THE MONITORING AND CEMENTATION BEHAVIOR OF ELECTROKINETIC STABILISATION TECHNIQUE ON BATU PAHAT MARINE CLAY

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ABSTRACT: This paper outlines the monitoring and soil fabric results from an experimental study of electrokinetic stabilisation (EKS) technique. The monitoring results were important in assessing the efficiency of the technique towards Batu Pahat marine clay. Two reactors were set up; 1.0 M of calcium chloride ($CaCl_2$) and sodium silicate (Na_2SiO_3) as the electrolyte and stainless steel plates as the electrodes. EKS technique was continued for 21 days with a constant voltage gradient (50 V/m). This technique was performed in two phases where the alteration of EKS was the combination of stabilizers used. The combinations of stabilizers in phase 1 and 2 were $CaCl_2$ – distilled water (DW) and $CaCl_2$ – Na_2SiO_3, respectively. The technique was monitored using electric current, total inflow and outflow of electrolytes and pH of electrolytes. It showed fluctuated profiles of electric current for both phases, attributed by the introduction of calcium ions from the anode compartment. The inflow and outflow of electrolytes results showed that electromigration and electroosmosis occurred during EKS and it indicated the movement of anion and cation to the opposite direction. The pH of electrolytes kept constant value and balanced by electrolysis process at the cathode. Image of soil fabric for untreated and treated clay were presented where most images shows a flaky particles. The observation of those images indirectly explained the effect of cementation behavior of treated clay.

Keywords: Electrokinetic Stabilisation, Marine Clay, Calcium Chloride, Sodium Silicate.

1. INTRODUCTION

Marine clay is an uncommon type of clay and normally possesses a soft consistency. Batu Pahat marine clay is classified as clayey silt with low organic content [1] and usually found in the ocean bed [2]. It can be found onshore as well. Their properties rely on their initial conditions, where the saturated marine clay soil differs significantly from moist and dry soil. Marine clay is microcrystalline in nature. Clay minerals and non-clay minerals are also present in the soil. The clay minerals contained in marine clay are chlorite, kaolinite and illite while non-clay minerals found in marine clay are quartz and feldspar. Furthermore, the higher proportion of organic matter in the soil acts as a cementing agent [2]. The location of marine clay deposits in Peninsular Malaysia are shown in Figure 1 [3].

Enhancing the substructure of soil is the major aspect concerned in construction work before any superstructure can be applied on it. It is important to strengthen the soil so that it can surpass the maximum imposed load to evade any failure that might occur afterwards. There are two options in ground improvement, either by physical or chemical stabilisation technique [4].

EKS is the one of the principles of chemical stabilization and has been chosen as a potential technique to enhance the characteristics of soil [5]. It is suitable for soft clayey soils which have low hydraulic conductivity and require strengthening to improve the soil condition. Furthermore, it can also be used to stabilize the over consolidated clayey soil. The advantage of EKS instead of using traditional mix-in-place chemical stabilization is that the technique allows for remote treatment through soil without any excavation work [6]. The technique can be enhanced by use of non-toxic stabilizing agents such as lime or $CaCl_2$ solutions [7-9] that can be fed either at the anode or cathode depending on the ions to be transferred into the soil. A few soil parameters such texture, plasticity, compressibility and permeability will be altered by addition of these stabilizing agents, hence it can be very effective in improving soil characteristics by reducing the amount of clay size particles and increasing the shear strength [10].
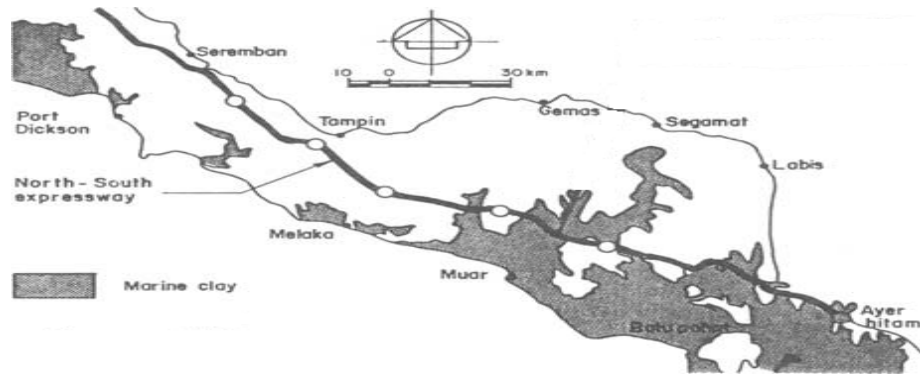
Fig. 1 Location of marine clay deposits in Peninsular Malaysia

