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Stabilization Soft Clay Soil using Metakaolin Based Geopolymer

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ABSTRACT

Chemical stabilization is one of the most alternative methods using on soil stabilization with various materials. In recent decades geopolymer has been attention from engineers and experts geotechnical to use it for improvement of soil, because of considered eco-friendly and cost-effective. This paper aims to investigate the influence of used MK-based Geopolymer in geotechnical engineering and to enhance the properties of soil. Where the MK is considered eco-friendly material and cost-effective compared to other materials. Different percentages of Metakaolin-based Geopolymer were used, which are 8, 10, 12, and 14%. It can be concluded that the peak value of strength illustrated when used MK of 10% with curing time 14 days. In addition, Scanning Electron Microscope (SEM) results show the clay particles covered by cementations compounds due to the reaction of the Geopolymer with clay which led to the production of binder particles.

1. Introduction

Most of buildings are construction challenges, especially when the subgrade soil is found to be clay soils. These soils normally tend to change in its volume if there is any change in moisture content. There are several causes of the change in moisture content like floods, water evaporation, and sewer liner. These states cause the cracking and breaking up of foundations, embankments, highways, railways and, and channels [1]. Therefore, to avoid these problems, several techniques were investigated since earlier years. (i.e stone columns are ideally suited for structures with widespread loads) [2]. Besides, many additives were used like a traditional binder (i.e. cement, lime, slag, and others) that was used extensively throughout the world. Using cement with water to improve soil causes significant improvement in soil (i.e increase in gain strength, decrease in shrinkage–swelling behavior, reduction in the settlement) [3]. Unfortunately, the use of cement generates effects negatively on the environment related to CO_2 emission according to official health safety [4] where the production of cement could give as much as 8% of cumulative emissions [5]. Recently, several materials are available to stabilize soft clay soil (fly ash, rice husk ash, reeds) are used instead of cement and lime [6, 7].

Using fly ash-based Geopolymer studied by [8] to stabilize sandy soil for self-compacting rammed earth construction. All samples were cured at 80 °C for curing time 1d, 3d, and 7 days. Several additions were used as concrete admixtures such as calcium hydroxide, sodium chloride, and concrete superplasticizer to illustrate the effect them in the soil. Also, the effect of temperature on strength of soft clay soil treated with fly ash-based Geopolymer had studied by [9, 10]. The results illustrate the temperatures and concentration of hydroxide sodium under different conditions affected on gain strength.

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Therefore, this study included the soil improvement by adding different concentration of MK activated by two materials.

2. Materials and sample preparation

2.1 Soft soil

The soft clay soil used in the present study was brought from Al-Bawya Village/ Diyala Governorate/ Iraq. Standard tests were conducted to investigate the physical and chemical properties of soil used.

Table 1: Properties of natural soil used

Property	Index value	Specification
Specific gravity	2.72	ASTM D 854
Liquid limit	39	ASTM D 4318- 00
Plastic limit	25	ASTM D 4318-00
Plasticity index	14	-
Passing No.200	96%	-
Percent of sand	4 %	ASTM D 422
Percent of clay	56%	ASTM D 422
Percent of silt	44%	ASTM D 422
Maximum dry density	١٦.8 kN/m^3	ASTM D
Optimum moisture content	18.4 %	ASTM D 698
UCS	0.433 MPa	ASTM D 2166
USCS classification	CL	ASTM D 2487

2.2 Metakaolin based Geopolymer

MK is a pozzolanic material. It's achieved by calcination of kaolinite clay at temperatures about 650°C to 800°C. Chemical reaction of Kaolin shown in Eq 1. While Table 2 show the chemical compositions of Metakaolin evaluated by EDX analysis.

$$2Al_2Si_2O_5\,(OH)_4 \;\rightarrow\; Al_2Si_2O_7 + 2H_2O \quad \ldots\ldots 1$$

Kaolinite Metakaolin

2.3 Silicate sodium

A chemical material with the formula Na_2SiO_3 is Silicate sodium. It was originally in liquid form. It is also known as water glass or liquid glass and its use in different applications.

2.4 Hydroxide sodium

An organic compound with the chemical formula NaOH. It is also known as caustic soda. sodium hydroxide is available in various forms. In this study flakes form was used. The flakes should be dissolved in distilled water at a specific weight to achieve the desired molar concentration.

2.5 Water

In present study the distilled water was used.

Table 2: EDX analysis for Metakaolin used.

