Soil Stabilization using Industrial Waste and Agro Waste

Shinde Ravindra Mansubrao[1] Pushpendra Kumar Kushwaha[2]
[1]Research Scholar [2]Assistant Professor
[1,2]Department of Civil Department
[1,2]RKDF College of Engineering, Bhopal (M. P.), India

Abstract — Soil stabilization is an important technique in geotechnical engineering for improving the engineering properties of weak, expansive, and problematic soils. Conventional stabilizing agents such as cement and lime are effective; however, their extensive use is associated with high cost, energy consumption, and environmental impacts. The experimental investigation involves the collection and characterization of the natural soil followed by the addition of selected industrial and agro-waste materials in different proportions. Laboratory tests such as Standard Proctor Compaction Test, Atterberg Limits, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR) are conducted to evaluate changes in the soil's compaction characteristics, strength, and bearing capacity. The effect of individual and combined waste materials is assessed to determine the optimum percentage for achieving maximum improvement in engineering properties. Soil stabilization is a vital technique in geotechnical engineering used to improve the physical and mechanical properties of soil. With the increasing demand for sustainable construction practices, the use of industrial and agro waste materials has gained significant attention. This thesis explores the potential of industrial waste (such as fly ash, blast furnace slag, and red mud) and agro waste (such as rice husk ash, coconut shell ash, and bagasse ash) in enhancing soil properties. The study focuses on improving strength, durability, and permeability characteristics of soil while reducing environmental impact. Laboratory investigations including Atterberg limits, compaction tests, CBR, and UCS tests were conducted. The results indicate that waste materials can significantly improve soil performance, making them viable alternatives to traditional stabilizers.

Keywords: Soil Stabilization, Industrial Waste, Agro-Waste, Fly Ash, GGBS, Rice Husk Ash, Bagasse Ash, CBR, UCS, Sustainable Construction

I. Introduction

Soil is one of the most commonly used natural materials in civil engineering construction. Roads, railway embankments, foundations, retaining structures, airports, and other infrastructure projects depend on the strength and stability of the underlying soil. However, naturally occurring soil does not always possess the required engineering properties for construction. Weak and expansive soils may exhibit low bearing capacity, high compressibility, excessive plasticity, poor shear strength, and considerable swelling and shrinkage. These characteristics can cause premature deterioration of pavements, differential settlement, cracking, and foundation failures.

Soil stabilization is the process of modifying soil properties to obtain improved engineering performance. The objective may be to increase strength and bearing capacity, reduce plasticity and swelling, improve workability, control moisture sensitivity, or enhance durability. Conventional stabilization methods generally use cement, lime, bitumen, or chemical additives. Although these methods are established, their environmental and economic implications have encouraged researchers to investigate alternative materials.

The generation of industrial and agricultural waste has increased considerably with population growth, urbanization, industrial development, and agricultural production. Thermal power plants generate large quantities of fly ash, the steel industry produces slag, stone industries produce quarry dust, and cement manufacturing generates cement kiln dust. Similarly, agriculture generates rice husk, sugarcane bagasse, groundnut shells, sawdust, coconut residues, and other biomass materials. When these wastes are disposed of without adequate management, they may create land, air, and water pollution.

Several industrial and agro-wastes contain useful chemical constituents, particularly silica, alumina, calcium, and iron compounds. When suitably processed, some of these materials can interact with soil minerals and water to produce improved soil structure. Rice husk ash (RHA), for example, can contain substantial amounts of silica, whereas GGBS and other industrial residues may provide calcium-rich or hydraulically reactive components.

The concept of utilizing waste materials for soil stabilization therefore provides a dual benefit: improvement of soil engineering properties and beneficial utilization of waste. This approach can reduce the quantity of waste requiring disposal and potentially reduce dependence on conventional stabilizing agents.

The stabilization mechanism depends on the material being used. Some wastes primarily improve soil through physical modification and particle rearrangement, whereas others participate in chemical reactions. Calcium-rich additives can promote cation exchange and flocculation of clay particles. Silica- and alumina-rich materials can participate in pozzolanic reactions in the presence of suitable calcium and moisture, producing cementitious compounds.

The most commonly investigated performance parameters include Atterberg limits, maximum dry density (MDD), optimum moisture content (OMC), UCS, CBR, direct shear strength, swelling pressure, free swell index, permeability, and durability.

The present review therefore focuses on the application of industrial waste and agro-waste for stabilization of problematic soils and evaluates their potential from technical, economic, and environmental perspectives.

