# Investigation of the behavior of Ahvaz sand soil stabilized with metakaolin

**Pouria Daneshgar, Saeed Ghaffarpour Jahromi* and Hamed Arzani**

Faculty of Civil Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran

* Saeed_ghf@sru.ac.ir

**Abstract**

Considering the growth of the population for the development of the country's infrastructure, stabilization and improvement of low-quality land in order to create a strong and resistant base is needed more than ever. So far, many improvement methods have been proposed in the world, which is one of the most common methods of chemical stabilization using lime or cement, which are not compatible with the environment. Therefore, nowadays, the use of pozzolans and geopolymeric cements instead of Portland cement has attracted the attention of various researchers. In this study, the stabilization of sandy soil in Ahvaz city with the help of metakaolin as an additive has been investigated. In this research, the effect of different amounts of variables such as the percentage of metakaolin, the ratio of sodium silicate to sodium hydroxide, the concentration of sodium hydroxide, and the ratio of alkaline activator solution to the additive at the curing ages of 7 and 28 days have been discussed. Samples are subjected to unconfined uniaxial compressive strength (UCS) evaluation and microstructural investigation, X-ray diffraction (XRD) and scanning electron microscopy (SEM) analyzes are used. The results of this research show that in order to achieve optimal resistance, it is necessary to mix 20% metakaolin, the ratio of sodium silicate to sodium hydroxide is 2.5, the concentration of sodium hydroxide is 12 Molar, and the ratio of activator solution to additive is 0.5. The strength of the sample with 28-day curing reaches about 5 MPa, which is about 3 times more than cement samples and 23 times more than unstabilized soil, which can be seen in the microstructural analysis of the presence of N-A-S-H gel as the main factor in increasing the strength in the geopolymerization process.

**Keywords:** soil stabilization, soil improvement, geopolymer, metakaolin, unconfined compressive strength

## 1. **Introduction**

Nowadays, due to the population growth and the need for better use of available resources, stabilization of poor lands and creation of strong foundations are needed more than ever. In this regard, there are various methods. One of the ways to improve the engineering properties of soils is to use the chemical stabilization method. One of the main disadvantages of common chemical improvement methods is their lack of compatibility with the environment in the last century. Cement, lime, all kinds of natural and industrial additives and common polymers that are obtained from crude oil refining today are environmentally undesirable and cause harm to humans and the environment, including increasing $CO_2$ production and warming air.[1]

One of the alternatives to cement and lime to reduce $CO_2$ production is to use pozzolans and geopolymeric cements. The origin of geopolymer chemistry was in the 1970s and civil engineers started using it in the 1990s because it brought advantages such as reducing $CO_2$ production compared to cement production and the use of natural materials and waste for its production.[2]

## 2. **Methodology**

Materials used in this research include soil, metakaolin (MK), portland cement (PC) and alkaline activator solutions (AA). In this research, Ahvaz sandy soil was prepared in order to investigate the changes in its mechanical strength and geotechnical behavior by stabilizing it in the presence of MK. In this research, an attempt is made to improve the soil by finding a new method to strengthen the bearing capacity and increase the resistance of Ahvaz sandy soil, and to investigate the changes created in the desired soil in a longer period of time. The studied soil belongs to Ahvaz city. This soil has 71.81% sand, 8.02% silt and 20.17% clay. The soil granulation diagram is shown in Figure 1. According to the preliminary tests on the soil studied in this research, the used soil based on (USCS) as SC-SM classifying.

Based on the results of Proctor's standard density test, the maximum dry weight is 1. gr/cm$^3$ and the optimal moisture content is 15.5%.

Metakaolin is a type of aluminosilicate material with high activity and is one of the pozzolans that was used first to improve the properties of concrete and then to help the properties of soils in construction projects. This pozzolan is created by calcining kaolin clay at a temperature between 550 and 850 degrees Celsius, and these temperature values are also dependent on the duration of the process, and it is the product of the activation of kaolin clay by heat.[3]

The alkaline activator solution used in this research is a combination of sodium hydroxide (SH) which has a density of 2.13 gr/cm$^3$ and its degree of purity is more than 95% and sodium silicate (SS) with a density of 1.56 gr/cm$^3$ and the ratio of silica to sodium oxide is 2.4.

