Experimental Investigation on Stabilization of Expansive Soil with Waste Tiles Powder

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Abstract*— Expansive soils, commonly known as black cotton soils, present serious challenges in civil engineering due to their high swelling and shrinkage characteristics, low bearing capacity, and poor volume stability. These properties often lead to structural distress in pavements and foundations. Waste tiles powder obtained from tile cutting and polishing industries was crushed and ground into fine powder form and mixed with expansive soil in varying proportions of 0%, 10%, 20%, and 30% by dry weight of soil. The test results indicate a significant reduction in plasticity and swelling characteristics with the addition of waste tiles powder. Strength and compaction properties improved considerably, with optimum performance observed at 10% waste tiles powder content. Beyond this percentage, marginal reduction in strength was observed due to excess fines. The study concludes that waste tiles powder can be effectively used as a low-cost, eco-friendly, and sustainable stabilizing material for expansive soils, while also providing an efficient solution for construction waste management.

Keywords: Black cotton soil; Waste tiles powder; expansive soil; standard proctor; Unconfined Compressive Strength; Direct shear test.

I. INTRODUCTION

Expansive soils exhibit significant volume changes due to moisture variation, mainly because of clay minerals such as montmorillonite, leading to problems like cracking, low bearing capacity, and instability in foundations and pavements; in India, black cotton soil is widely распростран and poses major geotechnical challenges. To address these issues, soil stabilization is commonly adopted to improve strength, durability, and volume stability. In recent years, the use of industrial and construction waste materials has gained attention due to their cost-effectiveness and environmental benefits. Waste tiles powder (WTP), a by-product from tile industries, contains high silica content and exhibits pozzolanic properties, making it a suitable stabilizing agent. Therefore, this study focuses on the experimental investigation of stabilizing expansive soil using waste tiles powder in different proportions to evaluate its effectiveness in improving geotechnical properties such as plasticity, compaction, strength, and overall soil performance.

II. LITERATURE REVIEW

Previous studies have demonstrated that industrial waste materials are effective in improving the engineering properties of expansive soils. Swapnil Chavan et al. (2023) reported that the addition of copper slag and fly ash enhances strength parameters such as CBR, MDD, and reduces plasticity, thereby improving soil behavior. Similarly, Shilpa Devi Gadde et al. (2019) found copper slag to be a cost-effective stabilizer that increases bearing capacity and durability. P. Bharath Goud et al. (2018) observed that combining copper slag with rice husk ash improves density and CBR while reducing swelling characteristics, making it suitable for road subgrades. Shubham More et al. (2018) highlighted that steel slag improves compressive strength and reduces moisture content due to better particle bonding. Studies by Shahu Patel et al. (2013) and S. A. Kanalli et al. (2015) confirmed that mixtures of copper slag, fly ash, and other additives significantly enhance CBR and permeability characteristics for pavement applications. Additionally, Bambhaniya Mehul Ashokbhai et al. (2018) and Jinka Chandrasekhar et al. (2015) emphasized the environmental benefits and suitability of copper slag as a non-hazardous stabilizer, while Mohammed A. Qureshi (2015) concluded that such materials reduce construction costs and environmental impact. However, most research focuses on slag and ash-based stabilizers, with limited studies on waste tiles powder, indicating a need for further investigation in this area.

III. METHODOLOGY

The present study adopts a systematic experimental approach to evaluate the effectiveness of waste tiles powder (WTP) in stabilizing expansive soil. The methodology involves collection of materials, preparation of soil–WTP mixes, laboratory testing, and analysis of results.

Initially, black cotton soil was collected from a selected location and air-dried to remove natural moisture. The soil was then pulverized and sieved through a 4.75 mm and 425 µm sieve to obtain a uniform sample for testing. Waste tiles powder was obtained from tile cutting and polishing industries, dried, and ground into fine powder to ensure proper mixing with soil.

The experimental program was carried out by preparing soil samples mixed with different percentages of waste tiles powder, namely 0% (untreated soil), 10%, 20%, and 30% by dry weight of soil. Each mix was thoroughly blended to achieve uniform distribution of WTP within the soil matrix. Adequate water was added to bring the samples to the required moisture content for various tests.

A series of laboratory tests were conducted on both untreated and treated soil samples to evaluate changes in engineering properties. These tests include Atterberg limits to determine plasticity characteristics, specific gravity test, Standard Proctor compaction test to determine optimum moisture content (OMC) and maximum dry density (MDD), unconfined compressive strength (UCS) test to assess strength improvement, and direct shear test to evaluate shear strength parameters such as cohesion and angle of internal friction.

