Sustainable Stabilization of Black Cotton Soil Using GGBS–Red Mud Blends for Pavement Subgrade Applications

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ABSTRACT

Black cotton soil is an expansive soil whose strength and volume-change behaviour are sensitive to moisture variation. This study examines the use of Ground Granulated Blast Furnace Slag (GGBS) and Red Mud (RM) blends for improving black cotton soil considered for pavement subgrade applications. The soil was reported as collected from Hussainapuram along the Cuddapah–Kurnool section of NH-40, Andhra Pradesh. GGBS and RM were reported as sourced from Chettinad Cement, Visakhapatnam, and the NALCO storage pond at Damanjodi, Odisha, respectively. Five GGBS:RM ratios—100:00, 70:30, 50:50, 30:70 and 00:100—were considered at a fixed total stabilizer content of 25% by dry weight of soil. The thesis reports an untreated-soil free swell index (FSI) of 52.28%, unconfined compressive strength (UCS) of 131 kPa and soaked California Bearing Ratio (CBR) of 1.50%. Among the reported stabilized results, the 70:30 blend recorded a 28-day UCS of 920 kPa, while the 100:00 blend recorded a 28-day soaked CBR of 22.8%. The reported FSI was lowest for the 70:30 blend at 15%. These results indicate that the blend giving the highest UCS is not the same as the blend giving the highest CBR. The findings are presented as thesis-reported values and must be checked against original laboratory records before journal submission. Environmental assessment and field validation are also required before practical adoption.

Keywords: Black cotton soil; GGBS; Red mud; Soil stabilization; Pavement subgrade; UCS; CBR; Free swell index.

1. INTRODUCTION

The subgrade is a fundamental component of a pavement system because it supports the pavement layers and influences pavement deformation and service performance. Black cotton soil is problematic in pavement construction due to its expansive nature and moisture-sensitive behaviour. Changes in water content can cause swelling and shrinkage, potentially leading to differential movement, cracking and loss of support.

Soil stabilization is used to improve the engineering behaviour of problematic soils. Ground Granulated Blast Furnace Slag (GGBS), a by-product of iron production, and Red Mud (RM), a residue from alumina production, are potential industrial by-products for geotechnical applications. Their use requires assessment of both engineering performance and environmental acceptability.

The present work compares five GGBS:RM proportions at a fixed total stabilizer content of 25% by dry weight of soil. The comparison considers compaction characteristics, UCS, soaked CBR and swelling behaviour, with wet–dry durability results included as reported in the thesis.

2. REVIEW OF RELATED STUDIES

Research on blended industrial by-products

The literature summarized in the dissertation covers the use of industrial residues and blended binders for improving problematic soils. Anburavel et al. (2023) considered eggshell ash and rice husk ash and reported improvements in UCS and reductions in plasticity and swelling behaviour. Bandopadhyay and Giri (2023) examined Red mud with

phosphogypsum and reported improvements in strength and swelling characteristics. These studies indicate the potential value of combining industrial by-products, although their results are specific to the materials and soils investigated.

Studies involving Red Mud

Dwivedi and Kumar (2025) examined fly ash and Red mud for black cotton soil and reported beneficial changes in soil behaviour. Kushwaha, Kishan and Gupta (2025) investigated Red mud and gypsum for black cotton soil. Sahoo et al. (2024) considered Red mud, phosphogypsum and lime. Singh et al. (2024) investigated Red mud with iron and zinc tailings and included strength, CBR, durability and leachability considerations. Wang et al. (2023) examined Red mud, cement and phosphogypsum mixtures. Collectively, the studies reviewed in the thesis show that Red mud has been investigated in several blended stabilization systems.

Studies involving GGBS and activated binders

Gupta and Kumar (2024) investigated GGBS–dolomite blends activated with sodium hydroxide and sodium silicate. Hamad and Demiroz (2024) considered fly ash and GGBS blends with alkaline activation. Miraki et al. (2022) studied volcanic ash and GGBS in an alkali-activated binder. Singh et al. (2023) investigated Jarofix and GGBS, while Singh et al. (2024) considered GGBS with cement and lime. Mypati and Saride (2022) studied alkali-activated fly ash for expansive soil. The literature indicates that binder composition, activation, curing and soil type can influence the performance of stabilized materials.

