## The Effects of sodium silicate on Stabilization of organic soil

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**Abstract:** Sodium silicate was added to organic soil in order to study its effects on soil shear strength in this research. The different types of soil including sand, clay, peat have been used in this study. Different percentages of sodium silicate (5%, 9%, 12%, 15%) have been used for soil stabilization. In this study, the curing times were 3 days, 7 days, 28 days. Finally, after performing the necessary tests on soil shear strength and comparing the effects of sodium silicate on organic soils, it was observed that soil shear strength has increased after adding sodium silicate gradually. Therefore, lime can be replaced in organic soils to be mixed with sand and clay in with different percentages.

**Keywords:** Chemical Improvement and Stabilization; Sodium Silicate; Shear strength; peat (organic matter).

### 1. Introduction

In recent years, the use of surplus construction and industrial materials, such as dredged clays and slags has been strongly recommended for embankment applications in the base and sub-base courses by increasing environmental information and emphasizing on optimal use of natural resources. In some engineering projects, due to inaccessibility or uneconomical preparation of aggregates, the stabilization methods along with changing soil texture and properties will solve the problem.

In completely organic soils such as peat, organic matter is accumulated in the form of loosely twisted fibers. Due to the high percentage of organic matter, the engineering properties of these soils are completely different in all applications. The properties of organic soils are derived from the organic constituents, and their engineering properties and behavior vary depending on the type and content of organic matter. The wide diversity of organic soils results from their constituents' abundance and diversity and this makes some difficulties in classifying, testing, and predicting the engineering behaviors of these soils.

In recent years, chemical methods for organic soil improvement have been increasingly concerned and deep stabilization in form of stabilized soil columns has been proposed as one of the most ideal solutions to deal with large settlements in these soils. Numerous laboratory and field studies have been performed on the stabilization of completely organic soils (Pt) and successful consequences have been reported on the soils improvement with 20% organic material accumulation and richness of calcium additive (Hartlen & Wolski, 1996). However, there are little coherent researches on the stabilization of fine-grained soils with low percentages of organic matter.

According to the statistical studies on some stabilization projects in soils with low percentages of organic matter (more than 1% and less than 8%), soil stabilization has not been reported and even the soils improvement has also been decreased over time. It seems, the soil binder has lost its effectiveness in the presence of organic matter (Hartlen & Wolski, 1996).

Two methods are advised in engineering activities and construction projects, while applying organic soils. In the first method, displacement, removal of organic matter and soil replacement are emphasized depending on the spatial conditions; and in the absence of economic and engineering justification of the first method, soft soil remediation method is recommended. Soil improvement can be completed by mechanical or chemical methods. Mechanical methods mainly comprise of load adjustment, preloading and surcharge application and multi-stage construction. In chemical improvement, soil is combined with materials such as cement, lime, gypsum, and industrial derivatives such as blast furnace slag, fly ash, and pozzolans such as silica and alumina. The chemical reactions between the materials added and the soil causes higher loading strength, better compaction and mobility, lower shrinkage and plasticity percentage in the produced mixture compared to the original natural soil.

Applying lime to dry and temporarily changing of the soil is the minimum operation for soil improvement. The soil structure must be permanently changed for further improvement. For this purpose, further engineering testing and control and proper mixing design are needed, these mixing designs should provide the most economical implementation methods in addition to affording all the claims of the project.

The stabilization process in soils plus suitable value of clay results in following consequences.

- Increased long-term strength
- Permanent reduction of soil swelling and shrinkage potentials

• Decreased soil plasticity index

• Increased soil durability to resist the harmful effects of melting, freezing and periodic drying and wetting.

Soil stabilization occurs after a 28-day curing time. Increased temperature during the curing time, the stabilization process can be accelerated (Manual, 2004).

There is no concern about deficiency and trace elements of calcareous soils in Iran. These elements often present in large quantities in soils, but there are many problems in absorbing the trace elements due to the presence of lime and calcium ions. There are not many methods for calcareous soils changing and improvement. Calcareous soils are extremely poor in organic matter and lack of organic matter and humus is one of the disadvantages in these soils. On the other hand, adding organic matters to lime prevent endangering plant growth. Another method is adding soil acidity chemical fertilizers which are rare and have less effect. One of these fertilizers is ammonium sulfate.

