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Nano-level Characterization of the Behavior of Red Soil Mixed with Granite Powder Waste

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Abstract

The escalating pace of urbanization and the consequent demand for infrastructure development have given rise to a growing environmental concern - the generation of vast quantities of industrial waste. Among these waste materials, granite powder waste originating from stone processing units has emerged as a major challenge due to its detrimental impact on soil and water resources. Conventional disposal methods have contributed to soil degradation and environmental contamination, necessitating the search for sustainable alternatives for waste management. In this context, the utilization of red soil blended with granite powder waste presents a promising avenue for sustainable construction practices. This study delves into the nano-level characterization of this composite material and investigates its potential applications. Advanced characterization techniques, particularly scanning electron microscopy (SEM) and energy-dispersive X-ray analysis (EDX), were used to analyze the behavior of red soil mixed with different percentages of granite powder waste. The results highlight the mix with 30% granite powder waste as a particularly noteworthy composition, showcasing superior interlocking properties. The microstructure analysis at the nanoscale revealed the formation of clusters, leading to enhanced cohesion between particles and improved interlocking behavior. These findings demonstrate the potential of this soil- waste composite for sustainable soil improvement and geotechnical applications in construction. By understanding the nano-level interactions between red soil and granite powder waste, this study paves the way for innovative and environmentally conscious approaches to soil stabilization, promoting the efficient utilization of waste materials in construction projects. The research concludes with insights into future directions, focusing on long-term stability studies and potential environmental impacts. The application of nano- additives in soil stabilization opens up new possibilities for sustainable development and resource efficiency.

Keywords

Red soil, Granite powder waste, Nano-level characterization, Scanning electron microscopy, Energy-dispersive X-ray spectroscopy, Interlocking properties, Sustainable construction, Geotechnical engineering

Introduction

The rapid growth of urbanization and infrastructure development has led to an increased demand for construction materials, resulting in a significant generation of industrial waste. Among the various waste materials generated, granite powder waste from stone processing units is a major environmental concern due to its harmful impact on soil and water resources. Traditional disposal methods of such waste have led to soil degradation and contamination, raising the urgency to find sustainable alternatives for waste management. Red soil and granite powder waste are two commonly available materials with significant potential for sustainable construction practices. The utilization of these materials in various applications, such as road construction, embankments, and building foundations, can help reduce environmental impact and promote resource efficiency. To better understand the behaviour and properties of red soil mixed with granite powder waste at the nano-level, advanced characterization techniques are employed. This article delves into the nano-level characterization of this mixture and highlights its potential applications. The study of soil behaviour and waste management is crucial for sustainable development and environmental conservation. Red soil, also known as laterite soil, is a type of soil that is rich in iron oxide and commonly found in tropical regions. Granite powder waste is a by-product of the granite industry, which consists of fine particles and water. Understanding the behaviour of red soil mixed with granite powder waste at the nano-level can provide valuable insights into its physical, chemical, and mechanical properties. Nano-level characterization involves analyzing materials at the nanoscale, which is the scale of individual atoms and molecules. This level of analysis allows for a detailed understanding of the interactions and behaviour of materials. By studying the nano-level characteristics of red soil mixed with granite powder waste, researchers can gain insights into its particle size distribution, surface area, porosity, mineral composition, and other properties. The characterization of this soil-waste mixture can have significant implications for various applications, such as agriculture, construction, and environmental remediation. For example, understanding the behaviour of red soil mixed with granite powder waste can help optimize its use as a construction material, and to assess its potential environmental impact. In this research paper, the authors aim to investigate the nano-level characterization of red soil mixed with granite powder waste. By conducting detailed analyses and experiments, they seek to contribute to the understanding of the behaviour and properties of this mixture. The core objectives of this current research are to examine the nano-level interactions between red soil and granite powder waste and assess the impact on soil behaviour. The study aims to provide valuable insights for sustainable soil improvement techniques. The findings of this study can potentially inform sustainable waste management practices and provide insights into the utilization of red soil and granite powder waste in various industries.

