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Review Article

Groundnut Shell Ash as a Stabilizing Agent for Clayey Sand: A Review

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A B S T R A C T

This review examines the potential of groundnut shell ash (GSA) as an eco-friendly stabilizing agent for clayey sand soils. The focus is on the chemical composition of GSA, its impact on soil properties, and its effectiveness compared to traditional stabilizers like cement and lime. GSA, a byproduct of groundnut processing, contains significant amounts of silica, alumina, and calcium oxide, which contribute to its pozzolanic activity and soil-binding properties. The addition of GSA to clayey sand reduces the liquid limit and plasticity index, improves particle size distribution, and significantly enhances mechanical properties such as unconfined compressive strength (UCS) and California Bearing Ratio (CBR). Durability tests show that GSA-treated soils exhibit reduced weight loss under wet-dry cycles, indicating improved durability. However, the effect on permeability varies, with some studies reporting decreased permeability due to void filling, while others note increased permeability from larger pore formation. Compared to traditional stabilizers, GSA requires higher dosages to achieve similar strength improvements but offers substantial cost savings and environmental benefits, reducing stabilization costs by up to 40% and CO_2 emissions by approximately 30%. Future research should explore long-term performance, optimize GSA particle size, combine GSA with other agricultural wastes, standardize production, and conduct life cycle assessments. Overall, GSA presents a sustainable alternative for soil stabilization, turning agricultural waste into a valuable resource for construction.

Keywords: Groundnut Shell Ash (GSA), Clayey Sand Stabilization, Pozzolanic Reactions, Eco-friendly Construction, Soil Mechanical Properties, Agricultural Waste Utilization

Introduction

Soil stabilization is a critical process in geotechnical engineering, aimed at improving soil properties such as strength, durability, and resistance to deformation[1]. Clayey sand, a common soil type, often presents challenges due to its high plasticity and low bearing capacity[2]. Traditionally, cement and lime have been used as stabilizers, but their production is energy-intensive and environmentally detrimental[3].In recent years, there has been a shift towards using agricultural waste materials as soil stabilizers, aligning with global sustainability goals[4]. Groundnut (Arachis hypogaea), also known as peanut, is widely cultivated worldwide, with an annual production exceeding 45 million tonnes5. The shells, accounting for about 25% of the total weight, are often discarded or burned, creating disposal issues[6]. Converting these shells into ash presents a potential solution, offering both waste management benefits and a valuable resource for soil stabilization.

Chemical Composition of GSA

The effectiveness of GSA as a soil stabilizer is largely attributed to its chemical composition. X-ray fluorescence (XRF) analysis reveals that GSA is rich in silica (SiO_2), alumina (Al_2O_3), and calcium oxide (CaO)[7]. GSA containing 56.4% SiO_2, 18.3% Al_2O_3, and 11.2% CaO. These compounds are key in pozzolanic reactions, which form cementitious products that bind soil particles together[8].Different blend ratios of GSA (between 0 and 16%) were used as replacement for Portland cement in the production of the concrete mixes. X-Ray diffractometry, X-Ray fluorescent spectrometer, scanning electron microscopy, pozzolanic reactivity in suspension, and compressive strength measurements were used as basis to assess the reaction mechanism and hydration behaviour of the concrete and paste mixes produced[9]. The principal chemical constituent of GSA is silica, and the SiO2 + Al2O2 + Fe2O3 sum of 69.2 wt% observed for the GSA falls into class C pozzolans. Hydration efficiency evaluated by assessing the amount of calcium silicate hydrate formed, quantity of calcite present in the hydrated paste and integrity of microstructural interlocking of particles indicated the efficiency use of 8 wt% GSA [10].Moreover, GSA contains moderate amounts of iron oxide (Fe_2O_3), magnesium oxide (MgO), and potassium oxide (K_2O), contributing to its stabilizing properties[11]. The high silica content makes GSA particularly effective in clayey soils, as it reacts with calcium hydroxide ($Ca(OH)_2$) formed during hydration to produce calcium silicate hydrate (C-S-H) gel, a primary strength-giving compound [12].Table 1 presents the chemical composition of GSA.

Effects on Soil Properties

Physical Properties - GSA significantly influences the physical properties of clayey sand. Its observed that adding 2-8% GSA to clayey sand reduced the liquid limit from 38.5% to 34.2% and the plasticity index from 18.3% to 13.5% [13]. This decrease in plasticity is attributed to the cation exchange capacity of GSA, which alters the soil's texture [14].GSA also affects particle size distribution. It is reported that incorporating 4-12% GSA increased the percentage of fine particles, enhancing the soil's gradation. This change improves the soil's compactibility and reduces its susceptibility to erosion[15].