Chemical composition	Percent %
CL	0.192
Loss of Ignition	11.616
SO_3	0.344
SiO_2	39.934
CaO	17.344
Al_2O_3	26.445
Fe_2O_3	8.819

To be continued

K_2O	5.6
TiO_2	0.874
MnO	0.158
Cr_2O_3	0.064
SrO	0.052
V_2O_5	0.044
ZrO	0.019
NiO_2	0.013
CuO	0.013
ZnO	0.011
Y_2O_3	0.003
Rb_2O	0.002

3. Sample preparation

Samples of soil for the unconfined compressive strength test were prepared by using a cylindrical mold that has an internal diameter of 44 mm and a length of 100 mm. The L/D ratio of 2.27 decreases the edge effects during UCS testing. Firstly, mixing silicate sodium with hydroxide sodium with a ratio of ½ because of the viscosity of silicate sodium. This mixing represents an alkali activate solution. Dry mixing made up by mix dry soil in 330 g with Metakaolin in various percentages (8%, 10%,12 %, and 14%) by weight of dry soil. Later that, the alkali activate solution added at 0.38 to dry soil-geopolymer mix and blend all components well to be homogenous. After the prepared sample, the mixture was set in five layers in the mold. Each layer was compacted with 20 blows distributed uniformly on the soil sample surface. Figure.1 shows the stepes of mixing Metakaolin-soil with activator.

Figure. 1 Steps of mixing Metakaolin-soil with activator

4. Curing condition

Samples were placed in the oven for four hours as a primary treatment at temperature 40 °C. After that, samples stored in the curing chamber with a room temperature of about 23 °C to complete-time 1 d, 3d, 7d, 14d, and 28 days. Figure. 2 shows the curing chamber.

Figure. 2 Curing chamber

5. Experimental work

5.1 Unconfined compressive strength test

This test is commonly used to evaluate the maximum axial compressive strength that a soil mass can resist before failing, according to ASTM D-2166 [11]. As well as, the load applied as axial on the samples until failure with loading rate 2% mm/min according to the and achieve the maximum load and axial deformation after failure to plot the stress-strain curve. Figure. 3 show the Matest device of UCS test.

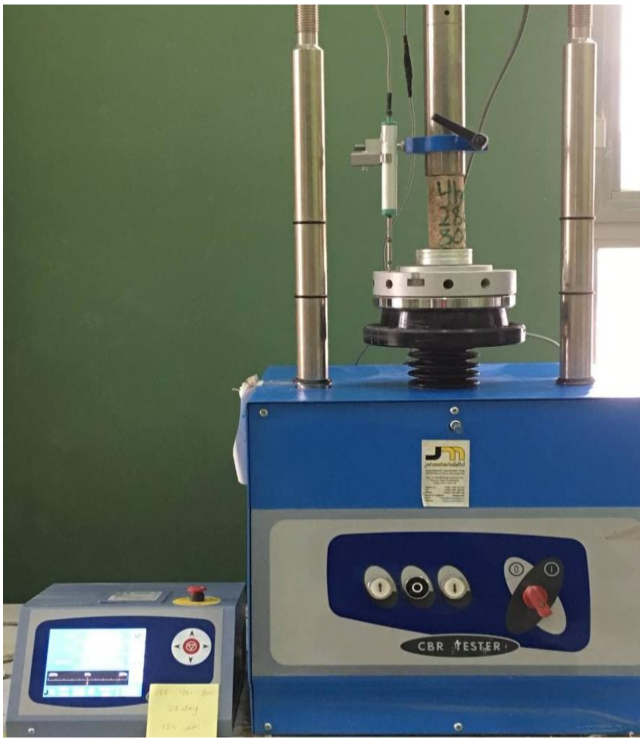


Figure. 3 Matest device of UCS

6. Results

6.1 The effect of MK percent on UCS

Figure. 4 shows the variation of UCS treated with 8%, 10%, 12 %, and 14 % MK by weight of dry soil at temperature 40 °C and cured for 1d, 3d, 7d, 14d, and 28 days. The results show that the gain strength increase as Metakaolin content increase expect the addition of 14% cured for 3 days is seems to decrease.

