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Influence of Biomass Silica Stabilizer on Unconfined Compression Strength of Sodium Silicate Stabilized Soft Clay Soils

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ABSTRACT

Soft clay often causes difficulty in construction operations with regards to strength and low hardness properties. Therefore, the need for soil stabilization is crucial in construction to ensure the stability of the soil strength and stiffness for each building to be built. This research was carried out to study the stabilization of clay in Batu Pahat using additional materials namely sodium silicate liquid and biomass silica powder. Soft clay samples were collected from the Research Centre for Soft Soils of Universiti Tun Hussein Onn Malaysia. The result shows that the liquid limit of the soil decreases while plastic limit increases with the addition of sodium silicate and biomass silica. As a result, the plasticity index reduces with the increment of both stabilizer's content. The strength increases at as early as 3 days after stabilization and constantly increases from 7 to 28 days curing period. The results of the unconfined compression strength test showed that the optimum amount of this stabilization process for the soil sample was three and nine percents of sodium silicate and biomass silica stabilizers, respectively. Additionally, the voids were filled with a stabilizing substance during the SEM testing. Cementation product was detected via the SEM test as a result of the stabilizer given to treated samples. The EDAX test established that the appearance of the Calcium element in the treated sample is a result of the stabilizer's chemical composition. This study demonstrates how biomass Silica significantly affected the increase in soil strength by creating cementation in the soft clay structure. Furthermore, sodium silicate plays a role in increasing soil strength, largely by acting as a binder between soil particles.

Keywords:
Clay stabilizer; EDAX; liquid stabilizers; SEM; unconfined compression strength

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1. Introduction

Development in the construction industry and the increase of human population nowadays require additional soil surfaces for construction purposes. Geotechnical engineer plays an important role in determining the quality of pore water pressure, soil bearing capacity, soil pressure, either horizontal or vertical, soil sediment, and water from the soil. Each execution of the building load

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carried must have good soil bearing capacity and good physical to secure the strength of the bearing capacity of the soil [1].

Stabilization of the soil is very important in the construction to ensure the stability of the strength and stiffness of soil for each building to be constructed. The soil stabilizers are categorized as traditional and non-traditional [2]. Traditional additives include cement, lime, fly ash, and bituminous materials, while non-traditional additives consist of various combinations such as enzymes, liquid polymers, resins, acids, silicates, Ions, and lignin derivatives.

Cement one of the traditional soil stabilization material was used widely for ground improvement on the various projects that have led to the accelerating production of ordinary Portland cement. It has provoked to release of huge amounts of greenhouse gases, carbon dioxide (CO_2), into the atmosphere. To produce 1 ton of ordinary Portland cement is approximately equivalent to releasing 1-ton of carbon dioxide (CO_2) into the air [3,4]. While the non-traditional stabilizer are more economical, sustainable, and environmentally friendly [5,6].

Nowadays, a variety of suppliers and manufacturers developed a new agent to stabilize soil to increase its strength. The new products namely biomass silica (SH-85) in powder form and sodium silicate (TX-85) in liquid form were introduced to increase the strength of soils. Previous research shows that the stabilization using SH-85 increases the strength of soil [7–11].

To improve the workability of the stabilization process, the replacement of powder stabilizers such as biomass silica is one of the best options. The sodium silicate was sold with the commercial name 'TX-85' (liquid form) one of the Probase products has been established. The fundamental mechanical properties of TX-85 stabilized soils have been investigated by many researchers [10–14]. Pakir *et al*., [14] reported that the strength of clay soils increases with the increment of TX-85 content and curing period. As a result, this product can be categorized as a stabilizer agent [15].