Research gap and relevance of the present study

The dissertation identifies a need for further assessment of the specific GGBS–Red Mud combination for black cotton soil. It also identifies the importance of comparing blend ratios at a common stabilizer content, considering curing period, and assessing more than one engineering property. The present study therefore compares five GGBS:RM ratios at a fixed 25% total stabilizer content. Since the studies reviewed use different soils, binders, dosages and test procedures, their numerical results are not directly compared with the present results.

3. OBJECTIVES AND SCOPE

The objective is to examine the influence of GGBS:RM blend ratio on the engineering properties of black cotton soil for pavement subgrade applications. The study is limited to one reported soil source, two reported stabilizer sources, five blend ratios and a fixed total stabilizer content of 25%. The curing periods reported for strength and bearing comparisons are 7, 14 and 28 days. The untreated soil is used as the reference material.

4. MATERIALS AND METHODOLOGY

3.1 Materials

The thesis identifies the black cotton soil source as Hussainapuram on the Cuddapah–Kurnool NH-40 section, Andhra Pradesh. GGBS was reported as obtained from Chettinad Cement, Visakhapatnam, and Red Mud from the NALCO storage pond at Damanjodi, Odisha.



Figure 1. Black cotton soil sampling activity (photograph reproduced from thesis).



Figure 2. GGBS material used in the investigation (photograph reproduced from thesis).



Figure 3. Red Mud material used in the investigation (photograph reproduced from thesis).

Material	Reported source / property
Black cotton soil	Hussainapuram, Cuddapah–Kurnool NH-40, Andhra Pradesh
GGBS	Chettinad Cement, Visakhapatnam; specific gravity 3.15; 88% passing 75 μm
Red Mud	NALCO storage pond, Damanjodi, Odisha; specific gravity 2.90; 97% passing 45 μm

3.2 Properties of untreated soil

Property	Value
Specific gravity	2.62
Gravel / sand / silt / clay	2% / 18% / 28% / 52%
Liquid limit	62%
Plastic limit	28%
Plasticity index	34%
Free swell index	52.28%
Soil classification	CH
UCS (reported)	131 kPa
Soaked CBR (reported)	1.50%

3.3 Mix proportions

The total stabilizer content was fixed at 25% of the dry weight of soil. The stabilizer was divided between GGBS and RM according to the proportions shown below.

GGBS:RM ratio	BCS (%)	GGBS (%)	RM (%)
100:00	75	25.0	0.0
70:30	75	17.5	7.5
50:50	75	12.5	12.5
30:70	75	7.5	17.5
00:100	75	0.0	25.0

3.4 Testing and evaluation

The thesis describes material characterization, compaction, unconfined compressive strength, soaked California Bearing Ratio, free swell index and wet–dry durability assessment. It lists IS 2720 (Parts 3, 4, 5, 7 and 40) for relevant soil characterization and compaction procedures. The thesis identifies UCS, soaked CBR and wet–dry durability as laboratory evaluations; the exact test records, specimen details, replicate counts and calculation sheets should accompany the final manuscript.

4.4 Specimen preparation and curing

As described in the thesis, the soil was prepared for mixing and the GGBS and Red Mud were proportioned to obtain the selected GGBS:RM ratios. The total stabilizer was maintained at 25% of the dry weight of soil. For example, the 70:30 blend corresponds to 17.5% GGBS and 7.5% Red Mud by dry weight of soil. The prepared mixtures were moisture-conditioned and compacted for the relevant laboratory evaluations. The thesis considers curing periods of 7, 14 and 28 days for strength-related comparisons. Exact specimen dimensions, number of replicate specimens, curing environment and moisture-conditioning details should be reported from the laboratory records in the final submission.

4.5 Engineering tests and interpretation

Compaction testing is used to establish the relationship between moisture content and dry density. The optimum moisture content is the water content corresponding to the peak of the compaction curve, and the maximum dry density is the corresponding peak dry density. These values are important for defining field compaction requirements.

