



ORIGINAL RESEARCH ARTICLE

EFFECT OF SAND ADDITION ON THE GEOTECHNICAL PROPERTIES OF CLAY

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ABSTRACT

Clay is commonly characterized by high plasticity, low permeability, and significant volume changes, which can result in reduced bearing capacity, excessive settlement, and instability of geotechnical structures. This study investigates the stabilization effect of sand addition on the geotechnical performance of clay for construction applications. Clay-sand mixtures containing 0% to 60% sand were prepared to evaluate Atterberg limits, soil classification, compaction behavior, unconfined compressive strength (UCS), shear strength, and hydraulic conductivity under both heavy (BSH) and light (BSL) compaction energies. The results showed that increasing sand content significantly reduces the Plasticity Index (PI) from 41.5% to 12.96%, aligning with the USCS recommended PI threshold of < 20% for suitable fill materials. Soil classification improved from CH (A-7-6) to SC (A-2-6), indicating enhanced constructability. Compaction results showed that maximum dry density increased from 1.848 to 2.17 g/cc, while optimum moisture content decreased from 16% (BSH) and 19% (BSL) to 9.6% (BSH) and 11.2% (BSL), meeting performance expectations for engineered fill. UCS increased from 120.51 kPa to 199.49 kPa, and internal friction angle rose from 8.2° to 22.3°, demonstrating greater strength and stability. In addition, hydraulic conductivity increased nearly fivefold, enhancing drainage characteristics. Overall, sand-clay mixtures with 40–60% sand content meet or approach USCS criteria for low plasticity, high density, and improved permeability, making them suitable for road embankments.

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1.0 Introduction

The geotechnical properties of soil are central to the performance and safety of civil engineering works. Clay, a commonly encountered foundation material, often exhibits high plasticity, low permeability, and pronounced volume change, which can cause low bearing capacity, excessive settlement, and instability in geotechnical structures (Alnmr and Ray, 2021). Improving the behavior of clayey soils is therefore essential, particularly in regions where clay is the dominant in-situ material.

A practical and widely studied method for improving clayey soils is the addition of sand to clay. Numerous investigations have reported that incorporating sand into clay reduces liquid limit and plasticity index, modifies compaction characteristics, and alters shear strength parameters (Boukhatem et al., 2025; Qusai et al., 2025; Alnmr and Ray, 2023; Al-Badran and Al-Ameri, 2020; Karakan and Demir, 2020). In general, increasing sand content tends to decrease Atterberg limits, increase maximum dry density, reduce optimum moisture content, enhance internal friction angle, and mitigate swelling and compressibility. However, cohesion often decreases beyond certain sand percentages (Boukhatem et al., 2025; Alnmr and Ray, 2023; Karademir and Diskaya, 2024). These changes directly influence the load-bearing capacity, deformation behavior, and durability of sand-clay mixtures in the field.

Despite clear evidence that sand can beneficially modify clay behavior, the magnitude and direction of these effects depend on factors such as sand content, gradation, clay mineralogy, and stress–moisture conditions (Karademir and Diskaya, 2024; Deng *et al.*, 2017). For example, several studies have identified optimal sand contents—often in the range of 20–30% or higher—at which improvements in density, strength, and volume stability are most pronounced before unfavorable trade-offs such as reduced cohesion or increased erodibility becomes significant (Al-Badran and Al-Ameri, 2020; Boukhatem *et al.*, 2025; Alnmr and Ray, 2023; Karademir and Diskaya, 2024). This highlights the need for systematic experimental evaluation to determine appropriate sand proportions for specific engineering applications.

In practical construction, modifying the sand fraction within clay soils is often more economical and environmentally sustainable than complete soil replacement, particularly for applications such as embankments, and foundation soils (Alnmr and Ray, 2021; Alnmr and Ray, 2023; Karademir and Diskaya, 2024). Despite this practical relevance, there remains a lack of project-specific and systematically generated data on how varying sand contents influence key geotechnical properties under different compaction conditions. This data gap can result in conservative assumptions or suboptimal design decisions, limiting the effective application of sand–clay mixtures in engineering practice.

Accordingly, this research investigates the effect of sand addition on the geotechnical properties of clay through controlled laboratory testing. By examining changes in compaction behavior, shear strength, consistency limits, and related parameters with varying sand content, the study aims to clarify how sand modifies clay behavior and to identify mix ranges that provide improved performance for safe and economical geotechnical design.

