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Investigation of Laterite and Black Cotton Soil Using Agricultural and Industrial Waste for Road Embankment

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Abstract

The rapid growth of urban areas and industrial activities has substantially increased the solid waste production, resulting in serious environmental and disposal challenges. The reuse of agricultural and industrial by-product in geotechnical engineering applications offers a sustainable alternative for both waste management and soil improvement. The research examines the enhancement of engineering characteristics of laterite soil and black cotton soil using waste glass (WG), plastic waste (PW), rice husk (RH), bagasse husk ash (BHA), and fly ash (FA) as stabilizing agents. Soil samples were treated with 0-9% waste admixture along with 5-20% fly ash by dry weight. Laboratory tests were conducted according to the Indian Standard (IS) procedures, including index property, modified proctor test, direct shear test, constant head permeability test, and California Bearing Ratio (CBR) test. The increase in the engineering performance of the soils was observed after soil stabilization. The maximum dry density for laterite soil increased by 65% and that for black cotton soil by 68% at optimum stabilization levels. The permeability decrease by nearly 26-29% for both soils. The shear strength parameters, cohesion and internal friction angle, showed considerable enhancement, particularly at 7% waste admixture combined with 15% fly ash. Furthermore, CBR values increased from 8.50% to 14.81% for laterite soil and from 6.75% to 11.21% for black cotton soil, indicating improvement in load carrying capacity. These improvements contributed to an estimated pavement thickness reduction of approximately 11-12% resulting in potential construction cost savings. The findings confirm that controlled incorporation of agricultural and industrial waste material can significantly improve soil performance and support sustainable road construction. However, excessive addition of waste materials may adversely affect compaction and strength characteristics. Therefore, identification of optimum stabilization proportions is essential. Field-scale validation and long-term performance studies are recommended for practical implementation.

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Introduction

The continuous increase in population, urban expansion, and industrial development has increase the solid waste generation across the world. Improper management and disposal of agricultural, municipal, and industrial waste materials have created serious environmental problems, including contamination of groundwater, land degradation, and public health hazards [2]. Conventional waste disposal methods such as landfilling require large land areas and often result in long-term ecological damage. Consequently, the beneficial reuse of waste materials in civil engineering applications has gained significant attention as a sustainable solution [25].

Construction of transportation infrastructure, particularly road embankment and pavement subgrades, requires enormous quantities of natural soil and aggregates. Excessive Extraction of this material not only increases construction expenses but also contribute to environmental degradation. Incorporation of waste materials as soil stabilizers provides a viable alternative by enhancing engineering properties of soil while simultaneously addressing waste disposal issues. Industrial by-product such as fly ash and waste glass and agricultural residues like rice husk and bagasse ash possess pozzolanic properties which can improve soil strength, reduce compressibility, and enhance durability.

Laterite soil and black cotton soil are widely found in several region of India and present considerable challenges for construction. Laterite soil generally exhibits moderate strength but often shows variability in permeability and compaction behaviour. In Contrast, black cotton soil contains expensive clay minerals such as montmorillonite, which cause significant swelling and shrinkage, resulting in low shear strength and poor stability. Stabilization of these soils using waste- based materials can significantly improve their engineering behaviour and provide environmentally sustainable alternatives.

Fly ash, a by-product generated during coal combustion in thermal power plants, is abundantly available and widely used in soil stabilization due to its cementitious characteristics and cost-effectiveness [4]. Similarly, waste glass, plastic waste, rice husk, and bagasse husk ash have gained attention for their ability to improve soil mechanical properties. However, the combined effect of multiple waste material on different soil types requires further investigation.

Several researchers have explored the use of waste materials for soil stabilization. Olufuwobi et al. 2014 [1] reported enhancement in clay soil strength using powdered glass and cement. Renu and sonthwal 2018 [2] highlighted the potential of various solid waste materials for stabilizing soft soils and emphasized their environmental benefits. Tiwari and mahiyar 2014 [4] investigated stabilization of black cotton soil using fly ash and natural fibers, demonstrating improvement in engineering properties.