The unconfined compressive strength test provides an indication of the compressive resistance of the compacted soil specimen without lateral confinement. The reported UCS values are compared at the specified curing periods to examine the variation in strength with blend ratio and curing age. The final paper should state the specimen dimensions, loading rate, corrected area calculation and replicate results based on the actual test sheets.

The soaked CBR test is used to assess the bearing response of the material under soaked test conditions relevant to pavement subgrade evaluation. CBR is calculated by comparing the corrected load at the specified penetration with the

standard reference load. The original load–penetration curves and any correction applied to the curves should be retained to substantiate the tabulated CBR values.

The Free Swell Index test compares the equilibrium sediment volumes of equal quantities of soil in distilled water and kerosene. The index is calculated as FSI (%) = [(Vd − Vk)/Vk] × 100, where Vd is the sediment volume in distilled water and Vk is the sediment volume in kerosene. The thesis identifies IS 2720 (Part 40):1977 for this determination.

The wet–dry durability results in the thesis are expressed as percentage mass loss. To make this result reproducible, the final manuscript should specify the exact number of wetting and drying cycles, duration of each stage, drying temperature, brushing or handling procedure, and initial and final dry masses. These details are not fully established by the summary data alone.



Figure 10. Laboratory activity (photograph reproduced from thesis).

For UCS and soaked CBR, the thesis presents results for untreated soil and the five stabilized blends at initial, 7-, 14- and 28-day conditions. The reported FSI values are compared across the untreated and stabilized mixtures. The wet–dry durability comparison is expressed as mass loss percentage.

5. RESULTS AND DISCUSSION

4.1 Compaction characteristics

The thesis reports the following optimum moisture content (OMC) and maximum dry density (MDD) values. These are reproduced from the thesis tables and should be verified against the original compaction observations and plotted moisture–dry density curves.

Mixture	OMC (%)	MDD (g/cm³)
Untreated BCS	21	1.58
GGBS:RM 100:00	18	1.60
GGBS:RM 70:30	21	1.62
GGBS:RM 50:50	24	1.61
GGBS:RM 30:70	24	1.60
GGBS:RM 00:100	27	1.59

The reported MDD is highest for the 70:30 blend at 1.62 g/cm³. The reported OMC varies from 18% to 27% among the stabilized blends, indicating that the blend composition is associated with different moisture–density responses.

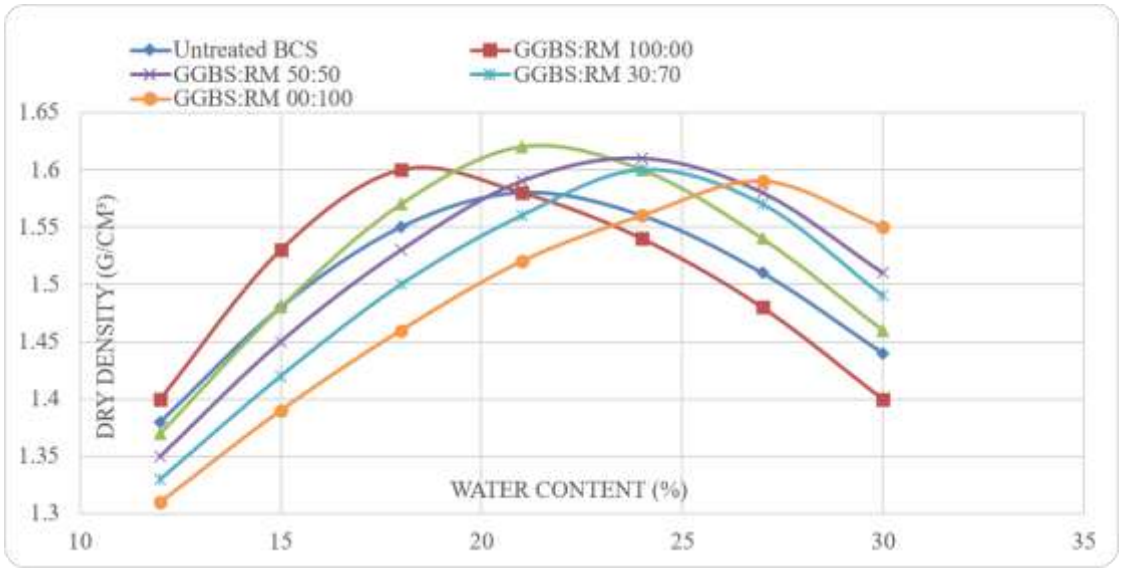


Figure 4. Moisture content versus dry density curves (reproduced from thesis).