In this research, response surface Methodology (RSM) has been used as a statistical method based on the design of experiments with the least possible number using Design Expert 12 software. The response surface method is based on a nonlinear multivariable model, which includes experimental design to provide sufficient and reliable response values and provide a mathematical model with the best fit of experimental design information and determines the optimal value of independent variables [4]. The variables examined in this research include 4 parts. the weight amount of MK, the ratio of SS/SH, the concentration of SH (molar) and also the ratio of the AA/MK (L/S), which details the values of each Variables are presented in Table 1. Central Composite design (CCD) has 30 combinations of variables, which include 24 different mixing design experiments and 6 replications at the central point in order to provide high accuracy in estimating the test error, the details of which are presented in Table 2.

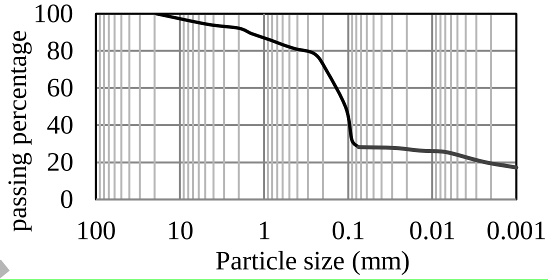


**Figure 1. Grading curve of Ahvaz sandy soil**

**Table 1. Independent input variables in the design of experiments**

| MK (%) | SS/SH | SH (Molar) | AA/MK |
|---|---|---|---|
| 5 | 1 | 6 | 0.2 |
| 10 | 1.5 | 8 | 0.3 |
| 15 | 2 | 10 | 0.4 |
| 20 | 2.5 | 12 | 0.5 |
| 25 | 3 | 14 | 0.6 |

**Table 2. Suggested mixing plan of Design Expert software**

| Run | MK (%) | SS/SH | SH (Molar) | AA/MK |
|---|---|---|---|---|
| | (A) | (B) | (C) | (D) |
| 1 | 10 | 2.5 | 12 | 0.3 |
| 2 | 10 | 1.5 | 12 | 0.5 |
| 3 | 15 | 2 | 14 | 0.4 |
| 4 | 20 | 1.5 | 8 | 0.3 |
| 5 | 15 | 1 | 10 | 0.4 |
| 6 | 20 | 2.5 | 12 | 0.5 |
| 7 | 15 | 2 | 10 | 0.4 |
| 8 | 10 | 2.5 | 12 | 0.5 |
| 9 | 15 | 3 | 10 | 0.4 |
| 10 | 15 | 2 | 10 | 0.4 |
| 11 | 10 | 2.5 | 8 | 0.3 |
| 12 | 20 | 2.5 | 8 | 0.5 |
| 13 | 25 | 2 | 10 | 0.4 |
| 14 | 20 | 1.5 | 8 | 0.5 |
| 15 | 15 | 2 | 10 | 0.4 |

| | | | | |
|---|---|---|---|---|
| 16 | 20 | 1.5 | 12 | 0.3 |
| 17 | 15 | 2 | 10 | 0.4 |
| 18 | 10 | 1.5 | 8 | 0.3 |
| 19 | 10 | 2.5 | 8 | 0.5 |
| 20 | 5 | 2 | 10 | 0.4 |
| 21 | 15 | 2 | 10 | 0.6 |
| 22 | 20 | 2.5 | 8 | 0.3 |
| 23 | 20 | 2.5 | 12 | 0.3 |
| 24 | 15 | 2 | 6 | 0.4 |
| 25 | 15 | 2 | 10 | 0.4 |
| 26 | 10 | 1.5 | 8 | 0.5 |
| 27 | 20 | 1.5 | 12 | 0.5 |
| 28 | 15 | 2 | 10 | 0.4 |
| 29 | 15 | 2 | 10 | 0.2 |
| 30 | 10 | 1.5 | 12 | 0.3 |

## 3. **Discussion and Results**

After making the samples and performing the UCS tests and entering the results in the software and then analyzing the data, in order to reach a sample with the maximum UCS strength, the optimal mixing plan shown in Table 3 can be used.

