IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

INVESTIGATING THE USE OF BIOCHAR FOR CLAY SUBGRADE STABILIZATION IN HIGHWAY CONSTRUCTION

NAVNEET SINGH YADAV (ASSISTANT PROFFESOR BBDITM) ISHANT KUMAR GUPTA, KUNAL VIMAL, KUNWAR KARTIKEY SINGH, KUSHAGRA SRIVASTAVA

Department of Civil Engineering, Babu Banarasi Das Institute of Technology & Management, Lucknow, India

Abstract

Clayey soils used as subgrades in highway construction often suffer from high plasticity, excessive swelling, low bearing capacity, and inadequate strength, leading to early pavement failure. To overcome these limitations in a sustainable manner, this study investigates the effectiveness of stabilizing clay with a hybrid combination of rice husk biochar, wood biochar, and lime are added in the ratio of 3:3:4. Biochar, a carbon-rich and porous by-product of biomass pyrolysis, has gained attention for its ability to improve soil structure and moisture behaviour, while lime remains a proven chemical stabilizer capable of inducing pozzolanic reactions and long-term strength gain.

In this research, natural clay was stabilized using rice husk biochar, wood biochar, and lime, selected based on their optimum performance ranges reported in literature and confirmed through preliminary assessment. A comprehensive experimental program was conducted, including Atterberg limits, California Bearing Ratio, Moisture test, and specific gravity tests.

Keywords:

Rice Husk Biochar; Wood Biochar; Lime Stabilization; Clay Subgrade; Soil Stabilization; California Bearing Ratio (CBR); Atterberg Limits; Sustainable Construction Materials; Eco-friendly Stabilizer; Soil Improvement Techniques.

1. INTRODUCTION

The subgrade is the natural soil or prepared foundation layer over which the pavement layers are constructed. Its primary function is to provide adequate support to withstand the stresses transmitted from the traffic loads through the pavement structure. The strength and stability of the subgrade play a critical role in determining the overall performance and life of the pavement. In many regions, especially in India, clay soils are commonly encountered as subgrade material. Clay soils are composed of very fine particles (<0.002 mm) with a large specific surface area and strong affinity for water. These properties make clay soils highly problematic for use as subgrade in highways. In this study we are mixing different combinations of wood biochar, rice husk biochar and lime to this clayey soi to enhance its physical properties and make it suitable for the use in construction work without any problems. We will examine this soil properties before and after the mixing of these admixtures to find out how much improvement has been there in the soil properties and on the basis of these findings we will make further future studies that this soil should be used.

The main contributions of this study includes:

- Improvement in Soil Strength Properties
- Reduction in Plasticity and Swelling Behaviour
- Enhancement of Compaction Characteristics
- Improvement in Durability and Moisture Resistance
- Environmental and Economic Benefits

2. LITERATURE REVIEW

Clayey subgrades typically suffer from high plasticity, low shear strength, low CBR, high compressibility, and moisture sensitivity—all of which reduce pavement life. Conventional stabilizers (lime/cement) work but raise cost and CO_2 footprint. In the last decade, biochar—a porous, carbon-rich material from biomass pyrolysis—has been explored as a sustainable stabilizer. Studies generally report reduced swell/shrinkage, improved CBR, altered compaction behaviour (↓MDD, ↑OMC), and microstructural changes (flocculation/aggregation, pore-structure modification). However, effects depend on feedstock, pyrolysis temperature, particle size, and dosage, and there's still a need for standardized mix design, durability under cyclic loading, resilient modulus (Mr) data, and field validation.

Previous studies in Geotechnical Engineering have extensively highlighted the challenges associated with clayey subgrade soils, particularly their high plasticity, low strength, and significant swelling–shrinkage behavior under varying moisture conditions. Traditionally, stabilizers such as cement and lime have been widely used to improve soil properties; however, their application is often limited by high costs and environmental concerns, including increased carbon emissions. Researchers have reported that the incorporation of biochar can enhance soil strength, reduce plasticity, and improve moisture retention characteristics, although the extent of improvement varies depending on soil type and biochar content.

Furthermore, biochar contributes to sustainable construction practices by promoting waste utilization and supporting Carbon Sequestration. Despite these advantages, existing literature indicates a lack of comprehensive studies focusing on its application in highway subgrade stabilization, particularly under long-term loading and field conditions.

