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Effect of Metakaolin on the Swelling and Shrinkage Behaviour of a highly Expansive Soil

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ABSTRACT

Chemical stabilization of soil is essential for construction work because it improves engineering characteristics of soil, such as swelling soil stability. The main objective of the research is to investigate the impact of adding Metakaoline (MK) on the behavior of expansive soil to reduce swelling. Different amounts of Metakaoline, such as 2 %, 4 %, and 6 % of the weight of dry soil, are used to prepare the soil specimens. The engineering properties of the soil sample are examined using a variety of laboratory tests (consolidation, swelling potential, and liner shrinkage) original and treated soil at various mixing ratios to determine the swell potential and swelling pressure. The findings showed that the addition of MK has caused a reduction in the swelling reaching about 91% with 4% MK at 14 days, Also, the swelling pressure decreased from 110 kPa to 30 kPa with 4% Metakaolin.

1. Introduction

Expansive soils are known as shrinking or swelling soils, these soils shrink when dried and swell when they are wetted [1]. Swelling soil poses a major threat to infrastructures built on it due to its volume and varied behaviour that causes a crack in sidewalks, basement floors, and foundations [2-3]. Figure 1 shows images of some styles of damage caused by expansive soil of various kinds of structures built on it [4]. Appeared many techniques for improving expansive soils such as chemical additives, surcharge loading, Vibro-compaction, etc to avoid the problems caused by this soil [5]. Chemical stabilization includes injecting or mixing the soil with chemically active compounds such as Portland cement, fly ash, lime, or sodium chloride. The lime and fly ash were successfully used for treating expansive soil [6]. Appeared Recently, many additions are available to stabilize expansive soil (rice husk, potassium chloride) are used instead of additives traditional [7]. These materials are simple in production and low in cost [8]. A study by [9] showed the impact (Lime Silica-Fume) Mixture of treating swelling soil, the results showed that swelling potential decreased with increased (Lime Silica-Fume) content. Impact of Polypropylene and Fly Ash on the Engineering Properties of Black Cotton Soil (expansive soil) [10]. [11] Studied the stabilization of expansive soil by using waste glass powder (WGP). Laboratory tests are conducted on the original soil and treated soil material with different proportions of Glass powder from 2.5% to 25%

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by the dry unit weight of soil. The effect of metakaolin (MK) on the geotechnical charities of expansive soils, it using different percent of metakaolin caused a reduction in swelling and increased shear strength, the percent (10%) MK is considered the best ratio because it gives the minimum swelling [12]. A study conducted by [13] showed the effect of Metakaoline on expansive soil behaviour, the treated samples were prepared by mixing the soil with the percentage of the additive (5%, 10%, 15%). Through the results obtained, the adding 15% of MK reduced swelling from 7.29% to 4.8%. According to previous studies, there is much little information about using Metakaolin (MK) as a soil stabilizer agent that requires more test works to cover all expected parameters. Therefore, this study is included the evaluation of the sustainability of the Metakaolin-based-geopolymer in improving the properties of swelling soils.

Figure 1. The damage of structures and cracks in expansive soil [4]

2. Methodology

2.1Materials used

2.1.1Expansive soil used

The Expansive soil used in the present study was brought from Anbar, Wadi Bashira, 35 km from the base of Al-Walid Anbar /Iraq. Before treatment, laboratory tests were done on the natural soil, and Table 1 showed its physical and mechanical characteristics of the natural soil.

Table 1: Summary of engineering characteristic of natural soil used

Property	Index value	Specification
Specific gravity	2.72	ASTM D 854
Liquid limit	80	ASTM D 4318
Plastic limit	28	ASTM D 4318
Plasticity index	52	ASTM D 4318
swelling %	9.2	
Compression Index (Cc)	0.16	ASTM D 2435
Swelling Index (Cs)	0.03	
Compaction Test OMC (%) MDD (kN/m^3) ASTM D 698	23 15.2	ASTM D 698
Unconfined compressive strength qu (kPa)	220	ASTM D 2166
USCS classification	CH	ASTM D 4318

2.1.2 Metakaolin

Metakaolin is known as a pozzolanic material ($2SiO_2$. Al_2O_3), it is produced by the calcination of kaolinite clay at (650°C) to (850°C) is de-hydroxylated aluminium silicate. MK is about (80 - 90%) less carbon dioxide than lime and cement because needs lower temperatures to calcine, so it is more ecological [14]. Table 2 shows the analysis for Metakaolin (MK) used.

