The test results showed that sand, laterite, and clay soils require 4%, 6%, and 7.5% Portland cement type 1 to achieve UCS grades that meet road requirements in Malaysia. Research from [16] used high plasticity silt soil / MH (A-7-5) from Malaysia stabilized with Ordinary Portland Cement (OPC) CEM-I. The soil requires 6% with a curing time of 7 days sufficient to stabilize laterite soils to achieve a minimum UCS value of 0.8 MPa and a CBR value of 80%, following the Malaysian Public Works Department standard for low-volume roads and gravel road replacement.

In the soil cement base course, the strength criteria are based on the value of Unconfined Compressive Strength [17]. From some of these studies, many have used UCS value criteria for determining cement content in soil stabilization for the base course of the road and have been applied to several types of soil, but silty sand soils are still rare. Research [18] uses sandy soil but is stabilized with a mixture of lime-silica fume and road subgrade. So, this research uses non-plastic coarse aggregate soil (especially silty sand soil) to increase the UCS value of silty sand soil to become a base course for flexible pavement.

The objectives of this study were to determine the optimum cement content in stabilizing sandy-silt soil that meets the requirements specified in General Specification of Highways 2018 for Road and Bridge Works for soil cement base course of pavement and determine the effect of the pH of soaking water. The optimal cement content is determined if it reaches an unconfined compressive strength value that meets the requirements of General Specification of Highways 2018 for Road and Bridge Works [19], namely 1961.33 - 3432.33 kPa (target 2353.60 kPa) with a curing time of 7 days. The pH of immersion water will also be discussed to determine the effect of the soil cement base course of pavement if submerged in acidic pH (acid rainwater) and alkaline (sea water). SEM-EDX analysis was conducted for further evaluation to provide insight into the factors influencing the increase in UCS value. The results of this research can provide an alternative aggregate base course material by utilizing local materials that do not meet the requirements of an aggregate base course.

2. RESEARCH SIGNIFICANCE

This study uses local soil in the Karanganyar area stabilized with cement to obtain materials that can be used as a base course for flexible pavements. The determination of the cement content used is based on the value of its unconfined compressive strength in Indonesia (UCS value 1961.33 - 3432.33 kPa), and its value is limited because if the higher the cement content, the higher the UCS value, but the UCS value that is too high will cause a crack of the soil cement base course easily. If the UCS value is much lower than the requirements, the base course cannot support heavy traffic loads, which will easily be damaged. In addition, to determine the effect of rainwater on the structure of road pavements, this study also varied the pH of soaking water before being tested for UCS. Indonesia is a tropical country that experiences rainy and dry seasons. Rainwater is acidic (pH<5); if it floods the road, it will affect the road layer material, such as the soil cement base course. The carrying capacity of the cement soil base course will decrease because it destroys the bond between the cement and the soil.

Meanwhile, an alkaline pH (roads near the sea) will cause the soil cement base course to crack easily, reducing its strength. Soaking water with acidic and alkaline pH will affect the performance of the base course, so in this research, immersion was carried out in pH water. The results showed that the sand-silty soil-cement mixture can be used as a substitute for the base course of pavement.

3. EXPERIMENTATION PROGRAM

3.1 Materials

The soil sample was provided from the cliff excavation beside the road of Matesih-Jatiyoso situated in Tunggulrejo Village, Jumantono District, Karanganyar Regency, Central Java. The soil is first taken to the laboratory and air-dried in the sun because the test specimens from the field are in damp/wet conditions, and so the soil becomes loose and not in lump form, so it is easy to filter. The drying temperature is limited to 60°C to avoid losing crystal water, especially peat, and soil containing gypsum [20]. The soils were screened through a sieve with a 4.75 mm aperture before preparing the specimens for testing. According to the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO), the soil can be classified as silty sand soil (SM) and belongs to group A-2-4. This soil has some such properties: specific gravity 2.57, plastic limit 27%, gravel 3.83%, sand 67.93%, silt 14.53%, optimum moisture content (OMD) 19.17%, maximum dry density (MDD) 1.519 g/cm^3, and UCS 102.97 kPa. The index properties of the soil sample are presented in Table 1.

