Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 55(8) (2023) 337-340
DOI: 10.22060/ceej.2023.21238.7675

Aeolian Sand Stabilization using Metakaolin and Calcium Carbide Residue as an Alkaline Activator

M. Kianynejad[1], M. Toufigh[1], V. Toufigh[2]*

[1] Department of Civil Engineering, Shahid Bahonar University of Kerman, Kerman, Iran
[2] Department of Civil Engineering, Graduate University of Advanced Technology, Kerman, Iran

ABSTRACT: Stabilizing weak and poorly graded soils in engineering projects is commonly achieved using lime and cement. However, the cement production process requires significant energy and generates a substantial volume of carbon dioxide, which presents considerable environmental risks. As an alternative to cement and lime, alkali-activated aluminosilicates have gained recognition due to their cost-effectiveness and environmental compatibility. This study aims to investigate the feasibility of utilizing metakaolin as a stabilizing agent for sandy soil, with Calcium carbide residue (CCR) serving as an alkaline activator. To this end, factors such as the concentration of alkaline activator, metakaolin content, curing time, and temperature of treated soil samples were examined through unconfined compressive strength (UCS) and California Bearing Ratio (CBR) tests. The results were then compared to those of sand stabilized with Portland cement. Furthermore, scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) were used to analyze the microstructures formed during the soil stabilization process. Moreover, the analysis of the developed microstructures in the stabilized soil samples demonstrates a noticeable bond between the binding gel and sand particles and the filling of intergranular space with alkali-activated binding gel. Overall, the findings of the present study suggest that the introduced binding gel has the potential to be an environmentally compatible stabilizing agent for stabilizing sandy soils.

Review History:

Received: Apr. 10, 2022
Revised: Nov. 30, 2022
Accepted: Jun. 15, 2023
Available Online: Aug. 07, 2023

Keywords:

Metakaolin
calcium carbide residue
soil stabilization
Alkali activation
aeolian sand

1- Introduction

With the continuous development of engineering infrastructure, the need for ground improvement processes has become increasingly apparent, especially when dealing with weak soils [1]. Geotechnical processes related to soil stabilization and foundation modification have traditionally relied on Portland cement as the most widely used additive [2, 3]. Unfortunately, Portland cement production involves significant thermal energy consumption and releases substantial greenhouse gases into the atmosphere. The cement production industry is responsible for more than 5% of the total carbon dioxide released, significantly contributing to global warming [4, 5]. As a result, economic constraints and environmental risks have pushed researchers to identify alternative materials for Portland cement in cementation processes.

Among the introduced alternatives for Portland cement, alkali-activated products have gained attention in recent years. Alkaline-activated materials refer to binding gels resulting from alkaline metal solutions reacting with aluminosilicate powders [6, 7]. The presence of silica and aluminum compounds in soils provides the potential for utilizing alkali activation methods in soils. Therefore, alkali activation methods have been investigated and explored in numerous studies aiming to improve soil engineering parameters.

Zhang et al.'s (2013) research examined the feasibility of using sodium hydroxide as an alkaline activator and metakaolin as a base material for stabilizing highly active clay soils [8]. The results obtained from this research demonstrated that alkali activation significantly improved soil mechanical properties compared to samples stabilized with 5% Portland cement. Previous studies, such as Marsh et al.'s (2019) or Pourabbas et al.'s (2018) research, have similarly focused on stabilizing clay soils using sodium hydroxide as an alkaline activator [9, 10].

The potential utilization of CCR as an affordable and effective alkaline activator compared to sodium hydroxide, along with the growing demand for stabilizing sandy soils in Iran, has led to the exploration of using this alkaline activator for stabilizing sandy soils. Considering the abovementioned factors, the current study aims to investigate the viability of using alkali activated mixture as a stabilizing agent to enhance the engineering performance of soil and compare the stabilization performance resulting from alkali-activation

*Corresponding author's email: vahiddavis@gmail.com

with samples stabilized with Portland cement.

Previous studies have primarily focused on improving the mechanical behavior of aeolian soil using stabilization agents such as cement, lime, and bitumen. However, using alkaline activators presents an economical and environmentally friendly option with considerable potential as a stabilizing agent for this soil type. In the current study, the geotechnical properties of aeolian sand, including particle size distribution, specific gravity, and standard density, were initially determined. X-ray fluorescence (XRF) analysis was used to identify the chemical components of soil particles, metakaolin, and CCR. Subsequently, unconfined compressive strength tests and California Bearing Ratio (CBR) tests were conducted to investigate the impact of factors such as metakaolin content, alkaline activator concentration, curing temperature, and curing time. Furthermore, the unconfined compressive strength of samples stabilized with Portland cement was examined to compare different stabilization methods. In addition, scanning electron microscopy (SEM) images and energy-dispersive X-ray spectroscopy (EDX) analysis were employed to analyze the formed microstructures and investigate the structures of various gel types.

