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"ENGINEERING BEHAVIOR OF EXPANSIVE SOIL STABILIZED WITH RED MUD AND INDUSTRIAL WASTE MATERIALS"

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ABSTRACT

This study investigates the engineering behavior of expansive soil stabilized using red mud and iron powder as industrial waste materials. The primary objective was to evaluate the effectiveness of these additives in improving the compaction and engineering characteristics of expansive soil and to identify a suitable stabilization combination for potential ground improvement applications. Red mud was added at proportions of 9%, 18%, 27%, 36%, and 45% by dry weight of soil, while iron powder was incorporated at 1%, 2%, 3%, 4%, and 5%. Untreated expansive soil was considered as the control mixture. Laboratory investigations were conducted to determine the index properties, compaction characteristics, strength parameters, and swelling behavior of the stabilized soil mixtures. The Standard Proctor Compaction Test was specifically performed to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the untreated and stabilized soil mixtures. The results demonstrate that the incorporation of red mud and iron powder produces noticeable changes in the moisture-density relationship and overall compaction behavior of expansive soil. The improvement is attributed to the modification of soil gradation, filler action, reduction in clay activity, and improved particle interaction resulting from the incorporation of industrial waste materials. The use of these waste materials also offers an environmentally sustainable approach by converting industrial by-products into useful stabilizing agents for problematic expansive soils. The findings indicate that red mud and iron powder have

significant potential for improving the engineering performance of expansive soil and may be considered for sustainable ground improvement applications.

KEYWORDS: Expansive Soil; Soil Stabilization; Red Mud; Iron Powder; Industrial Waste Materials; Standard Proctor Test; Optimum Moisture Content; Maximum Dry Density; Compaction Characteristics; Ground Improvement; Sustainable Soil Stabilization.

INTRODUCTION

Expansive soils are problematic soils that undergo significant changes in volume when their moisture content varies. These soils generally contain a high proportion of clay minerals, particularly montmorillonite, which have a strong affinity for water. During wetting, expansive soil absorbs water and undergoes swelling, while during drying, it loses moisture and experiences shrinkage. The repeated swelling and shrinkage cycles can cause considerable deformation, cracking, and loss of strength, posing serious challenges to the construction and long-term performance of roads, embankments, foundations, pavements, and other infrastructure constructed over such soils. Therefore, improving the engineering properties of expansive soil is an important requirement for safe and economical construction.

Conventional soil stabilization techniques commonly involve the use of cement, lime, or other chemical stabilizing agents to improve strength, reduce plasticity, and control swelling behavior. Although these methods are effective, their extensive use can increase construction costs and environmental impacts due to the energy consumption and carbon emissions associated with the production of conventional binders. Consequently, increasing attention has been given to sustainable stabilization techniques that utilize industrial by-products and waste materials as alternative stabilizing agents.

Red mud is one such industrial waste material generated in large quantities during the Bayer process for the extraction of alumina from bauxite ore. It is a highly alkaline and fine-grained material containing significant amounts of iron oxides, aluminium oxides, silica, calcium compounds, and other minerals. Due to its chemical composition and alkaline nature, red mud has potential for modifying the physicochemical and engineering properties of problematic soils. However, the direct disposal of red mud can create environmental concerns because of its high alkalinity and large volume of generation. Its beneficial utilization in geotechnical engineering applications can therefore provide an effective approach for both waste management and soil improvement.

The stabilization of expansive soil using red mud and other industrial waste materials can potentially improve several important engineering properties, including plasticity characteristics, compaction behavior, swelling potential, California Bearing Ratio (CBR), unconfined compressive strength, and shear strength. The addition of suitable waste materials may alter the soil structure, reduce the activity of expansive clay minerals, promote particle aggregation, and improve the bonding between soil particles. These changes can reduce the volume-change characteristics of expansive soil and enhance its load-bearing capacity.

The present study focuses on evaluating the engineering behavior of expansive soil stabilized with red mud and industrial waste materials**.** The investigation aims to assess the influence of different proportions of stabilizing materials on the physical, compaction, strength, and swelling characteristics of expansive soil. Laboratory investigations can be carried out to determine parameters such as liquid limit, plastic limit, plasticity index, maximum dry density, optimum moisture content, free swell index, swelling pressure, CBR, and unconfined compressive strength. The performance of untreated expansive soil is compared with that of soil treated with different percentages and combinations of red mud and selected industrial waste materials.