The aim of the current study is to assess the influence of SH-85, a commercially available calcium-based powder form additive prepared from biomass silica, for the stabilization of Batu Pahat Soft Clay treated with sodium silicate. To accomplish this task, changes in the macro and micro-structural properties of Batu Pahat Soft Clay stabilized with a combination of SH-84 and TX-85 were explored over various curing periods. A series of Atterberg limits and unconfined compression strength (UCS) tests were performed to examine the physical changes in soil strength induced by the additive stabilization process over time. In parallel, changes in the soil micro-structural over time were investigated using a series of scanning electron microscopy (SEM) and energy-dispersive X-ray spectrometry (EDAX) tests. The result from these tests is useful for understanding the influence of stabilizers on increasing soil strength.

2. Methodology

2.1 Materials

The soil sample is soft clay soil that was collected from the Research Centre of Soft Soil (RECESS) Universiti Tun Hussein Onn Malaysia (UTHM) campus in Johor, Malaysia at a depth of 3 metres. Table 1 shows the physical properties of this soil. Both stabilizers, SH-85 (powder stabilizer) and TX-85 (liquid stabilizer) were provided by the Probase Manufacture Sdn. Bhd., a local company in Malaysia.

2.2 Preparation of samples

The physical properties tests were carried out in accordance with BS 1377 (Part 2: 1990: 4) [18]. A standard proctor compaction test is the process by which the solid particles are packed more closely together, usually by mechanical means, thereby increasing the dry density of the soil. The dry density which can be achieved depends on the degree of compaction applied and on the amount of water present in the soil.

Table 1
Physical Properties of Soft Clay [9,10]

Physical Properties	Values
Liquid Limit, LL (%)	73.00
Plastic Limit, PL (%)	29.12
Plastic Index, PI (%)	43.88
Maximum Dry Density, MDD (kg/m3)	1343.00
Optimum Moisture Content, OMC (%)	30.00

A compaction test was used to determine the optimum moisture content (OMC) and maximum dry density (MDD) for the preparation of specimens. All preparation of samples were done by controlling the bulk density and moisture content to avoid influences of these variables at the strength of stabilization soil. The samples were prepared with 90% OMC (wet side) and 90% of MDD of natural soils. The method of sample preparation for these tests, with the quantity of soil and one sample only is required for the test and it can be used several times after progressively increasing the amount of water. Three specimens were prepared for the same mixture to obtain average data for more accurate results. All specimens at different curing periods (0, 3, 7, 14, and 28 days) with different percentages of TX-85 and SH-85 Probase stabilizers were made. All samples that undergo enough period curing were tested using LoadTrac II is defined as the maximum unit axial compressive stress at failure or 20% strain [19]. The high-resolution images of the fabric of the soil before and after the treatment were captured by SEM that was equipped with EDAX. The samples were completely covered by platinum under a high vacuum environment during sample preparation. Moreover, the EDAX method was used to find the major elemental composition on the surface of treated particles [8,15,20–22].

The Atterberg Limit test have done for classification to recognize the clay to investigate the influence of moisture content on the behavior of soil, especially fine-grained soil after the addition of stabilizers. The consistency limit tests were carried out to determine the influence of the stabilizer on the Atterberg limits of the treated and untreated soils. The samples were dried, crushed, and sieved passing 425 µm (by British Standards) and containing various contents of different stabilizers to establish the influence of the stabilizer on the Atterberg limits[23]. To facilitate the presentation of the result, several characters were designed where UT for untreated soils, L for Liquid stabilizer, and P for powder stabilizer. The other character is content in percent of liquid and powder stabilizers that are added to soft clay soils.

3. Results and Discussions

Figure 1 shows the Atterberg Limit values and chart of Batu Pahat Soft Clay soils after the addition of both stabilizers, respectively. The addition of SH-85 and TX-85 stabilizers to the soil affects the properties and strength of the soil. The liquid limit (LL) of the soft clay declines with the addition of 3% liquid stabilizer with an LL of 59.79% and begins to increase gradually to 60.06% after the addition of 3% powder stabilizer on this specimen. The plastic limit (PL) is upward and higher when reached 44.81% after the addition of 3% of both stabilizers compared to the LL decreased dramatically and PL begin to decline slowly when reached 41.61% after the addition of 3% liquid stabilizer and 6% powder stabilizer.