The peak value of UCS with the addition of 10% MK cured for 14 days that giving about 275% more than that 1 day treated with 40 °C and giving about 47 % more than 28 days treated with addition 10 %MK at 40 °C. and giving about 2186 % more than the reference sample. In general, the addition of 8 % MK recorded low values of UCS compared with other percent due to the high presence of water that leads to slow down the interaction between components also the decrease of development with the addition of 14 %MK is described that the gradual slowing of the geopolymerization reaction, due to the exhaustion of various components in the reaction conditions [12].

6.2 The effect of curing time on UCS

Figure 5. shows the effect of curing time on UCS treated at 40 °C, the results illustrate the increase in strength with increase time for all percent until 28 days the gain of strength is seems to decrease. The peak value of UCS recorded with curing time 14 days.

In general, the gain of strength of the geopolymer-treated soils is not constant and gradually decreases with the increase of curing time. The gradual decrease in the rate of increase of strength can be assigned to the progressive slowing of the geopolymerisation reaction because of the exhaustion of various components in the reaction environment as recommended by [12]. In addition, this gain of strength with time may be assigned to the chemical and physico-chemical bonds, which are formed Metakaolin with activator with the soil particles among time. Further, this development could be assigned to the gradual crystallization of structurally organized new minerals from the reaction products due to time.

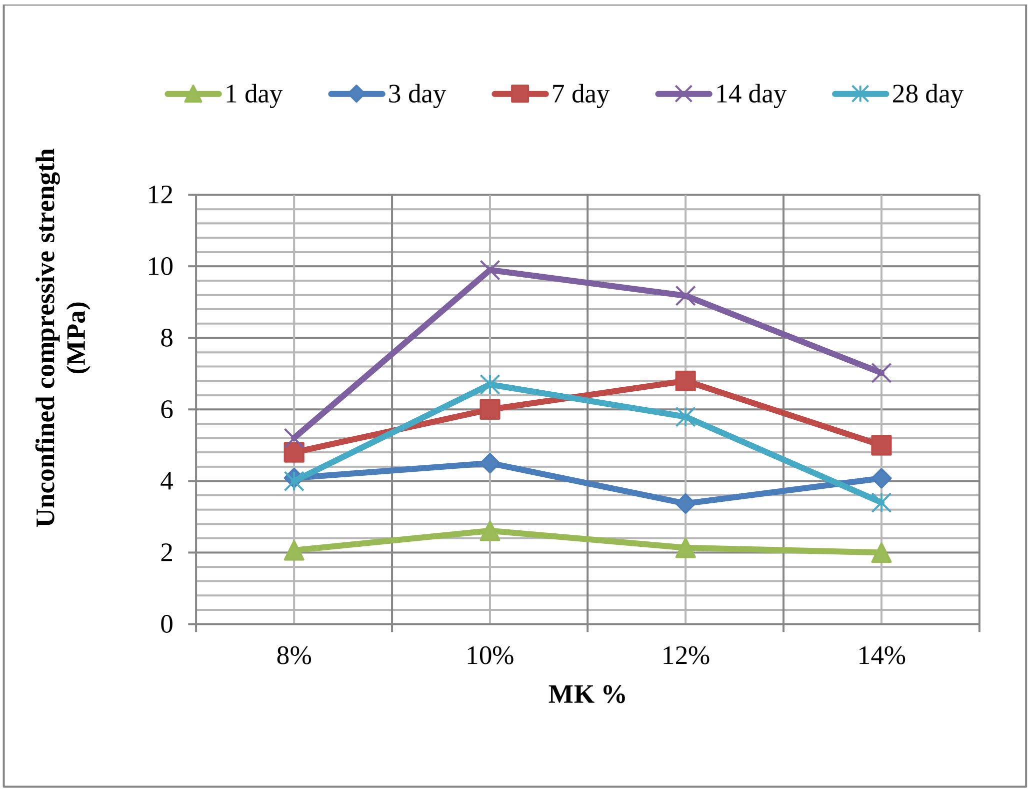


Figure. 4 The Effect of Metakaolin-based Geopolymer on UCS of treated soil at 40 ^{0}C