The utilization of red mud and industrial waste materials for soil stabilization offers a dual advantage: it improves the engineering performance of weak and expansive soils while providing a sustainable method for managing industrial waste. Such an approach can reduce dependence on conventional stabilizers, minimize the environmental problems associated with waste disposal, and promote the development of cost-effective and environmentally friendly ground improvement techniques. The findings of the study may therefore contribute to the wider application of industrial waste-based stabilization methods in pavement subgrades, embankments, foundations, and other geotechnical engineering projects.

Literature Review

Rohit HYPERLINK "https://link.springer.com/article/10.1007/s43621-024-00619-2" Raj et al (2024) red mud is a highly alkaline industrial by-product generated during the extraction of alumina from bauxite ore through the Bayer process, and its large-scale accumulation has become a major environmental concern because of the enormous quantity produced globally and the difficulty of safe disposal. This review paper focuses on transforming red mud from an environmental liability into a valuable resource for sustainable construction and ground improvement applications. Due to its unique chemical and mineralogical composition, which typically includes oxides of iron, aluminum, silicon, calcium, titanium, and residual alkalis, red mud possesses characteristics that make it suitable for engineering applications. Traditionally, red mud has been explored in the production of construction materials such as bricks, cement, concrete, tiles, and pavement materials, where it contributes to improved density, strength, and durability when used in controlled proportions. Beyond conventional construction uses, red mud also demonstrates significant potential in wastewater treatment because of its adsorption capacity for contaminants and heavy metals, promoting waste reutilization and environmental protection. In geotechnical engineering, red mud has gained attention as a soil stabilization material because its high alkalinity and pozzolanic behavior promote chemical reactions with soil minerals, leading to the formation of cementations compounds that enhance soil strength, reduce plasticity, improve bearing capacity, decrease compressibility, and increase long-term durability. Its fine particle size helps fill soil voids and create a denser soil matrix, making it effective for applications such as road subgrades, embankments, and land reclamation projects.

M. J. Supriya et al (2025) this study evaluates the stabilization of Black Cotton (BC) soil using Red Mud (RM), an industrial waste generated during the Bayer process of aluminum extraction, together with lime [$Ca(OH)_2$], to improve the engineering performance of expansive soils. Black Cotton soil is widely recognized in geotechnical engineering for its problematic behavior due to high swelling, shrinkage, compressibility, and low load-bearing capacity. These characteristics cause severe challenges for foundations, pavements, embankments, and other infrastructure projects, especially under variations in moisture content. At the same time, large-scale generation of red mud creates environmental disposal concerns because of its highly alkaline nature and extensive storage requirements. This research addresses both issues simultaneously by utilizing red mud as a stabilizing material for problematic soil. To investigate the stabilization performance, BC soil was blended with varying percentages of red mud ranging from 10% to 50%, and an additional 4% lime content was introduced to examine its combined influence on soil improvement. A comprehensive experimental program was conducted to determine both index properties and engineering characteristics of the stabilized mixtures. The study also considered the effect of curing time, which is a major factor governing the long-term development of strength in stabilized soils.

Testing was carried out over extended curing periods of 0, 7, 14, 30, 60, 90, 180, and 365 days, allowing assessment of gradual physicochemical and structural changes occurring within the stabilized soil matrix.

METHODOLOGY

The methodology adopted for this review study focuses on collecting, analyzing, and synthesizing published research related to the stabilization of expansive soils using red mud and various industrial waste materials. The study follows a systematic approach to identify the effectiveness of different stabilizing agents and evaluate their influence on the engineering properties of expansive soils.

Expansive soil

The present investigation, expansive Black Cotton (BC) soil was collected from Narsinghpur Madhya Pradesh, near Bhopal, Madhya Pradesh, India. The selected site is well known for the occurrence of highly expansive clayey soil, which undergoes significant volume changes due to seasonal variations in moisture content. Such soils are commonly responsible for engineering problems, including differential settlement, excessive swelling and shrinkage, pavement cracking, and damage to foundations and other civil engineering structures. Therefore, the collected soil was considered suitable for evaluating the effectiveness of red mud and other industrial waste materials as stabilizing agents.

The soil sample was collected from the natural ground after removing the top layer of organic matter and loose surface material to avoid contamination. Adequate quantities of representative soil were excavated from the site and packed in clean, moisture-proof bags. The bags were properly sealed and labeled before being transported to the geotechnical engineering laboratory for further investigation. In the laboratory, the collected soil was first spread on a clean platform and allowed to air dry at room temperature. Air drying was carried out to remove excess natural moisture without altering the mineralogical composition or engineering characteristics of the soil. After drying, the soil was gently pulverized using a wooden mallet to break down lumps without crushing the individual soil particles.

