



Improving the mechanical properties of soil and foundations through synthesis of diatomite, mica, and fly ash-based geopolymer

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ABSTRACT

This study aimed to improve the mechanical properties of soil and foundations through geopolymer synthesis. The soil used in this research was wind-blown sand exposed to erosion. To examine the mechanical properties of the soil, laboratory tests were conducted, including Atterberg limits, soil permeability coefficient, sand equivalent value, soil pH, optimum moisture content, unconfined compressive strength (UCS), and particle size distribution. The results indicated that the uniformity coefficient (C_u) and curvature coefficient (C_c) were 2.5 and 1.23, respectively, classifying the soil as poorly graded. Based on the soil's silt and clay content, it was classified as sand. The particle size distribution test showed that 5% of the soil passed through the No. 200 sieve. Hence, the soil is coarse-grained and poorly graded. The soil density was determined to be 2.65 g/cm^3 , confirming that the soil is sandy and quartzitic, and due to its lack of cohesion, it exhibits zero compressive strength. The permeability coefficient was $1 \times 10^{-3} \text{ cm/s}$, the sand equivalent value was 79%, and the soil pH was 7.7. The geopolymer sample with diatomite exhibited the highest strength. The key factor in the geopolymerization process is SiO_2 , and with strength comparable to cement, it is a suitable alternative to reduce the environmental impact of cement production.



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1. Introduction

The mechanical properties of soil, such as strength and compressibility, significantly influence its ability to withstand applied forces. However, environmental and anthropogenic factors, such as climate change and unregulated construction, can alter these characteristics and jeopardize the stability of structures (Wang et al., 2021). Environmental impacts, including soil erosion, chemical contamination, and moisture fluctuations due to variable climates, are among the factors negatively affecting soil and foundations (Khadka et al., 2020). Human activities, such as overextraction of resources, excessive use of fertilizers and pesticides, and unplanned construction, can weaken the natural soil structure and reduce its strength, increasing the risk of structural collapse and leading to severe economic and human consequences (Luo et al., 2022).

Mechanical properties like compressive strength, compressibility, and permeability play a crucial role in the load-bearing capacity and stability of structures (Andrade-Linares et al., 2021). Natural and human-induced factors can alter these properties, impacting foundation performance. For instance, heavy metal contamination changes dry density, reduces permeability, and decreases the compressive strength of contaminated soils (Zheng et al., 2019). Continuous cultivation and overgrazing can lead to soil compaction and reduced levels of nutrients, nitrogen, and organic carbon (Andrade-Linares et al., 2021). Additionally, tire waste affects the mechanical properties of fine-grained soils, such as strength and permeability. Industrial development introduces heavy metals into soils near industrial sites, causing further challenges (Zhao et al., 2023). Environmental factors such as topography and climate also influence soil properties (Bamutaze et al., 2021), while previous studies have not thoroughly examined the interrelations between these

characteristics and land use (Burst et al., 2020). In recent years, civil engineers have faced challenges such as low bearing capacity, undesirable mechanical properties, and soil swelling, leading to increased structural collapses and reduced structural lifespans. Soil stabilization has become a crucial solution to enhance the strength and load-bearing capacity of problematic soils in geotechnical projects (Zhang et al., 2013). Traditional methods, such as using cement-based materials, are often inefficient and environmentally harmful, while geopolymers have been proposed as sustainable alternatives (Almadani et al., 2022). Geopolymers, produced from natural and industrial resources, are considered suitable substitutes for traditional soil stabilization methods due to their favorable mechanical properties (Tadayonfar, 2024). These materials are known for enhancing soil strength while mitigating negative environmental impacts, positioning them as sustainable solutions for repairing damaged soils (Almadani et al., 2022). With high durability, low permeability, minimal shrinkage, and lower costs than cement, geopolymers offer products with high initial strength and reduced emissions. Additional advantages include lower production temperatures and reduced waste volumes.