2. MATERIALS AND METHODS

2.1 Experimental Apparatus

The EKS test rig was designed for this research. A schematic diagram of EKS test rig is shown in Figure 2. It was made using transparent acrylic plate with 420 mm depth, 170 mm width and 358 mm length. The thickness of the acrylic plate was 15 mm. The transparent acrylic plate for the EKS test rig was used to prevent short circuiting and to monitor the soil level during consolidation at the main compartment and level of water and/or chemical solution at the small compartments. The EKS test rig comprised of three compartments, which were separated with perforated walls. The soil sample was placed into the main compartment and the two small compartments were used to supply the chemical stabilizers into the soil.

The electrode, electrolyte and stainless steel plate were placed as shown in Figure 2. For the first phase, the combination of stabilisers was 1.0 M of $CaCl_2$ and DW and were fed at the anode and cathode compartment, respectively. While in the second phase, the combination of stabilizers was 1.0 M of $CaCl_2$ and 1.0 M of Na_2SiO_3 and were fed at the anode and cathode compartment, respectively. A constant voltage gradient (50 V/m) was applied to the soil sample and the experiment was performed for 21 days for both phases.
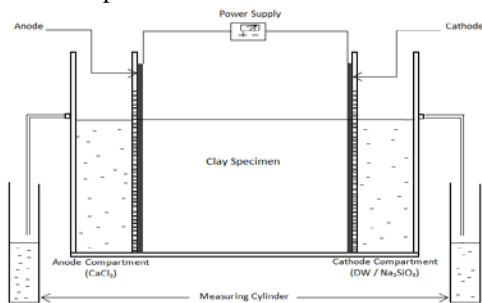

Fig. 2 Schematic diagram of EKS test rig

2.2 Soil Sample Preparation

Soil sample for EKS technique was prepared consistently throughout this research for all treatment periods. Batu Pahat marine clay was dried in the oven for 24 hours. The dried sample was ground using a grinder machine to get very fine material that would pass a 425 µm sieve. The slurry sample was prepared by mixing the soil samples with distilled water to achieve 90 % of water content. The water content of the slurry sample was chosen based on 1.5 times of liquid limit (LL). Then, the slurry sample was placed inside the main compartment (278 x 165 x 413 mm) and a uniformly distributed load was applied to it by using large strain consolidation to reduce the water content resulting in a stiffer soil condition [7-9].

2.3 EKS Monitoring

Throughout the EKS experiment the applied electric current, the pH of anode and cathode solutions were observed during the 21 days of EKS experiment for both phases. The total amount of stabilizers added and amount of effluent water collected from the measuring cylinder were monitored over the same period of time. On the first day of the EKS experiment, the reading of current value was taken at 1, 2, 4, 6 and 8 hours. From the second day onwards, reading of current value was taken every 24 hours. Volume of stabilizers added to the experiment was taken every 24 hours together with effluent water which was collected using measuring cylinders. The pH testing was performed on the extracted electrolytes taken from the electrolyte compartment. In addition, calcium chloride was constantly supplied at anode compartment for $CaCl_2$ – DW and $CaCl_2$ – Na_2SiO_3 systems, whereas sodium silicates were continuously supplied during the experiment in the $CaCl_2$ –

Na_2SiO_3 system to assure the effectiveness of EKS experiment towards the clay soil.

