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UNCONFINED COMPRESSIVE STRENGTH AND MICROSTRUCTURE OF CLAY SOIL STABILISED WITH BIOMASS SILICA

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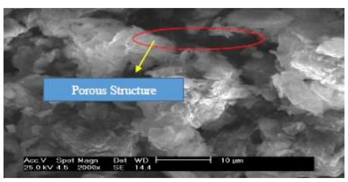
Fauziah Kasim[a]*, Aminaton Marto[a], Nur Amalina Abdul Rahman[a], Choy Soon Tan[b]

[a]Soft Soil Research Group, Faculty of Civil Engineering, Department of Geotechnics and Transportation, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Faculty of Engineering, Technology and Built Environment, UCSI University, 56000 Cheras, Kuala Lumpur, Malaysia

*Corresponding author
fauziahkasim@utm.my

Graphical abstract



Abstract

This study presents the Unconfined Compressive Strength (UCS) and microstructure of clay soil stabilized with locally made Biomass Silica (BS) in the form of SH-85. Since the construction of highway on soft soil raises many problems due to its low strength, understanding about the basic characteristics of soft clay and mixed with BS, play important role for improving the strength of the soft clay. The study carried out had the specific objectives to determine engineering properties of soft clay, to investigate the UCS of soft clay treated with BS and to analyze microstructure of the soft soil treated by BS with respect to various curing periods. In this study, 30 samples of clay soil were prepared under various curing periods (0, 7, 14 and 28 days) and mixed with BS at various percentages (5 %, 7 % and 9 %). The test results show that BS can increase the strength of the clay soil. The 9% BS treated sample for 7 days curing time achieved UCS of 710 kPa. This was approximately 6 times greater than that of untreated soil strength. The highest strength was 1216 kPa at 28 days curing for soil mixed with 9% BS. The images of Scanning Electron Microscopic show that the voids of the clay would filled by the new component resulted by the reaction of BS stabilizer with the natural clay samples. This led to a continuous soil fabric resulting with stronger and denser soil.

Keywords: Scanning Electron Microscope; curing period

Abstrak

Kajian ini membentangkan Kekuatan Mampatan Terkurung (UCS) dan kajian mikrostruktur tanah liat yang distabilkan dengan Silika Biojisim (BS), SH-85 yang dihasilkan dalam negara. Disebabkan pembinaan lebuhraya akan menimbulkan banyak masalah kerana kekuatan yang rendah tanah liat lembut, kefahaman tentang sifat-sifat asas tanah liat lembut dan tanah liat lembut dicampurkan dengan BS, memainkan peranan yang penting untuk meningkatkan kekuatan tanah liat lembut. Kajian yang dijalankan mempunyai objektif khusus untuk menentukan ciri-ciri kejuruteraan tanah liat lembut, untuk menyiasat UCS tanah lembut dirawat dengan BS dan untuk menganalisis mikrostruktur tanah lembut dirawat oleh BS yang berkaitan bagi pelbagai tempoh pengawetan. Dalam kajian ini, 30 sampel tanah liat telah disediakan untuk pelbagai tempoh pengawetan (0, 7, 14 dan 28 hari) dan pelbagai peratusan campuran BS (5 %, 7 % dan 9 %). Keputusan menunjukkan bahawa BS boleh meningkatkan UCS tanah liat. Sampel yang dirawat dengan 9 % BS selama 7 hari tempoh pengawetan mencapai kekuatan mampatan bernilai 710 kPa. Ini adalah lebih kurang 6 kali ganda lebih besar daripada kekuatan tanah yang tidak dirawat. Kekuatan tertinggi adalah 1216 kPa pada 28 hari pengawetan bagi tanah yang dicampurkan 9 % BS. Imej-imej Pengimbas Mickroskopik Elektron menunjukan bahawa lompang tanah liat telah diisikan oleh komponen baru yang terhasil daripada tindak balas penstabil BS dengan sampel tanah liat semulajadi. Ini menyebabkan fabric tanah berterusan menghasilkan tanah yang lebih padat dan kuat.