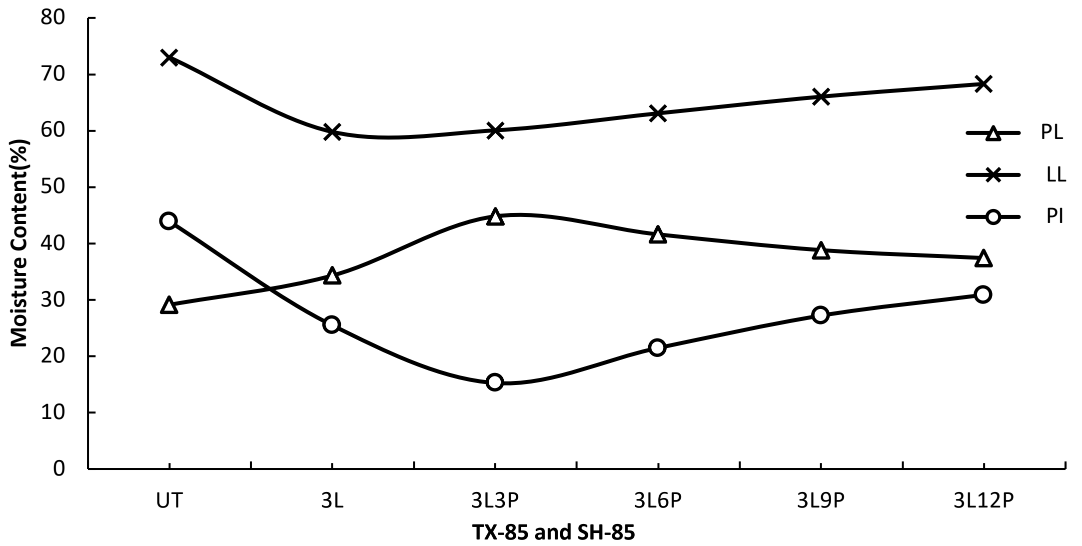

Fig. 1. Atterberg Limits of Batu Pahat Soft Clay soils after addition of Probase Stabilizers [24]

The reduction in LL along with the increase in plastic limit produced a considerable decrease in the plastic index (PI) of soils. The quantity of SH-85 (powder) required to bring changes in plasticity. This shows plasticity chart mixed with TX-85 and SH-85 were high in plasticity. The effects of the stabilizer on the plasticity of soft clay are due to the calcium ions from the stabilizer causing a reduction in plasticity and improving soil friability. This is because of the increase in coagulation and aggregation of the clay mineral particles under the influence of calcium ions. The increase of the optimum moisture content is because of the increase in the void volume of the specific surface area.

Figure 2 shows the effect of the mixture TX-85 and SH-85 at different percentages of soft clay. The shear strength values of the specimens were determined by the peak pressure respectively. It can be seen that increased strength in unconfined compression strength (UCS) leads to a percentage increase in the content of SH-85. The strength value increases gradually at SH-85 content of 3%L for all specimens at different percentages.

For instance, the combination between TX-85 with SH-85 Probase Stabilizer obtained by the addition of 3L12P on soft clay was 364.895 kPa as compared to only 33.625 kPa achieved on untreated soft clay. It was suggested that the ion calcium in SH-85 is only sufficient for flocculation and coagulation processes. It can improve the strength of soil to support the load of structure and decrease the settlement problem on construction over soft clay. It was found that the 3L6P treated samples after 7 days of curing gained a compressive strength of 168.47 kPa, which was approximately 4 times greater than the strength of untreated soil. However, a further increase in strength was slowly achieved by adding higher content of 3L6P. Overall, the addition stabilizer of 3L6P to 3L9P resulting a significant increase in strength and then continue with a slight increase with 3L12P. Hence, 3L9P was determined to be the optimum content of both stabilizers to stabilize these soils. Figure 3 shows the effect of curing time on a combination of TX-85 and SH-85 treated soft clay at different stabilizer contents.