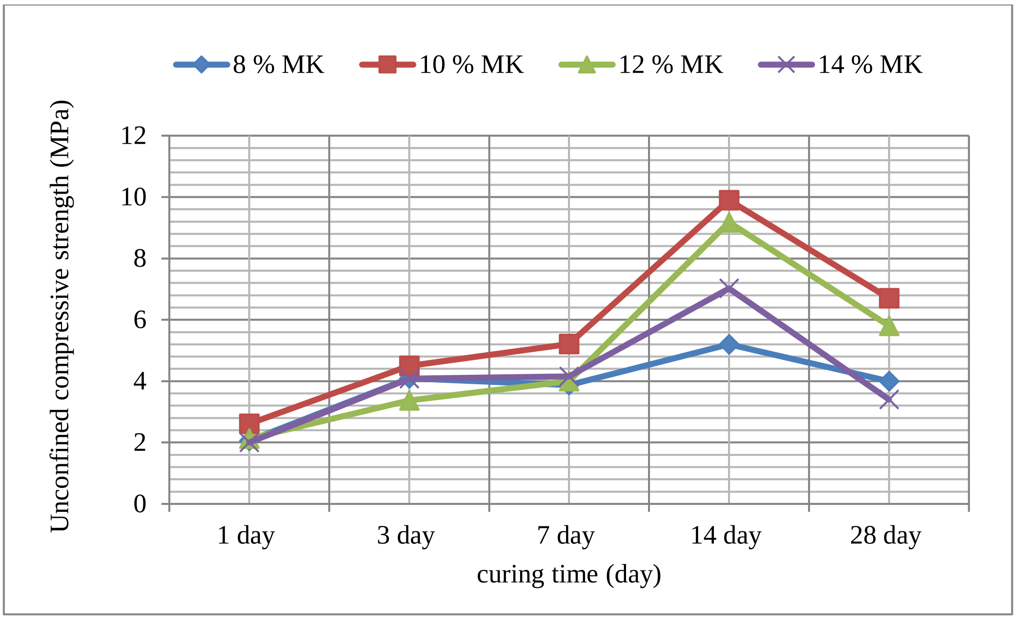
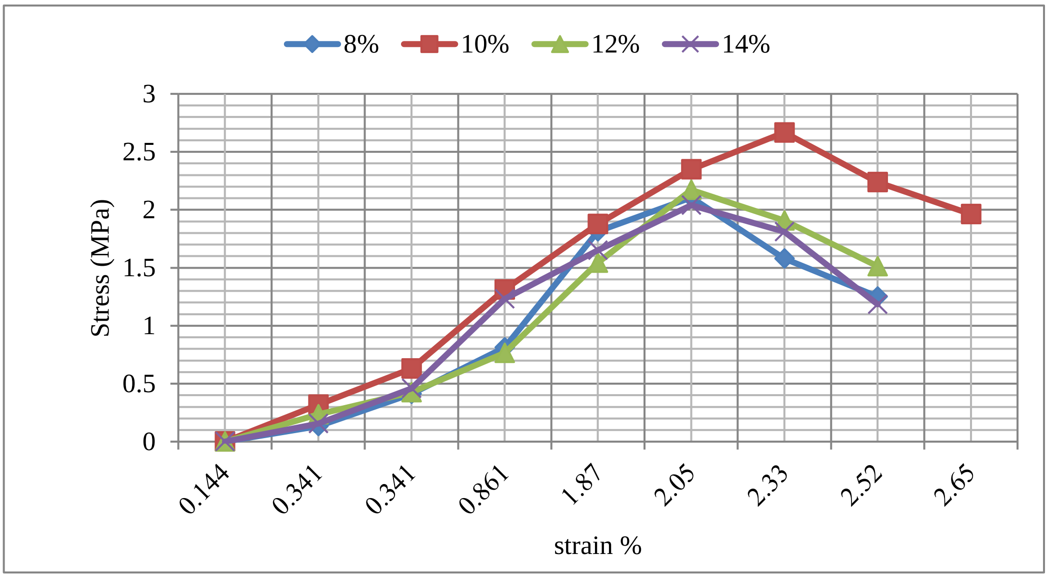