3. RESULTS AND DISCUSSION

3.1 Soil Classifications

Table 1 shows the soil classification for untreated Batu Pahat marine clay where it was used as the control value and as the comparisons with EKS treated values. Current results and results from Abdurahman [11] were presented and compared. Those aspects measured were plastic limit (PL), liquid limit (LL), plastic index (PI), specific gravity (G_s) and pH. They showed that the current results were in range and closed as reported by Abdurahman [11]. If the plastic and liquid limit of soil were in the range of 25-40 % and 30-110 %, respectively, hence the soils are considered as kaolinite soil [4]. Kaolinite soil which has a low cation exchange capacity will exhibit high electroosmotic water transport when the soil is saturated with dilute electrolyte solution due to the high water counter ion ratio in the internal phase. Furthermore the soil is generally used in EK application. The EK technique is particularly well suited for soils of low permeability such as kaolinite in which the application of stabilizing agents by hydraulic means is impracticable [5].

Table 1   Classification of Batu Pahat marine clay

Soil classification	Current results	Results from previous study[11]
PL	36 %	20 – 35 %
LL	61 %	37 – 65 %
PI	24.77 %	13 – 31 %
G_s	2.60	2.18 – 2.65
pH	2.73	-

(-)   Not stated

3.2 Monitoring Data

Figure 3 shows the profile of electric current for $CaCl_2$ – DW system during EKS experiment. On the other hand, profiles of electric current for $CaCl_2$ – Na_2SiO_3 system are shown in Figure 3. The electric current values were recorded at hour 0, 1, 2, 4, 6 and 8 on the first day of the experiment and every 24 hour afterwards for 21 days period of time.

For the $CaCl_2$ – DW system, the values on the first day of the experiment show a fluctuating trend and values remained constant afterwards until the end of the experiment. The highest value occurred at the 6th hour of experiment at 3.107 A, while the lowest value was recorded at the beginning of experiment at

3.082 A. After 8 hours the electric current values recorded were between 3.084 A to 3.094 A. In the $CaCl_2$ – Na_2SiO_3 system, a different trend was observed compared to the first phase. The profiles of electric current showed that the values increased from the beginning until the end of the experiment. At the 224th hour the electric current values started to remain constant until the end of the experiment and recorded as the highest value at 2.33 A. There was a fluctuating trend of current values that occurred at the 4th hour of experiment. The fluctuating trend that occurred in both phases was possibly caused by the introduction of additional ions by calcium chloride at the anode compartment.
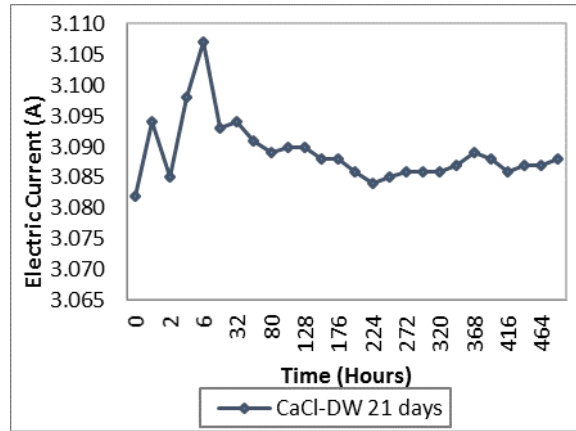

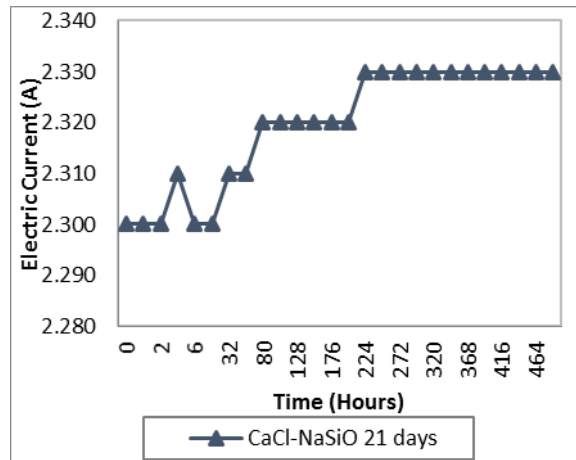
Fig.3 Electric current for $CaCl_2$ – DW system with time