Baldovino et al. [1] studied the use of waste glass as a soil stabilization agent. The researchers conducted unconfined compressive strength tests and SEM analysis to understand the impact of waste glass on the mechanical properties and microstructure of clay soil. The findings revealed that waste glass significantly improved the soil's strength and reduced settlement potential. Reddy et al. [2] investigated the potential of red mud, a waste byproduct from alumina production, as a soil stabilizer. Through a series of laboratory tests, including compaction and California Bearing Ratio tests, they evaluated the influence of red mud on the engineering properties of clay soil. The study concluded that red mud effectively reduced the soil's compressibility and settlement potential. Das et al. [3] investigated the use of industrial sludge, a waste byproduct from the paper industry, for soil stabilization. The researchers performed Atterberg limit tests and SEM analysis to analyze the effect of industrial sludge on the plasticity and microstructure of clay soil. The results indicated that industrial sludge effectively reduced the soil's plasticity and enhanced its stability. Bagriacik [4] investigated the use of slag, a byproduct of steel manufacturing, to improve settlement properties in sandy soil. Their consolidation tests demonstrated that incorporating slag led to a significant decrease in settlement rate, offering a cost-effective and eco-friendly approach for soil stabilization in civil engineering projects.

Jalal et al. [5] explored the utilization of marble dust, a waste material from marble processing industries, as a soil stabilizer. Through a series of compaction and consolidation tests, they assessed the impact of marble dust on the settlement behavior and compressibility of clayey soil. The study revealed that marble dust significantly improved the soil's strength and settlement characteristics. Shilar et al. [6] investigated the effectiveness of Wollastonite, a calcium silicate mineral ($CaSiO_3$), as an additive material to improve the properties of red soil. Various tests, including standard proctor compaction test and California bearing ratio test, were conducted to study the reaction between red soil and Wollastonite. The results indicated that Wollastonite significantly enhanced the strength characteristics of the soil. Long et al. [7] studied the utilization of coal gangue, a waste material from coal mining, as a soil stabilizing agent. Coal gangue was tested for its effects on clay soil's mechanical properties and microstructure through unconfined compressive strength tests and SEM analysis. The findings revealed that coal gangue significantly improved the soil's strength and reduced its settlement potential. Liu et al. [8] tested rice husk ash as a soil stabilizer and found it reduced swelling potential and improved stability. Tests, such as Atterberg limits and compaction, were used to analyze this impact. Prabakar et al. [9] studied the utilization of fly ash, a byproduct of coal combustion, to improve the settlement properties of clayey soil. Through laboratory tests, they evaluated the influence of different fly ash percentages on the soil's compressibility and settlement behavior. The findings revealed that the addition of fly ash led to a substantial reduction in the settlement potential of clayey soil. Naseem et al. [10] investigated the potential of cement kiln dust (CKD) as a soil stabilizing material. They performed various laboratory tests, including compaction and California bearing ratio tests, to evaluate the influence of CKD on the engineering properties of expansive soil. The results indicated that CKD effectively reduced the plasticity and settlement potential of the soil. As of the current literature, no prior investigations have addressed the specific research area of utilizing granite powder waste to partially replace red soil and studying the interlocking properties upon stabilization at the nano-level. This study aims to explore this unexplored aspect and contribute to the understanding of the novel composite's characteristics and its potential for sustainable soil improvement and construction applications. By focusing on the nano-level interactions between red soil and granite powder waste, this study aspires to pave the way for innovative and environmentally conscious approaches to soil stabilization, promoting the efficient utilization of waste materials in construction and geotechnical engineering projects.

Methodology

The methodology employed in this study involves a series of systematic and scientific procedures to characterize the behaviour of red soil mixed with granite powder waste at the nano-level. The research seeks to comprehensively understand the implications of microstructural properties of the soil-waste mixture using advanced characterization techniques, with a specific focus on SEM.

Sample collection and preparation

Samples of red soil and granite powder waste are collected from respective sources and carefully handled to ensure representativeness and avoid contamination. The red soil is air-dried to remove any excess moisture, and both materials are sieved to obtain particles of uniform size. In this study, a tank of specified dimensions of 1.2 m x 0.3 m x 0.45 m was filled with red soil, and its initial volume was calculated. Subsequently, different percentages (10%, 20%, 30%, 40%, and 50%) of granite waste powder were added to the red soil in separate trials. The photograph capturing the mixture of red soil blended with different percentages of granite waste powder is provided below in figure 1.

Characterization

SEM is the key technique used in this study for nano-level characterization. The prepared samples are subjected to SEM analysis to obtain high-resolution images of the soil-waste mixture's microstructure. SEM enables the visualization of individual particles, pore spaces, and interlocking interactions at the nanoscale. The SEM analysis was done at Jyothi institute of technology, Bengaluru, India.

Particle size distribution

The particle size distribution of the red soil and granite powder waste is determined using laser diffraction particle size analysis. This data provides valuable insights into the distribution of particle sizes in the mixture (Table 1). The particle size distributions of red soil are shown in the table. The particle size distribution of granite powder waste ranges from 0.1 to 100 μm.

Figure 1: Blended red soil with different percentages of granite powder for analysis.

Table 1: Properties of samples.