The stability of structures directly depends on the mechanical properties of the soil. Weak soils, such as clays or sands, pose challenges for engineers due to their low compressive strength and high permeability. Traditional stabilization methods, such as using cement or lime, are not only costly but also environmentally detrimental (Nurruddin et al., 2018). Geopolymers, with their superior mechanical properties and environmental sustainability, have emerged as suitable alternatives to conventional materials. Natural resources such as diatomite and fly ash, with their low cost and high silica and alumina content, serve as excellent bases for geopolymer synthesis and the enhancement of soil mechanical properties. This study explores the feasibility of using diatomite-, mica-, and fly ash-based geopolymers to improve the mechanical properties of soil and foundations. Producing cost-effective and eco-friendly geopolymers can enhance the performance of weak soils in construction projects.

2. Materials and Methods

The soil used in this study was aeolian sand collected from an eroded area located 30 km northeast of Tehran. The necessary tests were conducted in the central laboratory of the College of Agriculture and Natural Resources, University of Tehran. For the synthesis of geopolymers, wheat bran, sodium hydroxide, distilled water, diatomite, fly ash, and mica were utilized as raw materials. To determine the particle size distribution of the soil, two methods were employed: mechanical sieving for particles larger than 0.075 mm and hydrometer analysis for particles smaller than 0.075 mm. Since this study did not focus on fine soil particles, the tested soil primarily consisted of particles larger than 0.075 mm. The particle size distribution analysis was conducted using the sieving method based on ASTM D-422 and AASHTO T70 standards (Almadani et al., 2022).

2.1 Atterberg Limits Determination

The Atterberg limits tests were conducted following the ASTM D4315 standard. This test comprises three parts: the liquid limit, the plastic limit, and the plasticity index. The

procedure adhered to the aforementioned standard. The plastic limit was calculated using Eq. (1) (Rajabi and Hamrahi, 2019):

$$PL = \frac{M_w}{M_s} \times 100 \quad (1)$$

Where, PL is the plastic limit, M_w is the weight of the water in the sample, and M_s is the weight of the dried soil. Research results indicate that the liquid limit (Eq. 2) can be considered as the moisture content percentage at which the edges of the standard gap close over a distance of 12.7 mm under the impact of 25 blows (Burst et al., 2020).

$$LL = \omega_N \left(\frac{N}{25}\right)^{0.121} \quad (2)$$

Where, N is the number of blows required to close the standard groove, and ω_N is the corresponding moisture content expressed as a percentage. The soil density test for sandy soil was performed according to ASTM D854. The soil density was calculated using Eq. (3) (Tadayonfar, 2024).

$$G_s = \frac{G_T \times W_3}{W_s + W_1 - W_2} \quad (3)$$

Where, G_T is the water correction factor, which varies at different temperatures. W_3 is the weight of the soil, W_1 is the weight of the pycnometer with water, and W_2 is the weight of the pycnometer with water and soil.

2.2 Determination of soil permeability coefficient

In this study, due to the high permeability of coarse-grained sandy soil, the constant head test was conducted. The permeability coefficient was calculated using Eq. (4) and (5) (Song et al., 2022).

$$Q = V/t \quad (4)$$

$$K = QL/AH.A \quad (5)$$

where, Q is the amount of water discharged from the sample during the test (cm^3/min), V is the volume of the cylinder (cm^3), and t is the time (min). K is the permeability coefficient (cm/min), L is the length of the soil column (cm), A is the cross-sectional area of the cylinder (cm^2), and AH is the elevation difference from the water level to the drainage pipe (hydraulic head) (cm).