Kata kunci: Pengimbas Mickroskopik Elektron; tempoh pengawetan

1.0 INTRODUCTION

Soil stabilization is the changes of one or more soil properties, by mechanical or chemical means, for creating improvement of soft soil material possessing the desired engineering properties. The soil properties can be improved and the strength of soil can be increased by using chemical stabilization [1]. The mechanical and the chemical stabilization methods that are used in the soil stabilization are based on decreasing the void rate by compacting or changing the grain size by adjustment of the particle size composition of soil. The chemical stabilization method produces a better quality of soft soil with higher strength and durability than using mechanical stabilization method. The chemical stabilization method also depends on the chemical additives and the soil particles which produce a strong bond of the particles of the soil.

There are various categories of soil stabilization methods, such as vibration, surcharge load, structural reinforcement improvement by structural fill, admixtures, and grouting and other methods [2,3]. Methods to stabilize the soft soil such as using floating piles, stone columns, vertical drains and replacement method are many; however, they are costly and old methods. The soil properties can be improved and the strength of soil can be increased by using chemical stabilization. Various laboratory tests have been conducted for determining potential of Biomass Silica (BS). The factors for choosing chemical for stabilization of soil depend on the purpose, soil strength desired, and toxicity [2]. This project focuses on soft soil improvement method by using non-traditional stabilizer, Biomass Silica (BS), in the form of calcium-based powder named as "SH- 85". BS is the soil cement-like product which can be used for any types of soils for road construction.

Majority soft soils in Malaysia cover in west and east of Peninsular Malaysia. Geotechnical engineers will face many challenges with soft soil foundation as the soft soils present problems related to stability and settlement. The most problem that they would face is that the properties of soil which are unable to fulfill the specification requirements for construction activities such as highway construction.

The coastal areas of West Malaysia soils consist of a few types of soils. Mainly, the soils are low humic soils, being moderately and poorly drained soils developed over coastal plains and in the valleys and flood plains of the larger river, of very variable fertility. Furthermore, the soils have some muck and developed over mineral alluvial soils in poorly drained situation. There are small part of red and yellow latosols and yellow podzolic soils on flat gently sloping and strongly sloping land mostly of below average fertility developed over raised terraces and platforms of older alluvium and sub recent alluvium. Based on the type of soil, it is expected that the construction of highways will face challenges in terms of soft soil improvement.

With the rapid development of highway construction, the settlement of soft soil has become the problem for highway design. When height of a road embankment to be constructed over the soft soil, the stress in soft soils is increasing, so does the strain or settlement of the soft soils [1]. Highest yielding or plastic deformation in vertical and lateral direction of soft soil will occur if the traffic load is high and close to the ultimate bearing capacity of the supporting soft ground, then followed by tension crack or translational slip when deformation is large enough.

The aim of this study was to determine the strength characteristics of the soft soil and the treated soft soil with non-traditional stabilizer. By carrying out the study, the following objectives have been specified. To determine the engineering properties of soft soil, to determine the unconfined compressive strength (UCS) of soft soil treated with Biomass Silica (in the form of SH-85 powder form) and to analyze the microstructure of the soft soil treated by Biomass Silica with respect to various curing periods.

2.0 LITERATURE REVIEW

During the past decades, soil improvement has aged, and reached a new level of acceptance in the geotechnical community. It is now routinely considered in most projects where poor or unstable soils are encountered, especially on sites underlained by suspect or uncontrolled fills. In recent years, the innovative technique has lead to several investigations. The common stabilization method for the soft ground is using grouting technique, used for the strength improvement and the prevention of underground water flow. Grouting is a popular soft ground stabilization method.

Chemical or cement grouting techniques possibly the effective method of ground improvement, but people must be realized with the seriousness of the environmental issues that might be caused by the use of the traditional chemical grouting [4]. This is due to the cause of producing a large amount of carbon dioxide, air and water pollution during manufacturing and implementation processes when using chemical and cement grouting

On the other hand, by mixing of chemical into the soft soil can also increase the strength of the soil. For soft soil structures, which have involved relatively moderate loads that are distributed over large weak strata areas, the cost to use deep foundations to bypass soft soil layers may be extremely high. Thus, soft ground improvement techniques are normally preferred for economical consideration. The soft soil need to be treated before the construction start-up. The treated soil has higher strength, lower compressibility and lower hydraulic conductivity than that of the original soil [5].

2.1 Sodium Silicate Stabiliser

The action of dissolved silicates in the stabilization or cementation of granular strata is a natural geologic process, for example, the cementation of siliceous sandstones and conglomerates [6]. Natural soil is for the most part connected with high size and rates of creep and high compressibility. They might likewise be connected with a danger of extensive distortion and poor quality strength [7].