Property	Standard designation	Red soil
Specific gravity	BIS: 2720 (Part 3/Sec 1) 1980 (Reaffirmed 2002)	2.67
Grain size distribution	BIS: 2720 (Part 4) 1985 (Reaffirmed 2006)	-
Sand %		54
Silt %		40
Clay %		06

Red soil

The methodology described above ensures the systematic investigation of the nano-level behaviour of the composite material. This study uses advanced nano-characterization techniques to gain insights into the properties of red soil with granite powder waste mixtures, helping to advance sustainable soil improvement. Figure 2a shows the micro fabric of red soil, which is characterized by arrangement of particles of Al, Si, and oxides. A dense red soil is observed, and no connectors or aggregations were seen.

Granite powder

Figure 2b shows the microstructure of the granite powder, which is characterized by arrangement maximum number of Silica particles. Micro porous and pallets of regular shaped have been observed in granite powder.

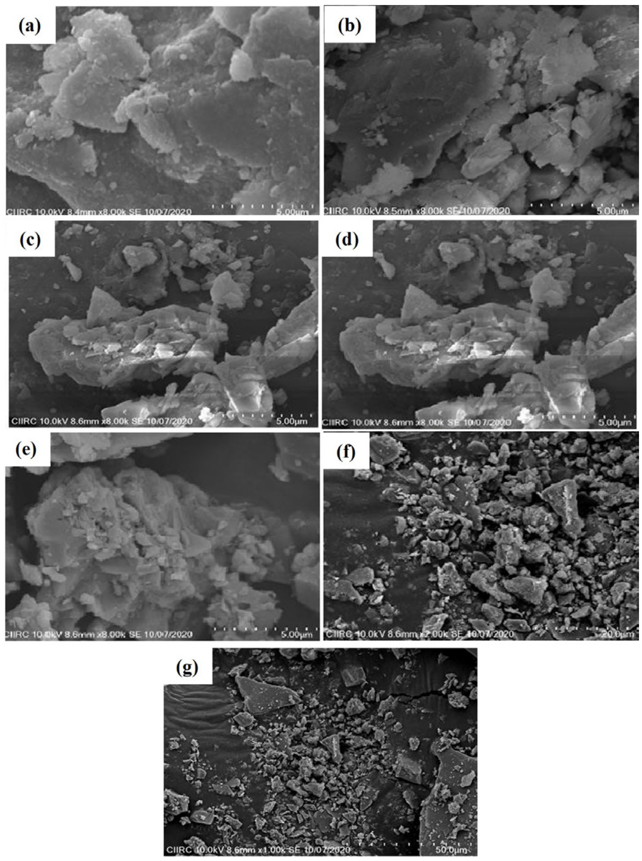

Figure 2: SEM analysis of samples.

Results and Discussion

Incremental dosages of granite powder waste in red soil

The red soil is mixed with different proportions of granite powder waste and the inferences are listed below. Figure 2c, 2d, 2e, 2f, and 2g depicts the red soil with 10, 20, 30, 40, and 50% of granite powder waste.

The microstructure for 10% of the granite powder indicates the formation of smaller clusters of oxide particles is observed in figure 2c. It can be also observed that the dissociation of oxide particles initiates the pozzolanic activity leading to the cluster formation. Whereas in the microstructure for 20% of the granite powder indicates the formation of smaller clusters of oxide particles is observed in figure 2d. It can be also observed that the dissociation of oxide particles initiates the pozzolanic activity and the cluster formation has been visualized clearly. While the microstructure for 30% of the granite powder indicates the deposition of clusters over the oxide's particle has been observed in figure 2e depicts foil like leafy structures with clusters, which may be the reason for binding and good the interlocking property. It can be also observed that the silica present in the granite powder has widespread high and deposited in oxide pallets. The microstructure for 40% of the granite powder indicates the formation of flaky shaped deposition has been observed in figure 2f small amount of micro porous in the surfaces has also been observed. The microstructure for 50% of the granite powder indicates the porous and cracks in the surfaces is observed in figure 2g. The development of such micro cracks in the microstructure leads to reduce its tendency to interlock.

Inferences from nano-micro structure study

SEM is a common experimental method used to analyze the intricate features, such as shape, size, texture, and compactness, of soil mixtures and red soil blended with granite powder at varying proportions. Based on the micrographs, it is clear that the addition of granite powder resulted in significant changes in the morphology of red soil. A noticeable transformation is observed in the structure, with the formation of clusters indicating an aggregation phenomenon. This transformation suggests a shift from the particle-based composition of red soil to a more integrated and cohesive composition due to the volumetric increment of granite powder.