2- Experimental Procedure

The primary objective of this study is to explore the feasibility of using activated metakaolin as a stabilizing agent for sandy soils. Consequently, sandy soil was heated at 60° for 72 h and mixed with varying percentages of soil-metakaolin and soil-CCR. Subsequently, by gradually adding water to the mixture, a consistent mixture was produced. The mixture was then poured into a cylindrical mold (diameter of 37 mm and height of 74 mm) and compacted to the specified γ_{dmax} value to ensure uniform compaction.

After the processing time of the samples had elapsed, unconfined compressive strength (UCS) tests were conducted to determine the compressive strength of the samples, as well as the failure strain at 7, 14, 28, and 54 days, per ASTM D2166-87 [11].

3- Results and Discussion

3- 1- Metakaolin Content

Aeolian sand was alkali-activated using metakaolin as a base material. The results show that the samples' compressive strength rapidly increases when metakaolin is increased from 3% to 9%. The compressive strength and failure strain growth rates decreased marginally as the increase was made from 9% to 12%. The overall findings demonstrate that stabilizing the sandy soil with metakaolin positively affects both the compressive strength and the strain at failure.

3- 2- Alkaline Activator Concentration Effect

In geopolymer materials, potassium hydroxide, and sodium hydroxide are commonly used as alkaline activators. However, due to its high alkalinity, CCR presents a cost-effective alternative to these chemicals, significantly reducing costs. The results revealed that the sample containing 8% CCR and 6% metakaolin demonstrated the highest compressive strength across all ages. Additionally, the findings indicated a positive effect of increasing CCR content on the samples' compressive strength and failure strain when CCR percentages up to 8% were applied. However, a notable decrease in compressive strength was observed at all ages, with an increase in CCR percentage to 11%. Hence, it can be inferred that while increasing CCR content results in higher compressive strength, beyond a certain level, it leads to a decrease in compressive strength.

3- 3- Microstructural Analysis

The unconfined compressive strength test resulted in fractured surfaces that were used for microstructural analysis. Figure 1 depicts the sand particles bound together by the gel in a 28-day-old sample.

The figure shows that the sand particles and the binding gel parts are distinguishable from each other. It is clear from the microstructure that the external surfaces of the sand particles are entirely embedded in the adhesive gel, which suggests a proper connection between the gel and the particles. Moreover, the penetration of the binding gels, C-S-H and C-A-S-H, into the intergranular structure of the sand particles is evident.

4- Conclusions

A significant increase in the alkali-activated soil samples' compressive strength and failure strain values is observed. In addition, a comparison with the results obtained from the metakaolin-CCR gel with 3% Portland cement-stabilized samples demonstrates the effectiveness of the alkali-activated gel in the soil stabilization process.

The metakaolin content directly affects the compressive strength of the stabilized soil sample. However, the strength development rate is reduced at higher metakaolin contents.

Higher amounts of alkaline activators lead to the deterioration of the alkali-activated matrix and adversely affect the engineering behavior of the samples.

References

[1] C.A. Anagnostopoulos, Strength properties of an epoxy resin and cement stabilized silty clay soil, Applied Clay Science, 114 (2015) 517–529.

[2] A. Mosallanejad, H. Taghvaei, S.M. Mirsoleimani-Azizi, A. Mohammadi, M.R. Rahimpour, Plasma upgrading of 4methylanisole: a novel approach for hydrodeoxygenation of bio-oil without using a hydrogen source, Chemical Engineering Research and Design, 121 (2017) 113–124.