**Table 3. Optimal proposed mixing plan resulting from statistical analysis**

| MK (%) | SS/SH | SH (Molar) | AA/MK |
|---|---|---|---|
| 20 | 2.5 | 12 | 0.5 |

Also, the comparison of the results for unstabilized soil, stabilized soil with 3 and 5% cement and stabilized soil based on the proposed optimal mixing scheme is shown in Figure 2. Comparison of the results of Figure 2 show that the strength of the sample made with the optimal mixing plan using metakaolin in the 7-day processing period with a compressive strength of about 0.8 MPa is lower than the samples stabilized with cement, but in the 28-day processing period with a strength of 5.5 MPa was able to have a big difference with the samples stabilized with cement. Also, the samples made with metakaolin were 5 times and 23.5 times more than unstabilized soil in the 7 and 28 days processing period, respectively.

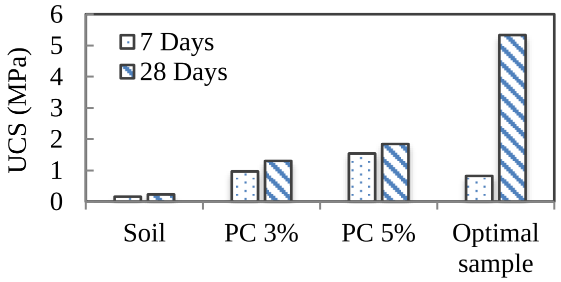


**Figure 2. Comparison of uniaxial compressive strength of different mixing designs**

## 4. **Conclusions**

• Results show that by increasing metakaolin from 5 to 20%, the UCS strength increases in proportion to the additive amount, and after that, increasing metakaolin does not increase the strength further. This increase in strength is the result of creating an amorphous gel in the sample.
• Investigating the effect of the ratio of SS/SH showed that the strength of the sample increased by a factor of 2 and then a decrease was observed. The above ratio is due to the excessive increase of sodium silicate and the degree of alkalinity caused by the size of the activating solution.
• In different concentrations of sodium hydroxide solution (6 to 14 M), the results showed that the maximum strength occurs at concentrations of 11 to 12 M and after that, we saw a decrease in UCS.
• AA/MK in the ratio of 0.4 causes the maximum value of UCS strength, and then the strength first becomes a constant trend and then decreases.
• Obtaining UCS strength of 5.5 MPa in the samples stabilized with metakaolin in the 28-day period is about 3 times the strength of the sample stabilized with Portland cement under similar conditions, which can be introduced as an alternative material.
• The uniaxial strength results of the 28-day curing period show a significant increase in the strength of the samples compared to the 7-day curing period, which proves the effect of time on the completion of geopolymeric reactions.
• In this research, by examining different factors, extensive changes to achieve maximum compressive strength led to the presentation and proposal of an optimal mixing plan based on statistical analysis (Table 3), which rarely existed in previous studies.

## 5. **References**


[1] R. Rehan, M. Nehdi, Carbon dioxide emissions and climate change: policy implications for the cement industry, Environmental Science & Policy, 8(2) (2005) 105-114.
[2] J. Davidovits, False values on CO2 emission for geopolymer cement/concrete published in scientific papers, Technical paper, 24 (2015) 1-9.
[3] M. Bellotto, A. Gualtieri, G. Artioli, S. Clark, Kinetic study of the kaolinite-mullite reaction sequence. Part I: kaolinite dehydroxylation, Physics and chemistry of minerals, 22(4) (1995) 207-217.
[4] M. Woodbridge, Use of soft limestone for road-base construction in Belize, Transportation research record, 1652(1) (1999) 181-191.