The base course of pavement requirements in Indonesia follows the specified in General Specification of Highways 2018 for Road and Bridge Works [19] and refers to AASHTO, ASTM (American Society for Testing Materials), and ACI (American Concrete Institute). Jumantono soil contains fine aggregate (clay), liquid limit, aggregate size, and CBR value that does not meet the requirements for road aggregate base course material in Indonesia [19] even though the plasticity index value meets that it requires improvement if it is to be used as base course pavement material. As seen in

Table 1, the amount of fine aggregate for the aggregate base course is limited by comparing the percentage of aggregate that passes sieves No. 200 and No. 40 so that the strength of the base course is maintained. According to the provisions of [21], the Plasticity Index value of Jumantono soil is 1%<15% and includes sandy soil; the soil meets the criteria if stabilized with cement, and if the Plasticity Index value is increased up to 50% then the soil will be difficult to mix with cement so that stabilization with cement will be ineffective. Likewise, with the requirements of [9], Jumantono soil with a Plasticity Index of 1%<30% can be stabilized with cement. Chemical characterization using scanning electron microscopy-energy dispersive x-ray (SEM-EDX) for soil is presented in Table 2. From the XRD test, this soil contains 12% anorthite and quartz, which makes the soil plasticity low.

The cement used in this study is Portland cement type PCC/Portland Composite Cement. According to [22], PPC results from mixing cement powder with organic powders such as slag, silicate compounds, and pozzolan (trass for fly as) with 6% to 35% organic content. This PCC complies with ASTM C 595-03. The SEM-EDX test result for PCC is shown in Table 2. From the XRD cement test, PCC contains many calcium and silicate compounds.

3.2 Methodology

Soil samples of known type that can be stabilized with cement are prepared for proctor standard and tested in the laboratory. The steps are:

1. Determination of cement content for soil stabilization.
2. Proctor standard testing.
3. UCS testing using optimum moisture content from proctor standard test results.
4. Determining optimum cement content for silt sand soil stabilization is based on UCS values that meet the requirements in Indonesia.
5. SEM and XRD testing of cement soil with cement content that produces UCS values according to requirements in Indonesia.
6. UCS testing with pH variations of immersion water with variations in cement content produces UCS values according to requirements in Indonesia.

The soil sample/SM was stabilized by mixing cement in proportions of 3%, 5%, 8%, and 10% by dry weight of soil. The cement content determination is based on research [9] showing that silty sand soils (A-2-4) can be stabilized with a 5-9% cement content by dry soil mass. Meanwhile, following [18], the cement content used in soil stabilizations is 3-8% of the dry weight of the soil sample.

Table 1 Index properties of the soil sample

Property	Value	Aggregate base course standard*
Plastic Limit (PL)-%	27	0-25
Plasticity Index (PI)	1	0-6
Clay-%	13.71	0-5
%pass filter No.4	96.17	29-44
%pass filter No.10	87.05	17-30
%pass filter No.40	63.62	7-17
%pass filter No.200	28.24	2-8
PI with sieve pass No.200	16.10	Maks.25
Comparison of Percent Passed Sieve No.200 and No.40	0.44	Maks.2/3
Soaked CBR-4 days	6.28	Min.90%

**based on General Highways Specification for Road and Bridge Construction Work 2018, Revision 2.*

Table 2 Chemical composition from SEM-EDX test for soil and PCC

Chemical Composition	Amount (%)	
	Silty Sand Soil	PCC
Si	19.12	8.22
Fe	7.74	1.64
Mg	7.59	-
Ca	5.77	39.27

Standard proctor test according to the Indonesian National Standard [20] based on ASTM D 559 and ASTM D 698 was performed to determine the maximum dry unit weight (MDD) and optimum moisture content (OMC) for soil.

The UCS test was performed on soil according to the Indonesian National Standard [23] based on ASTM D-558-1994. Based on this standard and to make soil uniform, the SM soil was passed through a 4.75 mm sieve (No.4) and then mixed with PCC and water at OMC obtained from the compaction test. If the size is increased, more cement is needed. For each mixture, three replicate specimens with a diameter of 50 mm and a height of 100 mm. Then, they were compacted in the cylindrical split mold and pounded with around and flat powder with a diameter of 50 mm and mass of 2.5 kg. The specimens are moisture-treated according to ASTM D1632. After that, it was soaked for 4 hours before the UCS test. In this test, variations in curing time (3, 7, 14, and 28 days) and soaking water (neutral pH water, acidic pH water, and alkaline pH water) were carried out. Neutral pH water uses tap water with a pH of 8 in the laboratory.