Figure. 5 The Effect of curing time on UCS of treated soil at 40 ^{0}C

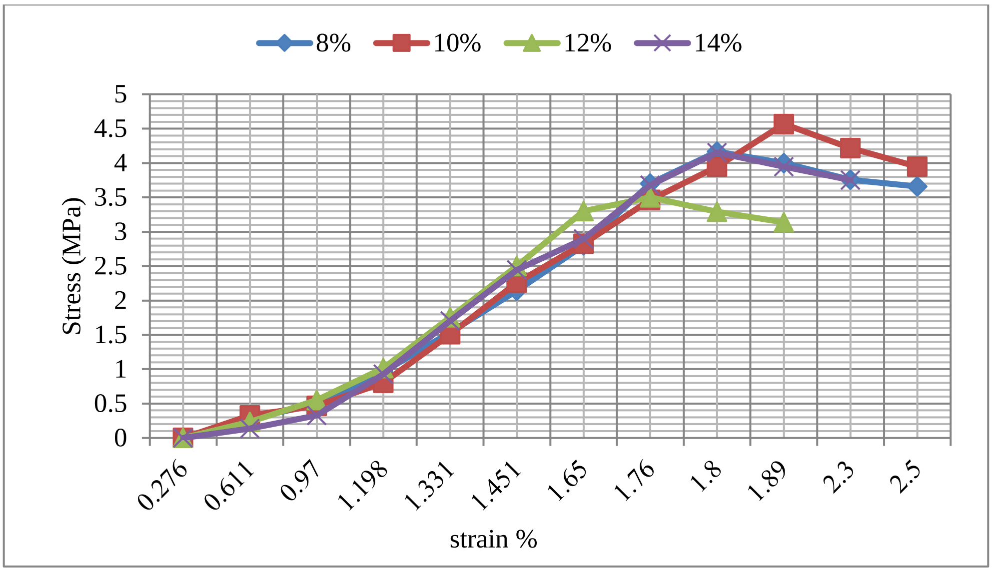
6.3 Stress-strain relationship

Stress-strain behaviour of treated with different percentages under different conditions are shown in the following Figures. All the specimens were conducted with a load rate of 2% mm/min without selecting the rate of strain. The peak value of UCS was determined depending on the results of stress from loading applied. Figure.6 illustrate the stress-strain relationship for samples treated at temperature 40 °C with different percentages of MK under different curing time, the result shows that the peak value of stress for samples cured for 1 day, 3days, 14 days, and 28 days were recorded with the addition of 10 % MK that giving about 2.61 MPa, 4.51 MPa, 9.92 MPa, and 6.72 MPa respectively. While the peak value of stress for samples cured for 7 days was recorded with the addition of 12 % MK that giving about 6.68 MPa. In general, the stress-strain behaviour of treated samples examined under vertical load indicates that the stress gradually increases with the increase in strain. After achieving the peak stress, it decreases with the increase in strain.

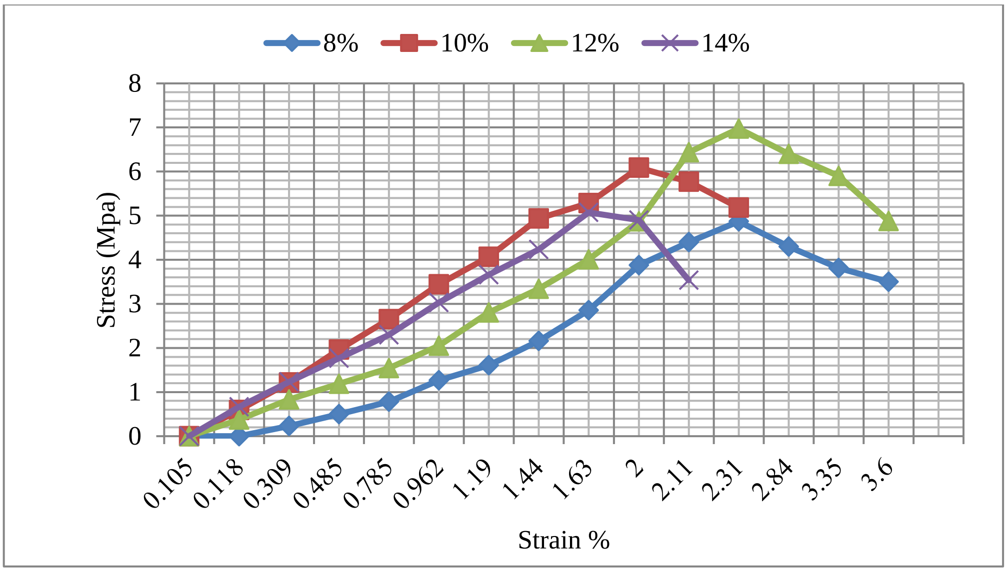
This increment in stress as shown in Figure 6. was observed because of the reaction between the silica in silicate sodium that produces cementations component and works to binds soil particles together to increase strength [13].