Fig.4 Electric current for $CaCl_2$ – Na_2SiO_3 system with time

The total volume of inflow and outflow of $CaCl_2$ at anode compartment for $CaCl_2$ – DW system is presented in Figure 5. It showed that there was no outflow value of $CaCl_2$ collected by the measuring

cylinder from the anode compartment where it remained zero from the beginning until the end of 21 days. At hour 224, the inflow values remained constant until the end of experiment. The total inflow and outflow values of DW at the cathode compartment for the $CaCl_2$ – DW system were shown in Figure 6. It showed that inflow of DW only occurred at 0 hour at 1705 ml, while the outflow volume increased at hour 32 of the EKS experiment. The volume of outflow was taken at the flushing chamber (cathode compartment) that was collected from the measuring cylinder. Thus, it indicated that there was no fluid discharge from the anode compartment throughout the experiment and it proved that the stabilisers have fully migrated to the soil sample.
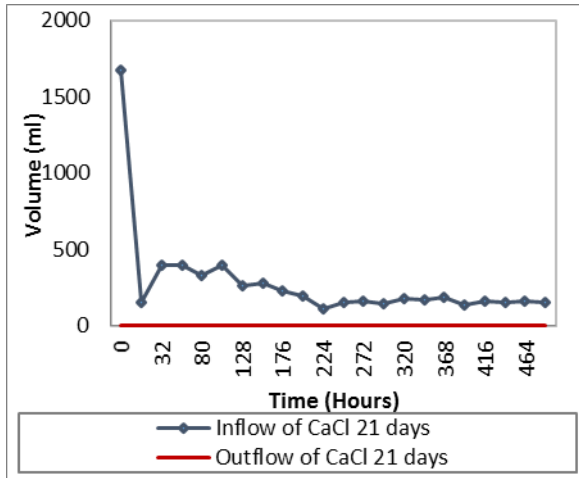
Fig.5 Inflow and outflow of $CaCl_2$ for $CaCl_2$ – DW system with time
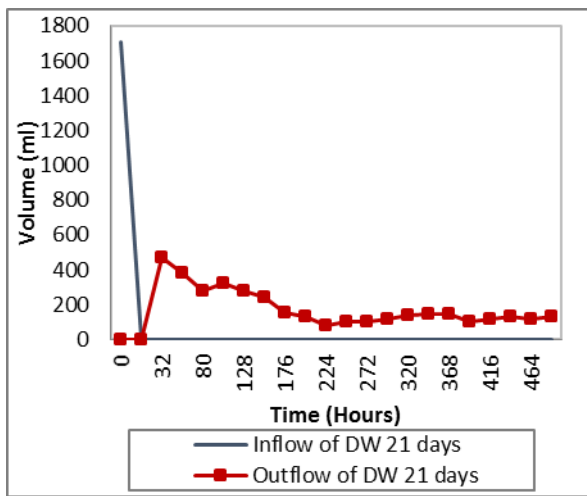
Fig.6 Inflow and outflow of DW for $CaCl_2$ – DW system with time

Figure 7 presents the volumes of inflow and outflow of $CaCl_2$ for $CaCl_2$ – Na_2SiO_3 system. It showed that there was no outflow volume from the anode compartment from the beginning until the end of experiment where it was similar to the first phase. The inflow volume of $CaCl_2$ showed that it decreased rapidly compared to amount at the beginning of the experiment. The total inflow and outflow of Na_2SiO_3 is presented in Figure 8 and it showed that the inflow of Na_2SiO_3 occurred at 0, 152 and 320 hours. This is because the cathode compartment was cleaned every 7 days during the experiment and the empty compartment was replaced with the same amount of Na_2SiO_3 to maintain and ensure the effectiveness of the experiment. The outflow volume from the cathode compartment occurred after 32 hours of experiment and the volume was in the range of 110 – 390 ml. The results explained that the process of electromigration and electroosmosis occurred during the experiment and that the anions and cations were moving in opposite directions.
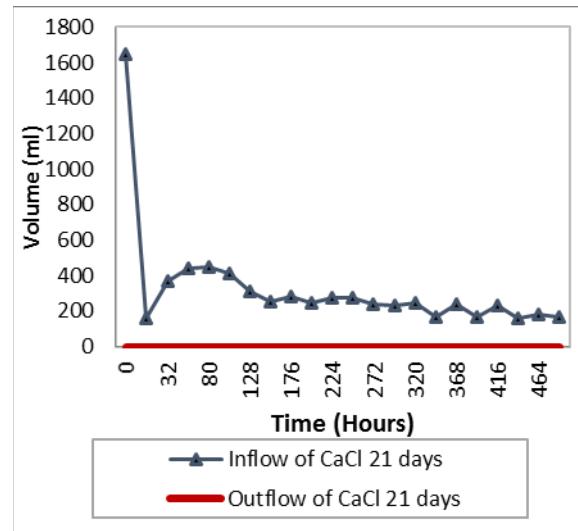