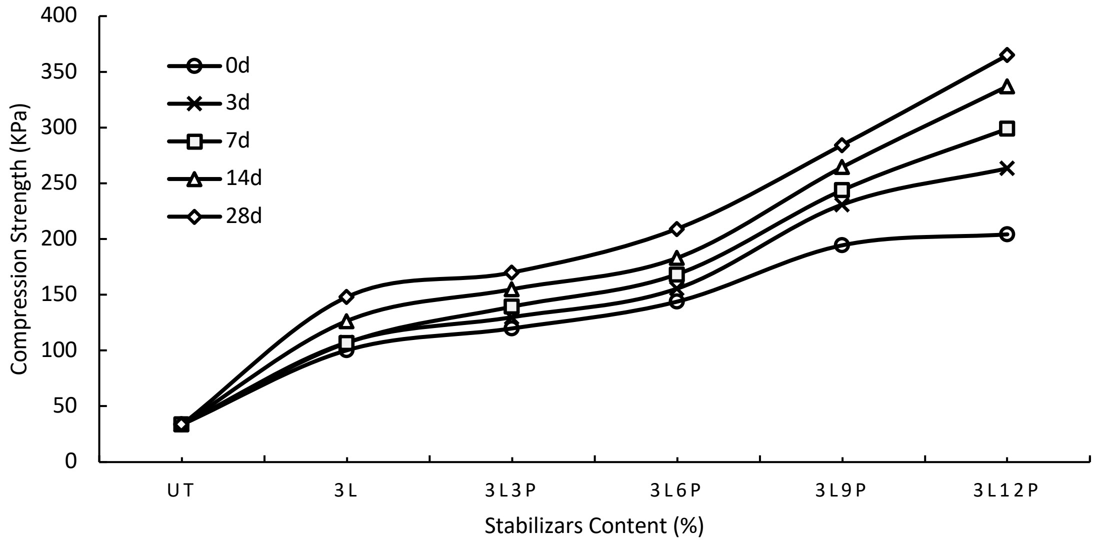

Fig. 2. Strength of treated soil with different SH-85 content[24]

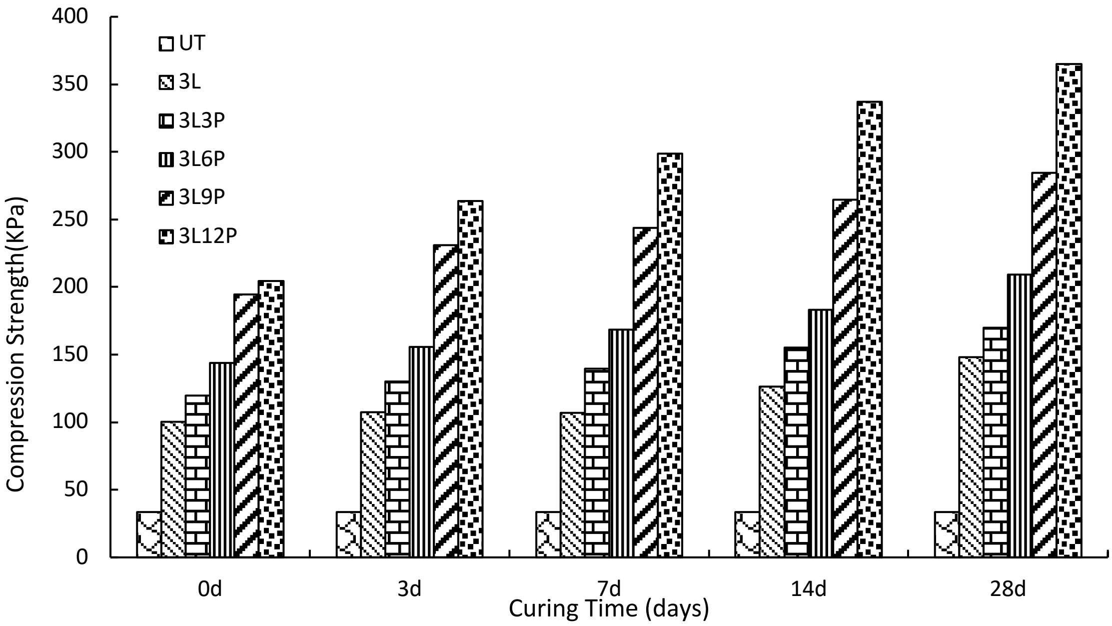

Fig. 3. Strength of treated soil with Probase Stabilizers content at different curing time[24]