The test results were recorded and compared for different WTP proportions to identify trends and improvements in soil behavior. Based on the analysis, the optimum percentage of waste tiles powder was determined, and conclusions were drawn regarding its suitability as a stabilizing material for expansive soil.

Table 1: Laboratory Tests and Relevant IS Codes

S.No	Test Name	Relevant IS Code	Results
1	Atterberg Limits (LL & PL)	IS 2720 (Part 5): 1985	2.5
2	Specific Gravity	IS 2720 (Part 3/Section 1): 1980	80%
3	Proctor's Compaction Test	IS 2720 (Part 7): 1980	30%
4	Direct Shear Test	IS 2720 (Part 13): 1986	1.57g/cc

IV. RESULTS AND DISCUSSION

Waste tiles powder (WTP), generated from ceramic tile industries and construction debris, is one such material. It possesses pozzolanic characteristics due to the presence of silica and alumina, which can react with soil minerals to improve strength and reduce plasticity. The utilization of WTP not only enhances soil properties but also addresses the issue of waste disposal, contributing to sustainable construction practices.

In addition to chemical stabilization, fiber reinforcement has emerged as an effective technique to improve the mechanical behavior of soils. Randomly distributed fibers, such as polypropylene or natural fibers, enhance tensile strength, ductility, and resistance to cracking. Fiber inclusion transforms the soil behavior from brittle to more ductile, thereby improving its performance under load.

The combined use of waste tiles powder and fiber reinforcement offers a hybrid stabilization approach, integrating both chemical and mechanical improvement mechanisms. This study focuses on experimentally investigating the effectiveness of this combination in enhancing the engineering properties of expansive soil.

A. Preparation of the Direct shear soil sample

The direct shear test on soil stabilized with waste tiles powder (WTP) is conducted by preparing mixes with 0%, 10%, 20%, and 30% WTP by dry weight of soil. Initially, the soil sample is air-dried, pulverized, and sieved through a 4.75 mm sieve to ensure uniformity. The waste tiles are crushed into fine powder and passed through a 425 µm sieve. The required quantities of soil and WTP for each percentage are calculated and mixed thoroughly in dry condition until a uniform blend is obtained. Water is then added gradually to bring the mixture to the desired moisture content (usually near Optimum Moisture Content), and the mix is properly kneaded to achieve homogeneity.

The prepared moist mix is placed in the shear box of the direct shear apparatus in layers, and each layer is compacted gently to avoid air voids. Porous stones and grid plates are placed at the top and bottom of the specimen to facilitate drainage. The shear box is assembled and fixed in the loading frame. A predetermined normal load (such as 50, 100, and 150 kN/m²) is applied vertically on the specimen, and the sample is allowed to consolidate under this load.

After consolidation, the locking screws of the shear box are removed, and horizontal shear force is applied at a constant rate. During shearing, the readings of shear force, horizontal displacement, and vertical displacement are recorded at regular intervals. The test is continued until the specimen reaches maximum shear stress or undergoes significant deformation, indicating failure. The peak shear load is noted for each normal stress.

The same procedure is repeated for all soil–WTP mixes (0%, 10%, 20%, and 30%) under different normal stresses. From the recorded data, shear stress and normal stress are calculated, and graphs are plotted to determine the shear strength parameters such as cohesion and angle of internal friction. This procedure helps in evaluating the influence of waste tiles powder on the shear strength characteristics of expansive soil.

B. Effect of TWP in Compaction

The compaction curves (Fig.1) clearly demonstrate the influence of waste tile (MT) content on the compaction characteristics of the soil. The untreated soil exhibits a lower maximum dry density (MDD) and relatively higher optimum moisture content (OMC) compared to modified mixes. With the addition of 10% MT, the MDD increases significantly while the OMC decreases slightly, indicating improved packing efficiency and reduced water requirement due to the non-plastic and granular nature of the tile particles. At 20% MT, the trend shows a moderate increase in density, but not as pronounced as the 10% mix, suggesting partial replacement of soil fines begins to reduce cohesion. The 30% MT mix shows a further shift, where the MDD does not improve substantially and the curve becomes flatter, indicating reduced compaction efficiency due to excessive non-cohesive material. Overall, the results suggest that 10% MT is the optimum content for achieving maximum dry density and better compaction behavior, beyond which the strength gain diminishes due to loss of soil matrix continuity.

