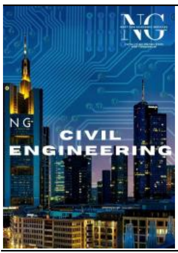

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Research Article *Open Access*

Enhancing Soil Properties through Ground Granulated Blast Furnace Slag: An Experimental Study

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HIGHLIGHTS

- GGBS improves soil properties like specific gravity, strength, and CBR.
- GGBS reduces the soil's liquid limit and plasticity index.
- The effectiveness of GGBS varies with the added percentage, requiring tailored use.

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ABSTRACT

This research examines the influence of Ground Granulated Blast Furnace Slag (GGBS) on soil properties based on a comprehensive experimental investigation. Soil specimens containing different percentages of GGBS (0%, 5%, 10%, 15%, 20%, and 25%) were evaluated for compaction, Atterberg limits, specific gravity, unconfined compressive strength, and California Bearing Ratio (CBR). Results show that GGBS can significantly influence soil properties. Specific gravity first increases and then becomes constant with increasing GGBS. Liquid limit and plasticity index reduce regularly, enhancing soil grading and minimizing plastic behavior. Optimum moisture content reduces first and varies, while the maximum dry density rises first and experiences regular change. Unconfined compressive strength reduces first but enhances with greater GGBS content. CBR of soaked and unsoaked samples experiences intricate regular change. Sieve analysis experiences enhanced soil grading with increased GGBS. The research concludes that GGBS is a good soil stabilizer but its performance depends on the percentage added and exact requirements of the application.

1. INTRODUCTION

Soil stabilization is a fundamental process in civil engineering, essential for constructing durable and cost-effective infrastructure (Zada et al., 2023). It involves improving the properties of soil to enhance its load-bearing capacity, reduce deformation, and increase its resistance to weathering and other environmental factors. Traditional methods of soil stabilization include compaction, which increases soil density by mechanical means, and the addition of stabilizers such as cement and lime, which chemically bind soil particles to improve their structural integrity.

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However, these traditional methods often come with significant environmental and economic costs. Cement production, for instance, is a major source of carbon emissions, and lime can be expensive and difficult to transport. In recent years, the use of industrial by-products has gained attention as a sustainable and potentially more cost-effective alternative (Correia et al., 2016). One such by-product is Ground Granulated Blast Furnace Slag (GGBS), a by-product of the iron and steel industry. GGBS is produced by quenching molten iron slag from a blast furnace in water to produce a glassy, granular product. This material can be ground into a fine powder and used as a partial replacement for cement in concrete and as an additive in soil stabilization.

The use of GGBS in soil stabilization offers several advantages (Abdolvand & Sadeghiamirshahidi, 2024; Jalal et al., 2020). It is an abundant and readily available material, often available at a lower cost than traditional stabilizers. Additionally, its use can reduce the environmental impact of construction projects by utilizing a waste product that would otherwise be discarded. Previous studies have shown that GGBS can improve the mechanical properties of soil, such as its strength and durability, while also enhancing its resistance to water infiltration and erosion.

This study aims to investigate the effects of adding varying percentages of GGBS on the engineering properties of soil. The research focuses on several key properties: compaction, Atterberg limits (liquid limit, plastic limit, and shrinkage limit), specific gravity, unconfined compressive strength, and California Bearing Ratio (CBR). These properties are critical for determining the suitability of soil for various engineering applications, including road construction, embankments, and foundations. By conducting a comprehensive series of tests on soil samples with different GGBS contents, this study seeks to provide valuable insights into the potential benefits and limitations of using GGBS as a soil stabilizer. The findings are expected to contribute to the development of more sustainable and cost-effective soil stabilization practices in civil engineering.

2. LITERATURE REVIEW

Several studies have explored the use of GGBS in soil stabilization, highlighting its potential benefits and limitations. For example, Estabragh et al. (2022) conducted a study on the stabilization of clay subgrade soils using GGBS. The results showed that GGBS significantly improved the soil's strength and durability, making it a viable alternative to traditional stabilizers.

Other studies have focused on the specific properties of soil stabilized with GGBS. For instance, research has shown that GGBS can reduce the liquid limit and plasticity index of soil, indicating improved soil grading and reduced plastic behavior. This is particularly beneficial for clayey soils, which often exhibit high plasticity and are prone to deformation under load.

In terms of compaction, studies have found that the addition of GGBS can increase the soil's maximum dry density (MDD) and reduce its optimum moisture content (OMC). This suggests that GGBS can enhance the soil's ability to achieve higher densities through compaction, leading to improved load-bearing capacity (Ali et al., 2024).