Chauhan and Kumar 2015 [6] studied stabilization using waste plastic and crushed glass and observed improvement in soil strength parameters. Blayia et al. 2020 [8] evaluated expansive soil stabilized with glass powder and reported enhancement in compaction and strength properties. Hanifi et al. 2016 [10] investigated aluminium can strip as soil reinforcement and observed reduction in swelling behaviour. Baloochi et al. 2020 [11] emphasized the importance of proper proportioning of waste materials for achieving effective stabilization.

Recent studies have also focused on agricultural wastes. Thangavel et al. 2021 [21] demonstrated significant strength improvement in expansive soil using bagasse ash and natural fibres. Rawat and Mohanty 2019 [22] examined municipal solid waste utilization in embankment construction.

Therefore, the present research aims to evaluate the effectiveness of these materials in improving soil compaction, strength, permeability, and load- bearing capacity using standardized testing methods. The study also assesses the potential reduction in pavement thickness and construction cost resulting from stabilization.

Although numerous studies have investigated the stabilization of expansive soils using individual waste materials such as fly ash, glass powder, plastic waste, or agriculture residues, limited research has comparatively evaluated the combined effect of multiple agricultural and industrial wastes on different problematic soil types under identical experimental conditions. Furthermore, previous investigations rarely integrate geotechnical performance improvement with practical pavement design implications such as thickness reduction and cost efficiency based on IRC guidelines. In particular, a comparative assessment between laterite soil and black cotton soil stabilized using blended waste materials remains insufficiently explored. Therefore, the present study aims to address this gap by systematically evaluating the combined influence of fly ash and selected agricultural and industrial waste admixtures on compaction characteristics, permeability, shear strength, and CBR behaviour of both laterite and black cotton soils. Additionally, the study quantifies the potential reduction in pavement thickness using IRC 37-2018 provisions to establish practical engineering relevance.

Material and Methodology

Soil Samples

Laterite soil and black cotton soil were selected for the experimental investigation. Soil samples were collected form warvandi region of Nashik Maharashtra India. The collected samples were air dried to natural weather condition and then as per Indian Standard (IS) soil were passed through 4.75mm sieve to remove the gravel particles and organic matter before testing. Laterite soil is used in road construction but shows high variability in permeability and compaction characteristics. The black cotton soil have the property of swelling and shrinkage due to the presence of active clay minerals. The engineering and index properties of both the soil were determined as per IS 2720.

Fly ash

Fly ash was obtained from ekhalare nashik thermal power plant for investigation. It is a fine pozzolanic fly ash of C type a by-product generated during coal combustion. Fly ash contributes to soil strength improvement through formation of cementitious compounds when mixed with water and soil particles [25].

Waste Admixtures

The following waste materials were used as soil stabilizing admixtures:

- Waste Glass (WG): Discarded glass materials were crushed and sieved to obtain particles smaller than 4.75 mm.
- Plastic Waste (PW): Collected plastic waste was cleaned and shredded into small strips.
- Rice Husk (RH): Agricultural Residue collected from local rice mill and agriculture field.
- Bagasse Husk Ash (BHA): Obtained from sugar industry waste after controlled burning of baggase.

All waste materials were processed to obtain uniform particle size and moisture conditions prior to mixing.

Mix Proportions

Soil stabilization was performed by mixing soil with different proportions of fly ash and waste admixtures based on dry weight of soil. Adopted mix proportions were:

- Fly ash: 5%, 10%, 15% and 20%
- Waste admixtures: 0%, 3%, 5%, 7% and 9%

The materials were thoroughly blended to ensure uniform distribution before testing.

Experimental Program with Result and Discussion

Laboratory testing was carried out in accordance with IS 2720 standards to evaluate engineering properties of stabilized and untreated soils. The testing program included index property determination, modified proctor test, shear strength parameters, free swell index as shown in table 1. Index properties of soils.

Table 1. Index properties of soils

Test	IS Codes	Laterite Soil	Black Cotton Soil
Specific Gravity	IS:2720 Part 2 - 1964	2.4	2.67
Moisture Content	IS:2720 Part 1	11.17%	15.11%
Particles Size Distribution	IS: 2720 Part 4 - 1985	Silt-74.15% Clay-25.87%	Silt-68.5% Clay-31.6%
Atterbergs Limit	IS: 2720 Part 5-1985		
Liquid Limit		54.96%	58.40%
Plastic Limit		24.43%	30.37%
Plasticity Index		34.53%	28.03%
Proctor Density Test	IS: 2720 Part 7 – 1965		
MDD		1.195 gm/cm^3	1.2118 gm/cm^3
OMC		18.12%	19.43%
Free Swell Index	IS: 2720 Part 40 – 1970	----	58%
Universal Soil Classification		CH	CH

As per index properties of both the soil the soil has been classified as CH = Inorganic clay of high plasticity. The inorganic clay of high plasticity have high settlement problem, expansive behaviour and low bearing capacity which can be improved by fly ash, lime or cement stabilization.