Meanwhile, acidic water uses tap water added with H_2SO_4 solution so that the pH becomes 4, and alkaline pH uses tap water added with NaOH solution so that the pH becomes 9. This method is according to research [24]. SEM-EDX analysis is performed to determine changes in the chemical structure formed before and after stabilization with cement. SEM-EDX samples were tested at less than 28 days curing times and more than 28 days on soil with a cement content of 8%.

4. RESULTS AND DISCUSSIONS

4.1 Compaction Test

Cement was added in amounts of 3%, 5%, 8%, and 10% by dry weight of the soil to follow the UCS test that will be carried out. The soil and cement were mixed thoroughly to a uniform color, and then the water was added to facilitate the mixing and compaction process. Figure 1 shows the MDD and OMC for silty sand soils and silty sand soil stabilized with 3%, 5%, 8%, and 10% cement by dry weight of materials. Cement addition influences silty sand soil-cement mixture compatibility. Likewise, if silty sand is replaced with clayey sand, the effect will be different; adding cement to silty sand soil will increase MDD and reduce OMC, while on clayey sand soil [25], it will increase MDD and OMC. This difference is due to differences in soil types, which influence water use requirements. In this case, clayey sand soil requires more water than clayey sand soil if cement is added. However, this study is only specific to silty sand soil.

The MDD value of silty sand soil is 1.519 g/cm^3, and after adding 3%, 5%, 8%, and 10% cement, the MDD value rises to 1.526 g/cm^3; 1.538 g/cm^3; 1.559 g/cm^3; and 1.571 g/cm^3. The increase in maximum dry unit weight is due to the specific gravity of cement (2.9 g/cm^3) higher than the specific gravity of the original soil (2.57 g/cm^3). It's like research [26]. In addition, the size of cement grains that are finer than silty sand soil causes the maximum dry unit weight to increase because refined cement grains will fill the voids between soil pores that previously contained air and will reduce the distance between soil grains so that the grain arrangement becomes tighter and plays a role in increasing soil density, as shown by [26]. These results contrast with the OMC value of silty sand soil of 19.17%, which drops to 18.74%, 18.6%, and 18.55% when adding 3%, 5%, 8%, and 10% cement.

The decrease in OMC value of about 0.5% to 3% in the stabilization of silty sand soil is due to the rapid compaction process; namely, after mixing with water, compaction is immediately carried out so that the function of water as a lubricant between grains that facilitate compaction and chemical reaction between cement and water/hydration reaction has not occurred. This result is according to research [26][27]. They both use silty-sand soil mixed with cement, which is immediately compacted after mixing. In contrast, if the compaction delay is 24 hours, OMC will increase.

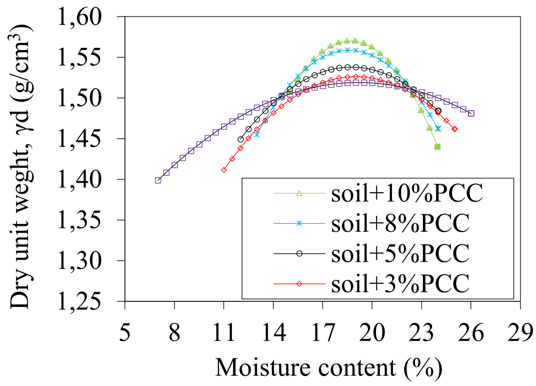

Fig.1 Compaction curves

4.2 The Unconfined Compression Strength Result

As the dose of cement increases, the UCS value of silty sand soil stabilized with cement would increase whether there are curing times of 3, 7, 14, or 28 days, as shown in Figure 2. The UCS value of silty sand soil 102.97 kPa will increase to 628.61 kPa, 1110.11 kPa, 2105.49 kPa, and 2582.10 kPa if added 3%, 5%, 8%, and 10% cement with seven days curing time. This result is according to research [28].

Several things can cause an increase in UCS value in stabilizing silty sand soil with cement. First, there is a chemical reaction between cement, soil, and water. The initial reaction that occurs is the reaction between cement and water that produces cementing materials, namely calcium silicate hydrate (C-S-H), calcium aluminate hydrate (C-A-H), and calcium hydroxide ($Ca(OH)_2$). The following reaction is between lime in cement and soil particles (silica and alumina) or the so-called pozzolan reaction, which will produce additional C-A-H and C-S-H, strengthening the bonds between particles and stabilizing the soil. This hydration and pozzolan reaction will make the structure more compact and denser, so the UCS value will increase as the cement increases. This result is based on the following research [29]. Second, cement stabilization that suits non-plastic soils such as silty sand soil in this study. This non-plastic soil will tend to achieve higher strength when stabilized with cement than soils with a higher plasticity value. This result is based on the following research [16].