The unconfined compressive strength (UCS) of soil stabilized with GGBS has also been investigated (Sheshde & Cheshomi, 2015). Results indicate that the addition of GGBS can initially decrease the soil's strength, but with increasing percentages of GGBS, the strength can be significantly improved (Ruffolo & Shakoor, 2009). This suggests that GGBS can be an effective stabilizer, particularly at higher concentrations

Finally, the California Bearing Ratio (CBR) of soil stabilized with GGBS has been studied. The CBR is a measure of the soil's ability to withstand compressive loads and is critical for designing road pavements and other infrastructure. Research has shown that the addition of GGBS can increase the CBR value of soil, indicating improved load-bearing capacity and reduced deformation under traffic loads.

3. MATERIALS AND METHODS

Soil samples were collected from the front of the Mining Building at B.I.T. Sindri, Dhanbad, Jharkhand. GGBS was sourced from the Sindri ACC plant. Tests were conducted on soil samples with 0%, 5%, 10%, 15%, 20%, and 25% GGBS. The experimental setup included standard Proctor compaction tests, Atterberg limit tests, specific gravity tests, sieve analysis, unconfined compressive strength tests, and CBR tests.

3.1. Experimental Investigation

Soil samples were collected from the front of the Mining Building at B.I.T. Sindri, Dhanbad, Jharkhand. GGBS was sourced from the Sindri ACC plant. Tests were conducted on soil samples with 0%, 5%, 10%, 15%, 20%, and 25% GGBS. The experimental setup included standard Proctor compaction tests, Atterberg limit tests, specific gravity tests, sieve analysis, unconfined compressive strength tests, and CBR tests.

3.1.1. Compaction Test

The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) were determined for each soil-GGBS mixture. Results showed that OMC decreased initially and then fluctuated, while MDD increased initially and then showed periodic changes.

3.2.2 Atterberg Limits

The Liquid Limit (LL), Plastic Limit (PL), Shrinkage Limit (SL), and Plasticity Index (PI) were measured. The addition of GGBS decreased the LL and PI, while SL and PL showed variable changes.

3.2.3 Specific Gravity

Specific gravity tests indicated that the addition of GGBS initially increased the specific gravity of the soil, which then decreased and stabilized.

3.2.4 Sieve Analysis

Sieve analysis revealed that the percentage of soil passing through a 75μ sieve decreased with the addition of GGBS, indicating improved soil grading.

3.2.5 Unconfined Compressive Strength

Unconfined compressive strength tests showed that the addition of GGBS initially decreased the strength, which then increased but eventually decreased again.

3.2.6 California Bearing Ratio (CBR)

CBR tests indicated that the addition of GGBS increased the CBR value for soaked samples initially, followed by periodic changes. For unsoaked samples, the CBR value increased, decreased, and then increased again.

4. RESULTS AND DISCUSSION

The comprehensive experimental investigation conducted in this study provides valuable insights into the impact of Ground Granulated Blast Furnace Slag (GGBS) on the engineering properties of soil. The results indicate that GGBS can significantly alter these properties, with both positive and variable effects observed across different tests (Table 1).

The specific gravity of soil samples was found to increase initially with the addition of GGBS, reaching a peak at 5% GGBS, and then decrease with further increases in GGBS content. This trend suggests that GGBS can enhance the density of soil particles up to a certain concentration, after which the additional GGBS may introduce lighter particles or alter the soil matrix in a way that reduces overall density (Thomas et al., 2018). This finding is crucial for applications where soil density is a critical factor, such as in the construction of embankments and foundations (Figure 1).

The Atterberg limits, including the liquid limit (LL), plastic limit (PL), and shrinkage limit (SL), were significantly affected by the addition of GGBS (Parhizkar et al., 2024). The liquid limit and plasticity index (PI) decreased consistently with increasing GGBS content, indicating improved soil grading and reduced plastic behavior (Fig 2). This is particularly beneficial for clayey soils, which often exhibit high plasticity and are prone to deformation under load. The reduction in LL and PI suggests that GGBS can make the soil more stable and less susceptible to volume changes due to moisture variations (Figure 3, 4).

The shrinkage limit (SL) and plastic limit (PL) showed more variable changes, with initial increases followed by periodic fluctuations (Figure 5). This complex behavior may be attributed to the interaction between GGBS particles and soil particles, which can alter the soil's moisture retention and shrinkage characteristics.

The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) are critical parameters for soil compaction. The results showed that OMC decreased initially with the addition of GGBS and then fluctuated, while MDD increased initially and then showed periodic changes (Figure 6, 7). This indicates that GGBS can enhance the soil's ability to achieve higher densities through compaction, but the effectiveness varies with the percentage of GGBS added. This finding is important for applications where compaction is a primary method of soil stabilization, such as in road construction and earthworks.