2.1.3 Activator

In this study, two materials used as activators that are (Silicate sodium and Hydroxide sodium) to accelerate the reaction. Sodium silicate is an important chemical compound with the formula (Na_2SiO_3), it also known as water glass. Sodium hydroxide (NaOH) is a white chemical compound that dissolves in water easily and it used in wide fields. Moreover, used the distilled water in present study.

Table 2: EDX analysis for Metakaolin (MK) used

Chemical composition (MK)	Percent %
CL	0.192
Loss of Ignition	11.616
SiO_2	39.934
CaO	17.344
Al_2O_3	26.445
Fe_2O_3	8.819
K2O	5.6
MnO	0.158
Cr_2O_3	0.064
Sr O	0.052
V2O5	0.044
ZrO	0.019
NiO2	0.013
CuO	0.013
ZnO	0.011
Rb2O	0.002

2.2 Sample preparation and Experimental programe

The sample was prepared in the laboratory by taking 250 g of expansive soil and mixing it with three percentages of metakaolin (2%,4%and 6%) by weight of dry soil and using the alkali activate solution added at 20% to dry soil with 10 Molal. After adding Metakaoline to the soil and distributing it equally as in (Figure 2a). The alkali activate solution is added and the mixture is kneaded manually to make sure well mixed as in (Figure 2b). The use of additional water as needed depending on the OMC of the respective samples are formed quickly to ensure that no water is lost.

(a) **(b)**

Figure 2. a) Mixing metakaolin with soil, b) adding alkali activate solution to Mix metakaolin /soil

2.2.1 Consolidation- Swelling tests

The samples of soil were installed into the oedometer consolidation apparatus and applied 7kPa as setting pressure on the specimen. At the oedometer ring (100 mm in diameter and 20 mm in height), the soil sample was submerged in water for 24 hours in order to know its maximum swelling potential. At last, swell readings were recorded for a period of at least 24 hrs and drawing an illustrative relationship between swelling and the proportions of the chemical additives MK. After the swelling period ends, the loads are gradually applied to the sample with wight (2,4,8 and 16) kg as shown in Figure 3. The consolidation curve can be plotted (pressure-void ratio relationship) from the data that obtained from consolidation test, it is helpful in determining swelling index, swelling pressure.