Mechanical Properties - The most significant impact of GSA is on the mechanical properties of clayey sand. Compressive strength, a key indicator of soil stability, markedly improves with GSA addition. It is found that 6% GSA increased the unconfined compressive strength (UCS) of clayey sand from 103 kPa to 287 kPa after 28 days of curing[16].California Bearing Ratio (CBR), which measures soil's bearing capacity, also shows substantial enhancement. A study by Suresh and Murthy (2018) revealed that 8% GSA increased the soaked CBR value from 4.2% to 11.8%, making the soil suitable for subgrade materials in road construction[17]. Consolidation characteristics are equally affected. It is observed that 10% GSA reduced the compression index (Cc) of clayey sand from 0.26 to 0.17, indicating improved resistance to settlement[18].

Durability and Permeability - GSA treatment enhances soil durability. Durability tests conducted by Ayodele and Agbede (2018) showed that clayey sand stabilized with 6% GSA had a weight loss of only 8% after 12 wet-dry cycles, compared to 21% for untreated soil[19].Permeability is

Table 1: Chemical Composition of GSA

Chemical Compound	Content (wt%)	Function in Soil Stabilization
Silica (SiO_2)	56.4	Primary constituent. Reacts with $Ca(OH_2)$ during hydration to form C-S-H gel, a key binding agent in stabilized soil [12].
Alumina (Al_2O_3)	18.3	Contributes to pozzolanic reactions and formation of cementitious materials that bind soil particles [8]. May also improve workability of the mix [9].
Calcium Oxide (CaO)	11.2	Participates in pozzolanic reactions. $Ca(OH_2)$ formed during hydration reacts with silica to create C-S-H gel [12].
Iron Oxide (Fe_2O_3)	Moderate amounts	May contribute to pozzolanic activity and improve soil strength [11].
Magnesium Oxide (MgO)	Moderate amounts	May improve workability and act as a filler material in the stabilized soil matrix [11].
Potassium Oxide (K_2O)	Moderate amounts	Potential contribution to pozzolanic activity and influence on soil chemical properties [11].

another critical factor, especially in drainage applications. Interestingly, GSA's effect on permeability varies. While some studies report a decrease due to the filling of voids, others note an increase, attributing it to the formation of larger pores during pozzolanic reactions[20].Table 2 presents the impact of GSA on soil properties.

Table 2: Effects of GSA on Soil Properties

Property	Effect of GSA	Reference
Physical Properties		
Liquid Limit	Reduces	[13]
Plasticity Index	Reduces	[13]
Particle Size Distribution	Increases fines content, improves gradation	[15]
Mechanical Properties		
Unconfined Compressive Strength (UCS)	Significantly increases	[16]
California Bearing Ratio (CBR)	Significantly increases	[17]
Compression Index (Cc)	Reduces, indicating improved resistance to settlement	[18]
Durability	Improves	[19]
Permeability	Variable; may decrease or increase	[20]

Comparison with Traditional Stabilizers

Several studies have compared GSA with conventional stabilizers like cement and lime. It was found that 8% GSA performed similarly to 4% cement in improving the UCS of clayey sand, both achieving strengths around 250 kPa[21]. However, GSA required a higher dosage to match cement's effectiveness.In terms of cost and environmental impact, GSA outperforms traditional stabilizers. It is also estimated that using GSA could reduce stabilization costs by up to 40% compared to cement, while also lowering CO_2 emissions by approximately 30% [22]. Similarly, GSA and fly ash are soil stabilizers, with GSA being a byproduct of agricultural waste and fly ash being a byproduct of coal combustion. Both have different chemical compositions, physical and mechanical properties, and permeability effects[23,26].GSA & fly ash are effective soil stabilizers, GSA is potentially more sustainable but availability depends on region, fly ash may be more readily available depending on location [27,31].

Conclusions and Future Directions

This review demonstrates that groundnut shell ash is a promising stabilizing agent for clayey sand. Its high silica content and pozzolanic properties significantly enhance soil strength, reduce plasticity, and improve durability. While higher dosages are needed compared to cement or lime, GSA offers substantial cost savings and environmental benefits.

Future research should focus on:

- Long-term performance evaluation under varying field conditions.
- Optimizing GSA particle size for better reactivity.
- Combining GSA with other agricultural wastes for synergistic effects.
- Standardizing GSA production to ensure consistent quality.
- Life cycle assessments to quantify its sustainability advantages.
- Implementing AI-driven predictive modeling.

In conclusion, groundnut shell ash represents a viable, eco-friendly alternative to traditional soil stabilizers, particularly for clayey sand. Its adoption could significantly contribute to sustainable construction practices, turning agricultural waste into a valuable geotechnical resource.

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