This cement stabilization research for silty sand soil, when compared to stabilization using poly-vinyl acetate (PVA) and micronized calcium carbonate (MCC) liquids [30], will result in higher UCS values, and UCS values will increase with curing time. Although both use chemicals, stabilization with PVA and MCC will increase the UCS value by 80% from the initial UCS value in just the first seven days of additive, after which the rate of increase will decrease. The UCS value using cement will increase up to 500% on seven days of curing at 3% cement content, and the UCS value will continue to rise until 28 days of curing time. This result makes stabilizing silty sand soil with cement more promising for soil improvement.

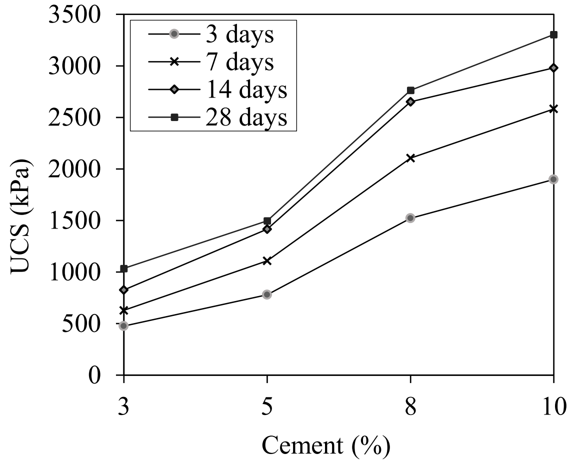

Fig.2 UCS value due to cement contents for different curing times

Figure 3 shows that the UCS value increases with increasing curing time at a constant percentage of cement. For example, at 8% cement content, the UCS value increased from 102.97 kPa after curing in 3 days to 1522.97 kPa; within seven days, it rose to 2105.49 kPa; within 21 days, it grew to 2652.70 kPa, and on day 28 it rose to 2762.53 kPa. Similar results were presented by research [31]. With increasing curing time, the UCS value of cement soil will increase because the hardened cement soil mixture is caused by a hydration or pozzolanic reaction during the curing process [32].

The results of studies such as Figure 3 also show that curing time and semen content affect UCS values. The rate of increase in UCS values in the early stage (less than three days of curing) is greater than the rate of increase after three days of curing. In the initial phase, the rise in UCS values is due to the hydration reaction, and the increase in UCS is slower in the pozzolanic reaction phase. A similar point is shown by [30]. Figure 3 also indicates that soil cement hardening depends on time; the longer the curing time, the higher the UCS value. This result corresponds to [26] because there is a secondary pozzolanic reaction between lime from cement and clay minerals from the soil, which produces additional calcium silicate hydrate and calcium aluminate hydrate, which increases the compressive strength of soil cement.

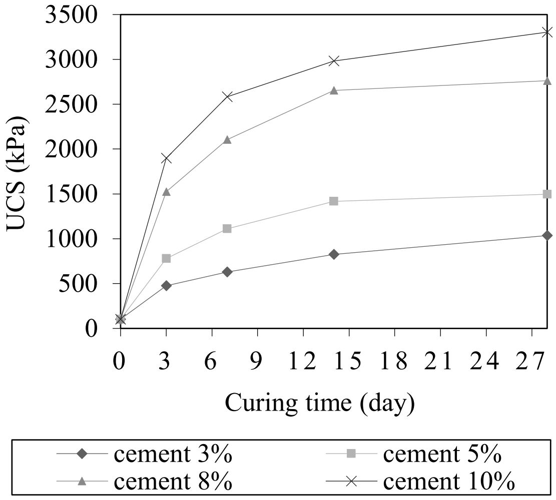

Fig.3 UCS value due to curing time for different cement contents

4.3 Microstructure Analysis

Figure 4a shows the SEM image of soil samples from Tunggulrejo Village, Karanganyar Regency. Figure 4b is the SEM test result of PCC cement, and Figure 4c is a picture of the reaction results and microstructural changes of soil stabilized with 8% cement at less than 28 days of age and after soaking in water for 4 hours. With a microstructure magnification of 10000 times (1μm), cement soils less than 28 days old can be found more pores than those aged more than 28 days (Figure 4d). CSH clumps at less than 28 days of age are seen getting bigger after more than 28 days and are interconnected so that the structure becomes denser. This result is according to research [33]. In addition, the result of the hydration reaction will close the pores between the soil particles and sand and make the structure more compact. This hydration reaction can take place ideally if water needs are met. As seen in Figure 4a, silt mixed sand soil still has pores or holes that cause the soil to have low strength. After mixing with PCC, Figure 4c and 4d, the structure becomes denser as the pores shrink. This result is according to research [34].

