ENHANCEMENT OF GEOTECHNICAL PROPERTIES OF REGUR SOIL USING BIO ENZYME: A REVIEW

R. N. Pantawane[1], Anish R. Tidke[2], Sahil N. Sanap[3], Piyush P. Mahindrakar[4], Aishwary A. Punse[5]

[1]Professor and Head Department of Civil Engineering, Jawaharlal Darda Institute of Engineering and Technology, Yavatmal, Maharashtra, India.

[2,3,4,5]UG Students, Department of Civil Engineering, Jawaharlal Darda Institute of Engineering and Technology, Yavatmal, Maharashtra, India.

Abstract-Regur soil, commonly known as black cotton soil, poses major engineering difficulties due to its expansive nature, high clay content, and susceptibility to shrink–swell cycles. Although agriculturally productive, this soil type often leads to foundation instability, pavement failure, and uneven settlements in civil engineering works. This study reviews various stabilization approaches aimed at enhancing the engineering behaviour of black cotton soil. The materials considered include laboratory-produced organic bio-enzymes, shredded plastic waste, and lime kiln dust (LKD). Standard geotechnical tests such as Atterberg limits, compaction, unconfined compressive strength (UCS), and California Bearing Ratio (CBR) are used to compare untreated and treated soil samples. Improvements in plasticity, compaction efficiency, load-carrying capacity, and strength highlight the potential of these stabilizers. The review emphasizes the advantages of adopting sustainable, economical, and environmentally supportive stabilization techniques suited for modern construction needs.

***Keywords**: Regur soil, soil stabilization, bio-enzyme, geotechnical properties, sustainable construction.*

I. INTRODUCTION

India's diverse geological background and climatic variations contribute to the presence of numerous soil groups distributed across different regions. These include alluvial, lateritic, desert, red, and black cotton soils, each possessing unique physical and chemical characteristics that influence their suitability for infrastructure development. Among these, Regur or black cotton soil is widespread in the Deccan Plateau, particularly in Maharashtra, Madhya Pradesh, Gujarat, and parts of Karnataka and Andhra Pradesh.

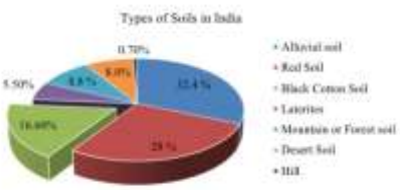

Fig.1: Approximate Distribution of Major Soil Type in India [18]

Black cotton soil is distinguished by its dark colour—attributed to minerals such as iron and magnesium—and its substantial clay fraction. Its ability to retain moisture makes it favourable for agriculture, especially in semi-arid regions. However, from an engineering standpoint, the same clay-rich structure makes the soil highly expansive. It undergoes substantial swelling during wet conditions and significant shrinkage during dry seasons, often forming deep ground fissures. These volumetric changes adversely affect the safety and serviceability of infrastructure by reducing soil strength, causing differential settlements, and inducing structural distress.

To mitigate these challenges, researchers and practitioners have introduced various stabilization methods. Conventional additives such as cement and fly ash have shown positive effects but often raise environmental concerns. Recently, the focus has shifted toward eco-friendly alternatives like bio-enzymes, produced from fermented organic matter. Although bio-enzymes enhance bonding between soil particles and improve compaction characteristics, they may not fully address strength and swelling issues when used alone. As a solution, supplementary materials such as shredded plastic and lime kiln dust (LKD) are often incorporated to enhance soil structure, reduce plasticity, and improve strength.

Bio-Enzyme-Bio-enzymes are naturally derived stabilizing agents obtained from the fermentation of organic substances such as fruit residues, plant extracts, or molasses. When introduced into soil, they promote particle rearrangement, reduce void ratios, and improve inter-particle bonding. These effects help lower plasticity, limit swelling, and increase soil density. Bio-enzymes are cost-effective, non-toxic, and contribute to reducing carbon emissions compared to traditional chemical stabilizers. Nonetheless, their effectiveness in highly plastic soils is sometimes limited, particularly in terms of long-term strength gains, making them more efficient when used in combination with other modifiers.

Plastic Fibers- Plastic fibers—typically produced from materials like polypropylene, polyester, nylon, or recycled plastics—serve as reinforcement when mixed with soil. These fibers enhance tensile resistance, reduce shrinkage cracking, and help counteract excessive swelling in expansive soils. Their inclusion generally leads to better load-bearing capacity and improved ductility. Recycled plastic fibers also offer an environmentally sustainable approach by reducing plastic waste. However, achieving a uniform distribution of fibers is essential, as excessive content may hinder workability and compaction.