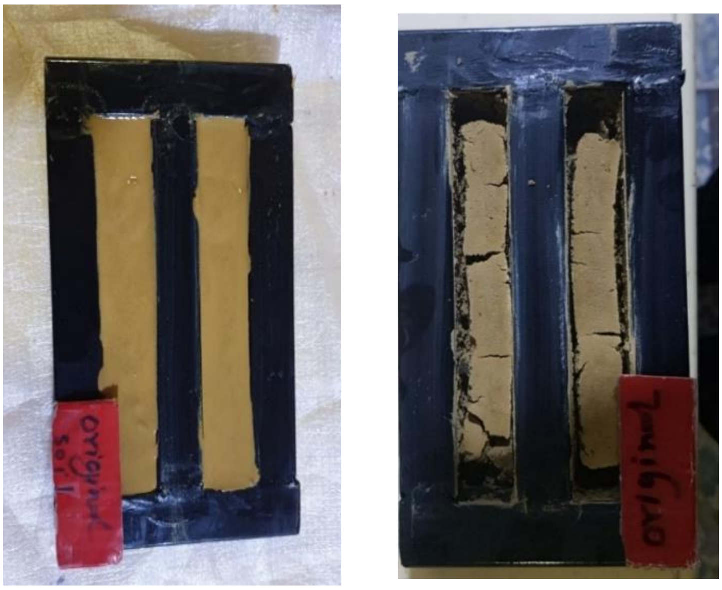
Figure. 3 Devices of consolidation

2.2.2 Linear shrinkage

Linear shrinkage tests (LS) are the change in soil volume due to a change in water content, were performed on original and geopolymer treated soils a, for three percentage of Metakaoline (2%,4% and 6%) after curing periods of 3 hours(0day) and 7 days accordance with TEX-107-E. A creamy paste was made by mixing the soil with distilled water and placing it in the mold with dimensions length(12.7mm) width and height (1.9mm) after coating the mold with grease to prevent the soil from sticking to the surface of the mold and then moving the mold to expel the air bubbles and placing it for a few hours until it changes color and then placed in an oven at a temperature of 105 degrees Celsius for a day. The temperature in the oven must not exceed 105.Shrinkage limit was measured by using Equation 1, Figure 4 shows the step of testing linear shrinkage and behaviour of soil after exposure to heat.

$$LS = \frac{(LW - LD)}{LW} * 100 \tag{1}$$

where:
LS: the linear shrinkage (%)
LD: the length of the dry soil bar (mm), LW the length of the wet soil bar (mm)



(a) (b)

Figure 4. (a) Soil slurry before oven drying (b) Soil slurry after oven drying

3. Results and discussion

3.1 The effect of MK percent on Swelling potential and Swelling index

The percent of free swell reduction reached 86.3% and 91% due to adding 2%, and 4% of MK, respectively, while Free swell reduction reached 80.4% when adding 6% to MK as shown in Figure 5. The swelling index (Cs) decreases with increasing MK content. The maximum decrease is found with the addition of 4% Metakaoline about 0.02, then it begins to increase at 6% MK about 0.03 as shown in Figure 6. This decrease in swelling and Swelling index are caused by the clay minerals' rapid cation exchange with the geopolymer, which reduces the clay minerals' capacity to absorb water which leads to the formation of the pozzolanic material, which fills the spaces. The same results were achieved with [12, 13]. Since Metakaoline acts as a desiccant when the content is increased to 6% for MK, the soil has been needing to absorb the water, so a swell occurred.