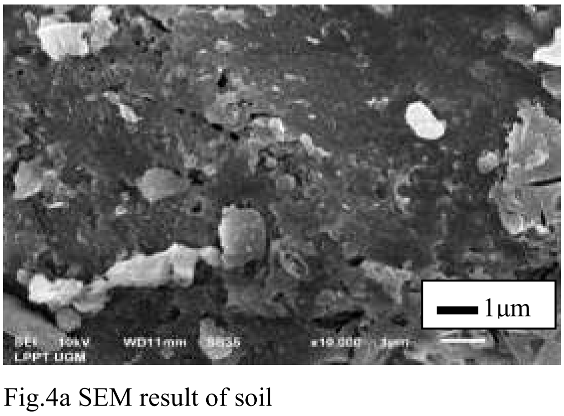

Fig.4a SEM result of soil

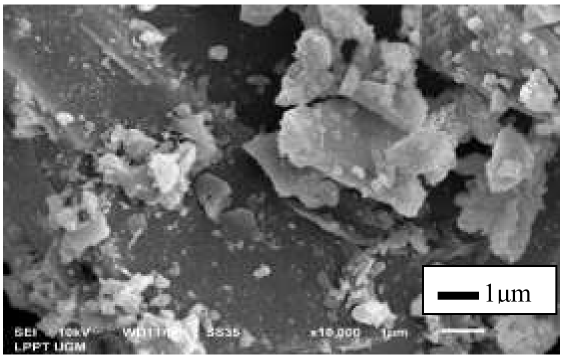

Fig.4b SEM result of PCC

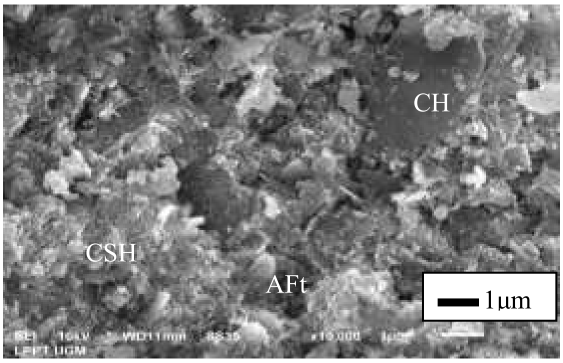

Fig.4c SEM result of soil and 8% cement mixture at less than 28 days old with 4 hours soaking

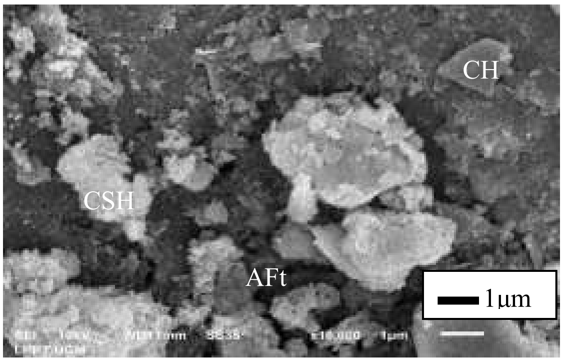

Fig.4d soil and 8% cement mixture at more than 28 days old with 4 hours soaking

Figure 5 shows the average elemental concentration of significant components in silty sand soil with cement content of 8% after less than 28 days (8a) and more than 28 days (8b). It is known that aluminum, calcium, and silicon are the main components in large quantities. The amount of elemental silicon and aluminum over 28 days old (29.16+7.30=36.46) is less than 28 days old (18.3+10.0=28.30). In contrast, the amount of calcium is the opposite. Calcium aged less than 28 days is 5.92, while over 28 days is 4.32. This condition can occur due to a hydration reaction that produces silicate hydrate and aluminate hydrate. This study is according to research [22].