4.2 Free swell index

Mixture	FSI (%)	Reduction from untreated (%)
Untreated BCS	52.28	—
100:00	25	52.18
70:30	15	71.31
50:50	19	63.66
30:70	21	59.83
00:100	23	55.93

The thesis-reported FSI decreases from 52.28% for untreated soil to values between 15% and 25% for the stabilized mixtures. The lowest reported FSI is 15% for the 70:30 blend, corresponding to a reported reduction of 71.31% relative to untreated soil.

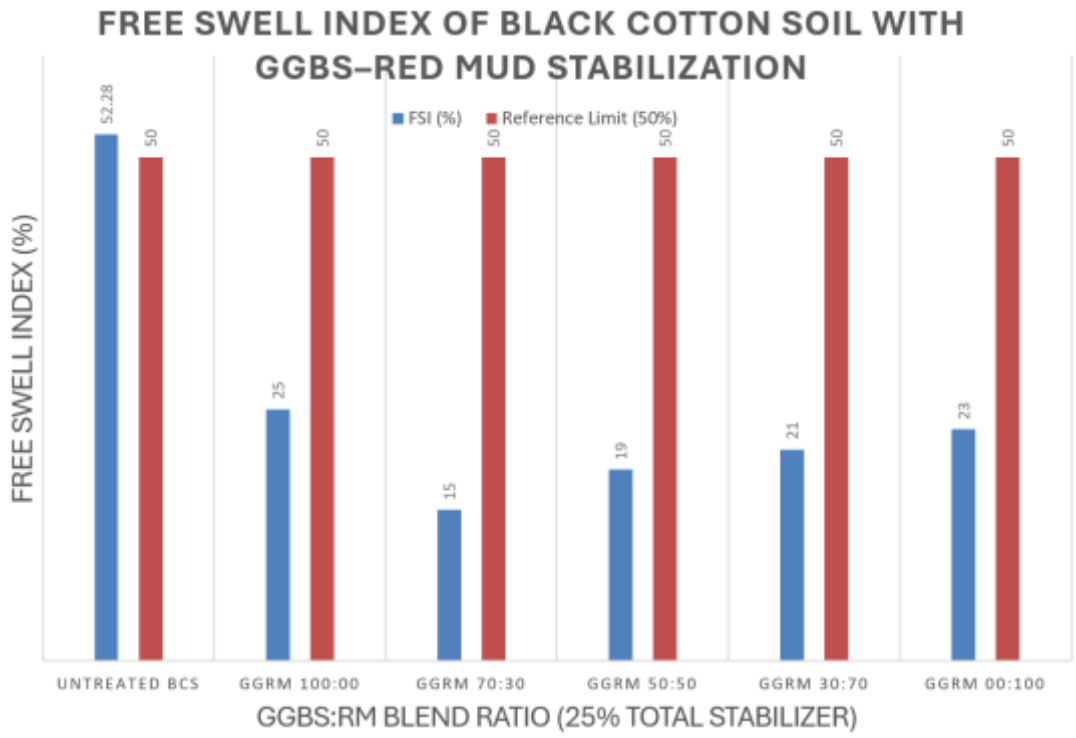


Figure 5. Free Swell Index comparison (reproduced from thesis).

4.3 Unconfined compressive strength

GGBS:RM ratio	Initial (kPa)	7 days (kPa)	14 days (kPa)	28 days (kPa)
Untreated BCS	131	131	131	131
100:00	145	350	520	686
70:30	168	450	680	920
50:50	151	390	570	780
30:70	142	320	470	650
00:100	140	250	360	500

The thesis-reported UCS increases with curing period for each stabilized blend. At 28 days, the 70:30 blend has the highest reported UCS of 920 kPa, followed by 50:50 at 780 kPa and 100:00 at 686 kPa. The reported result suggests that the 70:30 blend performs best among the compared mixtures when UCS is used as the selection criterion.

