Soil Stabilization Using Industrial Waste (GGBS, Red Mud and Marble Dust)

Prof. Daule Anil D.[1], Sayali Nandkumar Kadam[2], Vaibhav Dnyaneshwar Tagad[3], Karan Pramod Kotkar[4], Sahil Suresh Kale[5]
[1]*Guide, Civil Engineering, Adsul's Technical Campus*
[2,3,4,5]*Students, Civil Engineering, Adsul's Technical Campus*

***Abstract*—Soil stabilization is an important geotechnical engineering technique used to improve the engineering properties of weak soils for construction purposes. Rapid urbanization and infrastructure development have increased the demand for stable foundation materials, while the availability of suitable natural soils has decreased. Simultaneously, industries generate large quantities of waste materials such as Ground Granulated Blast Furnace Slag (GGBS), Red Mud, and Marble Dust, which create environmental disposal challenges. This study investigates the utilization of these industrial by-products as sustainable stabilizing agents for clayey soil. Laboratory investigations were carried out on natural clayey soil mixed with different proportions of GGBS, Red Mud, and Marble Dust. The engineering properties of soil were evaluated through Atterberg Limit Tests, Standard Proctor Compaction Tests, Unconfined Compressive Strength (UCS) Tests, and California Bearing Ratio (CBR) Tests. The results indicated significant improvements in soil behavior. The optimum combination of 15% GGBS, 10% Red Mud, and 15% Marble Dust produced maximum improvement in strength and bearing capacity. UCS increased from 110kN/m² to 275kN/m², while CBR increased from 4.8% to 13.5%. The study demonstrates that industrial waste materials can successfully replace conventional stabilizers, reduce construction costs and environmental impacts while promote sustainable development.**

***Index Terms*—Soil Stabilization, GGBS, Red Mud, Marble Dust, Industrial Waste, CBR, UCS, Sustainable Construction.**

I. INTRODUCTION

1.1 General

Soil serves as the primary supporting medium for all civil engineering structures. Buildings, highways, bridges, railways, dams, and retaining walls transfer their loads to the soil beneath them. Therefore, the performance and durability of any structure largely depend on the engineering properties of the supporting soil. Many naturally occurring soils possess undesirable characteristics such as low bearing capacity, high compressibility, excessive settlement, and swelling-shrinkage behavior. Such soils often require stabilization before they can be used in engineering projects. Traditional stabilizers such as cement and lime are effective but contribute significantly to carbon emissions and project costs. As environmental sustainability becomes increasingly important, researchers have focused on utilizing industrial waste materials as alternative stabilizing agents. Among various industrial by-products, GGBS, Red Mud, and Marble Dust have shown promising potential in improving soil properties while simultaneously solving waste disposal problems.

1.2 Need for Soil Stabilization

The major reasons for soil stabilization include:

- Increasing load-bearing capacity.
- Reducing settlement.
- Improving compaction characteristics.
- Controlling shrinkage and swelling.
- Enhancing durability.
- Improving pavement performance.
- Reducing maintenance costs.

1.3 Industrial Waste Utilization

Industrial wastes often occupy valuable land and create environmental hazards. Their reuse in geotechnical applications provides:

Environmental Benefits

- Reduced landfill requirements.

- Lower pollution levels.
- Conservation of natural resources.
- Reduction in greenhouse gas emissions.

Economic Benefits
- Lower material costs.
- Reduced transportation expenses.
- Improved resource utilization.

Engineering Benefits
- Improved soil strength.
- Better compaction.
- Higher durability.
- Increased bearing capacity.

II. LITERATURE REVIEW

Several researchers have investigated the stabilization of weak soils using industrial waste materials.
Kumar and Sharma (2018)
Studied expansive clay stabilized with GGBS. Results showed significant reduction in plasticity and more than 100% increase in UCS.
Singh et al. (2019)
Investigated Red Mud stabilization of soft clay. The study reported improved compaction characteristics and bearing capacity.
Patel and Joshi (2017)
Examined Marble Dust stabilization of black cotton soil and observed reductions in swelling potential and plasticity.