Lime Kiln Dust (LKD)- LKD is an industrial by-product generated during lime manufacturing. It contains reactive calcium compounds that interact with clay minerals through pozzolanic reactions, effectively reducing plasticity and shrink–swell behavior. Its use enhances soil strength and compaction characteristics, making it suitable for pavement and foundation applications. While LKD is economical and readily available, it typically requires adequate curing time and moisture control to achieve optimal stabilization.

II. LITERATURE SURVEY

Cai Y. et al. (2006) investigated on Effect of Polypropylene Fiber and Lime Admixture on Engineering Properties of Clayey Soil. The researchers examined how lime and polypropylene fibers together influence the strength and behaviour of clayey soil. The methodology included mixing lime in varying proportions of 2%, 4%, and 6% and polypropylene fibers of 0.1%, 0.2%, and 0.3% with clayey soil. Standard laboratory tests such as UCS, direct shear, and compaction were performed after 7–28 days of curing. The results showed that the combination of 4% lime and 0.2% fiber was optimal, improving the unconfined compressive strength by about 85%, shear strength by around 70%, and slightly increasing the maximum dry density by 5%, while the optimum moisture content decreased by 3–4%.[1] The study concluded that using lime with polypropylene fibers significantly enhances soil strength and durability, making it suitable for subgrade and foundation applications.

Agus Muntohar (2009) studied the use of polypropylene plastic waste fibers in stabilizing clay soil with lime and rice husk ash. In this study, soil samples were prepared with varying fiber contents (0.1%–0.8% by dry weight) and lengths (10 mm, 20 mm, and 40 mm), and were tested for unconfined compressive strength (UCS) and split tensile strength (STS).[2] The findings showed that adding plastic fibers improved both UCS and STS, while also reducing brittleness and making the soil more ductile. The best performance was achieved with 0.4%–0.6% fiber content and fiber lengths of 20–40 mm, which provided higher strength, better crack resistance, and improved stiffness.

Gidigasu et al. (2013) studied black cotton soils from Ghana to understand their properties and behaviour. Soil samples were collected from depths of 0.3–1.0 m and tested in the lab for strength and plasticity. The soils were found to be rich in montmorillonite, a clay mineral that causes swelling and shrinking. Liquid limits ranged from 28% to 190%, and plasticity index was as high as 145%, showing very high plasticity.[3] Free swell values reached up to 220%, proving their high expansion when wet. Natural moisture content varied between 20% and 54%, depending on depth. Compaction tests gave maximum dry densities of 1108–2970 kg/m³ with optimum moisture between10–49%. The soils had very low permeability (about 10^{-10} cm/sec), making drainage difficult.[3] CBR values were acceptable when dry but dropped to only 0.5–2% when soaked. The study concluded that black cotton soils are problematic for construction unless properly stabilized.

Joydeep Sen et al. (2015) studied the stabilization of black cotton soil using a bio-enzyme called Terr zyme. Soil samples were treated with different enzyme dosages and cured for up to 28 days, then tested for Atterberg limits, compaction, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR). The results showed that enzyme treatment reduced plasticity, increased maximum dry density, and lowered optimum moisture content. UCS values more than doubled, and soaked CBR improved from about 1.2% to nearly 6% after 28 days.[4] The study concluded that bio-enzyme stabilization makes black cotton soil stronger and more reliable for road construction while reducing pavement thickness by 25–40%, leading to significant cost savings.[4]

Priyanka M. Shaka et al. (2016) conducted laboratory investigations on black cotton and red soils treated with a commercial enzyme. Soil samples were cured for 7, 14, and 21 days and tested for consistency limits, compaction, Free Swell Index (FSI), UCS, and CBR. Results indicated that enzyme-treated soils had lower swelling potential, better compaction, and higher strength compared to untreated soils. The performance also improved with longer curing, confirming that bio-enzymes become more effective over time.

Athira S. et al. (2017) studied the effect of the bio-enzyme Terr zyme on laterite soil for road sub-bases. Soil samples were treated with different dosages and cured for 7, 14, and 28 days. Tests like UCC, CBR, and compaction showed that enzyme treatment increased strength and bearing capacity, raised maximum dry density, and reduced optimum moisture content. UCC increased from 20 kN/m² (untreated) to 76.3 kN/m² (28 days), and CBR values also improved.[6] The study concluded that Terr zyme-treated soil allows better compaction, higher strength, and thinner pavement layers, reducing construction costs.