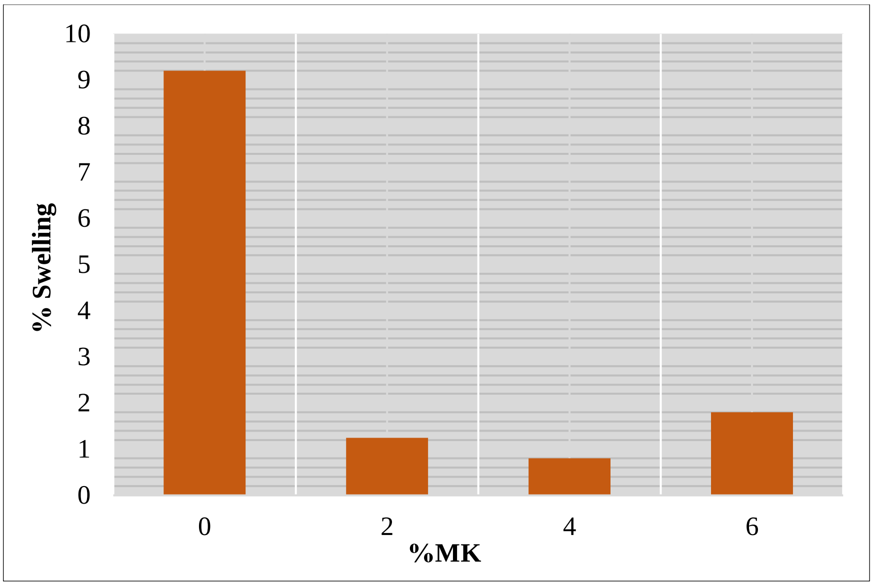


Figure 5. The Effect of MK on swelling soil

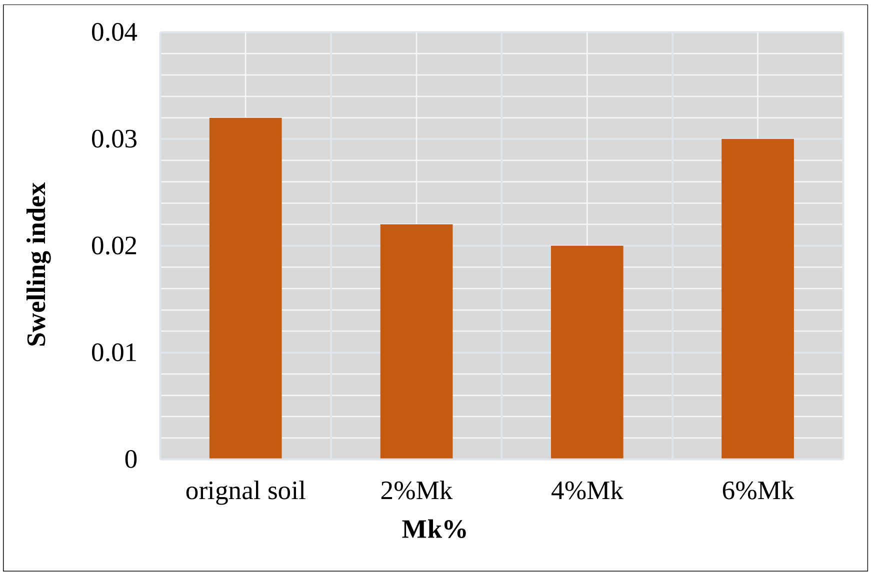


Figure 6. The Effect of metakaolin on swelling index

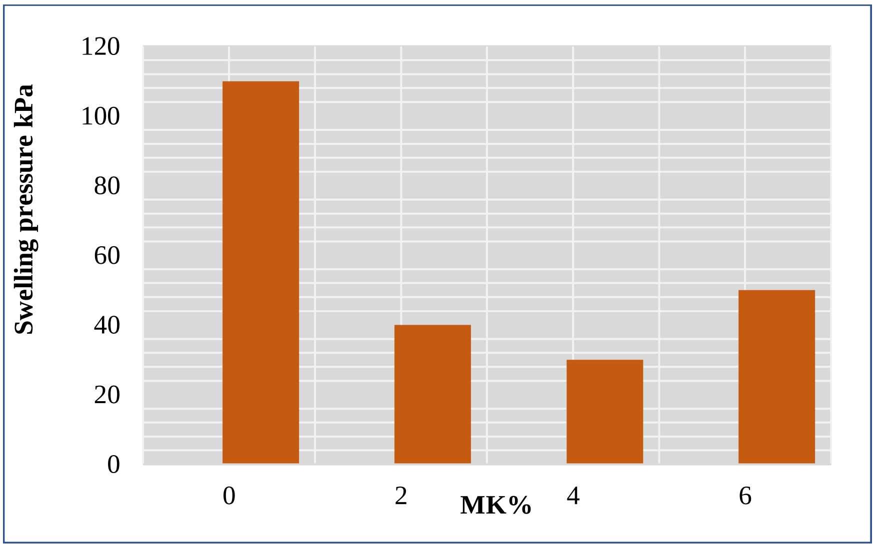


Figure 7. The Effect of MK on swelling pressure

3.2 The effect of MK percent on swelling pressure

Figure 7 shows the effect of the addition of different percentages of MK on Swelling Pressure. The results showed the swelling pressure decreased to give (40 kPa and 30 kPa) at (2% and 4%) of MK respectively while it the increased at 6% MK to give 50 kPa.

3.3 The effect of MK on Coefficient of Consolidation (Cv)

From Figure 8, it can be noticed that for soils samples 2%MK and 4%MK the coefficient of consolidation increased from (5.4×10^{-8} to 6.7×10^{-8}) m^2/sec. While 6%MK reduced of 4.7×10^{-8}). The reason is due to the high in the cation concentration where the diffuse double layer thickness was reduced due to the clay particles flocculation. The same results were achieved with [12].