4.4 Determine Cement Content Optimum For Soil Cement Base Course

This study's cement soil stabilization design is to find the optimum cement content to become a flexible pavement base course material that meets the requirements of the road base course by following the specified in the 2018 General Specification of Highways for Road and Bridge Works [19], which is 1961.33 - 3432.32 kPa (target 2353.60 kPa) with a curing time of 7 days. According to [35], if the UCS of cement soil is more than 5413.27 kPa, then it will act as a rigid pavement. Research using UCS value criteria to determine the level of stabilization material to meet the requirements as a road-based course material was also carried out [36]. Based on Figure 6, to stabilize the silty sand soil of Tunggulrejo Village, a minimum cement content of 7.6% is required. In this study, 8% and 10% cement content values met the UCS requirements of 1961.33 - 3432.32 kPa with a curing time of 7 days. Based on Figure 6, a cement content of 9% is needed to meet the target UCS value. This is evidenced by testing using 9% cement content obtained MDD 1.56 g/cm^3, OMC 18.56%, and UCS value 2353.60 kPa. From the results of this test, the optimum cement content of the silty sand soil mixture for the base course of pavement is 9%. This cement soil mixture also meets the requirements of ACI [37], namely the amount of cement for silty sand soil stabilization (SM), which is 5-9% of its weight.

4.5 Effect Soaking Water pH

Figure 7 shows that the UCS mixture of cement soil soaked in pH 4 water (water plus H_2SO_4 so that the pH becomes 4) and pH 9 (water plus NaOH so that the pH becomes 9) will decrease from cement soil soaked in pH 8 (tap water). The effect of immersion water pH is analyzed only on cement levels that meet the UCS value requirements, namely 8%, 9%, and 10%. UCS value of soil mixture with 8% semen aged seven days if soaked for 4 hours with water pH 8 of 2105.49 kPa; after being with water pH 9 for 4 hours, UCS value drops to 1936.81 kPa. When the soaking water is replaced with pH 4, the UCS value drops to 1883.86 kPa. From 8%, 9%, and 10% cement content, the highest decrease in UCS values in the mixture was 8% cement content at either pH nine or pH four immersion. The order of the highest UCS values is pH 8, pH 9, and pH 4.