[3] GP. Zhang, JA. He, RP. Gambrell, Synthesis, characterization, and mechanical properties of red mud based geopolymers, Transportation Research Record,

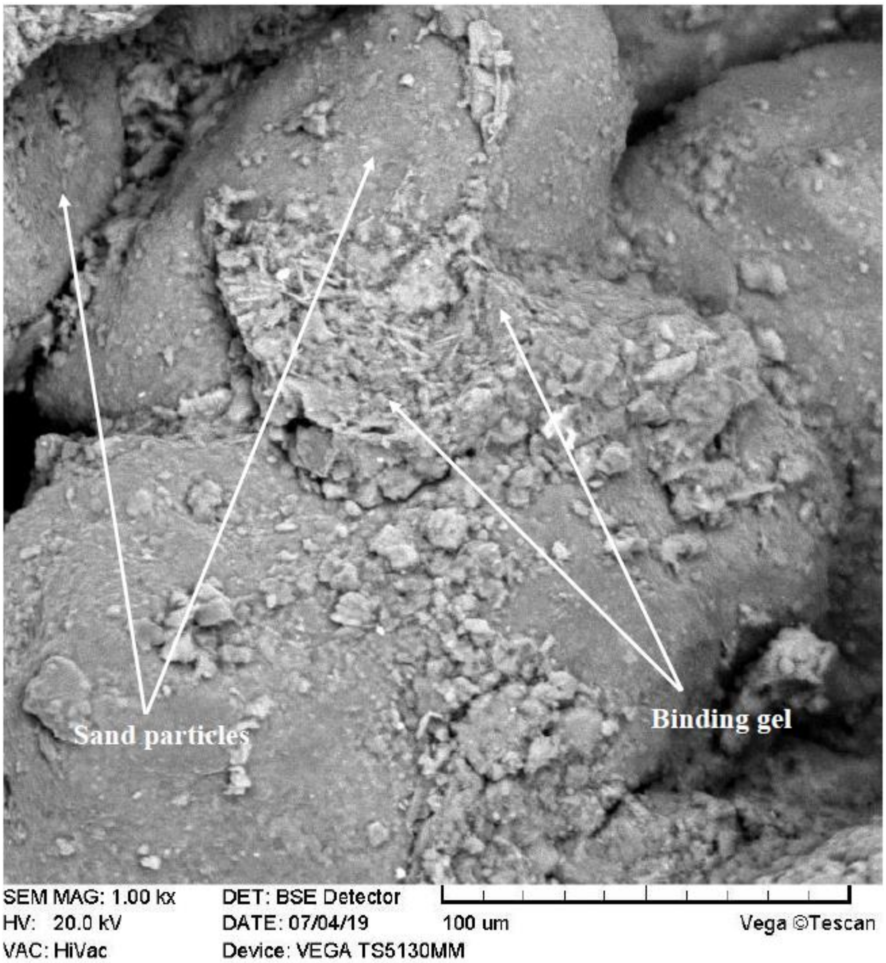

Fig. 1. SEM image of alkali-activated gel and soil particles

2167 (2010) 1–9.

[4] A. Bosoaga, O. Masek, J.E. Oakey, CO2 capture technologies for cement industry, Energy Procedia 1 (1) (2009) 133–140.

[5] H. Fatehi, S.M. Abtahi, H. Hashemolhosseini, S.M. Hejazi, A novel study on using protein-based biopolymers in soil strengthening, Construction and Building Materials, 167 (2018) 813–821.

[6] J. Davidovits, Geopolymer Chemistry and Application, Institut Geopolymere, France, 2008.

[7] C. Shi, P.V. Krivenko, DM. Roy, Alkali-activated Cements and Concretes, Taylor & Francis, London, New York, 2006.

[8] M. Zhang, H. Guo, T. El-Korchi, G. Zhang, M. Tao, Experimental feasibility study of geopolymer as the next-generation soil stabilizer, Construction, and Building Materials, 47 (2013) 1468–1478.

[9] A. Marsh, A. Heath, P. Patureau, P. Evernden, P. Walker, Influence of clay minerals and associated minerals in alkali activation of soils, Construction, and Building Materials, 229 (2019) 116816.

[10] M. Pourabbas Bilondi, MM. Toufigh, V. Toufigh, Experimental investigation of using a recycled glass powder-based geopolymer to improve the mechanical behavior of clay soils, Construction and Building Materials, 170 (2018) 302–313.

[11] ASTM D2166, Standard Test Method for Unconfined Compressive Strength of Cohesive Soil, Annual Book of ASTM Standards, West Conshohocken, 2016.

HOW TO CITE THIS ARTICLE

M. Kianynejad, M. Toufigh, V. Toufigh, Aeolian Sand Stabilization using Metakaolin and Calcium Carbide Residue as an Alkaline Activator, Amirkabir J. Civil Eng., 55(8) (2023) 337-340.

DOI: 10.22060/ceej.2023.21238.7675