Review of Previous Studies

2008 – Lehmann & Joseph Published "Biochar for Environmental Management". This foundational work explained biochar's physical and chemical properties, highlighting its role in improving soil structure, porosity, and stability. Although primarily agricultural, it opened the door for geotechnical applications.

2011 – Downie et al. Reported that biochar produced at higher pyrolysis temperatures showed better structural stability and higher surface area, which are useful for soil stabilization.

2014 – Zhang et al. Studied the effects of rice husk biochar on expansive clay. Results showed reduction in plasticity index and swelling potential, making clay more stable for subgrade applications.

2016 – Sutar & Sahoo Investigated the use of wood biochar in clayey soil stabilization. Findings showed increased CBR (California Bearing Ratio) values and improved load-bearing capacity of the treated soil.

2017 – Ghosh et al. Compared biochar with lime stabilization on soft clay. Biochar showed better improvement in permeability and durability, though lime provided higher initial strength.

2018 – Chen et al. Conducted a detailed study on the microstructure of biochar-amended clay. Reported pore-filling and flocculation effects, which enhanced shear strength and reduced compressibility.

2020 – Saha & Ghosh Evaluated biochar from rice husk in expansive clay stabilization for pavements. Found that optimum 6–8% biochar content increased UCS (Unconfined Compressive Strength) and reduced swelling index significantly.

2021 – Rajasekaran & Kumar Studied the durability of biochar-stabilized clay subgrades under cyclic loading. Found that biochar not only improved strength but also resisted fatigue and deformation under repeated traffic loads.

2022 – Zhang & Wu Analyzed different pyrolysis temperatures of biochar on clay stabilization. Found that high-temperature biochar (600–700 °C) offered the best long-term stability due to its high fixed carbon and surface area.

2023 – Singh et al. Conducted experimental studies on highway clay subgrades treated with rice husk and bamboo biochar. Reported that biochar addition improved CBR by 25–40% and significantly reduced plasticity.

2024 – Li et al. Recent research highlighted the use of biochar-lime blends for highway subgrades. Found that combining biochar with traditional stabilizers like lime/cement enhanced performance while reducing carbon footprint, making it highly suitable for sustainable pavement construction

3. METHODOLOGY

The present investigation aims to study the improvement in the engineering properties of clay subgrade soil by using a combination of rice husk biochar, wood biochar, and lime. The experimental program consists of material collection, characterization, sample preparation, and laboratory testing under controlled conditions. The methodology adopted is discussed in detail below.The materials used in this study include clay soil, rice husk biochar, wood biochar, lime, and water. The clay soil was collected from a nearby construction site where weak subgrade conditions were observed. The soil was air-dried, pulverized, and passed through a 4.75 mm sieve to obtain uniform consistency. Preliminary classification tests revealed it to be a highly plastic clay (CH) as per the Unified Soil Classification System.

Rice husk biochar (RHB) was prepared by pyrolyzing rice husk at temperatures between 400 °C and 600 °C under limited oxygen. It is a lightweight, porous, carbon-rich material with a high silica content that improves the binding and strength characteristics of clay soil. Wood biochar (WB) was obtained from hardwood waste pyrolyzed between 450 °C and 550 °C. Its rough, porous surface enhances inter-particle friction and increases the dry density and strength of stabilized clay. Lime used in this study was commercial hydrated lime conforming to IS 1514:1990. Lime was chosen for its pozzolanic reaction with clay minerals, forming cementitious compounds such as calcium-silicate-hydrate (C–S–H) and calcium-aluminate-hydrate (C–A–H), which contribute to long-term stabilization. All materials were stored in airtight containers to prevent moisture absorption before mixing. The entire procedure followed a logical sequence:

- Collection and identification of natural clay soil.
- Characterization of soil properties through preliminary tests.
- Preparation of rice husk and wood biochar.
- Mixing of biochar and lime with clay soil in different proportions.
- Determination of OMC and MDD through compaction.
- Preparation and curing of stabilized samples.
- Conducting strength and durability tests
- Analysis of results to evaluate improvements in subgrade performance