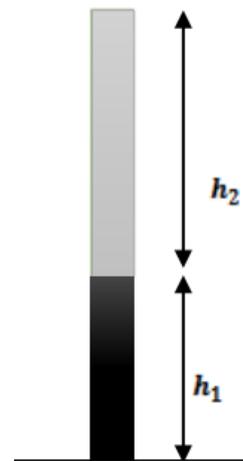


Fig. 1 Soil particles sedimentation (Song et al. 2022)

2.3 Sand equivalent

In the present study, the sand equivalent (SE) test was performed according to ASTM D-2419 standard. First, 100 g

of soil passing through a No. 10 sieve was placed into a graduated cylinder. Then, a stock solution was added to the soil up to a height of 10.2 cm (4 inches). The cylinder was shaken for 30 seconds at 90 strokes. In the final step, the cylinder was removed from the apparatus and left undisturbed for 20 minutes. According to Fig. 1, soil sedimentation occurred at two heights. The sand equivalent value was calculated using Eq. 6 (Rajabi and Hamrahi, 2019).

$$SE = \frac{h_1}{h_1+h_2} \tag{6}$$

where, h_1 is the height of the layer of settled soil particles, and h_2 is the height of the liquid layer above the settled particles.

2.4 Soil pH

The soil pH test was conducted according to ASTM D4972 standard. A 10 g sample of soil passing through a No. 200 sieve was mixed with 50 g of water in a container and allowed to rest for 30 min. The soil pH was then measured using a pH meter.

2.5 Optimal soil moisture

The compaction test (Proctor standard) was performed according to ASTM D698 standard. The compaction energy was calculated using Eq. 7, and its value for standard compaction was obtained as 585 kNm/m³.

$$\text{Compaction energy} = (a.b.w.g.h)/V \tag{7}$$

where, a is the number of blows, b is the number of layers, w is the weight of the hammer (g), h is the fall height (m), g is the acceleration due to gravity (9.81 m/s²), V is the volume of the mold (m³), and the compaction energy is expressed in kN.m³/m. The specifications for the standard compaction and UCS tests are presented in Table 1.

Table 1 Characteristics of standard density test

Specifications	Standard density test	UCS Test
Mold Volume (cm ³)	944	196.3
Mold Height (mm)	116.33	10
Mold Diameter (mm)	101.6	5
Ram Weight (kg)	2.5	4.5
Drop Height (mm)	304.8	40
Number of Layers	3	2
Number of Strokes per Layer	25	
Dummy Number		

The moisture content of the soil in each compaction test was determined according to Eq. 8:

$$\omega = \frac{a-b}{b-c} \times 100 \tag{8}$$

where, a is the weight of the container and moist soil, b is the weight of the container and dry soil, and c is the weight of the empty container.

2.6 Unconfined compressive strength of soil

The unconfined compressive strength (UCS) test was performed according to ASTM D2166 standard. The compaction test was calculated using Eqs. 9 and 10. Additionally, the results of the UCS test are presented in Table 1.

$$W = \gamma_{dmax} \times 196.350 \tag{9}$$

$$V = W \times \frac{\omega}{100} \tag{10}$$

where, W is the weight of the soil sample, γ_{dmax} is the maximum dry unit weight of the soil, V is the amount of water required to achieve the optimum moisture content, and ω is the optimum moisture content (%) obtained from the compaction test.

2.7 Synthesis of geopolymer-soil

For the synthesis of geopolymer-soil, the preparation of an alkaline activator was initially performed. Then, the soil compaction test was conducted, followed by γ_{dmax} the synthesis of the polymer-soil was carried out. Wheat bran ash was used as the silica source, and sodium hydroxide was employed as the alkaline agent. The mixing ratios were set as are defined as 1.5 =SiO₂:Na₂O, 10 = H₂O:Na₂O. Following these ratios, the amounts obtained were: 3.5 g of wheat bran ash, 6.55 g of sodium hydroxide, and 20 ml of distilled water. The resulting solution was placed in a magnetic stirrer for 2 hours at 100 °C to enhance silica dissolution. The solid phase was separated from the liquid phase using filter paper, yielding the extract.