2. Materials and Methods

2.1 Materials

The materials used in this study comprised of clay and river sand. The clay was sourced from Chanchaga, Minna, Niger State, while the river sand was obtained from a local supplier within Minna. The sand was clean, well-graded, and free from organic matter and visible debris. To prepare the tests samples, the river sand was blended with the natural clay in the proportion: 0, 20, 30, 40, 50, and 60% by weight of the clay sample. Table 1 present the geotechnical properties of the river sand, while Table 2 summarizes the oxide composition of both the clay and sand.

Table 1: Basic Properties of the River Sand (Godwin *et al.*, 2025)

Property	Description/value	
Percent passing No. 10 sieve (2.00 mm)	89.60	
Percent passing sieve 0.075 mm	3.52	
Specific gravity, G_s	2.69	
USCS classification, $C_c = 3.33$	SW	
	BSH	BSL
Maximum dry density, MDD (g/cc)	1.884	1.884
Optimum moisture content, OMC (%)	11	18

Table 2: Oxide Composition of Clay soil and River Sand (Godwin *et al.*, 2025)

Oxide	Clay soil (%)	Sand (%)
SiO ₂	56.30	40.25
AL ₂ O ₃	29.69	20.74
Fe ₂ O ₃	4.64	30.87
MnO	0.09	0.07
CaO	1.60	0.42
P ₂ O ₅	-	-
K ₂ O	0.89	0.66
TiO ₂	1.19	1.35
MgO	4.65	4.84
Na ₂ O	0.89	0.65
SO ₃	0.12	0.13
LOI	0.03	0.04

LOI = Loss on ignition

2.2 Methods

All laboratory tests were performed in accordance with BS 1377 (1990), with the relevant equations applied as specified in the standard.

2.2.1 Sieve analysis

Sieve analysis was performed on the natural clay and sand-clay mixtures to determine the grain size distribution. Approximately 500 g of air-dried soil was oven-dried and passed through a stack of standard sieves arranged in decreasing order of mesh size. Mechanical sieving was conducted using a Gilson 8-in vibratory sieve shaker (model SS-10) for 10 minutes. The percentage of the soil retained on each sieve was calculated from Equations 1 and the percentage passing determined accordingly using Equations 2. Also, the American Association of State Highway and Transportation Officials (AASHTO, 2021) classification group index for the various mixtures were computed from equation 3.

$$\% \text{ weight retained} = \frac{\text{weight retain}}{\text{total weight of sample}} \times 100 \quad 1$$

$$\% \text{ passing} = 100 - \text{Cummulative \% weight retained} \quad 2$$

$$GI = (F - 35)[0.2 + 0.005(LL - 40)] + 0.01(F - 15)(PI - 10) \quad 3$$

2.2.2 Atterberg limit

The Atterberg limit tests were conducted to evaluate the consistency characteristics of the clay and sand-clay mixtures: The Liquid Limit (LL) was determined using the cone penetration apparatus, while the Plastic Limit (PL) was obtained by manually rolling soil threads until they crumbled at approximately 3 mm diameter. The Plasticity Index (PI) was calculated as the difference between the LL and PL (Equation 4).

$$PI = LL - PL \quad 4$$

2.2.3 Compaction test

The compaction characteristics, namely the maximum dry density (MDD) and optimum moisture content (OMC), were determined using the Standard and modified Proctor methods. For each test approximately 3 kg of clay and mixtures with river sand were compacted in a 1000 cm³ mould in three layers using a 2.5 kg (British Standard Light, BSL) and 4.5 kg (British Standard Heavy, BSH) rammer dropped from a height of 300 mm. The test was repeated for different moisture contents, and the MDD and OMC were obtained from the plotted compaction curve.