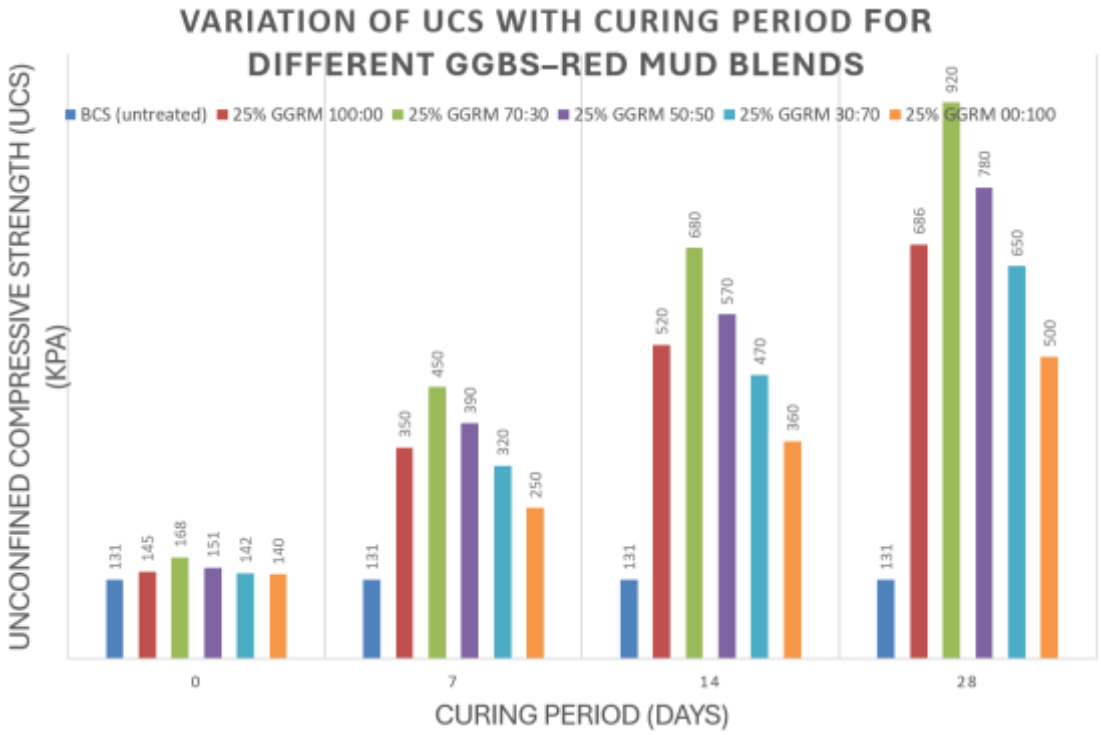


Figure 6. Variation of UCS with curing period (reproduced from thesis).

4.4 Soaked California Bearing Ratio

GGBS:RM ratio	Initial (%)	7 days (%)	14 days (%)	28 days (%)
Untreated BCS	1.5	1.5	1.5	1.5
100:00	4.5	8.8	13.2	22.8
70:30	3.8	7.3	8.8	11.5
50:50	3.3	6.4	8.0	9.8
30:70	2.9	5.1	7.2	8.4
00:100	2.1	4.7	5.9	6.2

The highest thesis-reported 28-day soaked CBR is 22.8% for the 100:00 GGBS:RM blend. The 70:30 blend records 11.5%, while the remaining blends record 9.8%, 8.4% and 6.2% for 50:50, 30:70 and 00:100, respectively. Thus, the blend with the highest UCS (70:30) is different from the blend with the highest soaked CBR (100:00). This difference should be considered when selecting a mixture for pavement subgrade applications.