2.8 Compaction of sand dunes and diatomite

For the compaction test, three main layers were initially added to the sand dune soil at the percentages specified in Table 2. In this table, S denotes sand dune soil, D denotes diatomite, FA denotes fly ash, M denotes mica, and AC denotes alkaline activator. The numbers next to these symbols represent the quantity of each of these components. In Table 2, the different percentages of diatomite, fly ash, and mica replacement in the sand dune soil for conducting the compaction test are specified.

Table 2 Different percentages of replacing diatomite, fly ash and mica in windy sand soil to perform compaction test

Substitute material	% Sample	Windblown sand	Replacement percentages
Diatomite	Witness S	100	0
	S+D 10%	90	10
	S+D 20%	80	20
	S+D 30%	70	30
Fly ash	Witness S	100	0
	S+FA 20%	80	20
	S+ FA 30%	70	30
	S+ FA 40%	60	40
Mica	Witness S	100	0
	S+M 10%	90	10
	S+M 20%	80	20
	S+M 30%	70	30

Subsequently, the standard compaction test was performed according to ASTM D698 and AASHTO T99 standards, and the maximum dry unit weight of the soil was determined.

2.9 Unconfined compressive strength of soil geopolymer

Table 3 illustrates the different replacement percentages of the three main components—diatomite, fly ash, and mica—in the sand dune soil, along with the addition of various amounts of the alkaline activator.

Table 3 different percentages of replacing diatomite, fly ash and mica in sandy loam soil with alkaline addition

Substitute material	Sample	Replacement (%)	Sand (%)
Diatomite	D10%	10	90
	S+D 10% + AC5Cc	10	90
	S+D 10%+ AC10Cc	10	90
	S+D 10%+ AC15Cc	10	90
	S+D 10% + AC20Cc	10	90
	D20%	20	80
	S+D 20% + AC5Cc	20	80
	S+D 20%+ AC10Cc	20	80
	S+D 20%+ AC15Cc	20	80
	S+D 20%+ AC20Cc	20	80
	D30%	30	70
	S+D 30% + AC5Cc	30	70
S+D 30%+ AC10Cc	30	70	
S+D 30%+ AC15Cc	30	70	
S+D 30% + AC20Cc	30	70	
Fly ash	FA 20%	20	80
	S+ FA 20%+ AC10Cc	20	80
	S+ FA 20%+ AC20Cc	20	80
	S+ FA 20% + AC30Cc	20	80
	FA 30%	30	70
	S+ FA 30%+ AC10Cc	30	70
	S+ FA 30%+ AC20Cc	30	70
	S+ FA 30%+ AC30Cc	30	70
	FA 40%	40	60
	S+ FA 40%+ AC10Cc	40	60
	S+ FA 40%+ AC20Cc	40	60
	S+ FA 40%+ AC30Cc	40	60
Mica	M 10%	10	90
	S+ M 10%+ AC10Cc	10	90
	S+ M 10%+ AC15Cc	10	90
	S+ M 10% + AC20Cc	10	90
	M 20%	20	80
	S+ M 20%+ AC10Cc	20	80
	S+ M 20%+ AC15Cc	20	80
	S+ M 20% + AC20Cc	20	80
	M 30%	30	70
	S+ M 30%+ AC10Cc	30	70
	S+ M 30%+ AC15Cc	30	70
	S+ M 30% + AC20Cc	30	70

The results from [Table 3](#) indicated that increasing the percentage of diatomite enhances mechanical properties such as compressive strength. The use of varying amounts of alkaline additives can further improve these properties.

3. Results and Discussion

3.1 Soil Gradation

Based on the values of the uniformity coefficient (Cu) and the curvature coefficient (Cc), which are 2.5 and 1.23, respectively, the studied soil is classified as poorly graded soil. According to the Unified Soil Classification System (USCS), sand is considered well-graded when the uniformity coefficient (Cu) is at least 6, and the curvature coefficient (Cc) falls between 1 and 3 ([Dassekpo et al., 2017](#)).