2.2.4 Unconfined compressive strength test

The Unconfined Compressive Strength (UCS) test was carried out to evaluate the undrained shear strength of the clay and sand-clay mixture for BSH and BSL compaction efforts. Cylindrical specimens (38 mm diameter × 76 mm height) were prepared and tested without lateral confinement. The axial load was applied at a constant strain rate of - 1.25 mm/mi - until failure. The maximum axial stress at failure was recorded as the UCS. Each test was performed on three specimens and average UCS was obtained. The axial stresses were computed using the relationships presented in Equations 5 to 9.

$$\text{Strain } (\epsilon) = \Delta L / L \quad 5$$

$$\text{Initial area } (A_i) = \pi \frac{d^2}{4} \quad 6$$

$$\text{Final area } (A_f) = \frac{A_i}{1 - \epsilon} \quad 7$$

$$\text{Load (kN)} = (\text{dial reading} \times 5) / 1000 \quad 8$$

$$\text{Stress (kN/m}^2\text{)} = \text{load (kN)} / A_f \quad 9$$

2.2.5 Triaxial test

Triaxial compression tests were used to determine the cohesion (c) and angle of internal friction (ϕ) of the soil samples. Cylindrical specimens (38 mm diameter \times 76 mm height) were subjected to confined water pressure of 50, 100, and 150 kPa. Axial loading was performed at a constant rate until failure and the corresponding stresses at failure were recorded. The shear strength parameters were obtained by plotting Mohr cycles and fitting the Mohr-Coulomb failure envelope using Microsoft excel.

2.2.6 Permeability test

The permeability characteristics of the clay and sand-clay mixtures was measured using the falling head permeability test which is suitable for fine-grained soils. Soil samples were compacted into a cylindrical mould with respect to BSL and BSH compaction effort. Water was allowed to flow through it from a standpipe and the rate of fall of the water level in the standpipe over time was used to calculate the coefficient of permeability (k) using the standard falling head permeability equation. Computation for the hydraulic conductivity was done from Equation 10.

$$k = \frac{2.303A_p L}{A_{sam} T} \times \log \left(\frac{h_1}{h_2} \right) \quad 10$$

Where: k = hydraulic conductivity; A_p = Area of standpipe; A_{sam} = Area of sample; L = length of standpipe; h_1 = initial reading on standpipe; h_2 = Final reading on standpipe

3. Results and Discussion

3.1 Atterberg Limit

The Atterberg limits results in Table 3 show a clear reduction in clay plasticity with increasing sand content. The natural clay, with an LL of 58% and PI of 41.5%, is classified as CH (high-plasticity clay) under the Unified Soil Classification System (USCS). Such soils are generally unsuitable for subgrade and fill without stabilization due to its high shrink–swell potential and low workability. The progressive addition of sand resulted in a decrease in both LL and PI with the most significant reduction observed beyond 30% sand. At 40% sand, the PI decreases below 20%, satisfying the USCS (1953) requirement for fine-grained subgrade and fill soils (PI < 20%, LL < 50%). By 60% sand, LL is reduced to 29.4% and PI to 12.96%, indicating a transition to low-plasticity behavior.

These reductions in consistency limits results in a gradual shift in the soil classification from CH toward CL and SC groups, which are generally favorable for engineered fills applications when properly compacted and moisture-controlled. Mixtures containing roughly 30–60% sand thus exhibit plasticity characteristics consistent with USCS guidance for construction suitability. This demonstrates that sand addition is an effective means of improving the plasticity-based geotechnical properties of clay and reclassifying problematic high-plasticity clay into more suitable categories for engineering use.

3.2 Classification Category and Group Index

The soil classification results presented in Table 3 demonstrate a progressive improvement in engineering behavior with increasing sand content. The natural clay is classified as CH (high-plasticity clay) under the Unified Soil Classification System (USCS) and as A-7-6 according to AASHTO, classifications that are typically associated with high plasticity, low strength, and poor performance in engineering applications.

With the addition of 10–30% sand, the soil classification shifts to CL (low-plasticity clay) in the USCS and improves to A-6 under the AASHTO system. These changes indicate a notable reduction in plasticity and an overall enhancement in engineering suitability, consistent with the trends observed in the Atterberg limits results. At higher sand contents (40–60%), the soil was reclassified as SC (clayey sand) under the USCS, while the AASHTO classification shifted from A-6 to A-2-6. These classifications reflects a material of superior quality, characterized by improved drainage, increased frictional resistance, and enhanced load-bearing capacity. Overall, the classification results indicate that the addition of sand substantially enhances the geotechnical properties of clay. In particular, mixtures containing 40–60% sand are significantly more suitable for use as fill materials in construction, as they conform to the USCS material specifications for road embankment applications (Anglade et al., 2022).

