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EXTENDED ABSTRACT

Effect of Metakaolin on Dispersivity Potential and Geotechnical Parameters of Dispersive Soils

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1. Introduction

Nowadays, the dispersion phenomenon is one of the main concerns for industrial and civil projects in southern regions of Iran. In this phenomenon, dispersive clay soil, under special situation, is dispersed and rapidly washed away. Due to the continuous developments in industrial and mineral additives, in this study metakaolin was used for soil improving dispersive soils. Researchers have always studied the use of additives for soil improvement. However, using cheap and environmentally friendly additives, such as natural pozzolans, are more desired. Natural pozzolans, are silica and alumina-silica materials with no apparent cement property but in presence of water, they make bonds with hydrate calcium and have cement properties. By reviewing previous studies, it can be seen that using pozzolanic materials are environmentally friendly, reduces energy consumption, reduces costs, reduces permeability and increases the chemical resistance of concrete. Metakaolin is a natural pozzolan with high permeability, with 50-55% SiO2 which reacts with Ca (OH)2 in room temperature and produces the calcium silicate hydrate (CSH) gel. Kolovos et al (2013) investigated mechanical properties of a soil improved by metakaolin. In this study, the optimum mix design of cement soil and its mechanical properties are investigated and the results show improved mechanical properties of soil. Wu et al (2016) studied the effect of metakaolin and cement on MHS strength and soil structure. The results show that adding metakaolin to soil reduces its sensitivity to water and significantly increased the uniaxial compressive strength and tensile strength of soil. Wianglor et al (2017) reviewed the effects of alkaline active metakaolin on compressive strength and particle structure of the improved mortar in 23 and 60 centigrade. The results show that increasing the amount of metakaolin and the temperature results in increased compressive strength and silicate and aluminate gel is apparently seen in mortar particle structure. In recent years, the compound effect of cement and metakaolin have rarely been studied, however there is no record for using metakaolin alone for soil improvement. This study aims to investigate the effects of different metakaolin percentages on reducing the clay dispersion potential, using crumb test, hydrometry, and also reviewing its geotechnical properties, such as Atterberg limits, maximum dry density, optimum humidity percentage, uniaxial compressive strength, and its validation using SEM.

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2. Materials and methods

The physical and mechanical properties of dispersive clay are shown in table 1. The metakaolin used in this study was provided by Jahan Poodr Delijan Company, with special weight of 2.63gr/cm3 and special surface of 9169 cm2/gr. The metakaolin chemical analysis are shown in table 2.

Table 1. Physical and mechanical characteristics of dispersive clay

Soil property	Value	Standard
Classification (USCS)	CL	ASTM_D2487
Liquid limit (%)	33	ASTM_D4318
Plastic Limit (%)	22	ASTM_D4318
Plasticity Index (%)	11	ASTM_D4318
Unconfined Compression Strength (kg/cm²)	3.36	ASTM_D2166
Maximum dry density (g/cm²)	1.75	ASTM_D698
Optimum moisture content (%)	17.21	ASTM_D698

Table 2. metakaolin chemical analysis

chemical mixture	Weight percent
SiO_2	70.46
CaO	0.68
Al_2O_3	22.48
Fe_2O_3	0.45
K_2O	2.03
Na_2O	0.62
MgO	0.24

To investigate the effect of metakaolin on the changes in soil divergence potential and also its role in improving the geotechnical properties of dispersive clay, metakaolin with different percentages of 0, 2, 4, 6, and 8 percent by weight of soil was added to dispersive clay during the testing processes. And the samples were kept for 7 days to perform the reaction. Then, crumb tests, double hydrometer, Etterberg limits, standard compaction, and unconfined compression strength were performed on different combinations of soil and metakaolin based on ASTM standards.

3. Results and discussion

3.1. Examining the changes in dispersivity potential

The rate of variation dispersion percentage is presented in Fig. 1. As can be seen, the greatest decrease in the dispersion percentage occurred for the addition of 8% metakaolin. In this case, the dispersion percentage has decreased by about 62%, which is considered to be in the category of soils with insignificant dispersion according to Bell and Maud's criteria. The data taken from Crumb's test presented in Table 3 confirm the results of this section.