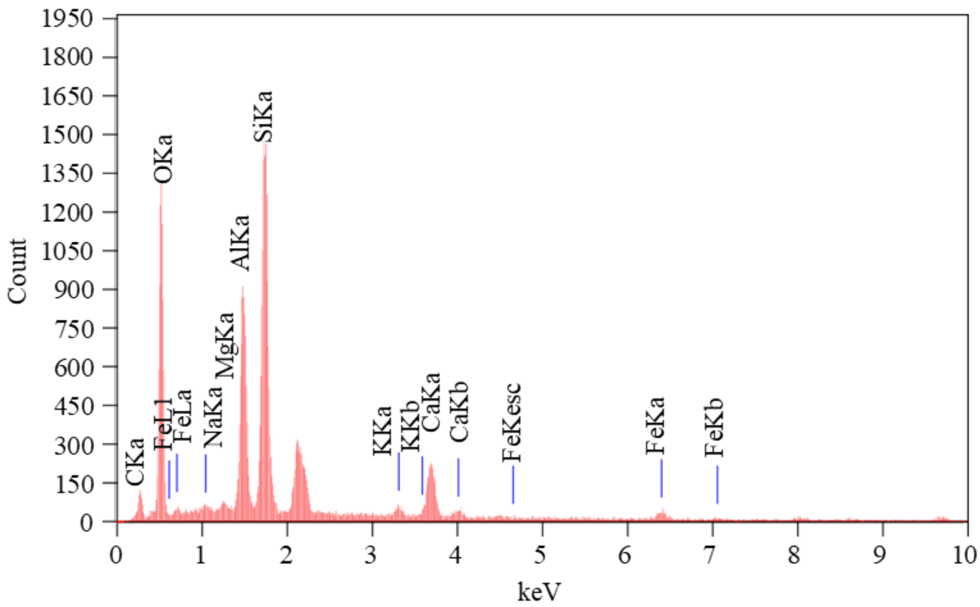

Fig.5a SEM-EDX result for soil+8%PCC<28 days

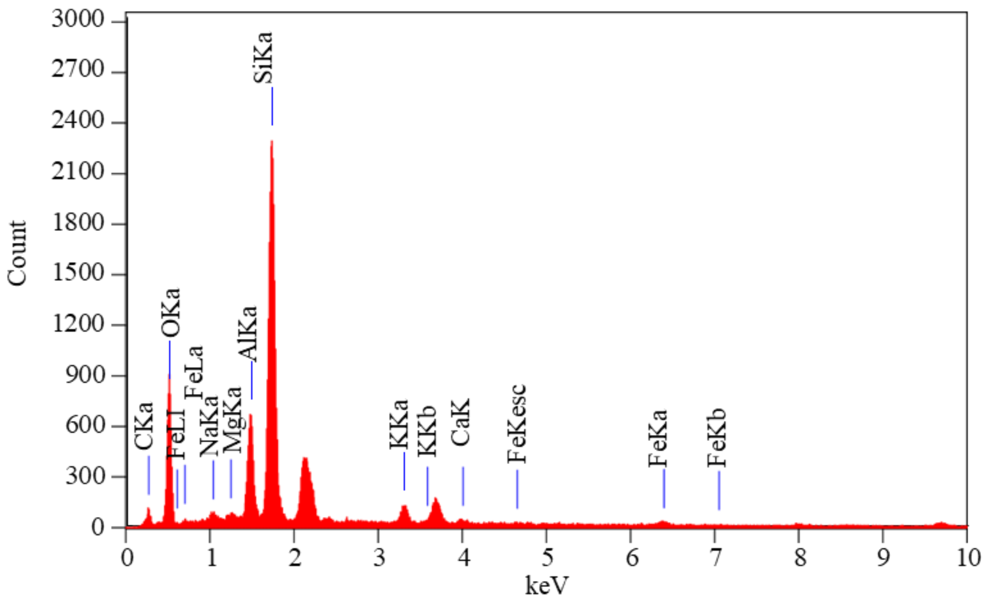

Fig.5b SEM-EDX result for soil+8%PCC>28 days

Cement content of 8%, 9%, and 10% and a 7-day curing time soaked with pH four and pH nine water for 4 hours lowers the UCS of pH 8. At 9% cement content, pH four bath water decreased the UCS value by 6.94% from the pH eight bath, and pH nine bath water decreased the UCS value by 1.58% from the pH eight bath. The decrease in UCS value due to immersion in water with pH four is caused by the release of Ca^{2+} ions that are absorbed and hydrated when mixing soil and cement for leaching because there is an exchange of Ca^{2+} ions with H^{+} making the soil stabilized with cement neutral thus lowering the UCS value. This result is according to research [24]. Reduced UCS value in pH nine water will break the bond between sand and silty soil with cement. This result is according to research [24].

Figure 8a shows the results of the SEM test on an 8% soil and cement mixture soaked in pH 4 water. From the image, the C-S-H block is reduced compared to Figure 8c, and the structure's shape becomes hollow, which causes the strength to decrease. As in the study of [38], H_2SO_4 will increase ettringite formation. In Figure 8a, excessive ettringite will damage the CSH block that has been formed and decrease strength. While Figure 8b is the result of the SEM test on a mixture of soil and cement 8% soaked with pH nine water, although it still looks floc CSH, there is a cavity more significant than Figure 8c, which causes a decrease in the compressive strength value of cement soil. It is like a study conducted [24].