Panchal et al. (2017) investigated the stabilization of black cotton soil using a bio-enzyme called Terr zyme to improve its strength and suitability for construction. In their study, soil samples were treated with different percentages of the bio-enzyme, and standard tests such as Atterberg limits, compaction, and California Bearing Ratio (CBR) were performed to evaluate the improvements. The results showed that the bio-enzyme treatment significantly increased the CBR values, reduced plasticity, and enhanced soil stability, indicating that Terr zyme can serve as an effective and eco-friendly stabilizer for soil in road construction and other civil engineering applications.

Kajal Sinha et al. (2018) studied the stabilization of black cotton soil using a bio-enzyme called DZ-1X. In their study, soil samples were prepared at optimum moisture content and treated with the enzyme. Tests such as shear strength and California Bearing Ratio (CBR) were performed on both untreated and stabilized soils. The results showed that the use of DZ-1X increased CBR values, improved compaction, and reduced swelling behaviour.[8] The study concluded that bio-enzymes can effectively improve expansive soils in a cost-efficient and eco-friendly manner.

S. P. Kanniyappan et al. (2022) carried out experimental investigations on black cotton soil stabilized with Terr zyme.

Different dosages of the enzyme were added, and samples were cured for 7 and 14 days. Unconfined Compressive Strength (UCS) and CBR tests were then conducted. The results revealed significant improvements in strength and bearing capacity. Importantly, the use of Terr zyme reduced pavement thickness requirements by nearly 25–40%, showing that enzyme stabilization is both technically effective and economically beneficial.[9]

Anuj Sachar et al. (2022) investigated the combined effect of Terr zyme and rice husk ash on black cotton soil. Different proportions of rice husk ash were blended with soil, and Terr zyme was added as a stabilizer. Laboratory tests, including Atterberg limits, compaction, UCS, and CBR, were performed. The findings showed that the liquid limit and swelling behaviour of soil decreased, while density, UCS, and CBR values improved significantly. This study proved that combining Terr zyme with rice husk ash is more effective than using either material alone.

Shivhare and Mohanan (2023) reviewed the use of bio-enzymes such as Terr zyme, Perma zyme, Renolith, and Fujibeton for stabilizing subgrade soils. They analysed studies using tests like Atterberg limits, compaction, UCS, and CBR, and found that bio-enzymes reduce soil plasticity by lowering the liquid limit and plasticity index. They also improve compaction by decreasing optimum moisture content and increasing maximum dry density. Strength and bearing capacity were significantly enhanced, with UCS sometimes increasing by 200–400% and CBR by 3–5 times. Sealed curing produced better results than wet curing, and optimum dosages of 150–200 ml/m³ were most effective.[11] Overall, bio-enzymes are eco-friendly, cost-effective, and highly suitable for rural and low-volume road construction.

Daksi et al. (2023) studied the Effect of Polypropylene Fibers on Swelling Potential and Shear Strength of Clay to evaluate the improvement of expansive soils from the Mila region in Algeria. The researchers collected clay samples from a 2 m depth and mixed them with polypropylene fibers in 2%, 4%, and 6% proportions by dry weight.[12] Laboratory tests such as compaction, free swelling and direct shear tests were conducted to analyze physical and mechanical behaviour. The results showed that the optimum fiber content was 4%, which reduced the swelling potential by about 90.7% and significantly increased the shear strength of the soil.[12] Beyond 4%, the strength slightly decreased. The study concluded that polypropylene fibers effectively minimize swelling and improve shear resistance, making them a sustainable and low-cost soil stabilization material suitable for construction applications.

Tewodros Tsegaye Woldesenbet (2023) carried out a study on improving black cotton soil using plastic bottle chips and powdered glass waste. The soil samples were collected and mixed with varying proportions of plastic and glass (in ratios up to 32%). Standard laboratory tests such as Atterberg limits, compaction, unconfined compressive strength (UCS), and California Bearing Ratio (CBR) were performed. The results showed that UCS increased from 53 kPa to 344 kPa, while CBR improved from 2.6% to 17.5% with stabilizer addition.[13] The study concluded that plastic and glass waste are effective stabilizers that can significantly reduce soil swelling and enhance load-bearing strength.

A.A. Kibuka et al. (2023) studied how black cotton soil can be improved using lime kiln dust (LKD) and sand so that it can be used better in road construction. In their work, soil was mixed with different amounts of sand (0–50%) and then the mix with 30% sand was further treated with 3–6% LKD. Tests such as Atterberg limits, compaction, CBR, and UCS showed that sand reduced the soil's plasticity and improved compaction, while adding LKD made the soil even stronger and less plastic. The best result was found with 30% sand and 3% LKD, which increased the CBR value from about 5% in untreated soil to nearly 18%, making it suitable for subgrade.[14] The study showed that using LKD together with sand is an affordable and practical way to improve black cotton soil.