Compaction Behaviour and Density Improvement

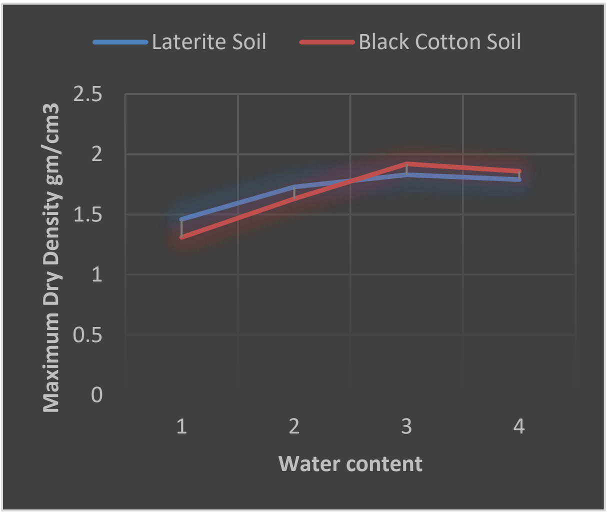
Compaction characteristics were determined using the modified proctor test following is 2720 (Part

7). Soil mixtures were compacted to determine maximum dry density (MDD) and optimum moisture content (OMC) with fly ash and waste admixture as shown in table 2.

Table 2. Modified proctor test of laterite and black cotton soil

Soil	**Laterite Soil MDD (gm/cm^3)**					**Black Cotton Soil MDD (gm/cm^3)**				
% FA	**% Waste Admixture** **0%**	**3%**	**5%**	**7%**	**9%**	**% Waste Admixture** **0%**	**3%**	**5%**	**7%**	**9%**
0%	**1.19**					**1.21**				
5%		1.27	1.36	1.46	1.37		1.24	1.28	1.31	1.26
10%		1.47	1.58	1.73	1.64		1.23	1.34	1.63	1.51
15%		1.73	1.81	**1.83**	1.65		1.51	1.61	**1.75**	1.64
20%		1.62	1.69	1.79	1.73		1.52	1.56	1.66	1.63

According to the findings presented in figure 1, the addition of fly ash and waste admixture significantly influenced compaction characteristics. For laterite soil, the maximum dry density increased from 1.19 g/cm^3 for untreated soil to 1.83 $g/cm^{3,}$ which represents an increase of approximately 65% at 7% waste admixture and 15% fly ash. Similarly, black cotton soil exhibited an increase in dry density from 1.21 g/cm^3 to 1.92 $cm^{3,}$ corresponding to an improvement of about 68% under similar stabilization conditions.



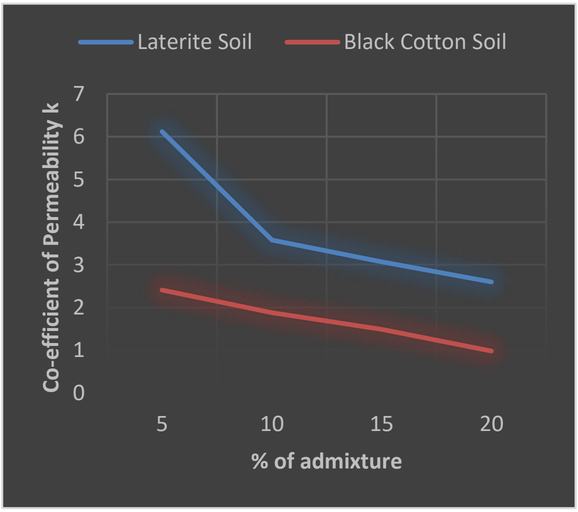


Figure 1. Maximum dry density **Figure 2. Co-efficient of permeability**

The observed increase in maximum dry density can be attributed to improved particle gradation and enhanced inter- particle bonding due to pozzolanic reactions between fly ash and soil minerals, resulting in denser packing and reduced void ratio. The optimum result are obtained for the 7% of admixture and 15% of fly ash, and 7% of admixture with different proportion of fly ash were further used for subsequent permeability, shear strength, and CBR tests.