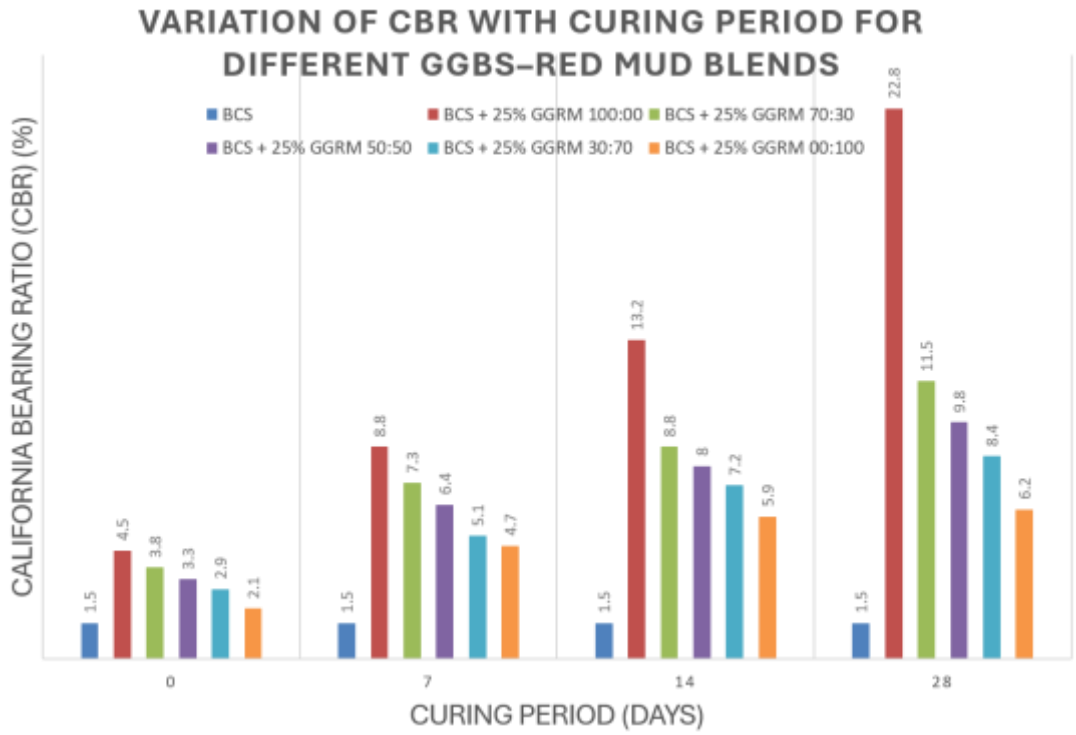


Figure 7. Variation of soaked CBR with curing period (reproduced from thesis).

4.5 Wet–dry durability

GGBS:RM ratio	Reported mass loss (%)
100:00	18.5
70:30	13.5
50:50	16.8
30:70	19.2
00:100	21.0

The thesis reports the lowest mass loss of 13.5% for the 70:30 blend and the highest mass loss of 21.0% for the 00:100 blend. The original initial and final specimen masses, cycle details and adopted test procedure must be supplied to substantiate these values. The manuscript should describe the procedure as an adapted comparative assessment unless the exact method and its applicability are confirmed.