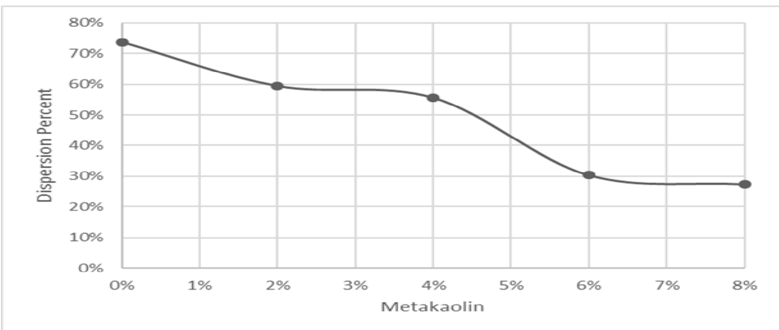


Fig. 1. Variation dispersion percentage based on double hydrometer test

Table 3. Variation dispersion percentage based on the Crumb test

Sample	Test result
Untreated Soil	Strong Reaction
Soil+2% Metakaolin	Moderate Reaction
Soil+4% Metakaolin	Moderate Reaction
Soil+6% Metakaolin	Slight Reaction
Soil+8% Metakaolin	Slight Reaction

3.2. The results of the Compaction test

By adding metakaolin to the soil, the necessary conditions for compaction and cohesion between the soil particles are provided and it causes the clay particles to become denser. Therefore, by reducing the space between the particles, which leads to a decrease in the optimum moisture content, when the soil particles are subjected to compaction, there is a relatively suitable connection between the soil particles, which helps in better compaction of the particles, and finally, the maximum dry density of the soil increases.

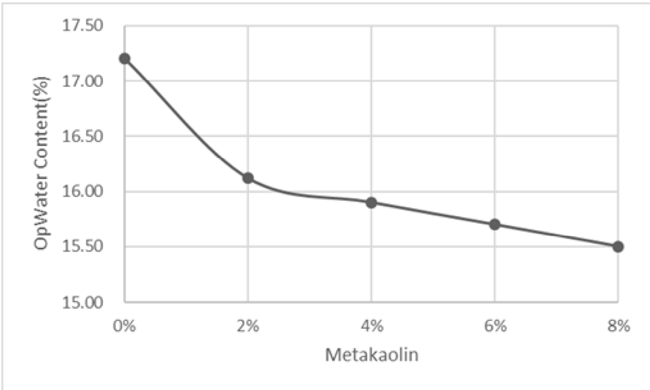


Fig. 2. Variations of optimum moisture percentage of stabilized samples with different percentages of metakaolin