Sodium silicate is a white powder or colorless solution that is readily soluble in water [8]. The laboratory tests that were carried by [9], series of batch test using composition of sodium silicate system binders to find their effects on physic-chemical properties of the organic soil. By adding 3 mol/L of sodium silicate into the soil, the strength of soil baseline can be achieved 220% in the batch tests unconfined compressive strength (UCS), while UCS results increases to 270% having an activator $CaCl_2$ or $Al_2(SO_4)_3$.

2.2 Non-traditional Additives, Biomass Silica

Ionic, enzymes, salts, polymers and tree resins are several examples of non-traditional additive that being used in treating the soil. The soil that stabilized with additive is a chemically method that used for improving the soft soil. Nowadays, different calcium- and non-calcium-based soil and aggregate stabilizers (in powder and liquid form) are actively marketed by several companies [10]. The exact chemical compositions of non-traditional additives are not disclosed to the proprietary nature of the commercial stabilization additives.

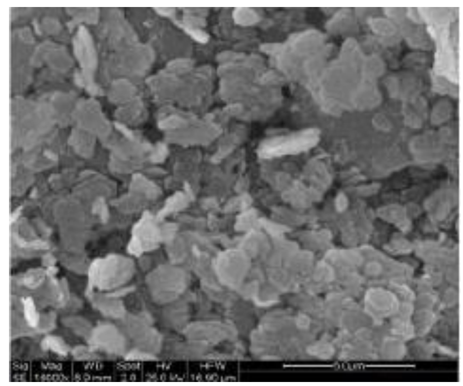
The research that was done by [11], the Unconfined Compressive Strength (UCS) test was used to identify the strength of laterite soil when mixed with SH-85 with different curing periods. The compressive strength of untreated laterite soil was 226 kPa. The results presented by [11] show that the compressive strength of the stabilized laterite soil increase with increasing curing periods, from 226 kPa to 1411 kPa at 28 days for 15 % SH-85 additives to the laterite soils.

2.3 Micro-structural of Stabilised Soil

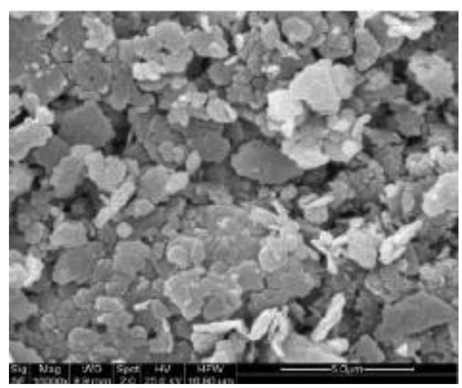
The tests conducted by [12], were performed for Scanning Electron Microscope (SEM) analysis on the kaolin tested with unconfined compression test. Lime treatment changed significantly the soil fabric depending on the curing time and the water content. Figure 1(a) shows the SEM-micrograph of the untreated kaolin clay. As can be seen from the figures, hexagonal particles were observed and the clay displayed flaky texture which almost disappeared after 5% addition of hydrated lime (Figure 1(b)).

3.0 METHODOLOGY

The clay soil was brought from Teluk Intan, Perak which was taken at 1.2 m depth of the soil strata. The particle size distribution of the clay soil is shown in Figure 2. This soil is classified as OH according to the Unified Soil Classification System (USCS) and Loss in Ignition (LOI) test. The properties of the soil properties are listed in Table 1.



(a) Untreated kaolin



(b) Kaolin treated with 5 % lime

Figure 1 SEM images of kaolin clay [12]

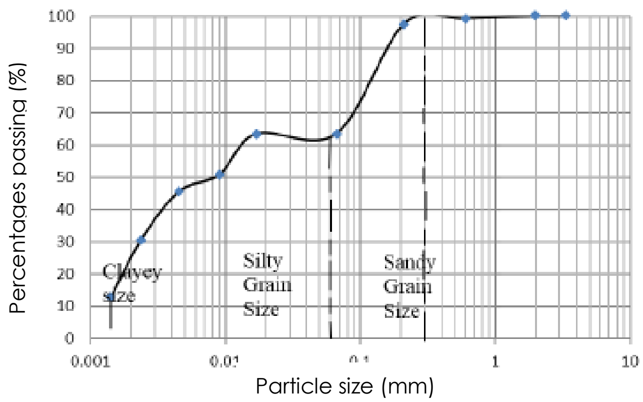


Figure 2 Particle sizes distribution

Table 1 Properties of clay soil in Teluk Intan

Properties	Values
Liquid limit in natural state	123%
Plastic limit in natural state	94%
Plasticity index in natural state	29%
Liquid limit in dry state	78%
Plastic limit in dry state	46%
Plasticity index in dry state	32%
Specific gravity	2.63
Loss on ignition	1.2%
Symbol	OH