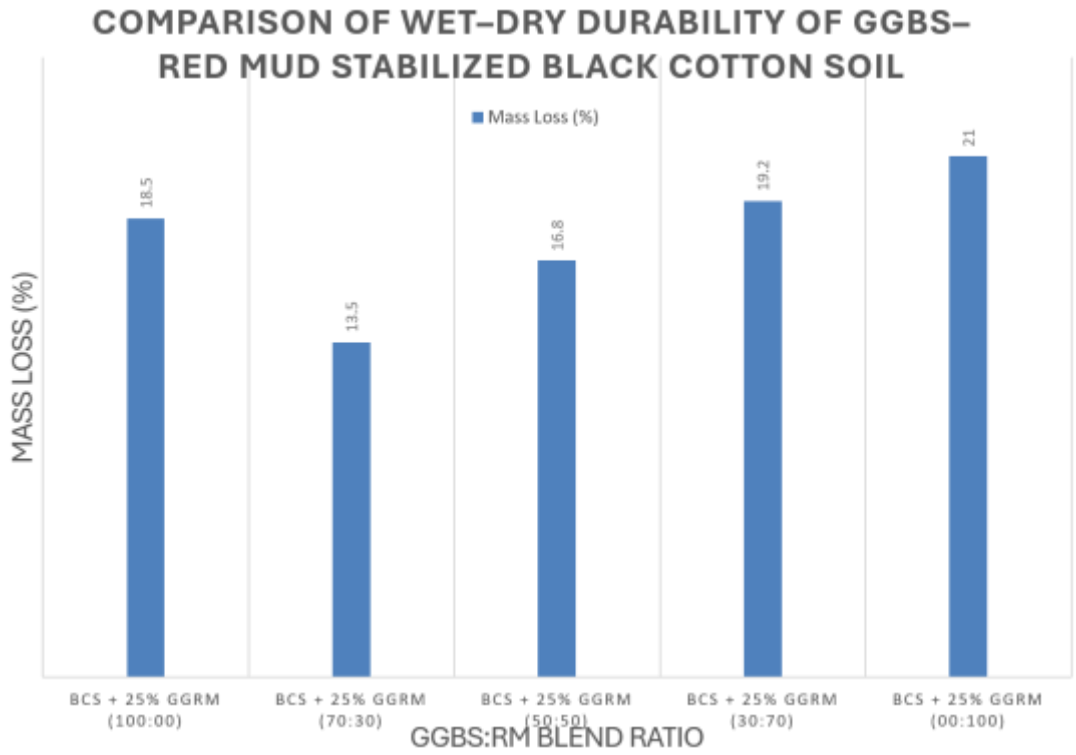


Figure 8. Wet–dry durability mass-loss comparison (reproduced from thesis).

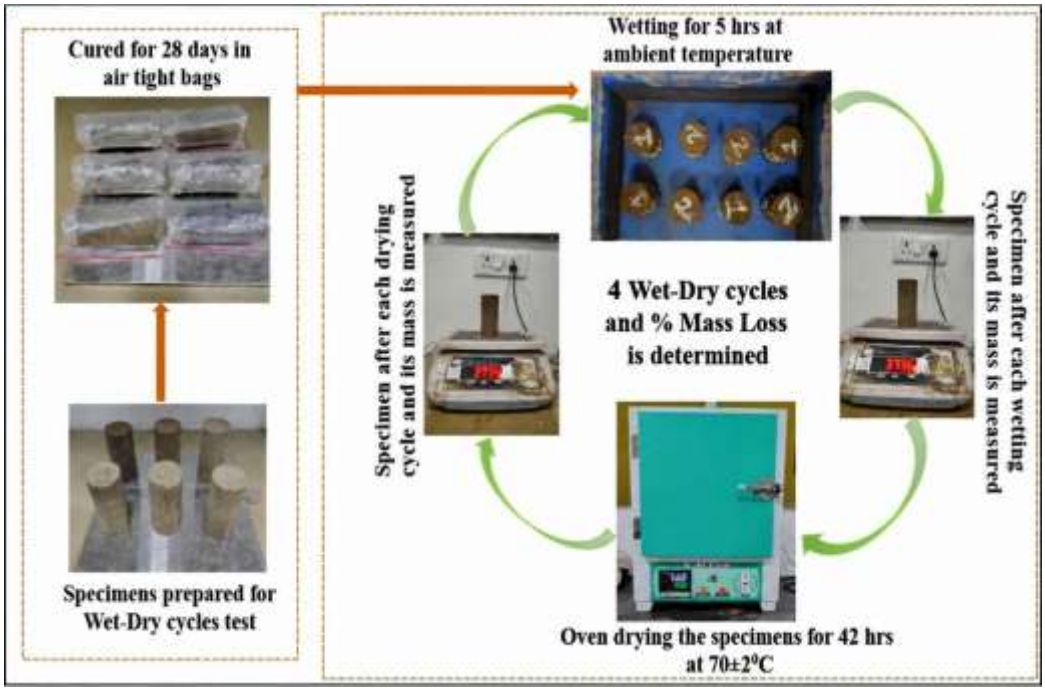


Figure 9. Wet–dry durability procedure (photograph reproduced from thesis).

4.6 Overall comparison

Performance parameter	Best reported blend	Reported value
28-day UCS	70:30	920 kPa
28-day soaked CBR	100:00	22.8%
FSI	70:30	15%
Wet–dry mass loss	70:30	13.5%
MDD	70:30	1.62 g/cm³

On the basis of the values presented in the thesis, the 70:30 blend shows the strongest overall response in UCS, FSI reduction, reported wet–dry mass loss and MDD, whereas the 100:00 blend provides the highest soaked CBR.