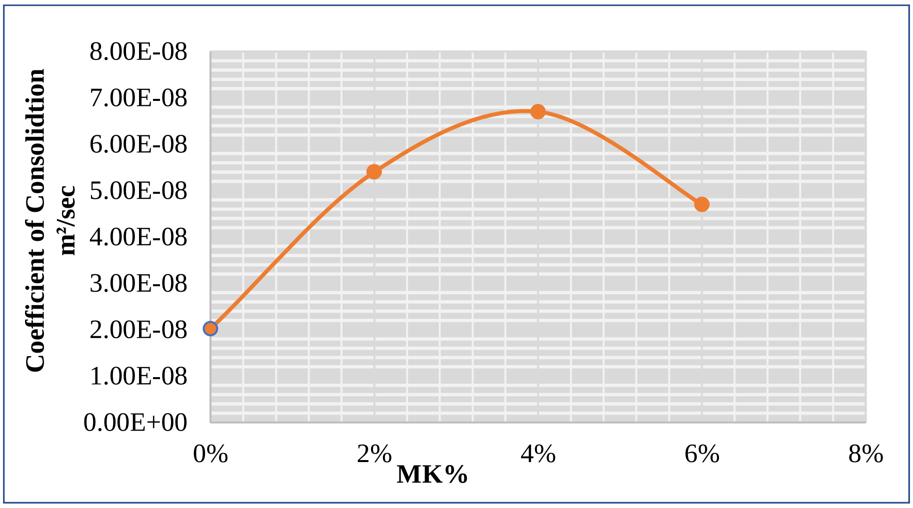


Figure 8. The effect of Metakaolin-based Geopolymer on Cv

3.4 The effect of MK on liner shrinkage (LS)

Figure 9 shows that use the percentages reduced the shrinkage liner by (43%, 55%, and 57%) after 0 day of curing. While after 7 days of curing the shrinkage also was decreased by about (64.9% 75 % and 74.6%) with treatment of (,2%,4% and 6%) MK. Generally, the useful effect of geopolymer treatment increased with an increase in geopolymer content and curing time according to the research on [15]. The results of linear shrinkage (LS) test indicate that Metakaoline is very active in reducing shrinkage properties of expansive soils.

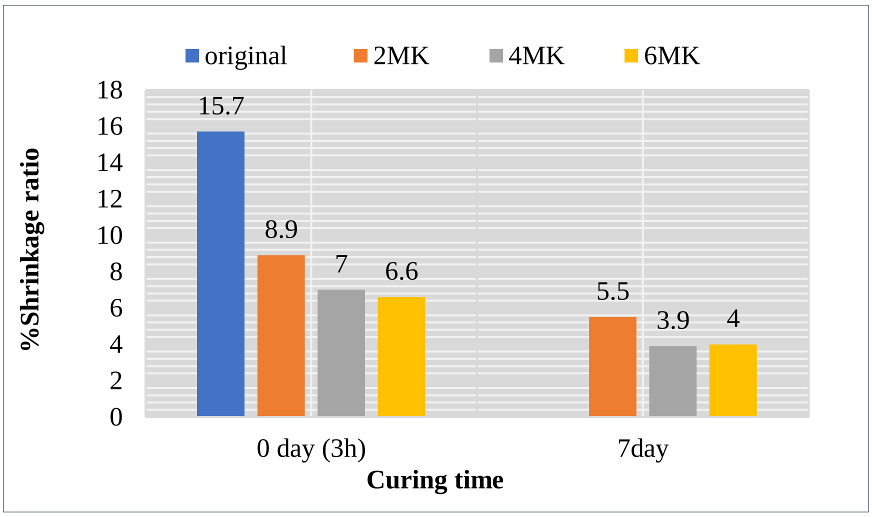


Figure 9. Indicate Shrinkage at the variation periods to the treated soil and untreated

4. Conclusions

1. The ability of Metakaolin to form cement compounds between clay particles makes it one of the effective stabilizers for soil improvement.
2. Reduction in the swelling percent can be recorded to 91% at 4% MK, so it can be considered the best percentage of improvement soil.
3. The swelling pressure decreases to 72.6.% with increasing MK percentage until 4% MK.
4. A gradual decrease in the value of the swelling pressure, reached a value of 30 kPa at 4% of MK after that it began to increase at 6%.
5. The linear shrinkage results of the control soil and MK-treated soil showed a decrease when the Metakaoline content was increased.

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