Referring to Figure 3, all the soil samples were cured for 3, 7, 14, and 28 days. Overall, the strength of all specimens increases with the increment of the curing time. The strength increases immediately after adding both stabilizers, for example, the strength for 3L9P is about 194kPa compared to untreated is 33kPa. The strength increases to 284kPa at a 28-day curing period.

Figure 4 shows the results of SEM for (a) showing that micrograph of untreated BPSC reveals that platy and feathery particles with a uniform texture organized in a scattered configuration. As observed in the image, the pores spacing in the untreated soft clay soil is quite considerable, indicating that the clay soil has a high permeability. Treated sample and cured for 7,14 and 28 days has also been scanned through an SEM machine to see how the microstructure behaved and what the cementation products looked like as shown in figure 4. Figure 4 (d) shows the appearance of the cementitious more clearly and solid compared to samples 7D and 14D. This also resulted in less porous and denser soil fabric. In addition, the filling of voids in the stabilized soil leads to an increase in bonding and interlocking forces between soil particles which was mainly responsible for the strength gained. This demonstrates how the soft clay, SH-85, and TX-85 constituents of treated soils can change or mix in a variety of ways, as illustrated in figure 4.

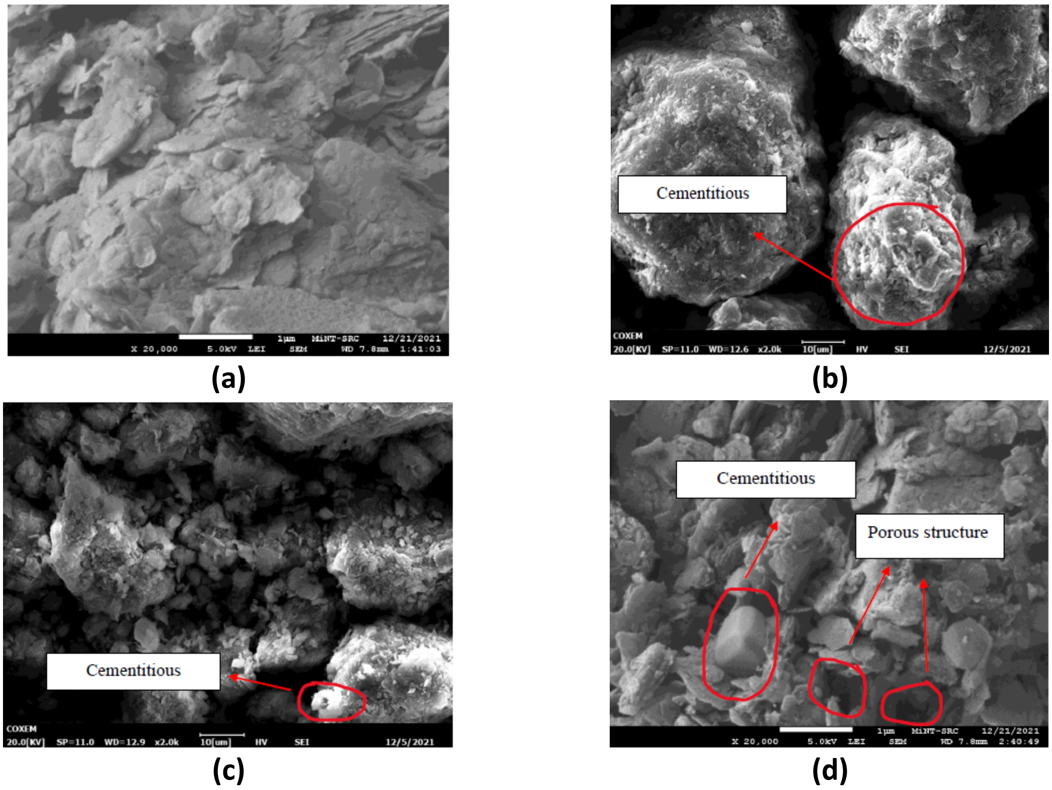

Fig. 4. Micrograph of untreated sample (a) and 3L9P at different curing intervals, 7 days (b), 14 days (c), and 28 days (d)

Figure 5 shows the chemical composition of the untreated and treated samples investigated using EDAX. The EDAX test can identify changes, reactions, or the addition of new chemical elements in samples. The EDAX result will display the concentration of chemical elements in samples via a spectrum graph, as represented in Figure 5.

Figure 5 (a) shows the EDAX spectrums for untreated BPSC and shows that Oxygen (O) has the highest weight percentage which is 51.53%, and then Silicon (Si) (17.52%), Carbon (C) (11.02%), and Alumina (Al) (10.27%) are the chemical elements that dominated compared to other elements. For figure 5 (b), the presence of Oxygen (O) fluctuated a little bit to 51.98%, and then Silicon (Si) keep increasing to 31.44%, Carbon (C) keep disappeared and Alumina (Al) drastically drop to 7.19%. Meanwhile, figure 5 (c) proved that the presence of Oxygen (O) has increased to 53.07 %, Silicon (Si) has decreased to 21.06 %, Carbon (C) has remained the same, and Alumina (Al) has increased to 10.17%. The 14 days curing time sample clearly shows that the weight percentage does not change significantly as compared to the untreated and 7 days curing time samples. Figure 5 (d) shows that Oxygen (O) has continued to fall to 26.94 %, followed by Silicon (Si) at 19.19%, Carbon (C) at 17.51 %, and Alumina (Al) at 5.30 %. The weight percentage changes dramatically in the 28 days curing time sample as compared to the untreated and 14 days curing time samples.