Table 3: Atterberg limit and classification category of clay with varying sand content

Mixture	LL (%)	PL (%)	PI (%)	Percent passing sieve 2.00 mm	Percent passing sieve 0.075 mm	USCS	AASHTO
Clay	58	16.5	41.5	98.93	84	CH	A-7-6
CL + 10% S	41.2	15.95	25.25	96.23	76.63	CL	A-7-6
CL + 20% S	37.75	15.74	22.01	96.6	67.7	CL	A-6
CL + 30% S	34.6	12.94	21.66	95.64	59.27	CL	A-6
CL + 40% S	34.5	13.39	21.11	94.74	49.54	SC	A-6
CL + 50% S	32.6	13.89	18.71	95.87	40.9	SC	A-6
CL + 60% S	29.4	16.44	12.96	92.4	34.87	SC	A-2-6

The Group Index also decreases progressively from 28 for the natural clay to 1 at 60% sand content, indicating a marked improvement as construction material with sand addition (see Table 4). This reduction reflects the combined effects of decreasing fines content, lower plasticity, and reduced compressibility, confirming the transition from poor-performing clayey A-7 soils to a significantly better A-2-6 granular material.

Table 4: Group index for the various soil mixtures

Mixture	AASHTO	Group index
Clay	A-7-6	28
CL + 10% S	A-7-6	17
CL + 20% S	A-6	12
CL + 30% S	A-6	9
CL + 40% S	A-6	6
CL + 50% S	A-6	3
CL + 60% S	A-2-6	1

3.3 Compaction Characteristics

The compaction results presented in Figure 1a and 1b clearly indicate that adding sand significantly improves its engineering performance by increasing the Maximum Dry Density (MDD) and reducing the Optimum Moisture Content (OMC). Well-compacted subgrade and embankment fills are expected to exhibit relatively high dry densities and moderate OMCs because these parameters correlate with higher strength, stiffness, bearing capacity, and improved long-term performance (USCS Appendix – B, 1953; Cabalar and Mustafa, 2017). Similar trends have been widely reported: increasing sand content in clay–sand mixtures typically yields higher MDD and lower OMC, reflecting a denser fabric with reduced water demand (Alnmr and Ray, 2021; Boukhatem et al., 2025; Alkroosh et al., 2021).

In this study, the natural clay for both energy level exhibited lower bound MDD and relatively high moisture requirements, characteristic of a material that is moisture-sensitive and more difficult to compact effectively. With sand addition up to 60%, the MDD increases to 2.17 g/cm³ (BSH) and 2.085 g/cm³ (BSL), values consistent with or exceeding densities typically sought for engineered fills and road subgrades, while OMC decreases to about 9.6–11.2%, indicating reduced water requirement and more efficient field compaction 3469. Studies on low-plasticity clays and aeolian-sand–clay blends similarly report MDD increases on the order of 10–15% and notable reductions in OMC when sand contents in the range of 20–40% or ~30% are adopted (Boukhatem et al., 2025; Alkroosh et al., 2021).

These findings suggest that sand–clay mixtures with about 40–60% sand meet or surpass common compaction performance thresholds for structural fills, aligning with the ranges reported for subgrade and embankment applications (Cabalar and Mustafa, 2017; Alkroosh et al., 2021). Previous investigations of clay–sand mixtures used in pavement subgrades and expansive soil improvement show that increasing sand content enhances dry unit weight, reduces OMC, and often improves bearing and deformation characteristics up to an optimal sand proportion, beyond which benefits may diminished. The current results therefore corroborate the broader body of evidence that incorporating an appropriate proportion of sand into clay transforms a

moisture-sensitive, low-density material into a denser, more compactable fill with improved engineering suitability for infrastructural applications.