Alkaline silicates used in Industrial applications (sodium and potassium silicates) are known as alkali oxide through the weight ratio of $SiO_2$. The molar ratio is obtained by multiplying the weight ratio of sodium silicate and potassium silicate by 1.032 and 1.468 respectively.

"Sodium silicate" is the common name for sodium metasilicate or $Na_2SiO_3$ and also called "glass water" or "liquid glass" with formula $Na_2SiO_3$. Sodium metasilicate is available in water solution or in solid form. Soluble Sodium silicates (or glass water) are water solutions and soluble glasses made from variable ratios of $Na_2CO_3$ and $SiO_2$. Sodium Silicate is mainly used in different industries depending on different industries and ratio. Sodium silicate is a white powder that dissolves in water easily and make an alkaline solution. It is one of the compounds that contains sodium orthosilicate, sodium pyrosilicate etc. They are all glassy, colorless and water soluble. Sodium silicate is stable in neutral and alkaline solutions. In acidic solutions, the silicate ion reacts with the hydrogen ions to make the acid silicate; heated acid silicate forms a hard glassy silica gel. Special sodium silicate adhesive is used to increase the strength of vertical walls and tunnel roof through spraying or mixing with grout sand through injection.

Several studies have been done on sodium silicate and its application. Moayedi et al. (2011) investigated the stabilization of organic soils using sodium silicate as a grout system. In this study, they studied the undrained strength of the soil, so that 2 kg of a load were laid out on the samples. After 14 days, the undrained shear strength of the soil was evaluated using additives such as sodium silicate, which they observed. High unrestrained compressive strength (UCS) have observed. He also used stimulants such as aluminum sulfate and calcium chloride in organic soils in his experiments and compared their results.

Several studies have been carried out on sodium silicate and its application. Moayedi et al. (2011) investigated the stabilization of organic soils using sodium silicate system grout. In this study, they examined the undrained strength in the soil; therefore, 2 kg of a load were laid out on the samples. After 14 days, the undrained shear strength of the soil was evaluated using additives such as sodium silicate and a high unrestrained compressive strength (UCS) has been observed. They also used other compounds like aluminum sulfate and calcium chloride in organic soils and compared their results together.

Mane and Rajashekhar (2017) has examined the stabilization of black cotton (The soils cause enormous shrink-swell properties) soils using red mud (Soils that contain large amounts of alkaline) and sodium silicate. This type of soil has been examined for the reason that engineers need to be informed sufficiently by the behavior of these poor and dangerous soils. Black cotton soils contain fine clay and silt that cause shrink-swell properties and finally dry cracks. CBR test was used in this study and the results show that 10% to 40% of red mud and 2% to 10% of sodium silicate are used to improve the strength of black cotton soil.

Fathi and Parvizi (2016) have studied the effect of sodium silicate on sandy soils using CBR test. Studies show that injecting sodium silicate into clay soil increases uniaxial compressive strength in sodium silicate ideally. Also, chemical injection of sodium silicate leads to reduced permeability and increased shear strength of sandy soil. Previous studies have also shown that adding the polyvinyl acrylic polymer to granular soils increases soil strength properties. All experiments were performed under optimal humidity of 9.4% and saturation for 96 hours. Liquid sodium silicate with percentages of 0, 1, 2, 3 and 4% was added to the soil and then was saturated and tested at setting time of 24 hours. After testing, the CBR number increases and optimal amount of liquid sodium silicate is 2% by weight of dry soil following the increased amount of sodium silicate, and this causes CBR to reach 47 that is three times the pure soil.

Pakir et al. (2016) have studied the effect of sodium silicate on the improvement of coastal clay soils. Coastal clay soils are one of the problematic soils due to high compressibility and swelling as well as low bearing capacity. Sodium silicate has been used to improve soil strength and soil quality for construction and road structures.