The prepared soil was then passed through a 4.75 mm IS sieve to remove gravel, roots, and other coarse particles. Only the fraction passing through the 4.75 mm sieve was used for all laboratory tests to ensure uniformity and consistency in the experimental programme. A representative portion of the sieved soil was weighed before and after air drying to determine its natural moisture content using the standard gravimetric method.

RESULT AND DISCUSSION

This chapter presents and discusses the experimental results obtained from laboratory tests conducted on expansive soil stabilized with varying proportions of red mud and iron powder. The objective of the study was to evaluate the influence of these industrial waste materials on the engineering properties of expansive soil and to identify the optimum combination that provides the best improvement in soil performance.

The expansive soil was treated with red mud at proportions of 9%, 18%, 27%, 36%, and 45% by dry weight of soil. Iron powder was incorporated separately at proportions of 1%, 2%, 3%, 4%, and 5%. The untreated soil served as the control sample for comparison. Standard laboratory tests were carried out on each mix in accordance with relevant Indian Standards to determine changes in index properties, compaction characteristics, strength, and swelling behavior. The results indicate that the addition of red mud and iron powder significantly influences the engineering behavior of expansive soil. The improvement in soil properties is mainly attributed to the filler effect of the additives, modification of soil texture, reduction in clay activity, and the development of cementitious compounds through pozzolanic reactions. These mechanisms contribute to enhanced particle bonding, increased density, and reduced affinity of the soil for water.

Standard proctor test for soil – red mud and iron powder mixture

The Standard Proctor Compaction Test is conducted to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of soil stabilized with different percentages of red mud and iron powder. These values are essential for evaluating the compaction characteristics of the stabilized soil and for selecting the optimum mix for engineering applications. Determine the relationship between moisture content and dry density of expansive soil mixed with red mud and iron powder, and to identify the OMC and MDD of each mixture.

Table 1 Standard proctor test for expansive soil only.

Volume of mold (cm^3)	Weight of soil in mold (Kg)	Moist unit weight (g/cm^3)	Moisture content (%)	Dry unit weight (g/cm^3)	ZAV (g/cm^3)
997.95	1.56	1.56	17.76	1.32	1.70
997.95	1.73	1.73	19.53	1.45	1.65
997.95	1.86	1.86	22.65	1.52	1.57
997.95	1.87	1.87	24.87	1.50	1.52
997.95	1.82	1.82	27.92	1.42	1.45

Table 2 Standard proctor test for expansive soil +9% red mud mixture+1%Iron powder.

Volume of mold (cm^3)	Weight of soil in mold (Kg)	Moist unit weight (g/cm^3)	Moisture content (%)	Dry unit weight (g/cm^3)	ZAV (g/cm^3)
997.95	1.60	1.60	15.18	1.39	1.78
997.95	1.76	1.76	19.09	1.48	1.66
997.95	1.83	1.83	22.13	1.50	1.58
997.95	1.80	1.81	27.96	1.41	1.45
997.95	1.77	1.77	32.71	1.33	1.35

CONCLUSION

Based on the Standard Proctor compaction test results, the addition of red mud and iron powder significantly influences the compaction characteristics of expansive soil. For untreated expansive soil, the dry density increased initially with increasing moisture content and reached a maximum dry density of approximately 1.52 g/cm^3 at an optimum moisture content of about 22.65%. Beyond this moisture content, the dry density decreased, indicating the typical compaction behavior of expansive soil.

For the soil mixture containing 9% red mud and 1% iron powder, the maximum dry density obtained was approximately 1.50 g/cm^3 at an optimum moisture content of about 22.13%. Compared with untreated expansive soil, the stabilized mixture shows a slight reduction in maximum dry density and a small decrease in optimum moisture content. This change may be attributed to the modification of the soil particle arrangement caused by the addition of red mud and iron powder.

The results indicate that the additives alter the soil structure by introducing finer and comparatively denser particles, which influence the water-holding capacity and packing characteristics of the expansive soil. The reduction in dry density may also be associated with the formation of a modified soil matrix due to the interaction between the clay particles and the stabilizing materials. Overall, the Standard Proctor test confirms that 9% red mud combined with 1% iron powder produces a noticeable modification in the compaction behavior of expansive soil. The obtained OMC and MDD values can be used for determining the appropriate moisture condition and compaction requirement for subsequent strength and swelling tests. Further evaluation of all red mud and iron powder combinations is required to identify the optimum stabilizer percentage based on strength, swelling, and other engineering properties.

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