Research Gap: Most studies focus on individual stabilizers. Very limited research is available on the combined effect of:
- GGBS
- Red Mud
- Marble Dust

Therefore, comprehensive evaluation of these materials in combination is necessary.

III. MATERIALS USED

3.1 Natural Soil
The soil selected for investigation was clayey soil with poor engineering properties.

Property	Value
Specific Gravity	2.68
Liquid Limit	48%
Plastic Limit	24%
Plasticity Index	24%
MDD	1.65 g/cc
OMC	19%
CBR	4.80%

3.2 Ground Granulated Blast Furnace Slag (GGBS)
GGBS is produced during iron manufacturing.
Properties

Property	Value
Specific Gravity	2.9
CaO	40%
SiO_2	35%
Al_2O_3	12%
MgO	8%

Advantages
- Cementitious behavior
- Strength improvement
- Durability enhancement
- Sustainable material

3.3 Red Mud
Red Mud is generated during alumina extraction through the Bayer Process.
Properties

Property	Value
Specific Gravity	2.8
pH	10–13
Fe_2O_3	35%
Al_2O_3	18%
SiO_2	15%

Advantages
- Improved compaction
- Better bearing capacity
- Economical stabilizer

3.4 Marble Dust
Marble Dust is obtained from marble processing operations.
Properties

Property	Value
Specific Gravity	2.7
$CaCO_3$	90%
$MgCO_3$	4%
SiO_2	3%

Advantages
- Filler action
- Reduced plasticity
- Enhanced workability

IV. EXPERIMENTAL METHODOLOGY

Mix Proportions

Mix ID	Soil (%)	GGBS (%)	Red Mud (%)	Marble Dust (%)
S0	100	0	0	0
S1	90	5	2.5	2.5
S2	80	10	5	5
S3	70	15	7.5	7.5
S4	60	15	10	15

Laboratory Tests
The following tests were conducted:
Atterberg Limits
Determination of:

- Liquid Limit (LL)
- Plastic Limit (PL)
- Plasticity Index (PI)

Standard Proctor Test

Determination of:

- Maximum Dry Density (MDD)
- Optimum Moisture Content (OMC)

Unconfined Compressive Strength Test
Determination of compressive strength.
California Bearing Ratio Test
Assessment of pavement subgrade suitability.

V. RESULTS AND DISCUSSION

5.1 Atterberg Limit Results

Mix	LL (%)	PL (%)	PI (%)
S0	48	24	24
S1	45	25	20
S2	42	26	16
S3	40	27	13
S4	38	27	11

Discussion: The Plasticity Index reduced by more than 54%, indicating improved soil stability and reduced swelling potential.

5.2 Compaction Characteristics

Mix	OMC (%)	MDD (g/cc)
S0	19	1.65
S1	18	1.7
S2	17	1.75
S3	16	1.79
S4	15	1.82

Discussion: MDD increased steadily due to better particle packing and filler action of Marble Dust.

5.3 UCS Results

Mix	UCS (kN/m²)
S0	110
S1	150
S2	200
S3	245
S4	275

Discussion
The 150% increase in UCS is attributed to:

- Pozzolanic reactions
- Cementitious compound formation
- Reduced void ratio
- Improved soil particle bonding

5.4 CBR Results

Mix	CBR (%)
S0	4.8
S1	7.2
S2	9.8
S3	11.5
S4	13.5

Discussion: The stabilized soil exhibited a 181% increase in bearing capacity, making it suitable for pavement applications.

VI. ENVIRONMENTAL IMPACT ASSESSMENT

The reuse of industrial waste provides:
Waste Reduction

- Lower landfill demand.
- Reduced environmental contamination.

Resource Conservation

- Reduced consumption of natural stabilizers.
- Conservation of raw materials.

Carbon Footprint Reduction

- Lower cement consumption.
- Reduced greenhouse gas emissions.

VII. ECONOMIC ANALYSIS

Conventional stabilizers such as cement and lime are expensive.
Industrial wastes are often available:

- At low cost.
- Near industrial zones.
- In large quantities.