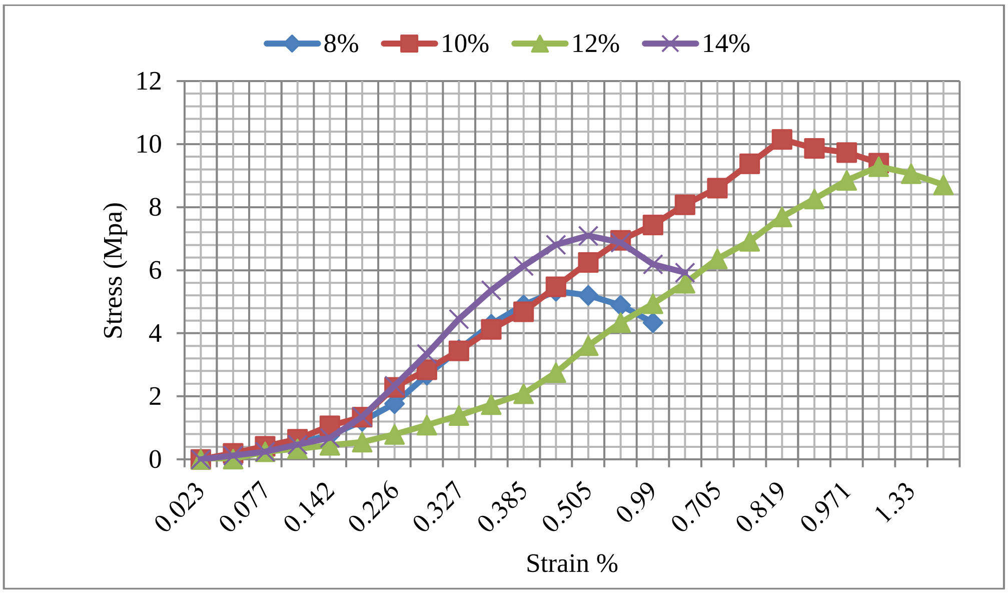
(a)


8%
10%
12%
14%
Stress (MPa)
strain %
0.276
0.611
0.97
1.198
1.331
1.451
1.65
1.76
1.8
1.89
2.3
2.5

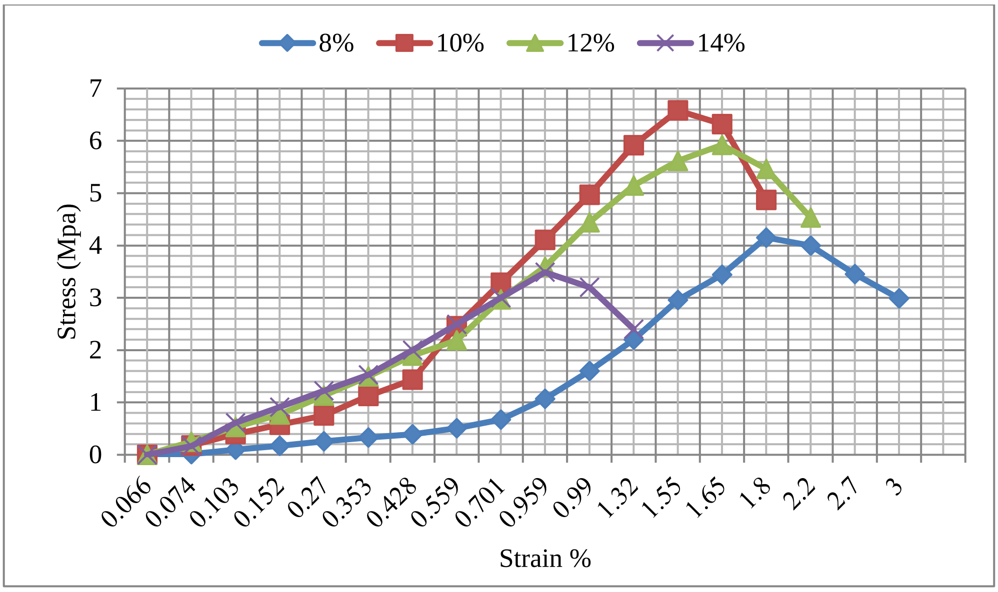
(b)


8%
10%
12%
14%
Stress (Mpa)
Strain %
0.105
0.118
0.309
0.485
0.785
0.962
1.19
1.44
1.63
2
2.11
2.31
2.84
3.35
3.6

(c)


8%
10%
12%
14%
Stress (Mpa)
Strain %
0.023
0.077
0.142
0.226
0.327
0.385
0.505
0.99
0.705
0.819
0.971
1.33