EDX analysis

EDX detector systems plot mid-energy (1 - 20 keV) X-rays collected during an analysis period in a single spectrum, which identifies the elements present and the number of atoms of that element in the irradiated area. X-rays are also produced as the electron beam slows from the electrostatic fields of the elements.

In the EDX of red soil, oxide contents are at the peak with a weight of 31.18%, then the other elements such as silica of 42.57% and alumina of 26.25%. The EDAX image of red soil is represented in figure 3a and the graphical representation of distribution of elements is represented in figure 3b. In the granite powder waste the maximum is silica content, oxides, and some amount of sodium. It is observed from the graph that 4.78% of C, 28.49% of O, 3.51% of Na, 12.1% of Al, and 51.12% of Si are present. The EDX image of granite powder is represented in figure 3c and the graphical representation of distribution of elements is represented in figure 3d.

While adding 10% of the granite powder the silica content seems to be higher and a small amount of carbon was encountered. 38.50% of O, 18.88% of Al, 42.63% of Si, and 4.78% of C were evidenced in the EDX image of red soil with 10% of granite powder is represented in figure 3e and the graphical representation of distribution of elements is represented in figure 3f.

On other hand the addition of 20% of the granite powder further increases the silica content by 6% and it is also found that 9.38% of C, 28.33% of O, 13.29% of Al, and 49.00% of Si are present which can be evidenced in EDX image of red soil with 20% of granite powder is represented in figure 3g and the graphical representation of distribution of elements is represented in figure 3h.

The accumulation of 30% of the granite powder further increases the silica content by 8% and it is also found that 4.36% of C, 28.11% of O, 10.87% of Al, and 56.67% of Si are present. The EDX image of red soil with 30% granite powder is represented in figure 3i and the graphical representation of distribution of elements is represented in figure 3j.

The accumulation of 40% of the granite powder further declines the silica content by 17% and it is also found that 9.92% of, 34.07% of O, 16.23% of Al, and 39.78% of Si are present. The EDX image of red soil with 40% of granite powder is represented in figure 3k and the graphical representation of distribution of elements is represented in figure 3l. The addition of 30% of the granite powder further increases the silica content by 14% and it is also found that 8.11% of C, 29.78% of O, 8.23% of Al, and 53.89% of Si are present. The EDX image of red soil with 50% of granite powder is represented in

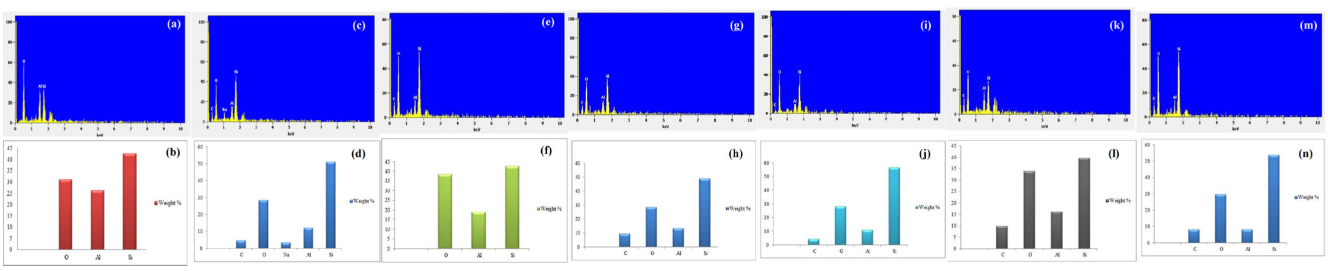

Figure 3: SEM and EDX analysis of samples.

figure 3m and the graphical representation of distribution of elements is represented in figure 3n.

Validation of research outcomes with the previous researchers

Based on the search results, it has been found that the interlocking property is good in red soil mixed with 30% granite powder waste. Shilar and Quadri [11] evaluated the performance of interlocking bricks made with granite waste powder and found that the addition of up to 30% granite powder waste improved the interlocking property of the bricks. Shilar and Quadri [11] conducted research on utilizing industrial waste for producing interlocking building bricks. They discovered that incorporating granite waste powder enhanced the compressive strength of the bricks. Similarly, Amulya et al. [12] explored the incorporation of granite powder waste in cementitious composites and observed improvements in the composites' mechanical properties, including interlocking strength. Both studies underscore the positive effects of utilizing granite waste in construction materials, leading to enhanced structural performance and sustainability.