Fig.7 Inflow and outflow of $CaCl_2$ for $CaCl_2$ – Na_2SiO_3 system with time

The variation of pH of electrolytes for the $CaCl_2$ – DW system for the 21 day experiment is shown in Figure 9. The fluids from the anode and cathode compartment were extracted to obtain the pH values of the electrolytes. It showed that the pH of $CaCl_2$ inside the anode compartment remained constant starting from the 80th hour of the experiment.
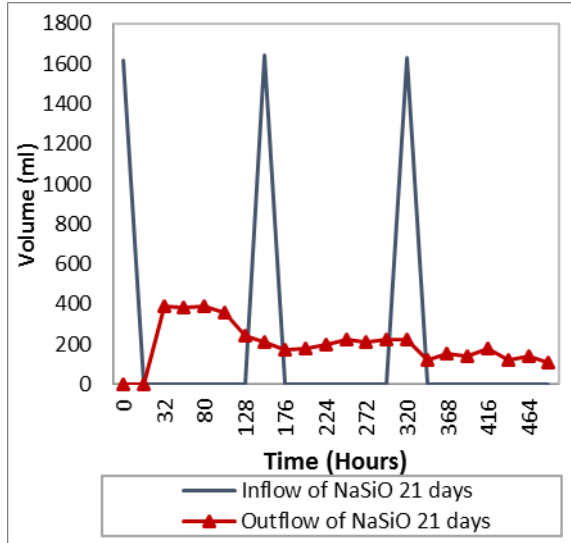
Fig.8 Inflow and outflow of Na_2SiO_3 for $CaCl_2$ – Na_2SiO_3 system with time

Fig.9 pH of electrolytes for $CaCl_2$ – DW system with time

Meanwhile, the pH for DW inside the cathode compartment or the flushing chamber shows a fluctuating trend from hour 0 until hour 104. It showed that the pH value increased at hour 32 and dropped at hour 56 and hour 80 of the experiment. The pH values for the $CaCl_2$ for 21 days of the experiment ranged between pH 3.9 to pH 5.5, while for DW the value were between pH 7 to pH 13.

Figure 10 presented the variations of pH of electrolytes for $CaCl_2$ – Na_2SiO_3 system. The pH value for $CaCl_2$ dropped considerably starting from hour 56 and stabilized until the end of the experiment. The highest value recorded was pH 6.06 at hour 56 and the lowest value was pH 3.09 at hour 464. The pH value of Na_2SiO_3 showed that almost the entire specimen was subjected to alkaline conditions showing a constant trend with a pH of around 13 during the experiment. The constant value of Na_2SiO_3 showed its continuous supply at the flushing chamber where it was cleaned and replaced every 7 days during the experiment to stabilise the pH value and balance the pH changes via electrolysis process at the cathode.