The optimum moisture content (OMC) and the maximum dry density (MDD) of the clay were obtained using the Standard Proctor compaction test carried out according to British Standard, which are respectively, 40% and 1.21 Mg/m³. The cylindrical clay soil specimens were prepared in the dimension of 38 mm in diameter and 76 mm in height for the Unconfined Compressive Strength (UCS) test (Figure 3) based on the optimum moisture content (OMC) obtained from the compaction test. The powder of chemical additive used in this study was prepared. Thirty (30) specimens were prepared (Figure 4), mixed with various percentages (5%, 7% and 9%) of biomass silica and cured for 7, 14 and 28 days. Four specimens which have the highest value for each category of UCS were selected for the microstructure study by using Scanning Electron Microscopic (SEM).

4.0 RESULTS AND DISCUSSION

This study was carried out in an attempt to further explain the effects of Biomass Silica on the clay soil. The most of the increment of the strength occurred in the first 7 days of curing. The 9% Biomass Silica treated sample with a 7 days the curing time achieved compressive strength of 710 kPa. This was approximately 6 times greater than that of untreated soil strength (117 kPa). For 9% Biomass Silica mixed with clay, 1216 kPa UCS was achieved at 28 day of the curing period (Table 2). The SEM results confirmed the existence of new products from the reaction of additives with the soil. These new products filled the porous voids within the soil that led to a continuous soil structure resulting with stronger and denser soil.

Figure 3 Unconfined Compressive Strength Test machine

Figure 4 Clay soil specimen mixed with Biomass silica

The compressive strength of the treated and the untreated clay soils were summarized in Table 2 and plotted as shown in figure 5. Figure 5 shows that the compressive strength of the untreated clay soil is 117 kPa (control data) and the addition of Biomass Silica to the soil has significant influence on the compressive strength of the soil. Moreover, it was clear from the graph that the compressive strength of the stabilized soil increases with increasing curing time.

Figure 5 also shows the results of UCS tests of clay soil and stabilized mixture of clay soil with various amounts (5%, 7%, and 9%) of Biomass Silica for various curing times. The Biomass Silica treatment significantly enhanced the strength characteristics of the natural soil. Based on the results, it can be said that the addition of Biomass Silica increased the UCS of the clay soil at all curing periods. However, for 5% of Biomass Silica, it shows decrease strength at 28 days of curing (Figures 6). This reduction happened because of the nature of water-based stabilizer and improperly compaction during the preparation of the specimen. The clay soil reached the maximum strength at curing time of 28 days for 5% Biomass Silica. In addition, the addition of 9% Biomass Silica showed the largest increment compared to the addition of 5% and 7% of Biomass Silica.

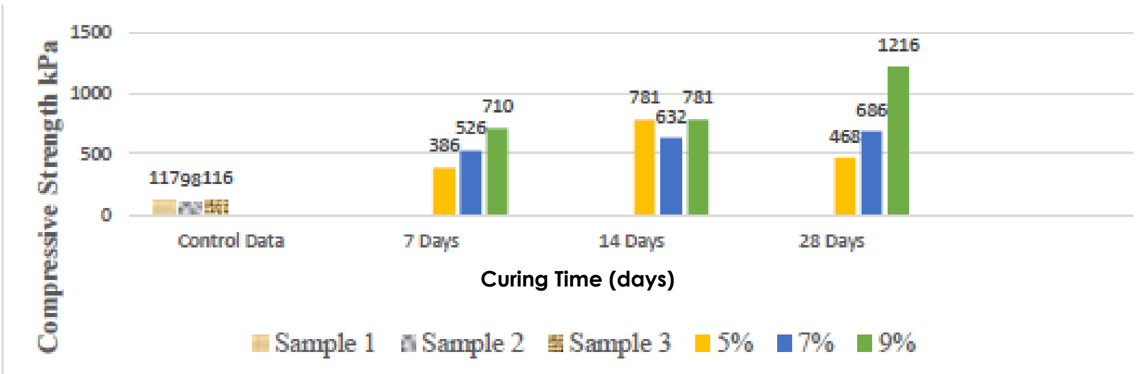


Figure 5 Strength gained for Biomass Silica treated and untreated clay soil for various percentages of stabilizer content and curing periods