Compressive strength (usc) and plasticity index of soil have been examined in the laboratory; after adding the sodium silicate, the ductility decreases and the uniaxial compressive strength increases slightly that has significantly risen over the time. In summary, the use of sodium silicate can be an economical and a good alternative for soil improvement methods in construction projects. In This study, we try to discover the effect of sodium silicate on organic soils stabilization?

## Materials and Methods

### *Consuming Materials*

Clay: In the soils classification, clay is a type of fine-grained soil. Clay particles are usually smaller than 0.002 mm. However, sometimes particles with a size of 0.002 to 0.005 mm may also be called clay. The particles that are placed in the clay classification by size do not necessarily include clay minerals.

Sandy soil: The shape of coarse grains is very useful on soil engineering properties. The sand soil has been prepared from Emamieh sand washing factory in Tabriz and were under granulation test based on ASTM D 422-87 method. The sandy soil contains mostly fine sand.

Peat soil: Organic matter in the soil consists of decomposed plant and animal material at different levels as well as their chemical and biological decomposed materials. To obtain organic matter, dry oxidation test or LO1 method has been used in accordance with Standard ASTM D 2974. Following the experiment, the amount of organic matter in peat soil was calculated at about 95.71%. The peat used in this study is prepared from lith peat factory at Lithuania.

### *Soil*

In this study, three types of soil composition have been used denominating A, B and C. The composition is selected in such a way that coarse grain is reduced and fine grain is added in the soil from A to C gradually.

**Table 1.** Soil Classification.

| Soil | Peat | Clay | Sand |
|---|---|---|---|
| A | 4% | 16% | 80% |
| B | 7% | 28% | 65% |
| C | 10% | 50% | 40% |

### *Stabilization Material*

Sodium Silicate: Liquid Sodium Silicate was used in this study, its concentration was about 48% and its ratio was 2.5 prepared by Mehran Silicate Alborz Company. This is the most common material used in industry (approximately 35% in detergents and soaps, about 25%as a catalyst, about 5% in the adhesive industry, 23% in pigments and 12% in miscellaneous). This is an environmentally friendly material and does not endanger animals and plants health.

### *Performed Tests*

*Granulation Test*

The granulation test was performed based on Standard ASTM D422-87. This test is used for predicting water movement in soil, permeability, capillarity, use of filtration and drainage, and soil sensitivity. Granulation is mainly done through two methods, sieve analysis and hydrometric analysis. Since, the soil used is a combination of several types and coarse grains are the majority, so the sieve analysis has been used.

*Density test*

This test is performed based on Standard ASTM 698-78. The density testing aims to reduce soil porosity. A certain amount of water can facilitate this test. The main objective of density test is obtaining the maximum moisture and dry specific gravity of the soil maxima after applying certain percussion energy.

*Atterberg Limits*

This test was performed based on Standard ASTM D4318-87. This test aims to specify the plastic and liquid of the soil. Fine-grained soils are changed, when the amount of water absorbed increases. The liquid limit (LL) of the soil is 50, so the clay is CL type.

PI: Plasticity Index

$PI_A$: Plasticity Index of Line A $\longrightarrow$ PI =0.9 (LL-20)

PL: Shrinkage Limit

*GS Test (Specific Density)*

This test is performed based on Standard ASTM D 854-10. This test aims to specify density of the solid part of a material to the density of water. The unit weights (density) of each soil are used for settlement and stability in soil engineering. The test was performed by method (b) for the wet sample as well as on A, B and C soils. The results are shown in Table 2.

**Table 2.** GS Results of Soils.

| Soil | Gs |
|---|---|
| A | 1.893 |
| B | 2.07 |
| C | 2.5 |

*Hydrometric Analysis*

The hydrometric analysis is one of the most common measures to estimate the particle size passed through the 200 sieve. The obtained data are plotted on a semi-logarithmic diagram. In hydrometric analysis, the relationship between the average velocity of spherical particles in liquid, the particle diameter, the specific gravity of a liquid, and fluid of viscosity known as Stokes' law are used.