3.3 Image of Soil Fabric

To investigate the effect of cementation behavior of stabilised clays, it can be observed at microstructural level through scanning electron microscopy (SEM) images [12]. Figure 11 illustrate the image of soil fabric of the untreated clay or control. It shows there were irregular shape of nodules appear on the foreground and some voids on background.
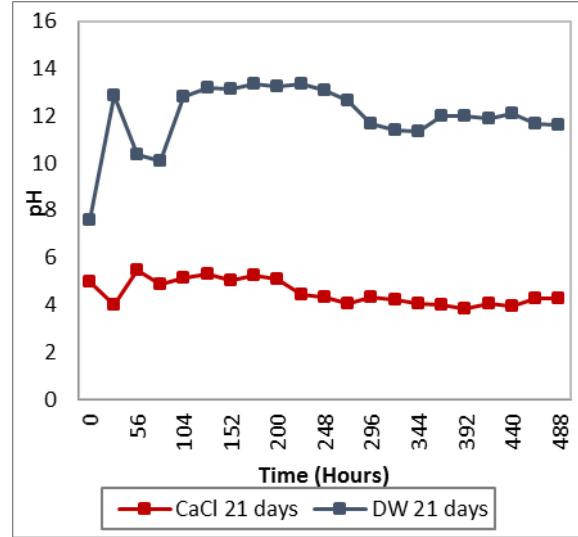

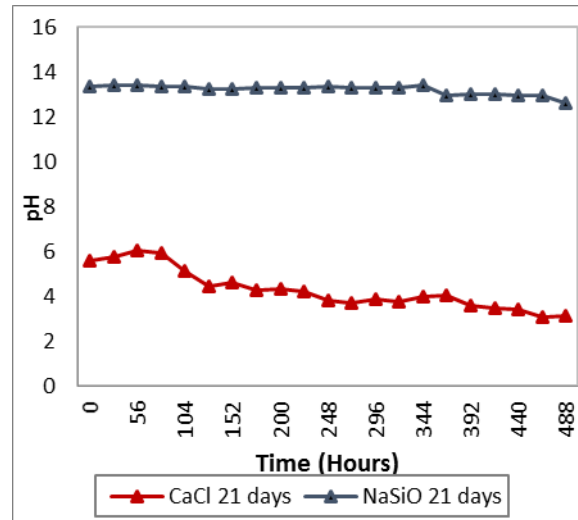Fig.10 pH of electrolytes for $CaCl_2$ – Na_2SiO_3 system with time

The images of soil fabric that treated with $CaCl_2$ – DW system were shown in Figure 12, Figure 13 and Figure 14. Near the anode, the particles showed it were interconnected and coated with calcium compounds and voids seem infrequently occurred on the background. It shows a flaky particle appeared at the middle and near the cathode area with various sizes and shapes of nodules. At the vicinity of cathode it shows the nodules appeared on the foreground with some voids on the background. The exposed of flaky particles probably caused by dissolution or ionization of the coating materials and

other compounds or precipitates due to the acidic environment [13].

Figure 15, Figure 16 and Figure 17 illustrate the images of soil fabric of the treated clay at three different areas for $CaCl_2 - Na_2SiO_3$ system. Near the anode, a various sizes of nodules with irregular shape were visible on the foreground of soil fabric. Whereas, some small voids were appeared on the background. Image of soil fabric at the middle area resulted with flaky particles and small nodules on the foreground. At the area, it was also created and packed with some voids on the background. While, near the cathode it resulted with the flaky particles and nodules with various sizes that visible within the treated soil matrix. Furthermore, it indicates the soil particles were interconnected and coated by sodium compounds hence some large particles with some voids were form at the area. The EKS experiment towards the clay that using selected stabilisers were caused of ion exchange, acidification, formation of sodium compounds and other chemical reactions, and this probably the reasons for such soil fabrics [13]. Through the observation of untreated and treated soil fabric images, it shows the untreated clay exhibits an open type of microstructure with thin and flat clay particles spreading over a large area. While the stabilised or treated clay showing the effect of cementation through flocculated structure with large treated particles clusters interspersed by large openings [12,14].
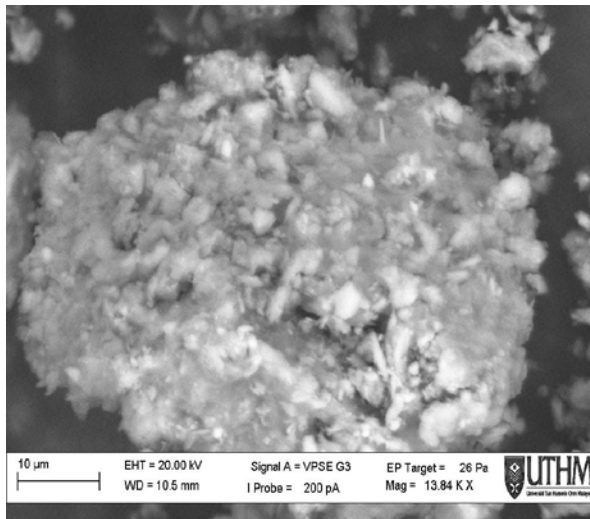