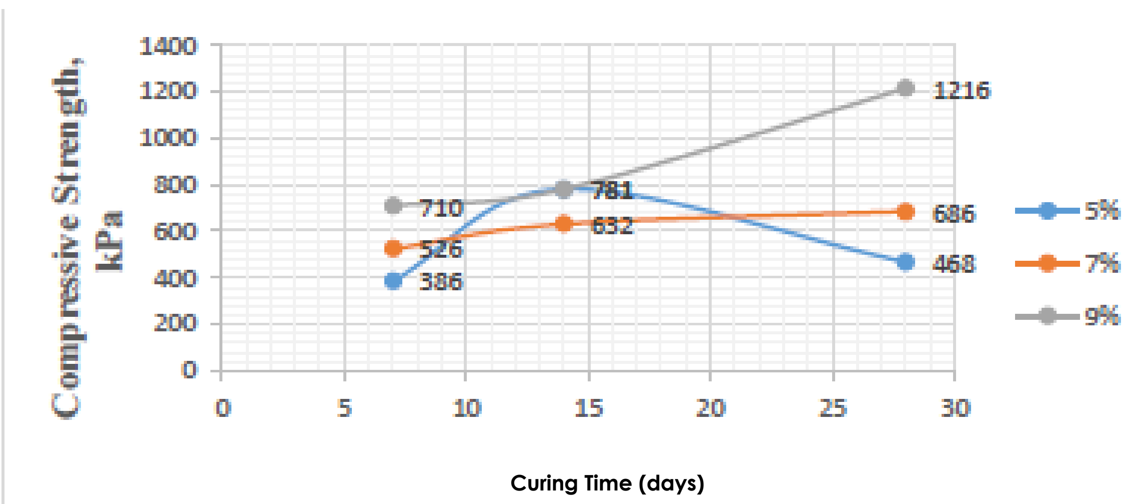


Figure 6 Curves for sstrength gained for Biomass Silica treated clay soil for various % of stabilizer content and curing periods

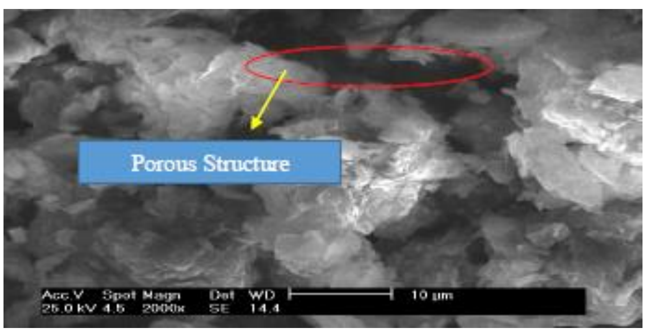
Table 2 Summary of results of Unconfined Compressive Strength test of untreated and treated clay soils with Biomass Silica at various curing times

Soil Description	Unconfined Compressive Strength (kPa)			
Curing time	**0**	**7**	**14**	**28**
Untreated Clay	117			
Clay + 5% Biomass Silica		386	781	468
Clay + 7% Biomass Silica		568	632	686
Clay + 9% Biomass Silica		710	781	1216

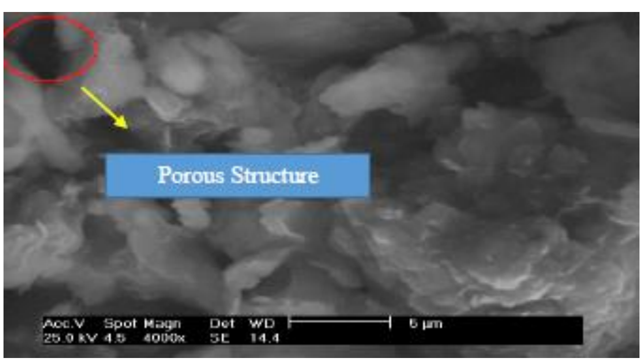
The results show that the highest strength gained due to the soil stabilizer reactions with natural soils. Generally, the strength increased during curing; can be explained through the cementing gel material (hydrates), formed through pozzolonic reactions. In order to confirm this finding, the micro-structural characterization was carried out using Scanning Electron Microscope (SEM). Figure 7 shows the specimen after being tested with UCS. It shows the inclined angle of the failure plane obtained for the unsaturated conditions was at about 75° (against 45° theoretically for saturated condition).