II. Literature Survey & Background

Radhakrishnan's 2026 work focuses on bagasse ash stabilization of black cotton soil, addressing challenges associated with expansive soils.

The study demonstrated that bagasse ash improves geotechnical properties such as strength, compaction, and

All rights reserved by www.ijsrd.com

plasticity. The ash particles enhance soil structure and reduce swelling behavior.

The research also emphasized the local availability of bagasse ash, making it a cost-effective solution for rural and developing regions. Improved CBR values indicated suitability for road construction. The study concluded that agro-industrial waste like bagasse ash is a sustainable alternative for stabilizing problematic soils.

Sridhar et al.2026 investigated the use of industrial wastes such as copper slag, iron ore tailings, and red mud for stabilizing lateritic soils. The study highlighted that these materials significantly improve strength and reduce compressibility. The stabilization process involved chemical reactions and improved particle packing. The research also emphasized environmental benefits, particularly the reduction of CO_2 emissions associated with cement production. The use of industrial waste helps in managing disposal problems and promotes sustainable construction.

The study concluded that industrial waste materials are viable alternatives to conventional stabilizers.

Chandana et al. 2026 conducted a study on soil stabilization using fly ash, lime, and quarry dust, focusing on strength and compaction properties The results showed significant improvement in CBR and load-bearing capacity. The optimum mix proportion provided maximum strength and stability. The study highlighted that combining multiple waste materials enhances performance due to synergistic effects. Fly ash contributes to pozzolanic reactions, lime improves bonding, and quarry dust enhances density.The research concluded that combined stabilization is highly effective for pavement and foundation applications.

Zishuai et al. 2026 studied the use of multiple industrial wastes including phosphogypsum, calcium carbide residue, and RHA for stabilizing soft clay soils.

The study demonstrated that combining multiple waste materials improves soil strength and durability more effectively than single stabilizers. The materials interact chemically to form strong cementitious compounds. The research also highlighted improved resistance to deformation and environmental stresses. This approach represents a new trend in multi-material stabilization.

The study concluded that advanced hybrid stabilization techniques are highly promising for future geotechnical applications.

Jebo & Jain 2026 Recent applied research by Jebo & Jain focused on the use of coffee husk ash and volcanic waste materials for stabilizing clay soils in road construction.

The study showed significant improvement in strength, density, and shrinkage control. The stabilized soils exhibited higher UCS and CBR values, making them suitable for road subgrades.

The research also emphasized cost-effectiveness and sustainability, particularly in developing regions where such waste materials are readily available.

The study concluded that unconventional agro waste materials can be successfully used in modern infrastructure development.

III. Research Gaps

Based on the review of existing literature, several important research gaps have been identified in the field of soil stabilization using industrial and agro-waste. Most previous studies have concentrated on the use of individual waste materials, while limited attention has been given to the combined use of industrial and agro-waste. The synergistic interaction between calcium-rich industrial wastes and silica-rich agro-wastes may enhance pozzolanic reactions and improve the strength and durability of stabilized soil.

Furthermore, many studies are based on short-term laboratory investigations, with limited evaluation of long-term strength development, durability, aging, and resistance to environmental conditions. The considerable variability in soil characteristics, chemical composition, and particle size of waste materials also contributes to inconsistent stabilization results.

Environmental aspects such as leachability, toxicity, groundwater contamination, and overall environmental impact have not been adequately investigated for several industrial wastes. In addition, advanced techniques such as alkali activation, geopolymerization, and multi-waste blending require further research to establish their practical applicability and long-term performance.

Finally, existing research has given comparatively less emphasis to the economic feasibility of waste-based stabilization, including material availability, processing, transportation, and cost-benefit considerations. Therefore, further research is required to develop an integrated, technically effective, environmentally safe, durable, and economically feasible soil stabilization technique using locally available industrial and agro-waste materials.

IV. Objectives of the Work

The specific objectives of this research are:

- To study the basic properties of natural soil.
- To analyze the characteristics of selected industrial and agro waste materials.
- To determine the optimum percentage of waste materials for stabilization.

V. Result

A. Standard Proctor Test

According to IS: 2720 (Part VII)-1983 [94] to determine the consistency and suitability of the soil for preparation of fills on as correct and the compaction test conducts determination of soil moisture density. The soil samples are thoroughly mixed, with varying percentages of water content. Then, it was filled in the mold in 3 layers and given 25 blows using a hammer weighing 2.89 kg. From each trial, soil samples are taken for water content analysis. A graph is plotted using water content in x-axis and dry density in the y-axis.