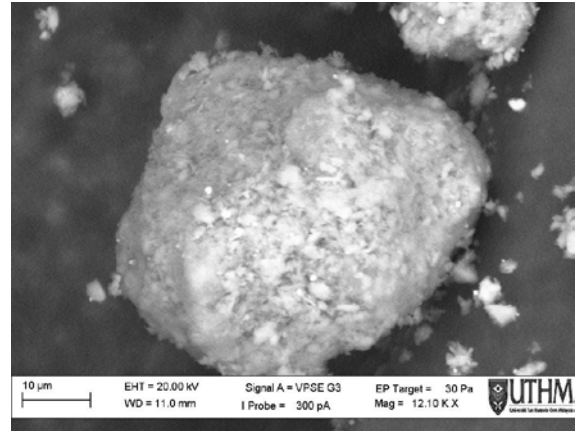Fig.11 Image of soil fabric for untreated clay

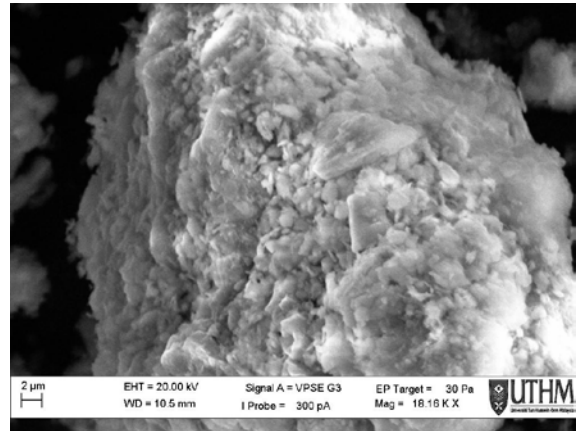Fig.12 Image of soil fabric treated using $CaCl_2 - DW$ system near the anode

Fig.13 Image of soil fabric treated using $CaCl_2 - DW$ system at the middle
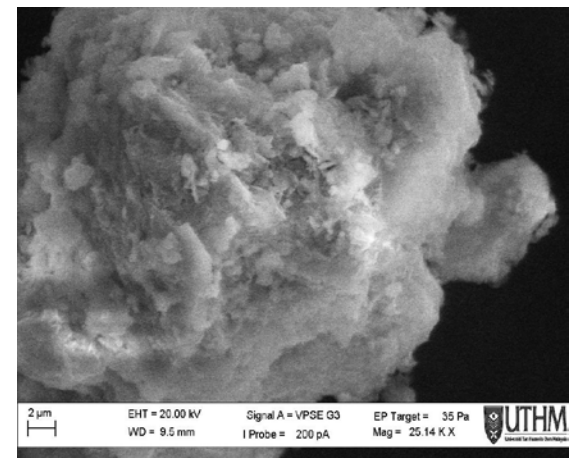

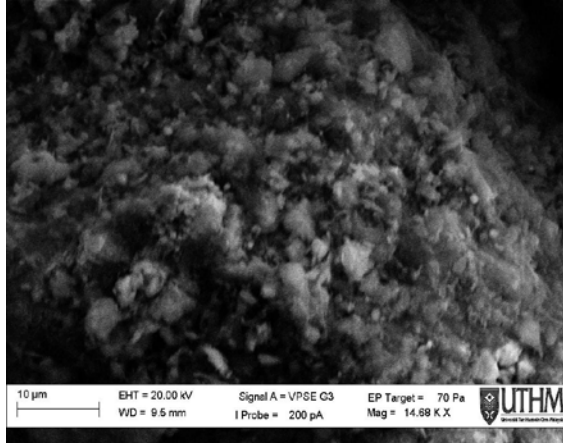Fig.14 Image of soil fabric treated using $CaCl_2 - DW$ system near the cathode