The unconfined compressive strength (UCS) of soil samples exhibited a complex relationship with GGBS content (Naeini et al., 2012). Initial additions of GGBS led to a decrease in UCS, but further increases in GGBS content resulted in improved strength. This suggests that GGBS can enhance the soil's load-bearing capacity, but the optimal concentration of GGBS must be determined based on specific application requirements. The periodic changes in UCS highlight the need for careful consideration of GGBS content to achieve the desired strength properties (Figure 8).

The California Bearing Ratio (CBR) is a critical measure of soil's load-bearing capacity, particularly for road construction (Yildirim & Gunaydin, 2011). The results showed that the addition of GGBS initially increased the CBR value for soaked samples, followed by periodic changes. For unsoaked samples, the CBR value increased, decreased, and then increased again. This indicates that GGBS can improve the soil's ability to withstand compressive loads, but the effectiveness varies with the percentage of GGBS added and the moisture conditions of the soil (Figure 9, 10).

Sieve analysis revealed that the percentage of soil passing through a 75µ sieve decreased with the addition of GGBS, indicating improved soil grading. This suggests that GGBS can enhance the soil's particle size distribution, making it more suitable for applications requiring well-graded soil, such as in road bases and subgrades (Figure 11).

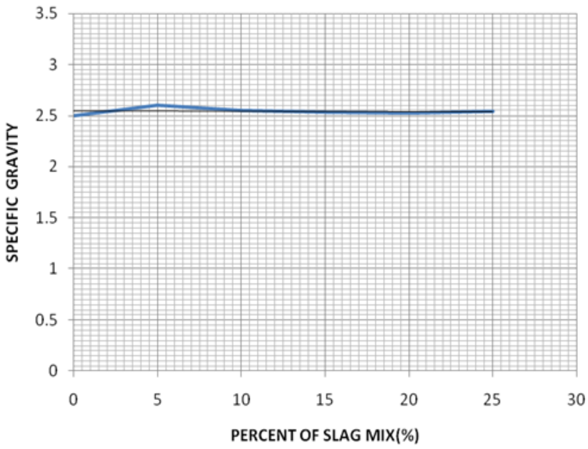

Figure 1. Specific Gravity vs % Slag Mix

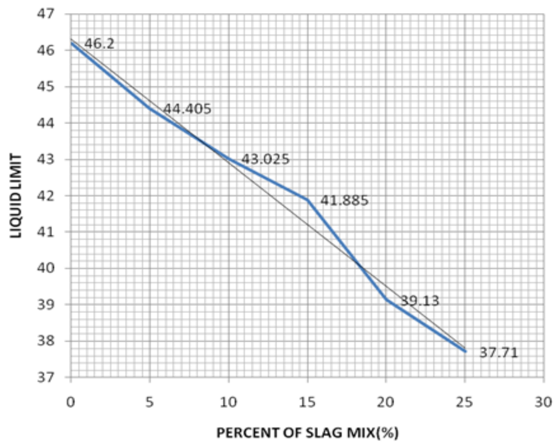

Figure 2. Liquid Limit vs % Slag Mix

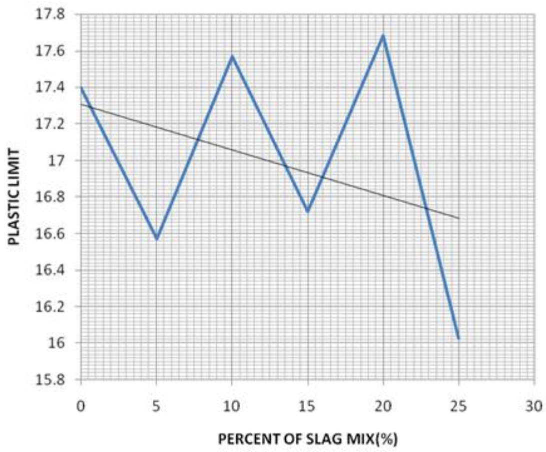

Figure 3. Plastic Limit vs % Slag Mix

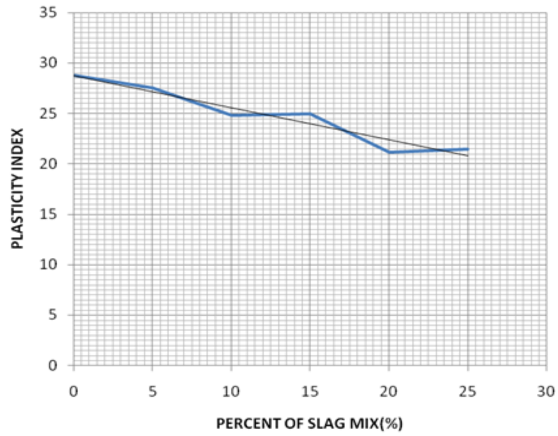

Figure 4. Plasticity Index vs % Slag Mix

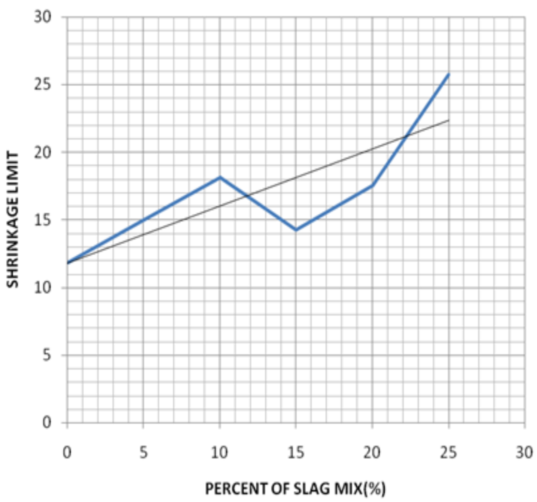

Figure 5. Shrinkage Limit vs % Slag Mix

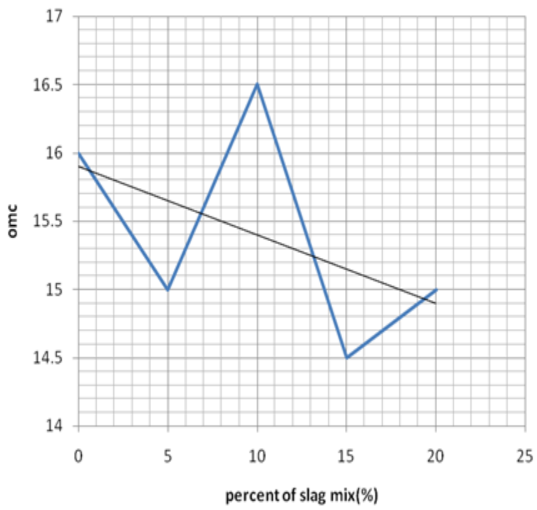

Figure 6. OMC vs % Slag Mix

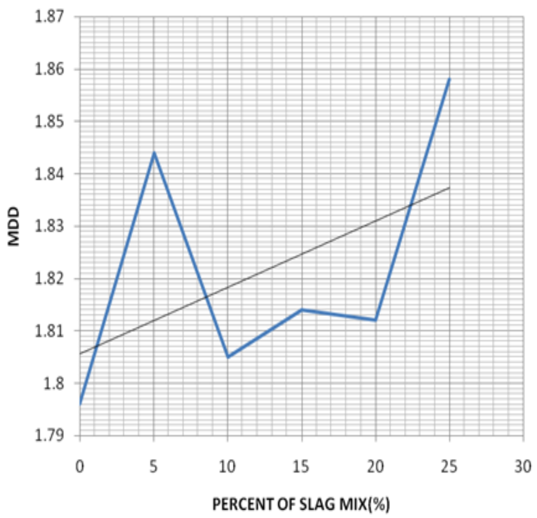

Figure 7. MDD vs % Slag Mix

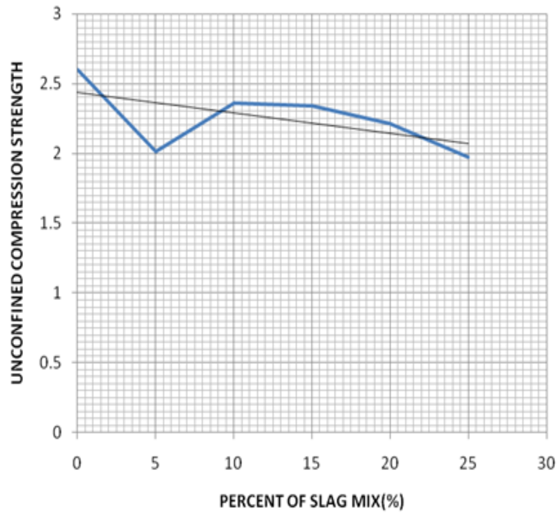

Figure 8. Unified Compression Strength vs % Slag Mix

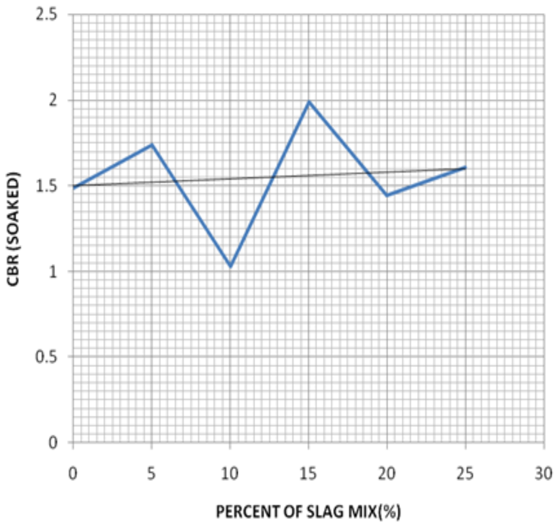

Figure 9. CBR (Soaked) vs % Slag Mix

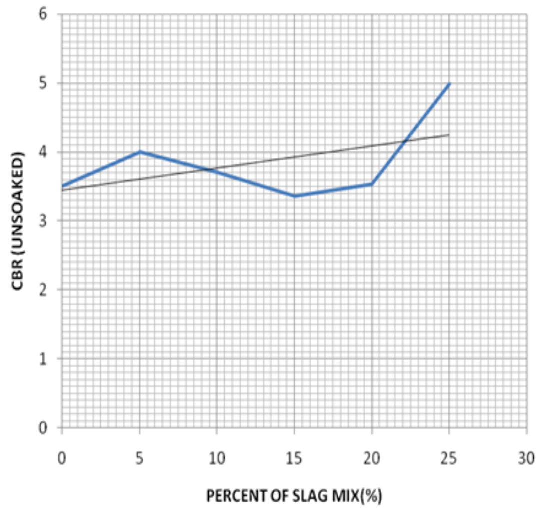

Figure 10. CBR (Unsoaked) vs % Slag Mix

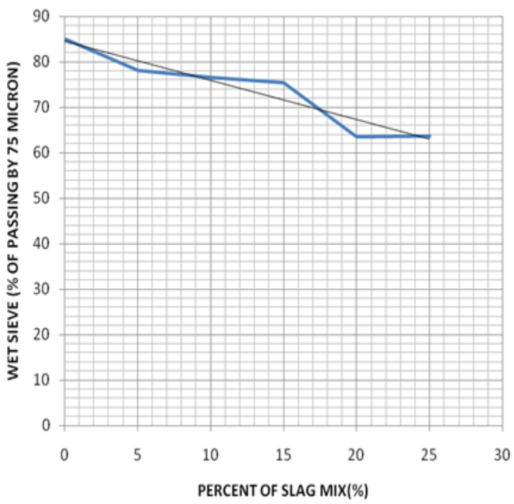

Figure 11. Wet Sieve Analysis vs % Slag Mix

Table 1. Summary of results

SI. NO	SOIL+ % OF SLAG	COMPACTION TEST		ATTERBERG LIMIT				SPECIFIC GRAVITY	UNCONFINED COMPRESSION STRENGTH (in kg/cm²)	C. B. R. VALUE		WET SIEVE (PASSING 75 MICRON)