The effect of Ground Granulated Blast Furnace Slag (GGBS) on the compaction characteristics of the soil was investigated by conducting the Standard Proctor Compaction Test. The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) obtained for different percentages of GGBS are presented in Table 4.1

All rights reserved by *www.ijsrd.com*

SN	GGBS in %	OMC, (%)	MDD, (kN/m3)
1	0	18	17.82
2	2.5	18.02	18.15
3	5	18.07	18.56
4	7.5	18.09	18.85
5	10	18.13	19.15

Table 1: Compaction characteristics values of soils and GGBS treated soil samples

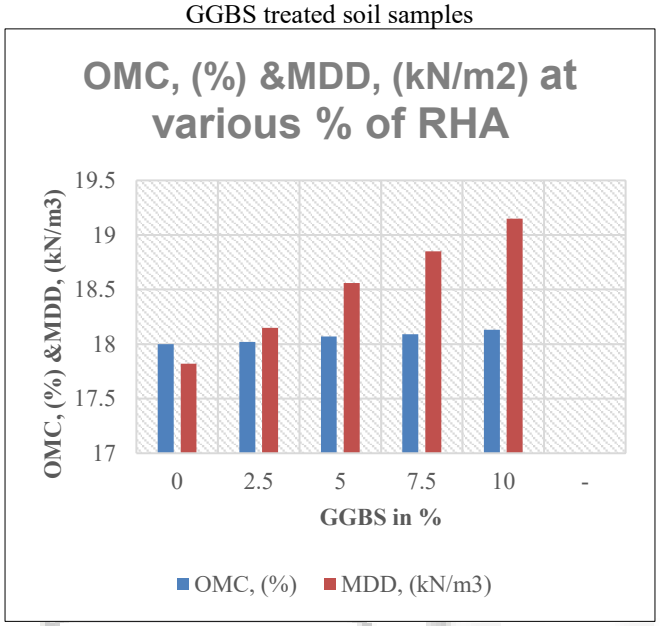


Fig. 1: OMC, (%) &MDD, (kN/m2) at various % of RHA

The untreated soil exhibited an OMC of 18.00% and an MDD of 17.82 kN/m³. With the incorporation of GGBS, the MDD increased progressively from 18.15 kN/m³ at 2.5% GGBS to 18.56 kN/m³ at 5% GGBS and 18.85 kN/m³ at 7.5% GGBS. The maximum MDD of 19.15 kN/m³ was obtained at 10% GGBS. This represents an increase of approximately 7.47% compared with the untreated soil.

The increase in MDD indicates that the addition of GGBS improved the packing and compaction of the soil particles. The relatively dense GGBS particles occupy the void spaces between soil particles, thereby reducing the volume of voids and increasing the dry density. The development of cementitious products due to the reaction of GGBS with water may also contribute to the formation of a denser and more stable soil matrix.

The OMC exhibited only a marginal variation with the addition of GGBS. The OMC increased from 18.00% for untreated soil to 18.02%, 18.07%, 18.09% and approximately 18.13% at 2.5%, 5%, 7.5% and 10% GGBS, respectively. The slight increase in OMC can be associated with the moisture requirement of GGBS during hydration and associated physicochemical reactions. However, the change in OMC is considerably smaller than the corresponding increase in MDD.

Overall, the compaction test results indicate that GGBS addition improves the compactability of the soil. Among the investigated mixtures, the 10% GGBS-treated soil achieved the highest MDD of 19.15 kN/m³, indicating that this proportion provided the most favorable compaction characteristics within the tested range. Therefore, 10% GGBS can be considered an effective dosage for subsequent experimental investigations, subject to confirmation through other engineering properties such as CBR, UCS and strength-related tests.

B. Unconfined Compressive Strength Test Values of Soil Samples

Strength characteristics of the soil can be identified by conducting UCS test on untreated soils as well as the soil samples treated with varying stabilizer content at various curing periods, and theses samples were tested at a speed of 1.25mm/min. The UCS samples of S1 and S2 treated with varying quantity of stabilizer, GGBS (2.5%, 5%, 7.5%, 10%); RHA (3, 6, 9, 12, and 15%); GSA (2%, 4%, 6%, 8% and 10%) were prepared using the compaction characteristics of the untreated soil samples. The addition of a various amount of stabilizers at various curing periods (3, 7, 14, 28, and 60 days) revealed a tremendous increment of UCS value than the untreated soil samples. Based on various curing periods, several graphs were plotted from that typical graph of 3, 14, and 60 days are presented in this section. Figure 2