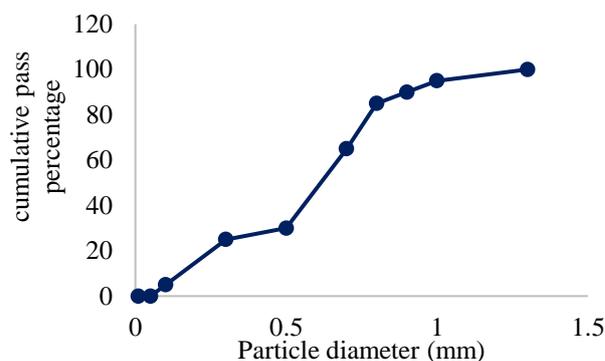


Fig. 2 Granulation curve diagram of windy sand soil

The curve in [Fig. 2](#) exhibits a steep slope, indicating uniform soil gradation and a lack of diversity in particle sizes. This suggests that the soil particles are confined to a specific size range with minimal variation in particle sizes.

3.2 Soil classification

Based on the research results and the percentage of silt and clay in the soil, the soil is classified as sand. According to the classification system of AASHTO and the results obtained from the particle size distribution test, where the percentage passing through the No. 200 sieve is 5%, which is less than 35%, the soil is classified as coarse-grained and poorly graded. The soil is designated as SP, which refers to poorly graded sand ([Raisi et al. 2021](#)).

3.3 Atterberg limits

Based on the soil classification system and the grain size distribution curve, the soil under study is classified as a sand dune with a small percentage of fine particles. The soil does not exhibit any plastic behavior at any moisture content, making the determination of the plastic limit impossible. Additionally, due to the closure of the groove created with less than 15 blows, determining the liquid limit is also not feasible. Therefore, the plasticity index of this soil is reported as NP (non-plastic soil) ([Soltani and O’Kelly, 2021](#)).

3.4 Soil density

The density of mineral grains commonly found in soil ranges from 2.6 g/cm³ to 2.9 g/cm³. Specifically, the density of light-colored sand grains, primarily composed of quartz, is approximately 2.65 g/cm³. Since the density of the soil under investigation was found to be 2.65 g/cm³, this indicates that the soil is primarily composed of quartz sand. ([Shabani et al. \(2022\)](#) improved the mechanical properties of sand dune soil using a binder (serish), achieving a soil density of 2.67 g/cm³ in their study.

Table 4 Permeability coefficient values in different soils

Soil type	Permeability coefficient
Clean Sand	1-100
Coarse Sand	1-01/0
Fine Sand	0.001-0.01
Silty Clay	0.001-0.00001
Clay	<0.000001

3.5 Soil Permeability Coefficient

The permeability coefficient of the soil under investigation was found to be 1×10⁻³ cm/s. [Table 4](#) presents permeability

values for different soils. According to the results from [Table 4](#), the soil is classified as fine sand.

3.6 Sand equivalent value of the soil

The sand equivalent (SE) value of the tested soil is 79%, indicating a high proportion of coarse sand particles and a reduction in fine particles (silt and clay) within the soil. Since SE is greater than 75%, this soil is considered suitable for construction operations ([Shi and Zhao, 2020](#)). Soils with high SE values require less water to achieve optimal compaction and tend to have higher water permeability. However, these types of soils typically have lower cohesion, which may pose stability issues for slopes, necessitating stabilization measures ([Simatupang et al., 2020](#)). Research by [Shabani et al. \(2022\)](#) demonstrated that bio-polymer serish can enhance the compressive strength of dune sands and significantly improve their resistance to wind erosion. Serish also helps in coating sand particles and forming a strong network.