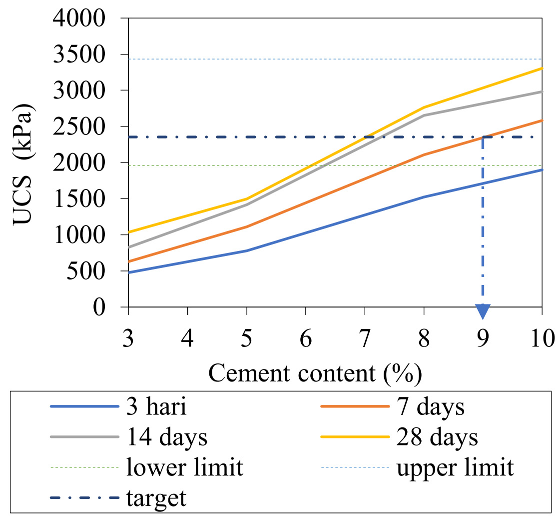

Fig.6 Cement content determination chart

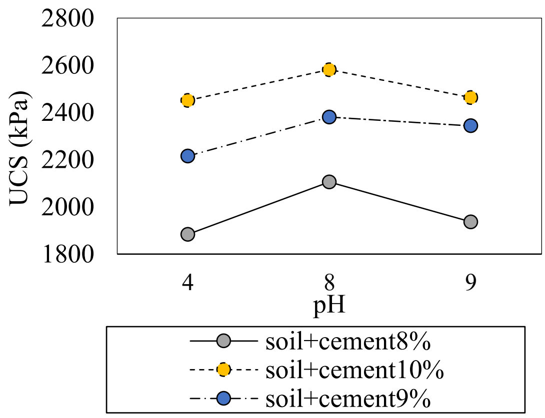

Fig.7 Graph of the effect of pH on UCS test results at seven days curing time

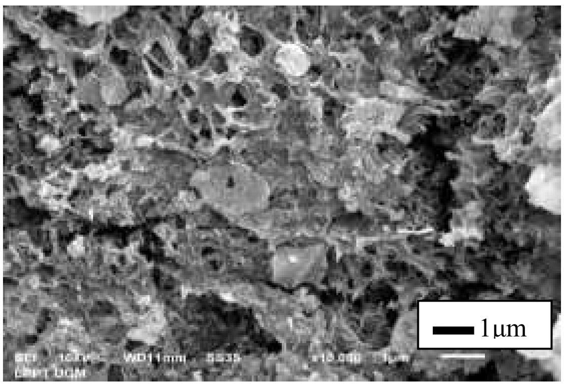

Fig.8a SEM test result from 8% cement soil mixture aged more than 28 days soaked for 4 hours pH 4

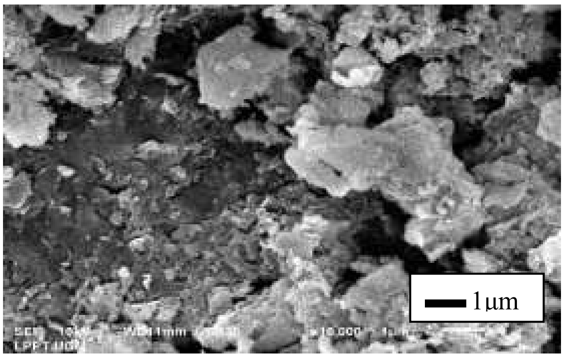

Fig.8b SEM test result from 8% cement soil mixture aged more than 28 days soaked for 4 hours pH 9

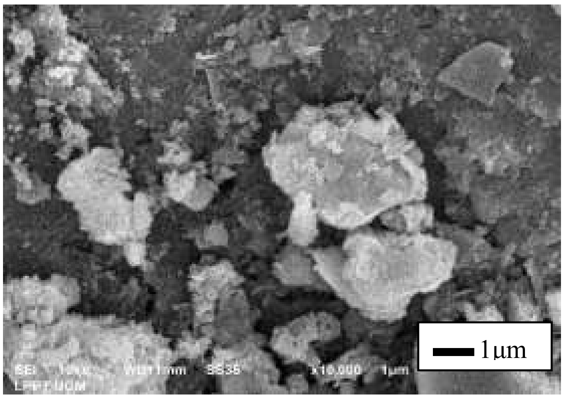

Fig.8c SEM test result from 8% cement soil mixture aged more than 28 days soaked for 4 hours pH 8

5. CONCLUSIONS

Considering the 2018 General Specification of Highways 2018 for Road and Bridge Works (revision 2) in Indonesia, the result indicated that untreated silty sand soil could only be utilized as a base course pavement if stabilized with cement. In general, according to the obtained results, the following conclusions can be drawn:

1. The addition of cement increased maximum dry density (MDD) and decreased the optimum moisture content (OMC) of silty sand soil.
2. The UCS of silty sand soil increases with cement percentage and curing time.
3. Seven days of soaked UCS of 2353.60 kPa are recommended as criteria to find the suitability of stabilized silty sand soil to be used as a base, and the optimum cement content is 9%.
4. UCS silty sand soil stabilized with cement will decrease when submerged in soaking water for 4 hours at pH 8 and 9.

The microstructure analysis illustrates that the amount of silica and aluminum increases with the addition of the cement process, and a reaction occurs when the silty sand soil is added with cement and water.

6. ACKNOWLEDGMENTS

The author sincerely thanks the Karanganyar Regency Government for the financial support of this research.

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