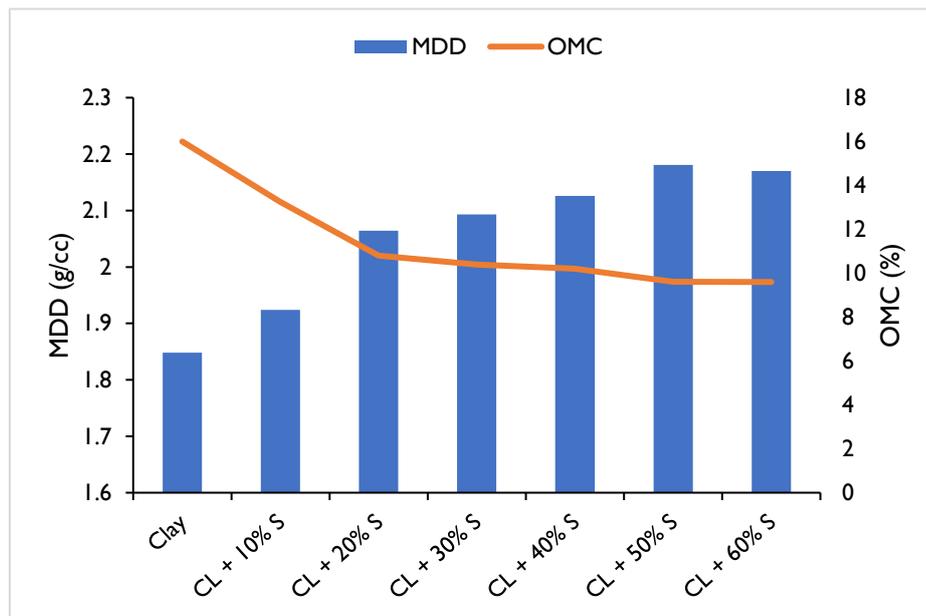


Figure 1a: Compaction characteristics of clay with variation in sand content under BSH compaction

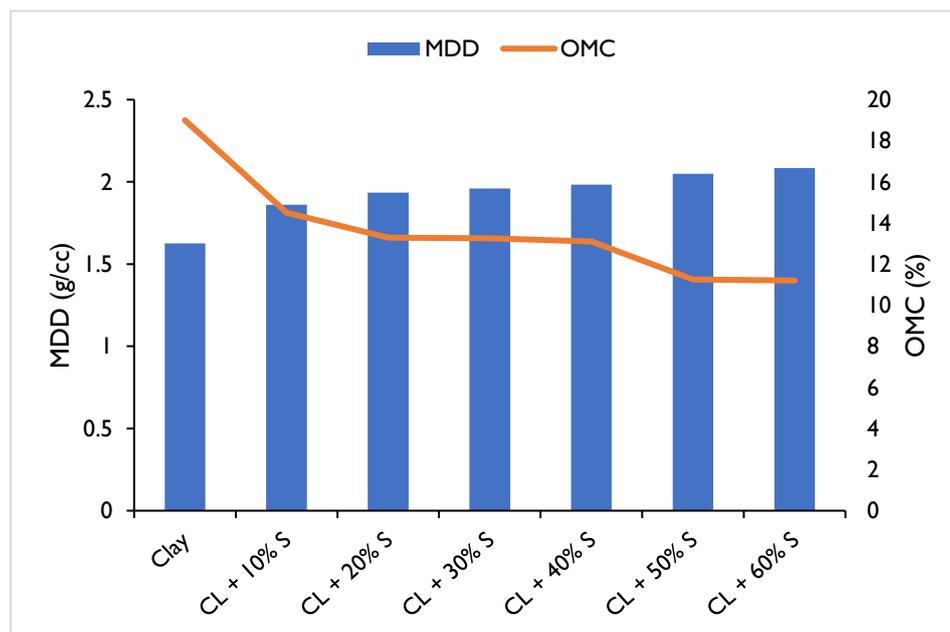


Figure 1b: Compaction characteristics of clay with varying sand content under BSL compaction

3.4 Unconfined Compressive Strength

The UCS results for the studied clay–sand mixtures indicate a clear overall increase in soil strength with increasing sand content, consistent with finding reported in previous studies on clay–sand stabilization (Budianto *et al.*, 2021; Hastuty and Hartawan, 2021). The natural clay shows relatively low UCS values under both BSH and BSL compaction, reflecting its weak and highly plastic character and its susceptibility to deformation at low densities. Similar low-strength behavior for untreated high-plasticity or weak clays has been reported by Hastuty and Hartawan (2021).