4. SURVEY WORK

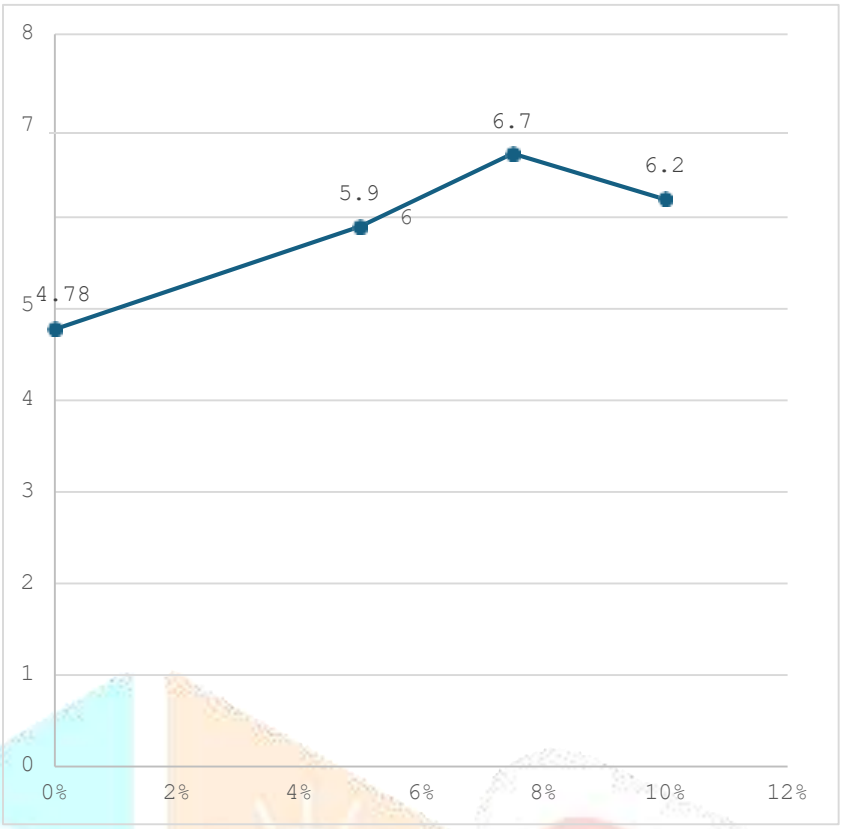
Work Location: Gomti River Bank The survey work for this study is contextually linked to the area surrounding the Gomti River Bank, which is known for its diverse soil characteristics and ongoing urban development activities the Gomti River Bank region was selected as the environmental reference location due to its predominant clay-rich subgrade and the pressing need for soil improvement solutions in nearby infrastructure works. The site's naturally occurring soft, wet, and highly plastic clay deposits provide a practical background for understanding stakeholder perceptions toward sustainable stabilizers such as rice husk biochar, wood biochar, and lime. This location also represents a typical scenario where weak subgrades affect road performance, making it an ideal contextual zone for evaluating the feasibility and acceptance of biochar-based stabilization techniques among engineers, students, faculty, and practitioners

5. EXPERIMENTAL RESULT AND ANALYSIS

The tests conducted include density test, moisture content determination, liquid limit test, and California Bearing Ratio (CBR) test. All tests were performed in accordance with relevant Indian Standard (IS) codes to ensure accuracy and reliability of results.

With these testing of the soil we get to know about the soil properties and its analysis and how well it performances without adding of the admixtures with in our case are the wood biochar, rice husk biochar and lime and how its properties get better with there addition and it becomes very more useful and far more economical. Final comparison is shown on the basis of change in CBR values with the change in percentage of soil.

Admixtures(%)	**CBR Values**	**% Increase in CBR values**
0	4.78	
5	5.9	23.43
7.5	6.7	40.17
10	6.2	29.71



6. CONCLUSION

The present study was carried out to evaluate the engineering properties of natural soil and to examine the effectiveness of stabilization using rice husk biochar and lime. Based on the laboratory investigations conducted, the soil was identified as a clayey-silty mixture with low plasticity characteristics. The Atterberg limits revealed a liquid limit of 38.5% and plastic limit of 23.49%, resulting in a plasticity index of 15.01%, indicating very low plastic behavior and poor cohesion. The natural moisture content was found to be relatively high, while the dry density was comparatively low, suggesting the presence of fine particles and voids within the soil structure. The strength characteristics of the soil were evaluated using the California Bearing Ratio (CBR) test, which yielded a value of 4.78% at 2.5 mm penetration. This low value indicates that the soil possesses poor load-bearing capacity and is not suitable for use as a subgrade material in highway construction without improvement. The results clearly establish that the natural soil, in its untreated state, cannot sustain traffic loads effectively and is prone to deformation. To improve the soil properties, stabilization was carried out using rice husk biochar and lime. The addition of these materials resulted in noticeable improvements in the engineering behavior of the soil. The most significant improvement was observed in the CBR value, which increased from 4.78% to a maximum of approximately 6.7% at an optimum mix of 7.5% rice husk biochar and lime. This increase in CBR indicates an improvement in load-bearing capacity and resistance to penetration