Hydraulic Behaviour and Permeability Reduction

The Constant Head Permeability Test was conducted following IS 2720 Part (Part 36) to determine the coefficient of Permeability of stabilized soils. From table 3, results indicate a noticeable reduction in the coefficient of permeability decreased from 9.66 x 10^{-3} cm/s to 3.07 x 10^{-3} cm/s, representing a reduction of approximately 26.9%. Similarly, the permeability of black cotton soil decreased from 3.43 x 10^{-3} cm/s to 1.49 x 10^{-3} cm/s, corresponding to a reduction of nearly 28.6%. This reduction in permeability can be attributed to the densification of soil structure and filling of void spaces by fine particles of fly ash wand waste materials. The formation of cementitious products further reduces pore connectivity within the soil matrix. Lower permeability improves resistance against water infiltration, which is particularly beneficial for expansive black cotton soils prone to swelling and laterite soils susceptible to erosion.

Shear Strength Enhancement

Shear strength parameters were evaluated using the direct shear test as per IS 2720 (Part 13). Soil specimens were prepared at their respective MDD and OMC conditions. Tests were conducted under varying normal stresses to determine cohesion (C) and internal friction angle (ϕ).

Table 3. Co-efficient of permeability and direct shear strength

Soil	Laterite			Black Cotton			
% of waste admixture with % of FA	Co-efficient of Permeability (cm/s)	ϕ	Shear Strength $S = C + \sigma \tan\phi$ (kg/cm^2)	Co-efficient of Permeability (cm/s)	C	ϕ	Shear Strength $S = C + \sigma \tan\phi$ (kg/cm^2)
0% of waste admixture with 0% of FA	9.66 x 10^{-3}	22°		3.43x 10^{-3}		21°	
7% of waste admixture with 5% of FA	6.12 x 10^{-3}	26°	7.31	2.41 x 10^{-3}	1.42	24°	6.67
7% of waste admixture with 10% of FA	3.58 x 10^{-3}	28°	7.97	1.88 x 10^{-3}	0.84	26°	7.31
7% of waste admixture with 15% of FA	3.07 x 10^{-3}	38°	11.71	1.49 x 10^{-3}	0.46	32°	9.36
7% of waste admixture with 20% of FA	2.6 x 10^{-3}	33°	9.73	9.82 x 10^{-4}	0.6	29°	8.30

From table 3, results displays a significant improvement in shear strength for soil stabilized with fly ash and waste admixtures. For laterite soil, the maximum shear strength was observed at 7% waste admixture and 15% fly ash, where the internal friction angle increased to 38°, resulting in a shear strength of 11.71 kN/m^2 . Similarly, black cotton soil exhibited a maximum shear strength of 9.36 kN/m^2 under the same stabilization conditions. This observation implies that an increase in normal stress leads to a proportional increase in shear force and increase in proportion with 20% decrease the result. The increase in strength is attributed to pozzolanic reactions, improved particle interlocking, and reduction in void ratio. Beyond 15% fly ash content, marginal reduction in shear strength suggests possible excess fines leading to lubrication effects and reduced interlocking efficiency.

Bearing Capacity Improvement and CBR Performance

Load bearing Capacity was evaluated using the CBR test as per IS 2720 (Part 16). Both soaked and un-soaked tests were performed, and results were used to estimate pavement thickness according to IRC 37-2018 guidelines as shown in table 4. The CBR result for unsoaked and soaked test are from 2.5 mm penetration as the result was greater than 5 mm penetration of CBR result.