Due to the fine-grained nature of the soil studied in this study, hydrometric method was used for granulation and the granulation curve is shown in Figure 1. Also, the measured Gs for the clay used in the experiments is 2.7.

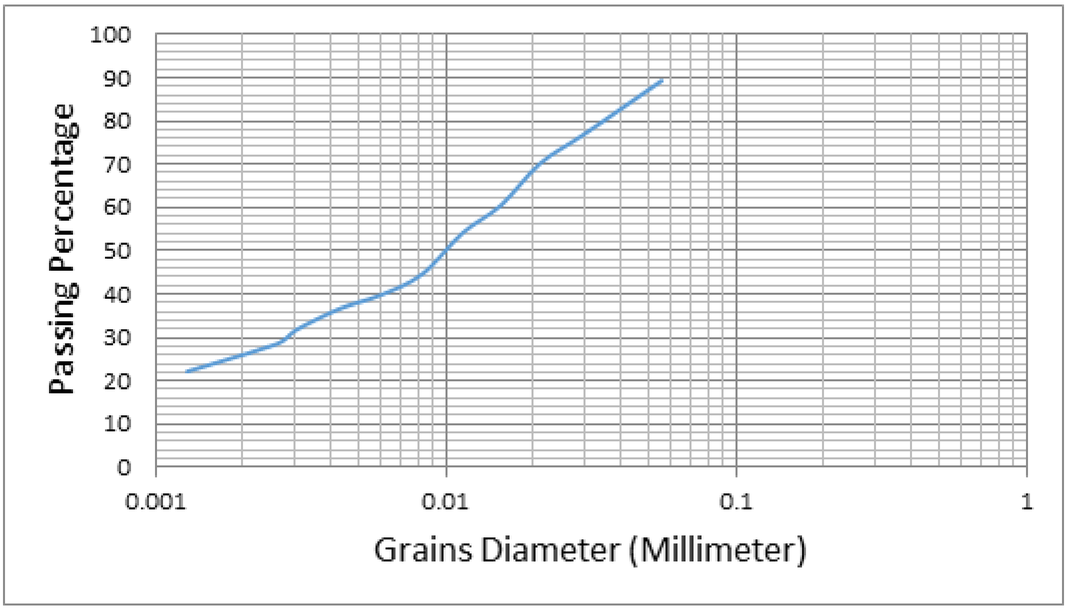


**Figure 1.** Hydrometric Test Curve.

*Direct Shear Test*

This test is performed based on Standard ASTM D 3080-90. In this test, by moving the upper half of a box containing soil proportional the lower half, we subject the soil inside the box under the shear stress to be disjointed. The top of the box is displaced than the bottom and results in cutting the soil sample in one direction.

If the cross section under the shear force has an area equal to A, we have:

$$\text{Shear Stress} = \frac{\text{Shear Force}}{A} \quad \text{Vertical Stress} = \frac{\text{Vertical Force}}{A}$$

Shear strength is the amount of stress required for slip on a grain surface:

$$\tau = \sigma \tan \phi + C$$

Where, C is Adhesion and ϕ is internal friction angle. The above equation is known as the Mohr–Coulomb failure criterion.

In direct shear test, either stress controlled test or strain-controlled tests can be used for loading. In a stress controlled test, the shear force is applied by a constant weight and the amount of strain is measured. In a strain-controlled test, deformation or strain is constant and shear force is measured. Shear tests were performed on soils produced (A, B, C) with sodium silicate as well as stabilized samples with lime. Sodium silicate with percentages (5%, 9%, 12%, 15%) and lime with percentages (4%, 6%) are combined with soils A, B and C. In order to prepare the samples, 6*2*6 molds have been used. The samples were examined during (3, 7 and 28 days).