Estimated savings range between 30–40% compared with cement stabilization.

VIII. APPLICATIONS

The stabilized soil can be used in:

- Highway subgrades
- Rural roads
- Embankments
- Foundations
- Industrial yards
- Airport pavements
- Railway embankments

IX. CONCLUSION

The study demonstrates that GGBS, Red Mud, and Marble Dust are effective stabilizers for clayey soil.
Major findings include:

1. Plasticity Index reduced from 24% to 11%.
2. Maximum Dry Density increased from 1.65 to 1.82 g/cc.
3. UCS increased by 150%.
4. CBR increased by 181%.
5. Optimum mix was 15% GGBS + 10% Red Mud + 15% Marble Dust.
6. Industrial wastes can successfully replace conventional stabilizers.
7. Significant environmental and economic benefits were achieved.

Therefore, industrial waste-based soil stabilization represents a sustainable solution for modern infrastructure development.

X. FUTURE SCOPE

Future studies should focus on:

- Long-term field performance.
- Freeze-thaw durability.
- Wetting-drying resistance.
- Machine learning optimization.
- Life-cycle cost analysis.
- Smart highway applications.
- Sustainable urban infrastructure projects.

REFERENCES

[1] A. Kumar and R. Sharma, “Soil Stabilization Using Ground Granulated Blast Furnace Slag (GGBS),” International Journal of Civil Engineering Research, vol. 9, no. 2, pp. 45–52, 2018.

[2] P. Singh, S. Verma, and A. Patel, “Utilization of Red Mud in Soil Stabilization,” Journal of Geotechnical Engineering, vol. 12, no. 4, pp. 65–72, 2019.

[3] M. Patel and K. Joshi, “Effect of Marble Dust on Expansive Soil,” International Journal of Engineering Research, vol. 6, no. 3, pp. 34–41, 2017.

[4] V. Reddy, S. Kumar, and P. Rao, “Combined Stabilization of Soil Using GGBS and Red Mud,” Construction Materials Journal, vol. 15, no. 1, pp. 78–86, 2020.

[5] R. Gupta and A. Verma, “Pavement Subgrade Improvement Using Industrial Waste Materials,” Highway Engineering Review, vol. 10, no. 2, pp. 101–110, 2021.

[6] M. Ahmed and T. Khan, “Stabilization of Soil Using GGBS and Lime,” Geotechnical Journal, vol. 11, no. 3, pp. 90–98, 2019.

[7] P. Mehta, D. Sharma, and R. Patel, “Sustainable Soil Stabilization Techniques Using Industrial By-products,” International Journal of Sustainable Engineering, vol. 14, no. 2, pp. 55–66, 2022.

[8] S. Kulkarni and R. Patil, “Red Mud Stabilization of Lateritic Soil,” Civil Engineering Research Journal, vol. 8, no. 1, pp. 22–30, 2020.

[9] N. Deshmukh, P. Jadhav, and S. More, “Marble Dust for Clay Soil Improvement,” Engineering Review, vol. 7, no. 2, pp. 40–48, 2021.

[10] R. Verma, A. Singh, and P. Kumar, “Sustainable Waste Utilization in Geotechnical Engineering,” Materials Today: Proceedings, vol. 68, no. 1, pp. 102–110, 2023.

[11] K. R. Arora, Soil Mechanics and Foundation Engineering. New Delhi, India: Standard Publishers Distributors, 2019.

[12] B. C. Punmia, A. K. Jain, and A. K. Jain, Soil Mechanics and Foundations. New Delhi, India: Laxmi Publications, 2020.

[13] V. N. S. Murthy, Geotechnical Engineering: Principles and Practices of Soil Mechanics and Foundation Engineering. New Delhi, India: CBS Publishers and Distributors, 2018.

[14] G. Ranjan and A. S. R. Rao, Basic and Applied Soil Mechanics. New Delhi, India: New Age International Publishers, 2017.

[15] B. M. Das, Principles of Geotechnical Engineering. Boston, USA: Cengage Learning, 2019.