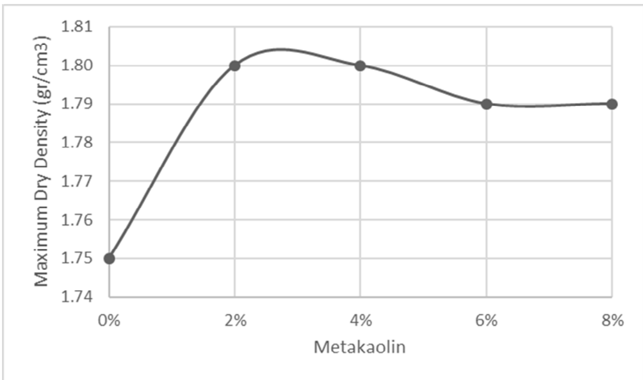


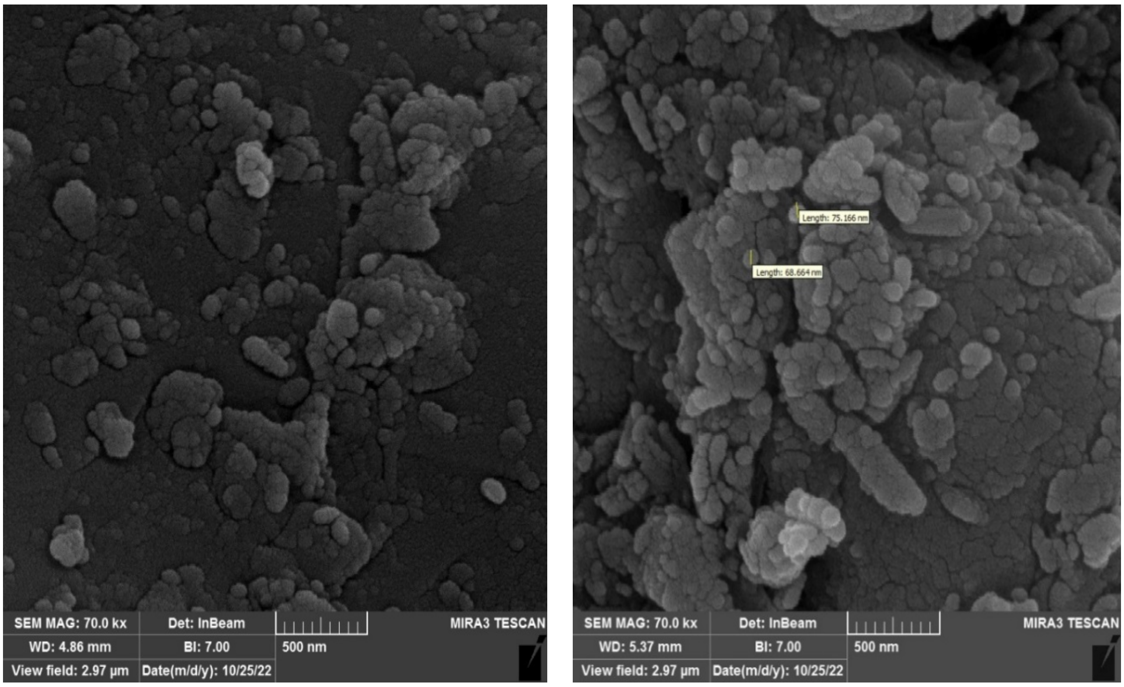
Fig. 3. Variations of maximum dry density of stabilized samples with different percentages of metakaolin

3.3. The results of the Etterberg limit test

The results of the Etterberg limit test have indicated that adding metakaolin decreases the liquid limit, plastic limit and plasticity index of the soil. A decrease in the plasticity index causes a decrease in flexibility and an increase in the density of dispersive clay, which also affects the properties of compaction, swelling and resistance of the soil. Therefore, the reduction of plasticity index can be considered as a useful change in improving the performance of modified soil samples.

3.4. The results of the unconfined compressive strength test

The results have shown that the 7-day compressive strength has increased for all samples. Adding metakaolin provides suitable conditions for pozzolanic reactions between SiO_2 and Ca^{2+}. As a result of these reactions, new compounds including CSH are formed. CSH fills the holes in the soil and reduces porosity and increases the density of the soil structure, which ultimately leads to an increase in soil resistance. This is shown in Fig. 4.



(a) (b)

Fig. 4. SEM images: **a)** natural soil, **b)** soil with 8% metakaolin

4. Conclusions

In this research, the effect of adding metakaolin on reducing the dispersivity potential of clay soils and improving their geotechnical properties has been investigated. The obtained results can be summarized as follows:

1) The dispersivity potential decreased by 62% and based on the results of the Crumb test, the soil was classified as Slight dispersive soils. The main reason for the decrease in dispersion is the immediate cation exchange reactions, including the replacement of Ca^{2+} with Na^{+} in the soil.

2) Based on the compaction test results, by adding metakaolin to the soil, the optimum moisture content is reduced and the necessary conditions for compaction and cohesion between the soil particles are provided and it increases the maximum dry density of the soil.

3) By adding metakaolin to the soil, the Etterberg limits decreased for all modified samples compared to the unmodified samples.

4) The unconfined compressive strength of the samples increased during the 7-day processing period by adding metakaolin. The main reason for the increase in resistance is the change in the structure of dispersive clay due to pozzolanic reactions and the formation of new compounds such as CSH.