The Unconfined Compressive Strength (UCS) test was conducted to evaluate the influence of Ground Granulated Blast Furnace Slag (GGBS) and curing period on the strength characteristics of the soil. The UCS values obtained at different GGBS contents and curing periods are presented in Table 2

Table 2: Comparison of UCS value of untreated soil and treated soil with GGBS

SN	GGBS in %	Unconfined compressive strength value (kPa)		
		Curing period (Days)		
		3	7	28
1	0	163		
2	2.5	173	201	296
3	5	265	394	792
4	7.5	375	568	1177
5	10	409	624	1302
	-			

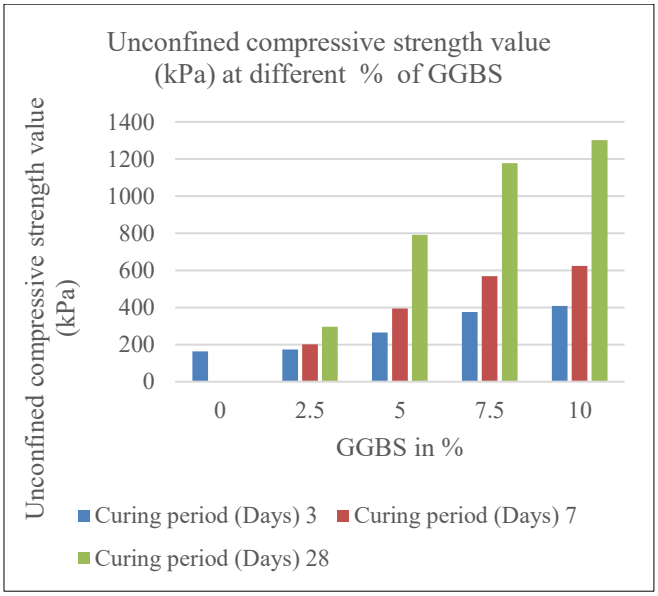


Fig. 2: Unconfined compressive strength value (kPa) at different % of GGBS

All rights reserved by *www.ijsrd.com*

The results demonstrate a significant improvement in UCS with increasing GGBS content. The untreated soil (0% GGBS) exhibited a UCS value of 163 kPa. With the incorporation of 2.5% GGBS, the UCS increased to 173 kPa at 3 days, 201 kPa at 7 days and 296 kPa at 28 days. Further addition of GGBS resulted in a substantial improvement in compressive strength.

At 5% GGBS, the UCS increased to 265 kPa at 3 days, 394 kPa at 7 days and 792 kPa at 28 days. At 7.5% GGBS, the corresponding UCS values increased further to 375 kPa, 568 kPa and 1177 kPa at 3, 7 and 28 days, respectively. The maximum UCS was obtained at 10% GGBS, with values of 409 kPa at 3 days, 624 kPa at 7 days and 1302 kPa at 28 days.

The increase in UCS with increasing GGBS content can be attributed to the development of cementitious and pozzolanic reaction products within the soil matrix. GGBS contains reactive calcium, silica and alumina-bearing phases. In the presence of water, these constituents participate in hydration and related reactions, resulting in the formation of binding products that improve the bonding between soil particles. Consequently, the treated soil develops a stronger and more stable soil structure.

C. CBR value of treated and untreated soil

The California Bearing Ratio (CBR) test was conducted to evaluate the effect of Ground Granulated Blast Furnace Slag (GGBS) on the bearing capacity of the soil. The CBR values obtained for different percentages of GGBS are presented in Table 4.X.