For preparing the samples, the amount of water for the samples were adjusted based on the percentage of moisture in the density test. The percentage of moisture for the sodium silicate additive in 5% of the polymer was the same as the percentage of optimal soil moisture. However, for the percentages (9%, 12%, 15%) of the polymer, half of the optimum moisture content of each soil was the same as the density test. Due to polymer-fluid nature containing liquid, a percentage of moisture exceeds its optimal limit after adding to the soil; that’s why, the percentage of moisture is the same as half of optimal soil moisture.

**Results**

The effect of sodium silicates during 28 days.

**Table 3.** The effect of different percentages of sodium silicate in three soil types during 28 days.

| Percent / Soil | 15% | 12% | 9% | 5% | 0% |
|---|---|---|---|---|---|
| Soil A | 12 | 12 | 7.95 | 4.7 | 4.29 |
| Soil B | 12 | 10.33 | 7.48 | 4.64 | 4.6 |
| Soil C | 9.33 | 7.1 | 7.14 | 5 | 4.1 |

The unit of direct shear test results is Kg / cm2.

According to Figure 2 and Table 3, the 28-day strength of all three soil types has increased after increasing the percentage of sodium silicate. In soil A, the maximum possible strength at 15% and 12% were observed, so that the direct shear machine was not able to break the samples and the maximum possible strength (12 kg / cm2). Also, soil B had the highest strength at 15%, which is shown at12 kg / cm2 in the figure. In summary, the effect of sodium silicate in soils A and B was more than soil C, which can be contributed to coarser grains of soils A and B than soil C. Sodium silicate, due to its concentration can easily passes through the coarse grains and affect whole sample grains; this increases adhesion of the grains to each other and shows a high strength. Over time, the molecular penetration of the polymer chains increases into the soil grains, when the water evaporates and the polymer clots between the grains, the soil becomes harder as well as shear strength increases.

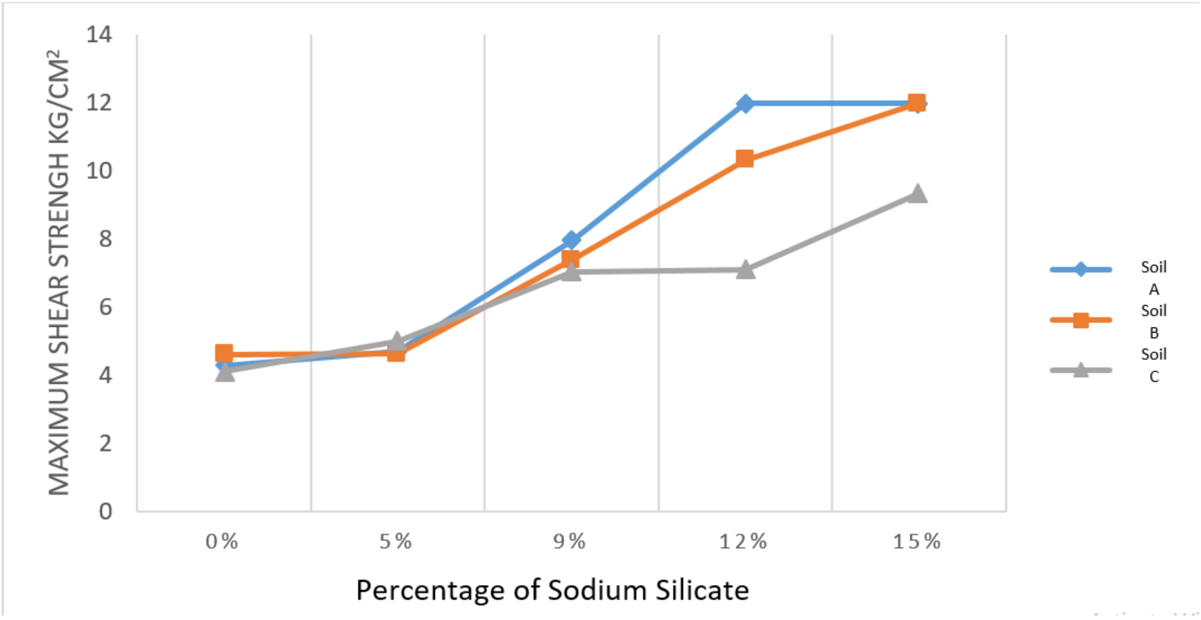


**Figure 2.** Comparison of sodium silicate strength in three soil types during 28 days.

***Examining The Shear Strength of 5% Polymer Samples***

The Samples containing 5% sodium silicate in three types of soil (A, B, C) with reduced percentage of coarse grain from A to C has been examined. Figure 3 shows the shear strength changes. All three soils (A0, B0, C0) * are pure.