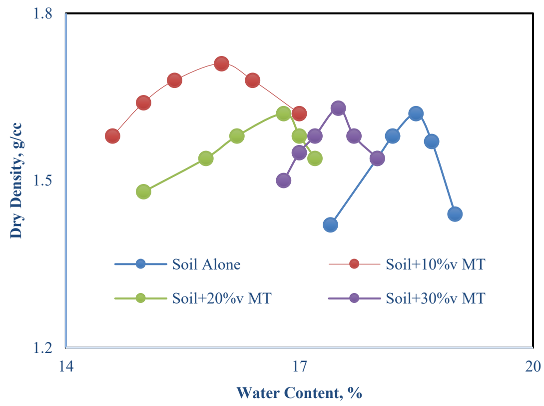

Fig.1 Dry density vs Water Content

B) Effect of shear strength in TWP

The Fig.2 illustrates the variation of shear stress with normal stress for expansive soil mixed with different percentages of waste tiles powder (WTP). It is evident that for all mixes, shear stress increases linearly with an increase in normal stress, indicating a typical frictional behavior governed by Mohr–Coulomb principles. The untreated soil (0% WTP) exhibits the highest shear strength at all normal stress levels. As the percentage of waste tiles powder increases (10%, 20%, and 30%), there is a gradual reduction in shear stress values. This trend suggests that the addition of WTP reduces the cohesion component of the soil, likely due to the replacement of clay particles with non-cohesive, granular tile powder. However, the rate of increase in shear stress with normal stress remains consistent across all mixes, indicating that the angle of internal friction is not significantly affected, or may even slightly improve due to the granular nature of WTP.

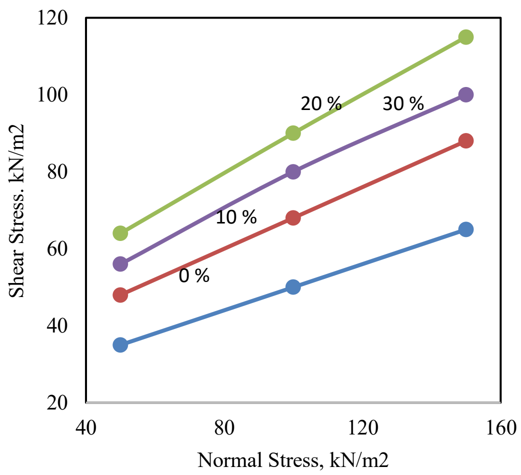

Fig.2 Shear Stress vs Normal Stress

The reduction in overall shear strength at higher WTP contents (especially 30%) may be attributed to insufficient binding and loss of clay matrix integrity. At lower percentages (around 10–20%), the soil still maintains reasonable strength while benefiting from reduced plasticity and swelling, suggesting a balance between strength and stability improvement. Beyond this range, excessive WTP leads to dilution of cohesive properties and reduced load-bearing capacity. Overall, the results indicate that while WTP contributes to improving certain properties like workability and swelling control, its content must be optimized. A moderate percentage (typically 10–20%) appears to be effective for achieving improved engineering performance without significant loss in shear strength.

C. Effect os SBC vs TWP

In fig.3 shows the Safe Bearing Capacity (SBC) with waste tile powder (WTP) content reveals a clear improvement trend up to an optimum level, followed by a decline. For both mixes—BCS + WTP and BCS + WTP with fiber—the SBC increases progressively from 0% to 20% WTP. This improvement can be attributed to enhanced particle packing, reduction in void ratio, and possible pozzolanic interactions between the soil and finely ground tile powder, which contribute to increased inter-particle bonding. The maximum SBC is observed at 20% WTP, indicating this as the optimum proportion for stabilization.

Beyond 20% WTP, a reduction in SBC is evident for both cases. This decrease is likely due to the excess addition of tile powder, which starts acting as an inert filler rather than a binding agent, leading to weaker soil structure and reduced cohesion. The dilution of the natural soil matrix and inadequate bonding at higher replacement levels results in lower load-carrying capacity.

A significant observation is the superior performance of fiber-reinforced mixes compared to non-reinforced ones at all WTP contents. The inclusion of fibers substantially increases SBC, nearly doubling the values at peak condition. This enhancement is due to the ability of fibers to provide tensile resistance, restrict crack propagation, and improve stress distribution within the soil matrix. Additionally, fibers contribute to ductility, preventing sudden failure and allowing the soil to sustain higher loads.

Overall, the combined effect of WTP and fiber reinforcement demonstrates a synergistic improvement in soil behavior, with the optimum performance achieved at 20% WTP with fiber inclusion. This combination is highly effective for improving the bearing capacity of expansive soils and can be recommended for practical foundation applications.