As shown in Figure 2, as sand content increases from about 20% to 50%, UCS increases more markedly, especially under the higher BSH compaction effort, which yields peak strengths near 200 kPa. This trend reflects the beneficial role of sand in developing a denser, frictional skeleton and lowering plasticity, leading to stronger and more stable mixtures (Hastuty and Hartawan, 2021; Al-Badran and Al-Ameri, 2020). Under BSL compaction, UCS also increases with sand content, although the improvement is less pronounced, emphasizing

the role of compaction energy in mobilizing the strength potential of clay–sand blends. A slight reduction UCS was observed at 60% sand under BSH, compared with 50% sand mixture. This reduction suggests that excessive sand content limits the continuity of the clay matrix required to provide cohesion, causing the soil structure to be dominated by a granular skeleton with lower overall bonding. Similar behavior has been reported in studies where excessive replacement of clay by sand led to diminished strength gains despite increased frictional resistance. Overall, the observed UCS pattern, at moderate to high sand contents (30–60%), aligns with previous work showing that carefully selected sand fractions significantly improve the strength, stiffness, and load-bearing performance of weak clays, making such mixtures suitable for subgrades, embankments, and other construction applications requiring enhanced durability (Bouchemella and Taibi, 2022; Budiando *et al.*, 2021; Al-Badran and Al-Ameri, 2020).

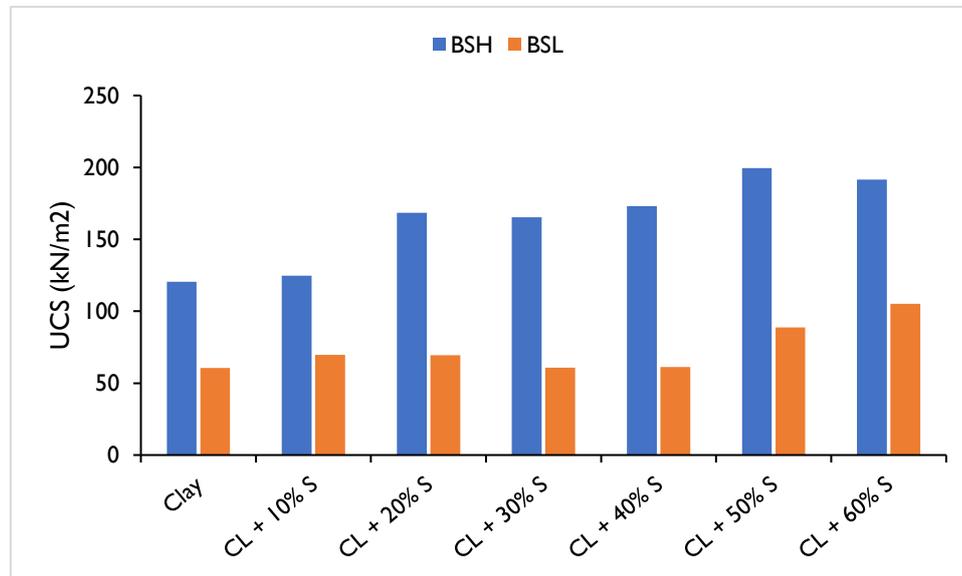


Figure 2: Variation of unconfined compressive strength with sand content at different compaction effort

3.5 Shear Strength

The shear strength test results reveal distinct changes in both cohesion and internal friction angle as sand is added to clay (Figure 3a and 3b). The clay sample shows high cohesion values of 43.4 kPa (BSH) and 17.81 kPa (BSL), but relatively low internal friction angles of 8.2° (BSH) and 7.4° (BSL). This is typical of highly plastic clays, which rely mainly on cohesion for strength, but exhibit limited frictional resistance due to their fine-grained nature (Miftah *et al.*, 2020). As sand content increases, the cohesion steadily decreases, reflecting the dilution of the cohesive clay matrix by non-cohesive sand particles.

Conversely, the internal friction angle shows a consistent increase with higher sand content, rising from 8.2° in pure clay to 22.3° (BSH) and 15° (BSL) at 60% sand. This increase demonstrates that the soil's shear strength is progressively governed more by frictional resistance between sand particles, enhancing the soil's overall stability and load-bearing capacity. The trade-off between decreasing cohesion and increasing friction angle is typical for sand-clay mixtures, where the strength mechanism gradually shifts from cohesion-dominated to friction-dominated behavior (Dasgupta, 2014).

From an engineering perspective, these results suggest that sand addition significantly improves the shear strength characteristics of clay soils, especially under higher compaction effort (BSH). Mixtures with sand content between 40% and 60% exhibit a favorable combination of moderate cohesion and high friction angle, making them more suitable for construction applications such as embankments and foundations where both strength and stability are critical. These findings complement the trends observed in UCS, Atterberg limits, and compaction tests, reinforcing the overall conclusion that sand-clay mixtures provide enhanced geotechnical performance over pure clay.