Therefore, the 70:30 blend may be considered the preferred balanced blend in this dataset, but the 100:00 blend should be recognized as the highest-CBR mixture. A final selection for field use requires verified test data, design criteria, environmental evaluation and field validation.

5.7 Engineering implications and limitations

The results presented in the thesis suggest that the response of black cotton soil to GGBS–Red Mud treatment depends on the engineering property considered. The 70:30 blend leads the reported UCS and FSI comparisons, whereas the 100:00 blend leads the reported soaked CBR comparison. A pavement subgrade material should not be selected using UCS alone or CBR alone. The design decision should consider the applicable subgrade acceptance criteria, compaction control, moisture sensitivity, drainage conditions and durability.

The present comparison is limited to a single reported soil source and one total stabilizer content of 25%. It therefore does not establish the optimum stabilizer dosage across a dosage range, nor does it demonstrate that the same blend will perform similarly with soils from other locations. The results also do not establish field performance under traffic loading, seasonal moisture changes or construction variability.

Red Mud is an industrial residue, and its use in pavement layers requires environmental evaluation in addition to geotechnical testing. Chemical characterization and suitable leachability assessment should be completed before field application. A trial section with construction quality control and performance monitoring would be required before recommending large-scale use.

6. CONCLUSIONS

1. The investigation compares five GGBS:RM ratios at a fixed total stabilizer content of 25% by dry weight of soil.
2. The untreated black cotton soil is reported to have an FSI of 52.28%, UCS of 131 kPa and soaked CBR of 1.50%.
3. Among the thesis-reported values, the 70:30 blend has the highest 28-day UCS of 920 kPa and the lowest FSI of 15%.
4. The 100:00 blend has the highest reported 28-day soaked CBR of 22.8%; therefore, the UCS-optimum and CBR-optimum blends are not identical.
5. The 70:30 blend is reported to have the lowest wet–dry mass loss (13.5%) and the highest MDD (1.62 g/cm³) among the compared mixtures.
6. The results indicate that blend selection should consider multiple engineering properties rather than a single strength parameter.
7. Before practical use, the reported results must be validated against original laboratory records, and the stabilized material must undergo appropriate environmental assessment and field validation.

ACKNOWLEDGEMENT

6.1 FUTURE WORK

Further work should verify the reported results through repeat laboratory testing with documented replicate specimens and complete calculation sheets. Additional stabilizer contents can be investigated to establish dosage sensitivity. Chemical and environmental testing of the Red Mud, extended durability testing, and field trials under representative pavement and drainage conditions are also recommended.

The authors may acknowledge the Department of Civil Engineering, Sanketika Vidya Parishad Engineering College, Visakhapatnam, and the project guide after confirming the final wording and institutional requirements.

Note on figures: Graphs and photographs are reproduced from the uploaded dissertation. Their numerical data, axes, units, captions and consistency with the result tables must be checked against original laboratory records before journal submission.

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AUTHOR VERIFICATION CHECKLIST – REMOVE BEFORE JOURNAL SUBMISSION

- Confirm the guide's full name, designation, department and consent to first authorship. The thesis identifies DR. G. TABITHA, Ph.D. (Geo Tech), Associate Professor.
- Confirm corresponding author and provide valid institutional email addresses for all authors.
- Verify every UCS, CBR, compaction, FSI and durability value against original laboratory notebooks, machine printouts, specimen dimensions, load readings and calculation sheets. Do not submit assumed or interpolated values as measured results.
- Check consistency between the CBR summary values and original load–penetration curves/calculations, including corrected curves where applicable.
- Provide complete and verified bibliographic details for the studies reviewed in Chapter 2. They have not been added here because the thesis text does not provide sufficiently complete publication metadata in the extracted material.
- Confirm the exact test standards and procedures actually followed, replicate counts, curing conditions and wet–dry cycle procedure.
- Check IJSREM's current template, author instructions, fees, ethics declarations and similarity requirements before submission.