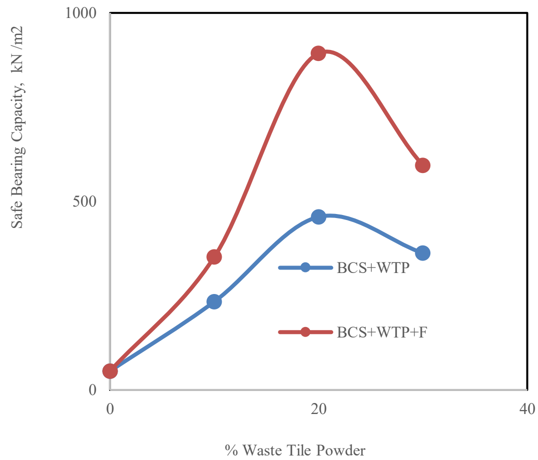

Fig.3 Safe Bearing Capacity vs % WTP

D. Effect of % od SBCE increa vs TWP

The fig,4 illustrates the percentage increase in Safe Bearing Capacity (SBC) with varying proportions of waste tile powder (WTP) for both unreinforced (BCS + WTP) and fiber-reinforced (BCS + WTP + F) soil mixes.

The results show a gradual increase in SBC for both mixes as the WTP content increases from 0% to 20%. In the case of BCS + WTP, the improvement is relatively moderate, reaching a peak increase of about 8–10% at 20% WTP. This indicates that the addition of waste tile powder enhances soil strength primarily through improved gradation and partial cementitious action, leading to better inter-particle bonding and reduced compressibility.

In contrast, the fiber-reinforced mix (BCS + WTP + F) exhibits a significantly higher improvement in SBC at all percentages of WTP. The increase is more pronounced, reaching a maximum of approximately 40–45% at 20% WTP. This substantial gain can be attributed to the combined effect of WTP stabilization and fiber reinforcement. While WTP improves the soil matrix, fibers act as discrete reinforcement elements that enhance tensile strength, control crack propagation, and provide better stress distribution within the soil mass.

Beyond the optimum content of 20% WTP, a decline in the percentage increase of SBC is observed for both mixes. This reduction is likely due to the excessive presence of tile powder, which reduces the effective cohesion and leads to weaker bonding between particles. In fiber-reinforced soil, although the decrease is noticeable, the SBC improvement remains significantly higher than the unreinforced case, demonstrating the continued beneficial role of fibers even at higher WTP contents.

Overall, the graph confirms that 20% WTP is the optimum content, and the inclusion of fibers markedly enhances the bearing capacity improvement. The combination of WTP and fiber reinforcement provides a synergistic effect, making it highly effective for stabilizing expansive soils and improving their load-bearing performance.

The addition of waste tile powder improves compaction characteristics up to an optimum level of 10% WTP, where maximum dry density is achieved due to particle packing and void filling. Beyond this, excessive replacement of cohesive soil reduces

The maximum Safe Bearing Capacity (SBC) is obtained at 20% WTP, owing to improved gradation, reduced void ratio, and enhanced inter-particle bonding. Further increase in WTP leads to strength reduction due to loss of soil matrix continuity.

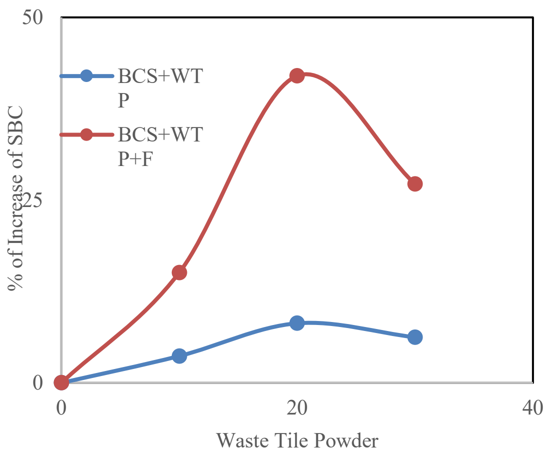

Fig.4 % of Increases of SBC vs WTP

IV. CONCLUSIONS

Fiber inclusion significantly enhances soil performance by increasing tensile strength, controlling crack propagation, and improving ductility. Fiber-reinforced mixes consistently show higher SBC compared to unreinforced mixes.

The combination of 20% WTP with fiber reinforcement provides the optimum overall performance, offering a balance of strength, stability, and durability, making it suitable for practical geotechnical applications such as foundations and subgrades.

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