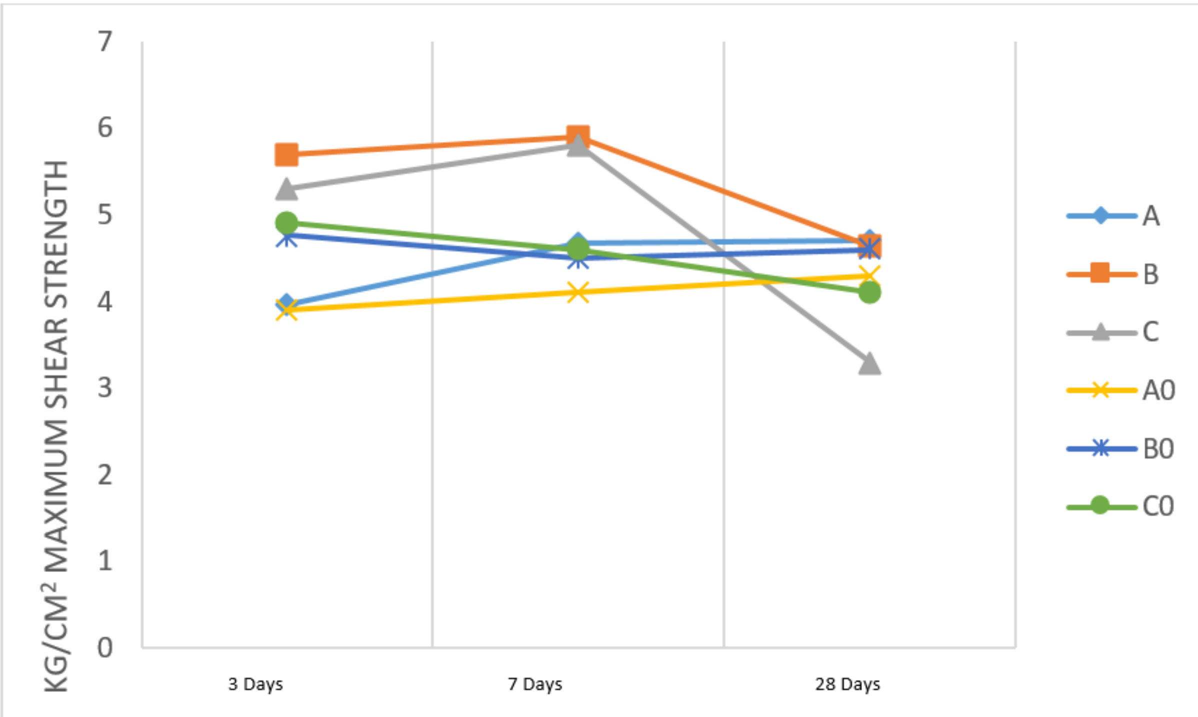


**Figure 3.** Changes of shear strength of 5% sodium silicate over time in different soils.

Figure 3 shows the shear strength changes of samples containing 5% sodium silicate over 28 days in three soil types. Soil A containing higher percentage of coarse grains than the other two types indicated low strength in 3 and

7 days, but, the shear strength of the soil has increased during 28 days. Soils B and C containing lower percentage of coarse grains showed high strength in 3 and 7 days, but their strength decreased during 28 days. The reason for that is the amount of coarse grains in the soil and the effect of adhesion between the grains over time. Fine-grained soils have good strength at first, but then grain adhesion is reduced within 28 days, but shear strength of coarser soils have increased due to the effect of polymer over time.