Table 4. California Bearing Ratio for unsoaked and soaked test

Soil		Laterite Soil		Black Cotton Soil	
	% of admixture with % of FA	**Unsoaked**	**Soaked**	**Unsoaked**	**Soaked**
1	**0 % of admixture with 0 % of fly ash**	8.50%	4.18%	6.75%	2.56%
2	**7% of admixture with 5% of fly ash**	8.55%	4.21%	7.21%	2.91%
3	**7% of admixture with 10% of fly ash**	9.92%	6.35%	8.72%	3.45%
4	**7% of admixture with 15% of fly ash**	11.43%	8.35%	10.31%	5.64%
5	**7% of admixture with 20% of fly ash**	14.81%	8.61%	11.21%	6.81%

The results demonstrate a substantial increase in CBR values with the addition of fly ash and waste admixtures. From figure 3 for laterite soil, the unsoaked CBR value increased from 8.5% for untreated soil 14.81%, representing an improvement of approximately 74.2%. Similarly, the CBR value of black cotton soil it increased from 6.75% to 11.21%, corresponding to an improvement of about 66.1%. From figure 4 under soaked conditions, the CBR value for laterite soil increased from 4.18% to 8.61%, while for black cotton soil it increased from 2.56% to 6.81%. These improvement indicated enhanced resistance to moisture-induced weakening of the soil. The increase in CBR value can be attributed to the combined effects of improved compaction, increased shear strength, and reduced permeability. The stabilized soil structure become more rigid and capable of supporting higher loads, which is essential for pavement subgrade performance.

Figure 3. Unsoaked Test

Figure 4. Soaked Test

For black cotton soil the CBR value increases by 2.56% to 6.81% which is almost an increase of 166% with waste material admixture. These improvements indicates enhanced load carrying capacity and reduced moisture-induced softening, which is particularly beneficial for expansive black cotton soils subjected to seasonal wetting and drying cycles.

Pavement Thickness Reduction and Engineering Implications

The cost analysis of road embankment depend upon the thickness of pavement, which is taken from IRC 37-2018.

Assume traffic density for Highway or Expressway = 40msa
According th the IRC 37-2018 the figure of catalogue for pavemnt with bituminous surface course with granular base and sub base of thickness of pavement vs design traffic in MSA (Million Standard Axle) depend upon the value of CBR %.

Untreated Soil:

- The CBR value of soil is 8.5% for laterite soil and 7.21% for black cotton soil.
- For 8% CBR the thickness of pavement is 595 mm for laterite soil and for 7% CBR the thickness of pavement is 605 mm for black cotton soil.
- Therefore the thickness of pavement for 8.5 % CBR By interpolation is 632.187 mm and for 7.21% CBR value is 612.85 mm.

Stabilized Soil (Soil + Waste Material):

- The CBR value of soil with waste material for laterite soil and black cotton soil is 14.81% and 11.21% respectively.
- The thickness of pavement for 15 % cbr value is 565 mm
- The thickness of pavement for 12% cbr value is 580 mm

Therefore the thickness of pavement for 14.81% is 557.84 mm and for 11.21% is 541.81 mm by interpolation. The thickness of pavement decreases by 74.347 mm i.e. 11.76% in laterite soil and in black cotton soil it decreases by 71.04 mm i.e. 11.6%. so it can be concluded that cost of road embankment construction decreases. The reduction in pavemnet thickness not only lowers material consumption and construction cost but also contributes to sustainable infrastructure development through reduced extraction of natural aggregates.

Conclusion

The stabilization of road embankment relies on the soil’s strength, and strength can be enhanced by adding an admixture to the soil. The laboratory investigation indicates that the inclusion of small percentages of admixture from 3% to 9% together with 5% to 20% fly ash improves several engineering properties of the laterite and black cotton soil.

- The maximum dry density increased and optimum moisture content showed changes consisted with denser packing.
- The direct shear strength parameters and CBR values were also improved for certain combinations notably 7% admixture with 15% fly ash for shear strength and 20% fly ash for CBR in laboratory conditions.
- The reduction in permeability enhances the moisture content resistance of the soil up to 26- 29%, which reduces the risk of swelling in black cotton soil and erosion in laterite soil.
- The thickness of pavement decrease about 74 mm which can save the construction cost of road embankment and total construction cost of road also.
- This research leads to the conclusion that both admixture and fly ash have the potential to alter the characteristics of laterite soil and black cotton soil, making it useful for various civil engineering applications.

These laboratory results suggest potential for reducing pavement thickness and construction cost with proper implementation. Moreover the results are superior compared to treating black cotton soil with admixture and fly ash. However, the findings are specific to the materials and test conditions used here; field validation, longer-term performance monitoring and environmental assessments are recommended prior to adoption in design practice.

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