3.6 Hydraulic Conductivity

The hydraulic conductivity results presented in Figure 5, indicate a clear increase in soil permeability with increasing sand content. The natural clay exhibits very low hydraulic conductivity values of 4.19×10^{-7} cm/sec (BSH) and 7.94×10^{-7} cm/sec (BSL), reflecting its dense, fine-grained, and low-permeability.

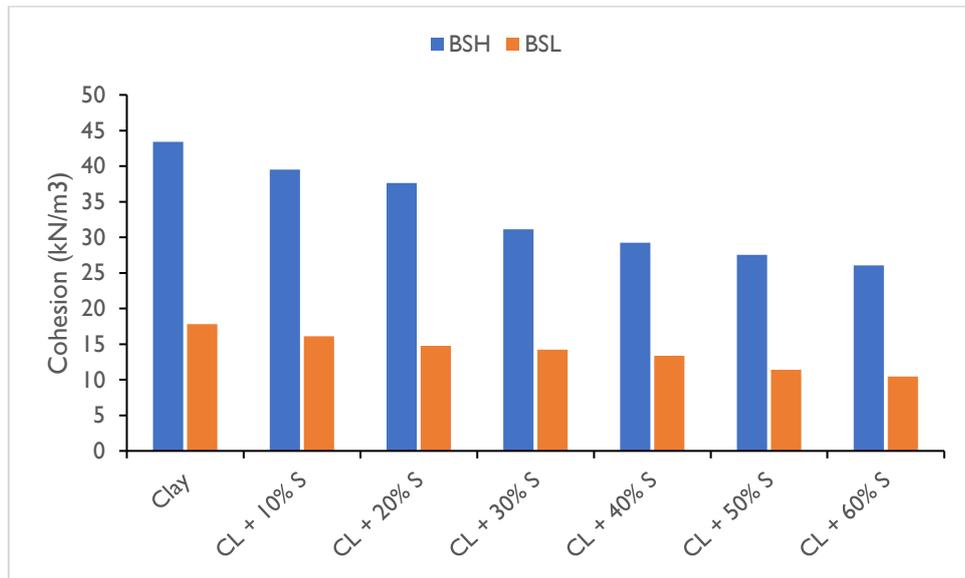


Figure 3a: Variation of cohesion with sand content at different compaction efforts

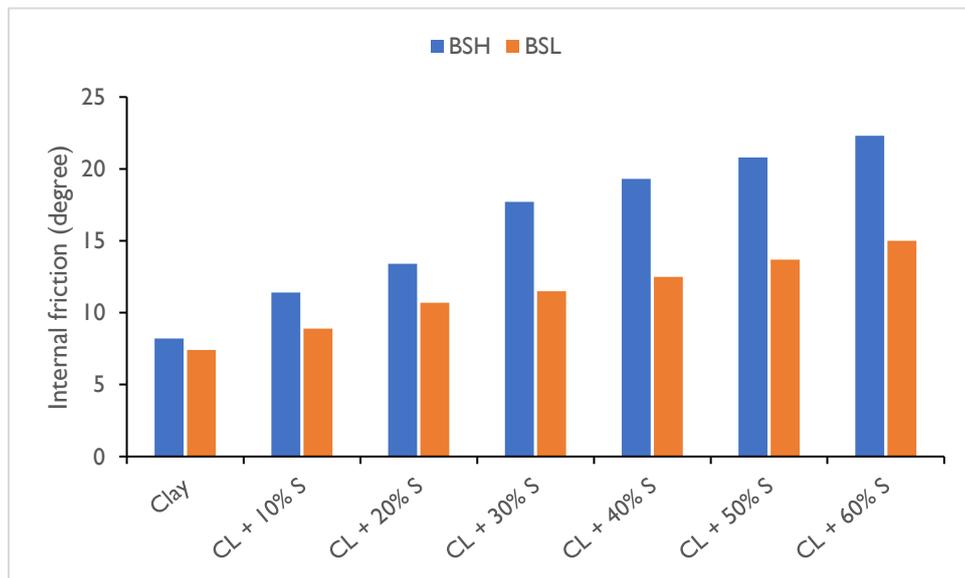


Figure 3b: Variation of internal friction with sand content at different compaction effort