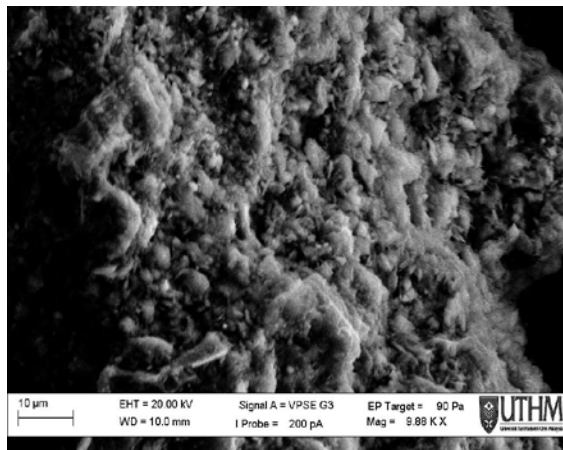Fig.15 Image of soil fabric treated using $CaCl_2$ – Na_2SiO_3 system near the anode

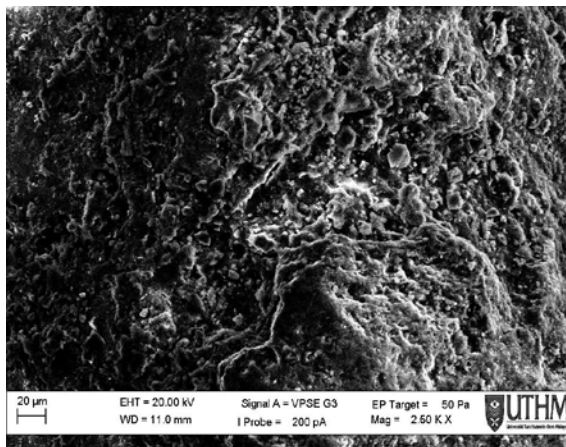Fig.16 Image of soil fabric treated using $CaCl_2$ – Na_2SiO_3 system at the middle

Fig.17 Image of soil fabric treated using $CaCl_2$ – Na_2SiO_3 system near the cathode

4. CONCLUSIONS

A 50 V/m of voltage gradient or equal to 14 V was applied towards the soil in the EKS experiment. The electric current values were strongly affected by the chemical composition of soil and influenced by the ionic concentration of the pore fluid within the soil matrices [15]. The electric current generated in the experiment was due to the existence of inorganic soil elements in high concentration for example iron, calcium and magnesium. The inflow and outflow volumes of the stabilizing agents towards the soil were affected by the physicochemical characteristics of soil, applied current and the pH. Those values were important in assessing the efficiency of electromigration and electroosmosis process in migrating stabilizing agents into the system hence improving the soil properties after EKS. The monitored pH values relied on the pH of electrolytes that was continuously supplied to the electrolyte compartment in the experiment since there were small changes of pH value shown during EKS. Monitoring data provided information on the efficiency of the EKS experiment as it proved that there were electric current and stabilizing agents being continuously supplied until the end of the experiment. It also acts as a precaution if any failure or error occurs during the experiment so that it could be detected immediately. Most images shows a flaky particle of soil fabrics where it probably caused by dissolution or ionization of the coating materials and other compounds or precipitates due to the acidic environment. It indicates the soil particles were interconnected and coated by stabilising agents hence created some large particles in various sizes and shapes with some voids were formed in the soil fabric. The EKS experiment towards the clay by using selected stabilising agents were caused of ion exchange, acidification, formation of sodium compounds and other chemical reactions, and this probably the reasons for such soil fabrics.

5. ACKNOWLEDGEMENT

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