SN	GGBS in %	CBR value (%)
1	0	5.47
2	2.5	8.6
3	5	14.3
4	7.5	18.5
5	10	21.3

Table 3: Comparison of CBR value of treated and untreated soil with GGBS

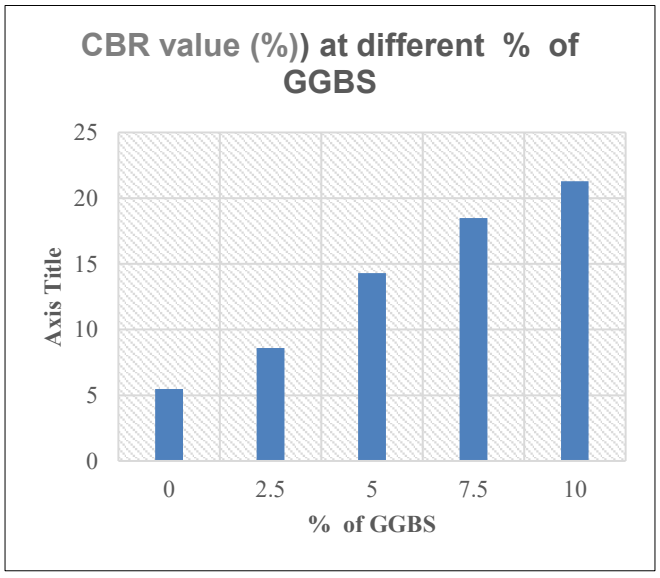


Fig. 3: Comparison of CBR value of treated and untreated soil with GGBS

VI. CONCLUSION

Industrial and agro wastes can effectively improve soil properties. Materials such as GGBS, fly ash, materials can modify the physical and engineering behavior of weak soils.

Compaction characteristics are significantly affected by stabilization. The addition of suitable waste materials generally changes the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). Depending on the type, particle size and percentage of additive, the soil can achieve improved packing and compaction characteristics.

Strength characteristics improve after stabilization. The inclusion of appropriate industrial and agro wastes can increase the Unconfined Compressive Strength (UCS) of soil through particle rearrangement, cementitious reactions and pozzolanic activity.

California Bearing Ratio (CBR) can be substantially enhanced. Stabilized soil generally exhibits better resistance to penetration than untreated soil. This improvement is particularly important for subgrade construction in flexible pavement systems.

REFERENCES

[1] P. V. Sivapullaiah, K. S. Rao, and J. V. Gurumurthy, "Stabilisation of rice husk ash for use as cushion below foundations on expansive soils," Proceedings of the Institution of Civil Engineers—Ground Improvement, vol. 8, no. 4, pp. 137–149, 2004, doi: 10.1680/grim.2004.8.4.137.

[2] "Modification of mechanical properties of expansive soil from North China by using rice husk ash," Materials, vol. 14, no. 11, Art. no. 2789, 2021, doi: 10.3390/ma14112789.

[3] "An overview of rice husk ash as a waste by-product material for sustainable soil stabilization," Cleaner Waste Systems, vol. 12, Art. no. 100446, 2025, doi: 10.1016/j.clwas.2025.100446.

[4] N. Sathiparan, A. Anburuvel, and V. V. Selvam, "Utilization of agro-waste groundnut shell and its derivatives in sustainable construction and building materials—A review," Journal of Building Engineering, Art. no. 105866, 2023, doi: 10.1016/j.jobe.2023.105866.

[5] M. P. Tochukwu and A. A. Junior, "A research on groundnut shell ash's impact on lateritic soils' soil stabilization," Journal of Engineering Research and Reports, vol. 24, no. 1, pp. 1–12, 2023, doi: 10.9734/jerr/2023/v24i12855.

[6] S. Jordan, R. Goyal, and H. Rani, "Groundnut shell ash as a stabilizing agent for clayey sand: A review," Journal of Advanced Research in Geo Sciences & Remote Sensing, 2024.

[7] A. O. Mohammed, I. I. Obianyo, A. Dayyabu, A. Sanusi, C. E. Mantilla Cabrera, R. Barba-Vera, S. Hanande, and V. Kamchoom, "Effects of wood and groundnut shell ashes on the geotechnical properties of lateritic soil," Scientific Reports, 2026, doi: 10.1038/s41598-026-59553-0.

[8] T. M. Petry and D. N. Little, "Review of stabilization of clays and expansive soils in pavements," Journal of Materials in Civil Engineering, vol. 14, no. 6, pp. 447–460, 2002.

All rights reserved by www.ijsrd.com

[9] J. Nelson, K. C. Chao, D. D. Overton, and E. J. Nelson, Foundation Engineering for Expansive Soils. Hoboken, NJ, USA: Wiley, 2015.
[10] B. M. Das and K. Sobhan, Principles of Geotechnical Engineering, 9th ed. Boston, MA, USA: Cengage Learning, 2018.
[11] B. M. Das, Advanced Soil Mechanics, 4th ed. New York, NY, USA: Routledge, 2014.
[12] R. F. Craig, Craig's Soil Mechanics, 8th ed. London, U.K.: CRC Press, 2012.
[13] K. R. Arora, Soil Mechanics and Foundation Engineering. Delhi, India: Standard Publishers Distributors, 2003.
[14] G. L. Sivakumar Babu and A. K. S. Chandrasekaran, Foundation Engineering. New Delhi, India: PHI Learning, 2013.

All rights reserved by *www.ijsrd.com*