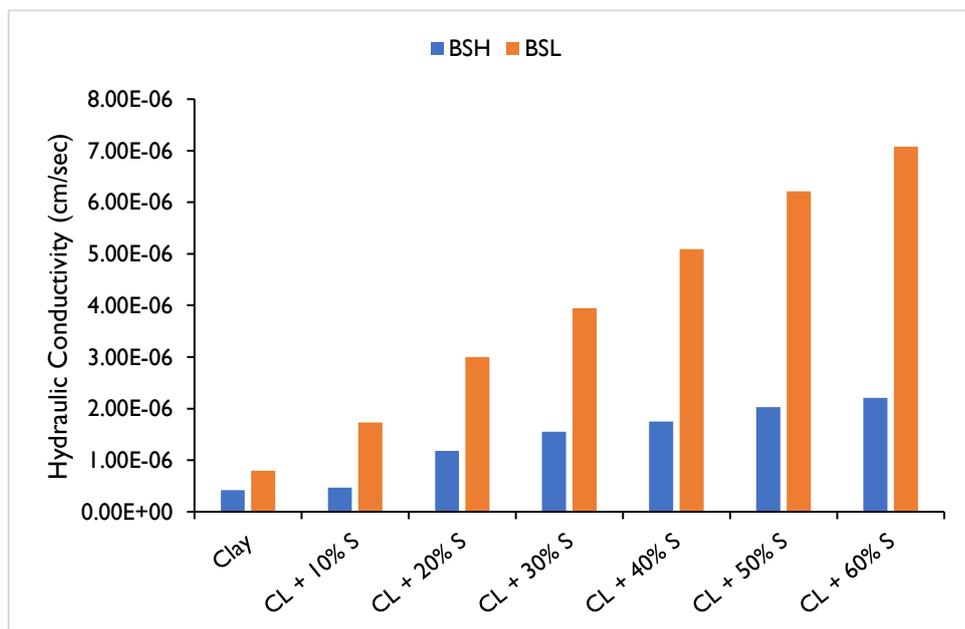


Figure 4: Variation of the hydraulic conductivity of clay with sand content

With the progressive addition of sand, hydraulic conductivity increased. Under the BSH compaction, permeability rises steadily from 4.69×10^{-7} cm/sec at 10% sand to 2.21×10^{-6} cm/sec at 60% sand. This trend demonstrates that the incorporation of granular sand particles enhances the soil's drainage capability by increasing pore size distribution and improving pore connectivity within the soil matrix. The increase in hydraulic conductivity is more pronounced under BSL compaction, where the soil structure is less dense. In this case, conductivity values rise from 1.73×10^{-6} cm/sec at 10% sand content to 7.08×10^{-6} cm/sec at 60% sand content, significantly higher than those obtained BSH compaction. This difference highlights how compaction effort influences soil permeability, with lower compaction leading to more void space and thus higher conductivity (Alnmr and Ray, 2021).

4. Conclusion

Based on the experimental investigation into the effect of sand addition on the geotechnical properties of clay under two compaction energy levels (BSL and BSH). The following highlights the key conclusions:

- i. Sand addition significantly reduced the liquid limit and plasticity index, transforming the clay from CH to CL and SC classifications.
- ii. At sand contents of 40–60%, the mixtures satisfied USCS requirements for subgrade and fill materials.
- iii. Soil classification improved from A-7-6 to A-2-6, with the Group Index decreasing from 28 to 1, indicating better engineering quality.
- iv. Maximum dry density increased while optimum moisture content decreased with increasing sand content under both BSL and BSH compaction.
- v. Higher compaction energy (BSH) consistently produced higher densities and lower moisture demand than BSL.
- vi. Unconfined compressive strength increased with sand content, peaking at 50%, particularly under BSH compaction.
- vii. Cohesion decreased while the internal friction angle increased, indicating a shift from cohesion to friction controlled behavior.
- viii. Shear strength improvement was more pronounced under higher compaction effort.
- ix. Hydraulic conductivity increased with sand content and was higher under BSL than BSH compaction.
- x. Overall, sand contents of about 40–60% combined with adequate compaction significantly enhanced the geotechnical performance of the clay.

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