It is remarked that that samples containing polymer have higher shear strength than pure samples on 3 and 7 days, but over time, their adhesion has decreased. Also, the find-grained soil; i.e. soil C showed less strength in 28 days than the sample.

***Examining the shear strength of 9% polymer samples***

The Samples containing 9% sodium silicate in three types of soil (A, B, C) with reduced percentage of coarse grain from A to C has been examined.

Figure 4 shows the shear strength changes of samples containing 9% sodium silicate over 28 days in three soil types. The samples containing sodium silicate showed less strength than pure soils during 3 days, but, the shear strength of the soil has increased during 28 days in the presence of polymer. The reason for decreased strength in the samples containing polymer during 3 days is non-adhesion of grains. The best shear strength yield for 9% polymer compared to pure samples was observed in soils A and B during 28 days.

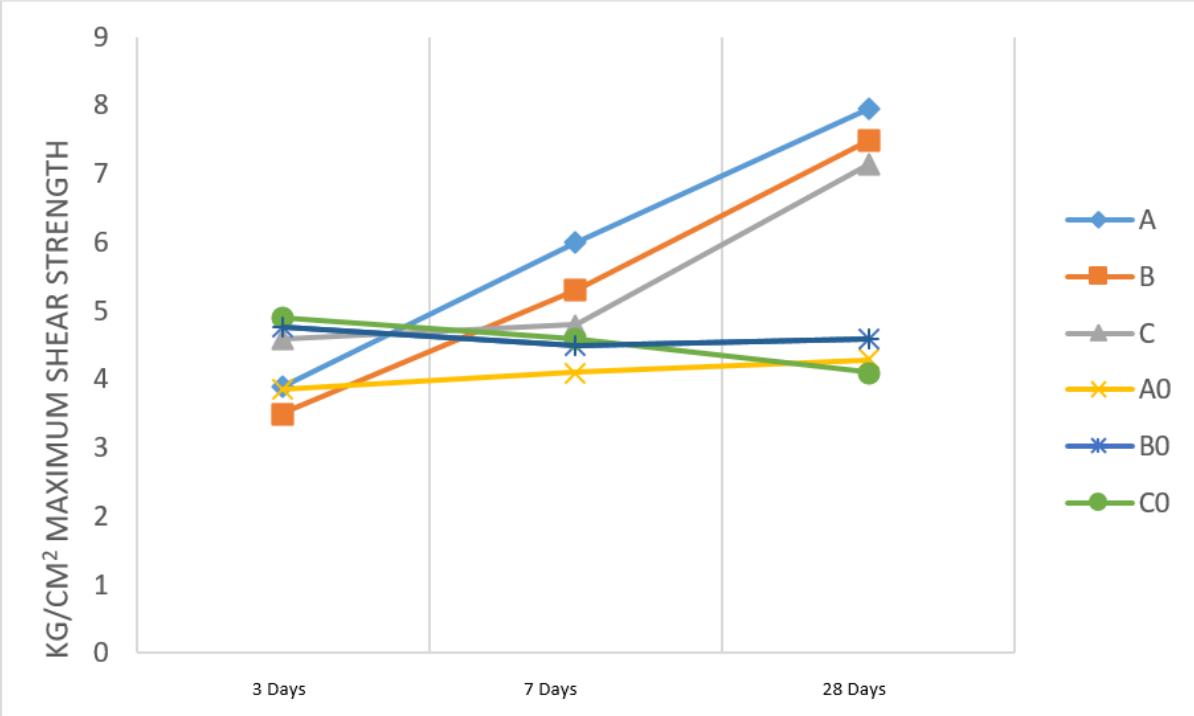


**Figure 4.** Changes of shear strength of 9% sodium silicate over time in different soils.

***Examining the Shear Strength of 12% Polymer Samples***

The samples containing 12% sodium silicate in three types of soil (A, B, C) with reduced percentage of coarse grain from A to C has been examined. Figure 4 shows the shear strength changes in all three types of soils during different time periods.