		OMC (in%)	MDD (in g/cc)	LL (in%)	PL (in%)	SL (in%)	PI (in%)			SOAK-ED	UN-SOAK-ED	
1.	0%	16.00	1.796	46.20	17.40	11.82	28.80	2.50	2.602	1.487	3.504	85.10
2.	5%	15.00	1.844	44.10	16.57	14.97	27.53	2.60	2.016	1.731	3.998	78.18
3.	10%	16.50	1.805	42.40	17.57	18.13	24.83	2.55	2.359	1.031	3.710	74.64
4.	15%	14.50	1.814	41.67	16.72	14.23	24.95	2.53	2.340	0.989	3.358	75.57
5.	20%	15.00	1.812	38.85	17.682	17.557	21.17	2.526	2.210	1.443	3.528	63.59
6.	25%	14.50	1.858	37.50	16.028	25.768	21.47	2.539	1.975	1.608	4.988	63.84

5. CONCLUSIONS

The findings of this study indicate that GGBS can be a viable soil stabilizer, offering several benefits such as improved specific gravity, reduced plasticity, and enhanced load-bearing capacity. However, the effectiveness of GGBS in soil stabilization is not uniform across all properties and depends on the specific application and environmental conditions. The periodic changes observed in OMC, MDD, UCS, and CBR values highlight the complex interactions between soil and GGBS, suggesting that optimal GGBS content must be determined through careful experimentation and analysis.

Conflicts of Interest: The authors declare no conflicts of interest.

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