3.7 Soil pH and moisture content

The pH of the soil was measured using a pH meter, yielding a value of 7.7. Based on the results from the double-peak graph, the maximum dry unit weight of the soil corresponds to the peak with the higher value. The optimum moisture content is 13.5%, and the maximum dry unit weight of the soil is 1.73 g/cm³ ([Fig. 3](#)).

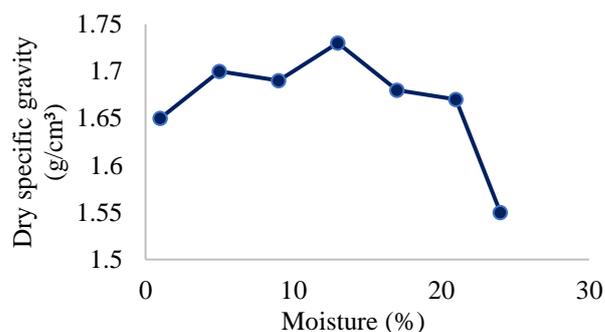


Fig. 3 Density diagram of windy sand soil

Based on the results, the soil under investigation is neutral and highly sensitive to moisture, with its compaction becoming more challenging at moisture levels higher than the optimum ([Songara & Patel, 2022](#)).

3.9 X-Ray diffraction chemical analysis results

X-Ray Diffraction (XRD) analysis was conducted to determine the chemical compositions of the materials used in this study, including wheat bran ash, diatomite, fly ash, and mica. Wheat bran ash was used as an amorphous silica source. The results of the XRF analysis of different materials used are provided in [Table \(5\)](#).

Table 5 XRF analysis of different materials used

Combinations	Mica	Fly ash	Diatomite	wheat bran ash
Silicon	46.95	23.511	69.937	89.233
Aluminum oxide	27.047	3.508	12.61	0.31
Hematite	7.763	45.227	2.97	1.391
Calcium oxide	2.689	12.08	4.62	0.081
Sodium oxide	1.797	0.43	2.421	0.059
Magnesium oxide	2.537	8.973	1.87	0.062
Potassium oxide	5.465	0.591	0.312	0.108
Titanium dioxide	1.101	0.213	0.348	0.054
Manganese oxide	0.064	0.059	0.049	0.022
Phosphate	0.273	0.547	0.045	0.424
Combustion waste	3.9	4.78	0.023	7.33

Moreover, silica (SiO₂) constitutes the highest composition in the ash, accounting for 89.233%. This high percentage highlights the potential of the ash as an effective pozzolanic source. In contrast, the amount of aluminum oxide (Al₂O₃) is only 0.31%, which is likely to have a minimal effect on the final mechanical properties of the products. In addition, diatomite, with 69.937% silica (SiO₂), is recognized as the primary pozzolanic source in this mixture. This high silica content indicates diatomite's strong capacity for pozzolanic reactions, enhancing the strength of the construction materials.

3.10 Effect of substrate replacement on soil mechanical properties

The results of the compaction of sand dune soil and diatomite mixtures showed that the dry unit weight of the sand dune soil alone was lower than that of the mixtures containing diatomite ([Fig. 4a](#)). This is because diatomite, with its finer particles, fills the void spaces between the sand grains, resulting in an increase in the maximum dry unit weight ($\gamma_{d,max}$).

The compaction test with different percentages of mica showed that the maximum dry unit weight of the sand dune

soil replaced with mica is higher than that of pure sand dune soil due to the filling of void spaces between the sand particles ([Fig. 4b](#)). However, as the percentage of mica increases, the maximum dry unit weight of the soil decreases ([Singhi et al., 2016](#)).

The compaction test with different percentages of fly ash showed that as the percentage of fly ash increases, the maximum dry unit weight of the soil increases ([Fig. 4c](#)). This increase is due to the higher specific gravity of fly ash compared to sand dune soil, and the reduction in porosity and friction between particles, which leads to better particle interlocking. The highest dry unit weight was observed in the sample containing 40% fly ash ([Singhi et al., 2016](#)).