In order to study the structure or the fabric texture of the stabilized soil, SEM test was carried out in the project. Figure 8 shows the micrographs of natural clay soil presented in different magnification factors. The untreated specimen shows the discontinuous structure where the void and the porosity are visible because of the presence of the hydration process.

Figure 7 Specimen of UCS test



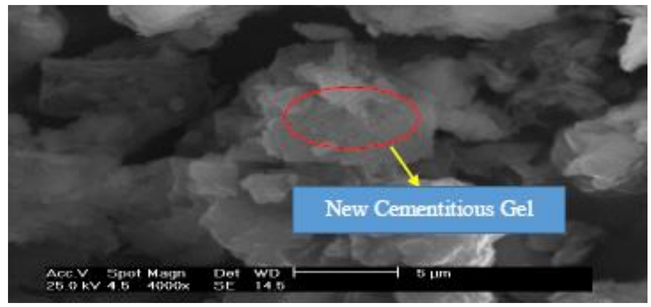
(a) 2000 magnification



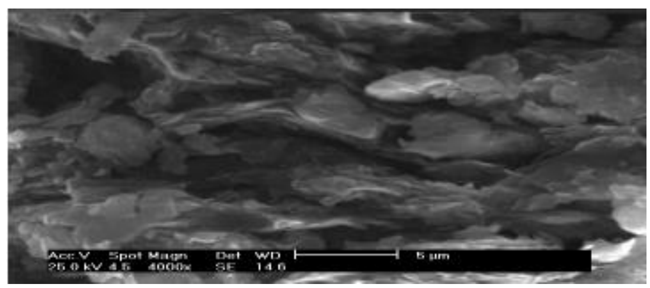
(a) 4000 magnification

Figure 8 SEM for untreated specimen

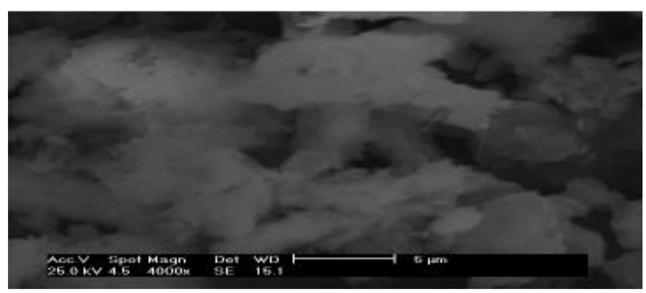
The SEM images at 4000 magnification of the treated clay soil with 9% Biomass Silica is shown in Figure 9 for various curing periods. It can be seen that the microstructure or fabric is flaky and continuous. Furthermore, it reveals the new product which is cementitious gel formed inside the soil. In general, it can be concluded that the new cementitious products filled the pores in the soil structure, occurred during the curing time. It should be stressed that, this is the main reason of the interlocking of the soil particles and resulting in the denser fabric that help to increase the strength and the compressibility resistance of the soil.



(a) 7 days curing period



(b) 14 days curing period



(c) 28 days curing period

Figure 9 SEM images of clay soils treated with 9 % Biomass Silica at various curing days

5.0 CONCLUSION

The test results from Unconfined Compressive Strength Test (UCS) indicated that when Biomass Silica in the form of SH-85 is added to the clay soil, the strength of the mixture increases with increasing amount of

Biomass Silica and curing periods. The strength of the clay stabilized with 9 % Biomass Silica at 28 days curing is the highest among others which is 1216 kPa. The immediate increase in rate of strength after 7 days of curing period is due to the stabilization process. The development of the strength is highly depended on the curing time and the percentages of Biomass Silica added to the soil.

The Scanning Electron Microscopic (SEM) results confirmed the existence of the new products, in jelly form from the reaction of the stabilizer additives with the natural soil. These new products filled the porous areas within the soil particles that led to a continuous soil structure-fabric resulting in stronger and denser soil.

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