7. FUTURE SCOPE

The present study provides a foundation for understanding the behavior of clayey-silty soil stabilized with rice husk biochar and lime; however, there is significant scope for further research and improvement. Future studies can explore the use of higher percentages of stabilizers or different combinations of biochar and lime to achieve greater strength and durability. Long-term performance studies should be carried out to evaluate the durability of stabilized soil under varying environmental conditions, including wetting-drying cycles and repeated traffic loading. This would provide a better understanding of the behavior of stabilized soil over time and its suitability for real-world applications. Further research can also focus on microstructural analysis using advanced techniques to understand the bonding mechanism between soil particles, biochar, and lime. This would help in optimizing the mix proportions and improving the efficiency of stabilization

8. ACKNOWLEDGEMENT

The author expresses sincere gratitude to the faculty members of the Department of Civil Engineering for there guidance and technical support in the development of this study. Appreciation is also expressed to the laboratory staff members for assistance in specimen preparation, curing, and testing. Existing scientific literature for investigating the use of biochar for clay subgrade stabilization in highway construction provides the technical foundation for structuring this paper.

9. REFERENCES

1. Hov, S., Paniagua, P., Sætre, C., Long, M., Cornelissen, G., & Ritter, S. (2023). "Stabilisation of Soft Clay, Quick Clay and Peat by Industrial By-Products and Biochars." *Applied Sciences, 13(16), 9048. .*

2. Domingo, E. K. F., & Florencondia, N. T. (2025). "Geotechnical Evaluation of Sawdust-Derived Biochar as a Sustainable Stabilizer for Clayey Soils." *International Journal of Progressive Research in Science and Engineering.*

3. (2025). "Effect of Fine-Grained Wood Biochar on the Geotechnical Behaviour of Expansive Clay as Pavement Subgrade." *Journal of Rock Mechanics and Geotechnical Engineering.*

4. Priyadarshi, S., & Sharma, A. K. (2025). "Mechanical Performance of Biochar-Amended Subgrade Soils." *International Journal of Pavement Research and Technology.*

5. (2025). "Performance of Soil Subgrade Improvement using Coconut Shell Charcoal." *International Journal of Engineering Science and Information Technology.*

6. Wang, D., Fonte, S. J., Parikh, S. J., Six, J., & Scow, K. M. (2017). "Biochar additions can enhance soil structure and the physical stabilization of carbon in aggregates." *Geoderma, 303, 110–117.*

7. Bhat, S. A., et al. (2022). "Application of Biochar for Improving Physical, Chemical, and Hydrological Soil Properties: A Systematic Review." *Sustainability, 14(17), 11104.*

8. Ritter, S., Paniagua, P., & Cornelissen, G. (2023). "Biochar in Quick Clay Stabilization: Reducing Carbon Footprint and Improving Shear Strength." *Geo-Congress 2023 (ASCE).*

9. (2019). "Possibilities to Improve Soil Aggregate Stability Using Biochars Derived from Various Biomasses." *Geoderma, 344, 40–49.*

10. Choudhary, M. P., Charan, H. D., & Acharya, B. (2021). "Effect of Biochar Application on the Geotechnical Properties of Expansive Soils." *Journal of Geotechnical Engineering.*

11. Hov, S., et al. (2023). "Stabilisation of Soft Clay, Quick Clay and Peat by Industrial By-Products and Biochars." *Applied Sciences, 13(16), 9048.*

12. (2025). "Feedstock Influence on Mechanical Properties and CO_2 Mineralization of Biochar-Amended Clay." *Transportation Geotechnics.*

13. Ikeagwuani, C. C., & Nwonu, D. C. (2019). "Emerging Trends in Expansive Soil Stabilization: A Review." *Journal of Rock Mechanics and Geotechnical Engineering.*

14. Sharma, A. K., & Sivapullaiah, P. V. (2016). "Strength Development in Fly Ash–Lime Stabilized Soils." *Ground Improvement Journal.*

15. Sukmak, P., Horpibulsuk, S., & Shen, S. L. (2013). "Strength Development in Clay–Fly Ash Geopolymer." *Construction and Building Materials, 40, 566–574.*