The changes in porosity with respect to the increasing percentage of diatomite substitution in sand dune soil are also presented in [Fig. 5](#) as a linear graph. With the increase in diatomite percentage in sand dune soil, the reduction in dry unit weight raised uncertainties about the effect of diatomite on soil compaction and porosity. To clarify these uncertainties, the porosity of the soil was examined. According to [Fig. 5](#), as

the diatomite percentage increases, the porosity of the soil decreases. This reduction in porosity leads to an improved bond between the sand dune particles and diatomite, resulting in enhanced soil compaction (El Alouani et al., 2024).

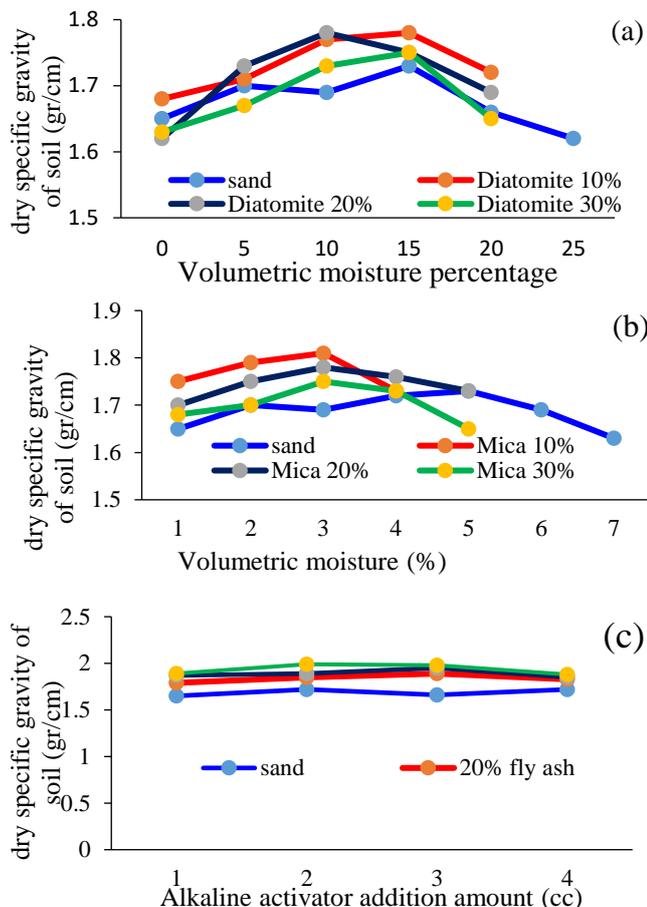


Fig. 4 Compaction of windy sand soil and replacement of different weight percentages of: a) diatomite, b) mica, and c) fly ash

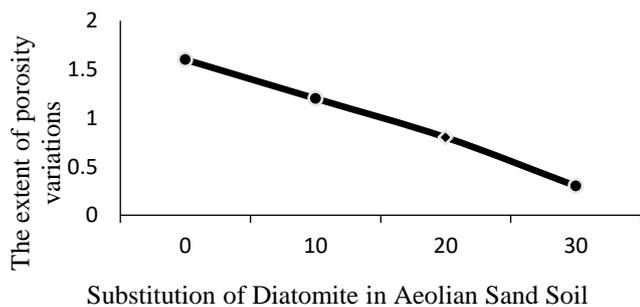


Fig. 5 Porosity changes with increasing percentage of diatomite substitution in windy sand soil

In addition, the results of the Unconfined Compressive Strength (UCS) test showed that sand dune soil without mica exhibited little resistance due to its brittleness and lack of cohesion. However, as the percentage of mica increased (10, 20, and 30%), the compressive strength improved. The highest resistance was observed at 30% mica substitution (Fig. 6), which was considered the optimal percentage (Yang et al., 2020).