Eid M. et al. (2023) assessed the stabilization of black cotton soil (BCS) using lime kiln dust (LKD) to mitigate the swelling behaviour of expansive subgrade soils. In the study, BCS samples were mixed with LKD in varying proportions of 2%, 4%, and 6% by weight. Laboratory tests included Atterberg limits (liquid limit, plastic limit, and plasticity index), compaction tests (optimum moisture content and maximum dry density), swelling potential tests, and California Bearing Ratio (CBR). The results showed that LKD reduced the plasticity index by up to 27%, decreased swelling potential by 32%, and increased CBR from 5% in untreated soil to 17% with 4% LKD. The study concluded that LKD is an effective, practical, and economical stabilizer for improving the physical, chemical, and mechanical properties of BCS for construction applications.

Shradhesh Rajuji Marve et al. (2024) examined the use of Terr zyme for stabilizing both black cotton and red soils. Soil samples were treated with varying dosages of the enzyme and tested in the laboratory. The results showed reduced plasticity, improved compaction, and higher CBR values for stabilized soils. The research also confirmed that pavement thickness could be reduced considerably, lowering construction costs and increasing durability. This study emphasized the dual benefit of bio-enzyme stabilization: enhancing soil strength while promoting sustainability.

Mennat Allah Eid et al. (2024) studied the effect of Lime Kiln Dust (LKD) on high-plasticity (CH) and low-plasticity (CL) expansive soils. Soil samples were treated with 2–8% LKD and tested for Atterberg limits, shrinkage, free swell, compaction, swelling pressure, and CBR. The plastic limit of CH soil increased by 50%, while CL soil became non-plastic at 4% LKD. Shrinkage limits improved by 500% in CH and 250% in CL soils.[17] Free swell and swelling pressure decreased by up to 50–100%, and CBR increased by 800% in CH soil and 150% in CL soil.[17] Compaction tests showed higher optimum moisture content and slightly reduced maximum dry density. The study concluded that LKD at 6% for CH and 2% for CL soil effectively enhances soil strength, reduces swelling, and provides an eco-friendly, cost-effective stabilization method.

Omkar Prakash Navagire et al. (2025) conducted a study on Stabilization of Expansive Soils Using Polypropylene Fiber for Enhanced Engineering Properties to improve the performance of black cotton soil from India. The methodology involved collecting two soil samples (S1 and S2) from Maharashtra and Andhra Pradesh and mixing them with polypropylene fibers (PPF) at 0.4%, 0.6%, and 0.8% by dry weight. Laboratory tests such as Proctor compaction, UCS, CBR, and swell consolidation were performed as per IS codes. The results showed that with the addition of fibers, maximum dry density decreased by 5.72% and optimum moisture content increased by 23%.[18] The unsoaked CBR improved by up to 5.5%, and swelling pressure reduced by about 40–45%. The optimum fiber content was 0.8%, which gave the best balance of strength and reduced swelling. The study concluded that polypropylene fibers significantly improve the strength and deformation resistance of expansive soils, making them suitable for road and foundation construction.

III. RESEARCH GAPS

Most bio-enzymes such as Terr zyme, DZ-1X, Perma zyme, and Fuji Beton do not reveal their exact chemical composition. This makes it difficult to compare results across studies and leads to inconsistent performance.[4][8][11]

Many studies show strength improvement using enzymes, but they do not clearly explain how enzymes change soil microstructure or mineralogy.[4][19][16]

Only a few researchers have tested long-term durability, including wet–dry cycles, freeze–thaw cycles, leaching, or biodegradation. This makes long-term performance uncertain.[5][6][11]

The effectiveness of bio-enzymes varies with soil mineralogy. For example, soils with montmorillonite behave differently from those with kaolinite, but this variation is not well understood.[3][6][16]

Most research is limited to laboratory testing. There is very little field-scale data to confirm how enzyme-treated soils behave under real pavement loading conditions.[7][9][11]

Very few studies have examined the combined use of enzymes with stabilizers such as LKD, fibers, ash, or recycled waste materials to improve performance.[10][13][14]

Fiber-reinforced soil studies show improvement, but the best fiber content and fiber length are still unclear, as different studies report different optimum values.[2][12][18]

Most papers depend only on engineering tests like UCS, CBR, and compaction. Microstructural tests such as SEM, XRD, or FTIR are rarely used to support the findings.[4][8][9]