Inferences from red soil blended with 30% of granite waste

SEM analysis

The SEM images of the red soil show a dense microfabric with particles of aluminum, silicon, and oxides arranged without significant connectors or aggregations. When 30% of granite waste powder is added to the red soil, the microstructure exhibits the formation of smaller clusters of oxide particles. This indicates the initiation of pozzolanic activity and the development of clusters contributing to improved interlocking properties. The red soil blended with 30% granite powder also shows foil-like leafy structures with clusters, which can further enhance the interlocking property and binding characteristics of the mixture.

EDX analysis

The EDX analysis of red soil reveals the presence of oxides as the major component with a weight of 31.18%, followed by silica (42.57%) and alumina (26.25%) with the addition of 30% granite powder, the silica content in the mixture increases by 8%, indicating the incorporation of silica-rich particles from the granite powder. The EDX results demonstrate that the red soil blended with 30% of granite powder has a higher silica content (56.67%) compared to the original red soil, which may contribute to the improved mechanical properties and interlocking behavior observed.

Inferences from red soil blended with 10, 20, 40, and 50% of granite waste

Based on the SEM and EDX analyses, the remaining mixes (red soil blended with percentages other than 30% of granite waste powder) may not be contributing a good interlocking property for the following reasons.

Red soil with 10% granite powder

The SEM analysis indicates the formation of smaller clusters of oxide particles, similar to the mix with 30% granite powder. However, the cluster formation may not be as pronounced, leading to lesser interlocking potential. The EDX results show a higher silica content compared to the original red soil, but the increase may not be sufficient to significantly enhance the interlocking properties.

Red soil with 20% granite powder

The microstructure reveals the formation of smaller clusters of oxide particles, similar to the 10% mix. Again, the cluster formation may not be as extensive as in the 30% mix. The increase in silica content is not as substantial as in the 30% mix, suggesting a less pronounced impact on interlocking behavior.

Red soil with 40% granite powder

The SEM analysis indicates the formation of flaky- shaped depositions, which may not promote efficient interlocking of particles. The EDX results show a decline in silica content by 17% compared to the original red soil, indicating reduced potential for enhanced interlocking.

Red soil with 50% granite powder

The SEM analysis shows porous surfaces and micro cracks, which may negatively affect interlocking behavior by reducing particle cohesion. The EDX results reveal an increase in silica content by 14%, but the high percentage of granite powder might lead to particle agglomeration rather than effective interlocking.

The variations in interlocking properties among the different mixes can be attributed to the specific proportions of granite waste powder and red soil in each mixture. The optimal interlocking behavior observed in the mix with 30% granite powder indicates that this specific composition promotes effective cluster formation and enhanced particle cohesion. Deviating from this optimal percentage can lead to either insufficient or excessive incorporation of granite waste nanoparticles, impacting the interlocking potential of the soil-waste composite. Overall, the nano-level interactions between the red soil and granite waste powder at the 30% composition seem to create a balanced and well-connected microstructure, contributing to the best interlocking properties among the tested mixes.

Conclusions

The research paper concludes that the nano-level characterization of red soil mixed with granite powder waste shows promising results for sustainable soil stabilization. The utilization of granite waste nanoparticles can enhance the soil's mechanical properties, making it a viable option for eco-friendly soil improvement in construction and geotechnical engineering projects.

- The research paper concludes that the nano-level characterization of red soil mixed with granite powder waste shows promising results for sustainable soil stabilization.
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the soil's mechanical properties, making it a viable option for eco-friendly soil improvement in construction and geotechnical engineering projects.

- The interlocking property of the red soil mixed with 30% granite powder waste exhibited superior performance compared to other mixtures.
- The nano-level characterization revealed that the presence of granite waste nanoparticles contributed to improved particle packing and enhanced cohesion between soil particles, resulting in enhanced interlocking behavior.
- The SEM and EDX analyses reveal significant differences between the red soil and the red soil blended with 30% of granite waste powder. The addition of granite powder leads to the formation of smaller clusters and increased silica content in the mixture, enhancing the interlocking properties and binding characteristics.
- These findings suggest that the nano-level interactions between the red soil and granite waste powder play a crucial role in improving the mechanical behavior and overall stability of the soil-waste composite.
- The results support the potential application of red soil mixed with 30% granite waste powder as a sustainable soil improvement material in construction and geotechnical engineering projects.

Future Directions

The future direction of research in this area could focus on further optimizing the percentage of granite powder waste to achieve the best interlocking properties in red soil. Investigating the long-term effects and durability of the soil-waste mixture under various environmental conditions would be essential for real-world applications. Additionally, exploring the potential use of other nanomaterials or additives in combination with granite waste powder could open up new avenues for improving the mechanical behavior of red soil in sustainable construction practices.

Acknowledgements

None.

Conflict of Interest

None.

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