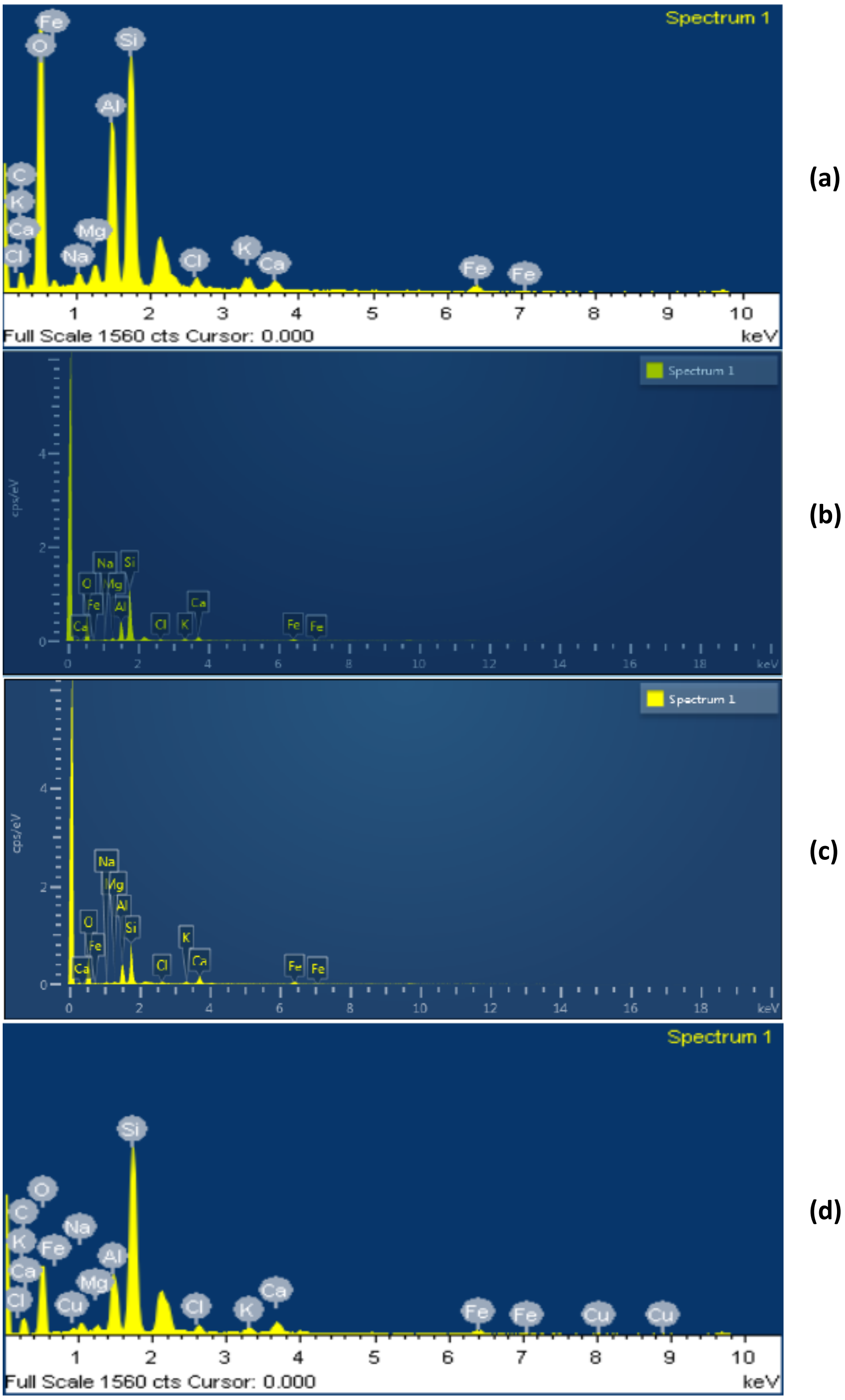

Fig. 5. EDAX spectrums of untreated (a) and 3L9P at different curing intervals, 7 days (b), 14 days (c) and 28 days (d)

4. Conclusions

The Current study is to examine the influence of biomass silica (SH-85) on the unconfined compression strength (UCS) of sodium silicate (TX-85) stabilized soft clay in terms of the effect of properties, strength, and changes in the mineralogy and microstructure. The liquid limit of the soil decreases while plastic limits increase with an increase of TX-85 and SH-85. As the result, the Plasticity Index (PI) reduces with the increment of SH-85 contents. The results of the Atterberg limit test show that soft clay with the content of a combination of TX-85 with SH-85 Probase stabilizer contains high plasticity. In other words, it can reduce the moisture content of soil clay in Batu Pahat. Overall, the strength was increasing significantly with the addition of stabilizer at 3L6P to 3L9P and then was slightly increased at 3L12P of Probase stabilizer content. The results indicated that the SH-85 is a stabilizing agent. The results of the unconfined compressive strength showed that 3L9P was the optimum amount of stabilization process for this soft clay soil.

The results of the 3L9P sample have been compared to untreated samples which proved that give a lot of changes in mineralogy and microstructure of the soft soil. Furthermore, the addition of sodium silicate (TX-85) and biomass silica (SH-85) increases the concentration of Silica (Si) in treated soils. Quartz is represented by the (Si) symbol in samples. The white structure that coated the treated soils exhibited a higher concentration of crystalline cementation products, as evidenced by the SEM result.

Finally, the outcome of this research confirms that biomass silica (SH-85) a lot influenced the increment of soil strength by forming the cementation in the soft clay structure. At the same time, sodium silicate (TX-85) is also involved in the increment of soil strength primarily to act as a binder between soil particles.

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