(d)

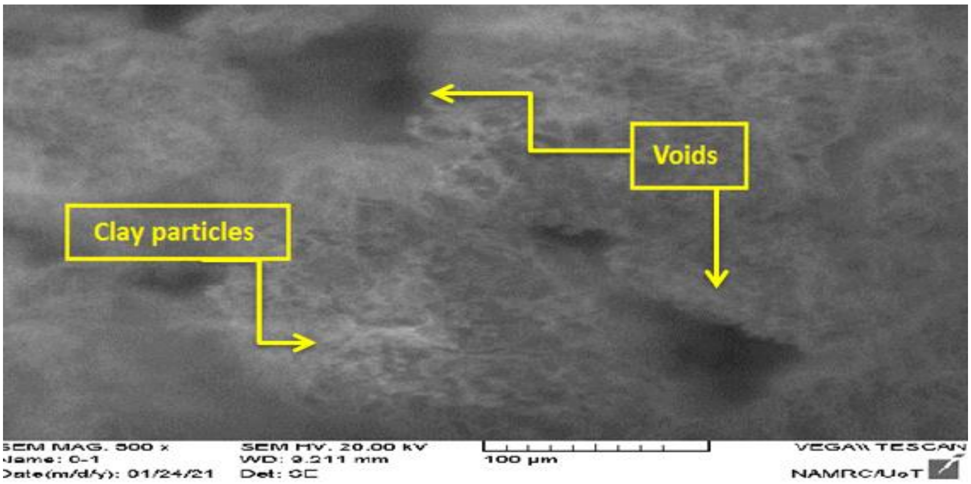


(e)

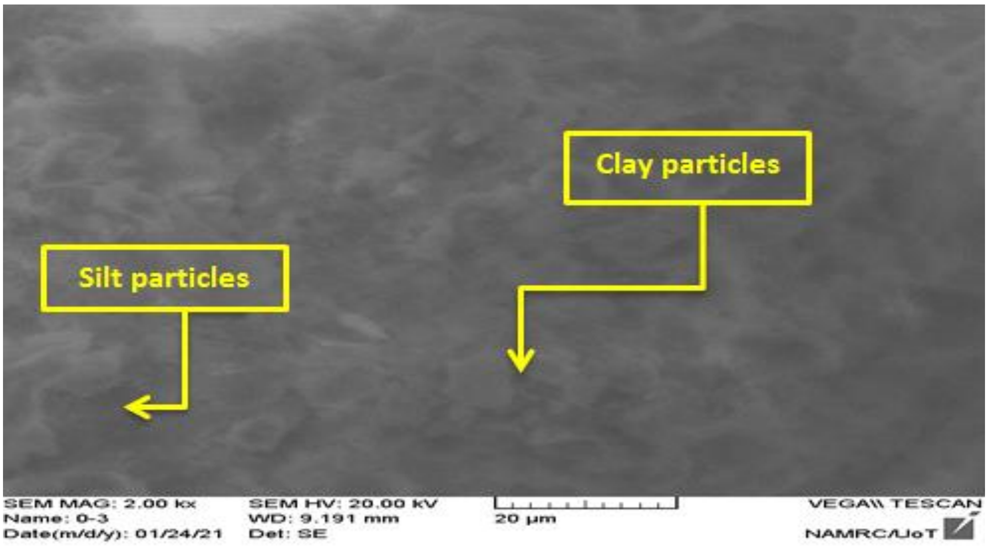
Figure. 6 Stress strain relationship treated at 40 °C cured for a) 1day, b) 3day, c) 7day, c) 14-day, e) 28 days

6.4 Scanning electron microscope

A scanning energy microscope was conducted on natural and treated soil to observed the formation of particles in the composition of both natural and treated soil. Where the SEM technique was the best method to prove the CSH presence inside the soil. SEM tests were conducted by using different amplifications. The specimens were tested cured at 40 °C by being subjected to an oven for 4 hrs and a complete curing time of 7 days. Figure 7 a and 7 b shows a micrograph of natural soil with different amplifications that showed the microstructure of the mixture. without Metakaolin-based Geopolymer additive is loose and contains a lot of voids that led to the soil is weak. While Figure 8 shows a micrograph of treated soil with amplification 500x. The results indicate the substance of the additive is apparent. After all, it is considered a binder because it contains sodium silicate, which leads to a decrease in cracks. As well, the results show the clay particles covered by cementations compounds. In addition, the reaction of the geopolymer with clay led to the production of binder particles. It can be observed in the treated soil.