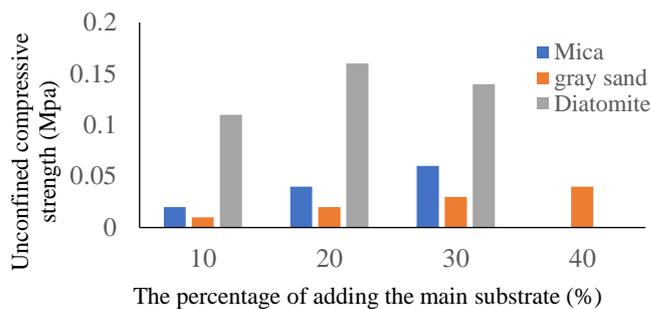


Fig. 6 Comparison of UCS values of windy sand soil by replacing different percentages of diatomite, fly ash and mica

The results tabulated in Table 6 show that as the curing time increased, the compressive strength of the diatomite geopolymer samples also increased. However, the strength gain at day 7 was much higher than at day 28. This can be attributed to the rapid pozzolanic and cementitious reactions in diatomite. Research also confirms that activators react quickly with diatomite (Dassekpo et al., 2017).

Based on the results of diatomite-geopolymer soil, diatomite is an appropriate additive compared to other additives for soil. With strength similar to that of cement, it can serve as a suitable alternative, helping to reduce the environmental impact of cement production. However, in the study by Nykiel et al. (2024), the addition of diatomite as a substitute for the main precursors of geopolymerization at 1% and 3% resulted in a 28% decrease in compressive strength. However, the introduction of crushed diatomite as a substitute for sand and gravel at 5% led to an increase in strength by 24%.

Table 6 Comparison of unconfined compressive strength of 7 and 28 days of diatomite geopolymer with other additives

additive	Soil type	28-day ucs	7-day ucs
S+D%30+AC20cc	sand	2.14	1.58
Cement	sand	2.28	1.25
Cement	clay	0.63	0.45
Cement + polypropylene fibers	clay	1.46	1.38
Cement	Graphite residual soil	-	0.35
Cement + RHA	Graphite residual soil	-	1.2

4. Conclusion

In this study, the effect of adding different amounts of the primary bedding material (10%, 20%, and 30% by weight) to the soil on its compaction and unconfined compressive strength (UCS) was investigated. Additionally, the impact of adding varying amounts of alkaline activator (from 5 to 30 ml) to the soil and bedding material mixture, as well as curing time, on the compressive strength of the soil was examined. The results showed that:

1. With an increase in the percentage of fly ash replacement, the optimum moisture content decreased, and the maximum dry density of the soil increased.

2. With an increase in the percentage of diatomite replacement, the compressive strength increased, and at 20% diatomite replacement, the strength was at its highest.
3. With an increase in the percentage of fly ash and mica replacement, the compressive strength increased.
4. With an increase in the alkaline activator, the compressive strength increased.
5. The geopolymer made with diatomite is the best stabilizer for sandy soil, and its strength is comparable to that of cement-stabilized soil.

The overall results indicate that diatomite-based geopolymer soil is comparable to cement-stabilized soil in terms of compressive strength, making it a suitable alternative to cement. This could lead to a reduction in carbon dioxide production and improve environmental issues. Geopolymers significantly increase the compressive, tensile, and shear strength of soil. Using waste materials as raw materials for geopolymer production helps in recycling and eliminating these wastes. As a result, geopolymers play a key role in overcoming challenges related to sandy soils and environmental preservation in civil engineering. The use of these materials offers numerous benefits, including improving soil mechanical properties, recycling waste, soil remediation, and maintaining environmental health.

Statements and Declarations

Data availability

The data used in this research are provided in the text of the article.

Conflicts of interest

The author of this paper declared no conflict of interest regarding the authorship or publication of this paper.

Author contribution

A. Moazzami: Modeling and Results Analysis; Research Management; Data Collection.

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