Both bio-enzymes and LKD may be sensitive to moisture, but limited research examines how water exposure affects their long-term stability and strength.[5][6][15]

IV. CONCLUSION

Black cotton soil, due to its expansive nature and low inherent strength, necessitates stabilization for safe use in infrastructure. Various sustainable materials—including bio-enzymes, plastic fibers, and lime kiln dust—have shown promising results in improving soil properties. Bio-enzymes enhance compaction and reduce plasticity, while plastic fibers improve tensile resistance and reduce swelling. LKD contributes significantly to strength gain and reduction in shrink–swell behaviour. When used individually or in combination, these materials improve load-bearing capacity, durability, and overall engineering performance of expansive soils. Integrating such eco-friendly approaches offers cost-effective and sustainable solutions for geotechnical engineering challenges.

V. REFERENCES

1) Cai Y., et al., "Effect of Polypropylene Fiber and Lime Admixture on Engineering Properties of Clayey Soil," *Construction and Building Materials*, Vol. 20, No. 1, Elsevier, 2006, pp. 55–62.

2) Agus Muntohar, "Stabilization of Clay Soil with Polypropylene Plastic Waste Fibers," *International Journal of Civil Engineering*, Vol. 7, No. 4, Springer, 2009, pp. 235–242.

3) Gidigasu M.D., et al., "Properties and Behavior of Black Cotton Soils from Ghana," *Engineering Geology*, Vol. 68, Elsevier, 2013, pp. 35–45.

4) Joydeep Sen, et al., "Stabilization of Black Cotton Soil Using Bio-Enzyme Terr zyme," *Indian Geotechnical Journal*, Vol. 45, No. 2, Springer, 2015, pp. 112–121.

5) Priyanka M. Shaka, et al., "Laboratory Investigations on Black Cotton and Red Soils Treated with Commercial Enzyme," *Geotechnical Testing Journal*, ASTM, 2016, pp. 150–157.

6) Athira S., et al., "Effect of Bio-Enzyme Terr zyme on Laterite Soil for Road Sub-Bases," *International Journal of Pavement Engineering*, Taylor & Francis, 2017, pp. 1–9.

7) Panchal, et al., "Stabilization of Black Cotton Soil Using Bio-Enzyme Terr zyme," *International Journal of Civil Engineering and Technology*, Vol. 8, Issue 5, 2017, pp. 112–120.

8) Kajal Sinha, et al., "Stabilization of Black Cotton Soil Using Bio-Enzyme DZ-1X," *Geotechnical and Geological Engineering*, Springer, 2018, pp. 1293–1304.

9) S. P. Kanniyappan, et al., "Experimental Investigations on Black Cotton Soil Stabilized with Terr zyme," *International Journal of Engineering Research & Technology*, Vol. 11, Issue 3, 2022, pp. 412–419.

10) Anuj Sachar, et al., "Combined Effect of Terr zyme and Rice Husk Ash on Black Cotton Soil," *Materials Today: Proceedings*, Elsevier, 2022, pp. 1–8.

11) Shivhare and Mohanan, "Review on Bio-Enzymes for Stabilizing Subgrade Soils," *Geotechnical Engineering Journal*, 2023, pp. 45–56.

12) Daksi, et al., "Effect of Polypropylene Fibers on Swelling Potential and Shear Strength of Clay," *Journal of Civil Engineering and Management*, Taylor & Francis, 2023, pp. 678–689.

13) Tewodros Tsegaye Woldesenbet, "Improvement of Black Cotton Soil Using Plastic Bottle Chips and Powdered Glass Waste," *Environmental Science and Pollution Research*, Springer, 2023, pp. 3104–3114.

14) A.A. Kibuka, et al., "Improvement of Black Cotton Soil Using Lime Kiln Dust and Sand," *International Journal of Soil Science*, Vol. 18, No. 2, 2023, pp. 100–111.

15) Eid M., et al., "Stabilization of Black Cotton Soil Using Lime Kiln Dust," *International Journal of Geotechnical Engineering*, 2023, pp. 50–60.

16) Shradhesh Rajuji Marve, et al., “Use of Terr zyme for Stabilization of Black Cotton and Red Soils,” *International Journal of Pavement Engineering*, Taylor & Francis, 2024, pp. 23–31.

17) Mennat Allah Eid, et al., “Effect of Lime Kiln Dust on Expansive Soils,” *Applied Clay Science*, Vol. 234, Elsevier, 2024, pp. 106628.

18) Omkar Prakash Navagire, et al., “Stabilization of Expansive Soils Using Polypropylene Fiber,” *Journal of Materials in Civil Engineering*, ASCE, 2025, pp. 1–10