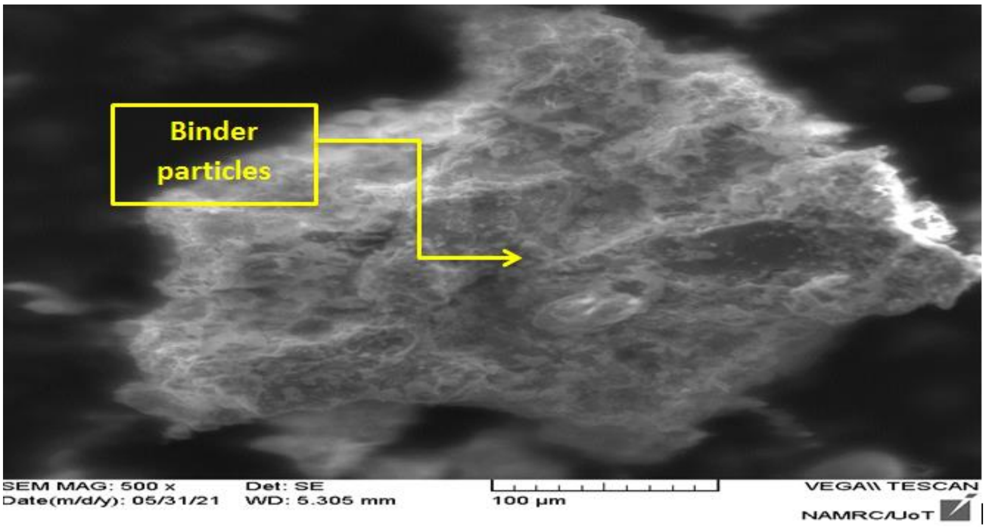


(a)

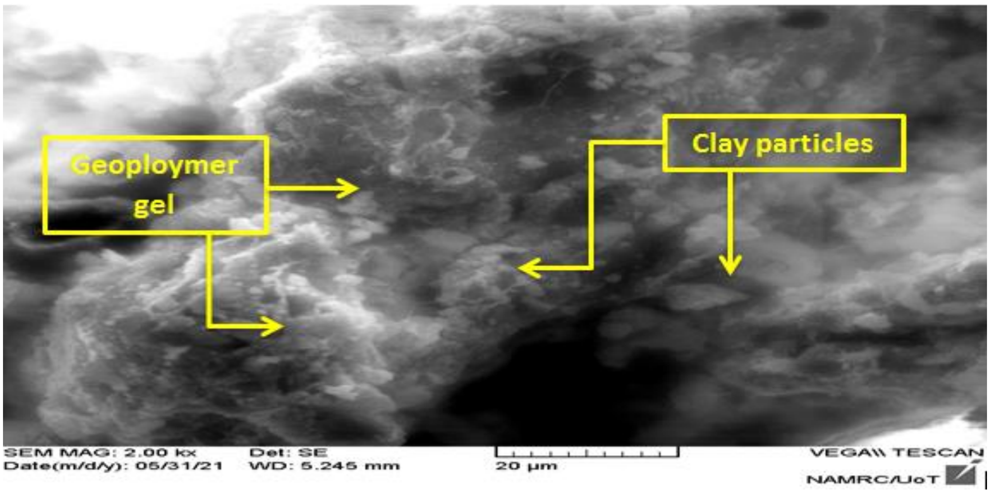


(b)

Figure 7. SEM images for natural soil



(a)



(b)

Figure 8. SEM images for treated soil

٧. Conclusions

1. The unconfined compressive strength of soft soil increased with the addition of MK especially with percent 10 % MK and 12 % MK. Where the UCS values give about 9.9 MPa and 9.18 MPa respectively.
2. Significant improvement of unconfined compressive strength was obtained by increasing the curing time from 1day to 14 days.
3. The development of improvement rate depends largely on curing time and curing temperature where the temperature of 40 °C is higher compared to 30°C or 20C.
4. Alkali-activated Metakaolin-based geopolymer can be used effectively as a chemical stabilizer for stabilizing soft clay soil
5. SEM results show the clay particles covered by cementitious compounds. In addition, the reaction of the geopolymer with clay led to the production of binder particles. It can be observed in the treated soil.

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