**Table 4.** Direct shear strength in kilograms per square centimeter (Kg / cm2) in samples containing 12% sodium silicate.

| Time \ Soil | A | B | C |
|---|---|---|---|
| 3 Days | 3.95 | 3.89 | 4.44 |
| 7 Days | 7.05 | 8.5 | 4.61 |
| 28 Days | 12 | 10.23 | 6.56 |

According to Table 4, the effect of 12% polymer in coarser soils was more significant than fine grains, so that sample in soil A was not broken by the machine during 28 days and maximum possible amount is shown in the figure. The reason for increased shear strength in soil A compared to other two soils is coarse grains and high sand ratio. The main characteristic of the soil, adhesion has greatly increased through liquid polymer with high concentration, so passes easily between large grains such as sand and its effect begins in 7 days. It is also observed that in the first days, soil A has low strength than others, which can be attributed to the lack of liquid and wetness of the soil; so that, the soil does not yet have the necessary adhesion to increase strength. In summary, the effect of sodium silicate on all three types of soil compared to pure samples has increased significantly.

***Examining The Shear Strength of 15% Polymer Samples***

The Samples containing 15% sodium silicate in three types of soil (A, B, C) with reduced percentage of coarse grain has been examined. Table 5 shows the shear strength changes in all three types of soils during different time periods.

**Table 5.** Direct shear strength in kilograms per square centimeter (Kg / cm2) in samples containing 15% sodium silicate.

| Time \ Soil | A | B | C |
|---|---|---|---|
| 3 Days | 4.30 | 4.29 | 4.28 |
| 7 Days | 6.9 | 6.44 | 7.32 |
| 28 Days | 12 | 12 | 9.33 |

According to Table 5, pure samples of all 3 soil types lost a small amount of their strength during 28 days, the shear strength of all did not change much. Samples containing 15% sodium silicate in soil C had a higher shear strength than pure samples. Also, soils A and B had low shear strength at first, but the strength increased significantly from day 7 until day 28 after adding sodium silicate; so that, the samples were not broken in the direct shear machine and the maximum value is shown in the figure.

The concentration of polymer and coarse-grained soil are the main reason for this increment; so that, the fluid passes through the coarse grains and result in higher effect and strength than other soils. Therefore, higher adhesion as the main feature of soil has been observed. The polymer chains increase into the soil grains, when the water evaporates and the polymer clots between the grains, the soil becomes harder soil as well as shear strength increases.

**Conclusion**

In this study, the effects of sodium silicate on the stabilization of organic soils were examined. The results showed that the effect of different percentages of sodium silicate in 3 days on soil A was almost the same compared to the pure samples (without binder) but after 3 days due to the setting material and its effect on soil, the shear strength begins to increase. Increased sodium silicate, the shear strength of the soil increases. It was also remarked that the percentages (12% and 15%) showed a very high strength during 28 days; so that, direct shear machine was not able to break the soil and the results of maximum possible strength of machine at 12 (Kg / Cm2) is shown in the figure. The samples containing 12% and 15% during 28 days was 67.5% compared to pure soil during 3 days.

It was observed that soil B had better efficiency in 3 days by adding 5% sodium silicate than other conditions, which increased the shear strength of soil by changing the time to 28 days and also by increasing the percentage of sodium silicate, so that adding 15% sodium silicate showed the best results and the machine was not able to break it. The samples containing 15% during 28 days was 60.34% compared to pure soil during 3 days.

According to the results, soil c containing 5% sodium silicate had higher strength during 7 days. There is negligible strength reduction during 28 days. Also, the soils containing 9%, 12% and 15% of sodium silicate showed higher strength over the time. The increment percentage of samples contacting 15% during 28 days was 47.49% compared to a pure soil during 3 days. This shows less effect than soil A and B due to increased fine-grained and high concentration of sodium silicate; so that, sodium silicate is not able to pass through the grains and prevents complete effects on soil samples.

Future researchers are suggested in this field in the future including consolidation experiments to investigate the effect of sodium silicate on the settlement of organic soils. Also, it is better to investigate the effect of sodium silicate on inclined planes and soil settlement due to overburden.

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