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Experimental Evaluation of Eco-Friendly Hybrid Reinforcement By using Jute and Industrial By Products for Pavement Subgrade Stabilization

Mr. Harinath N
Lecturer, R L Jalappa Polytechnic-599, Doddaballapura-561203

Abstract **- This study investigates the use of jute fibres and fly ash for sustainable pavement subgrade stabilization. Laboratory tests were conducted to evaluate the engineering properties of untreated and stabilized soil, including compaction characteristics, California Bearing Ratio (CBR), and unconfined compressive strength (UCS). The results reported in the study indicate that combining fly ash and jute fibres improves subgrade strength, load-bearing capacity, and resistance to deformation. A mixture containing 10% fly ash and 0.5% jute fibre was identified as the optimum combination. This eco-friendly approach utilizes industrial by-products and renewable natural fibres, offering potential for sustainable flexible pavement construction, particularly for rural and low-volume roads.**

Keywords - Jute fibre, Fly ash, Subgrade stabilization, CBR, UCS, Hybrid reinforcement, Sustainable pavement construction.

1- INTRODUCTION

The performance and service life of pavement structures largely depend on the strength and stability of the subgrade soil. Weak subgrade conditions often result in pavement distress such as rutting, cracking, and uneven settlement, leading to increased maintenance costs and reduced pavement life. Conventional subgrade stabilization techniques using cement, lime, or chemical additives, although effective, pose environmental challenges due to high carbon emissions, excessive energy consumption, and depletion of natural resources. With increasing emphasis on sustainable and eco-friendly construction practices, alternative stabilization materials are gaining importance in pavement engineering. Natural fibers such as jute are biodegradable, renewable, cost-effective, and widely available, particularly in developing countries. Jute fibers possess adequate tensile strength and frictional characteristics, which help improve soil reinforcement, crack resistance, and load transfer capacity. In parallel, industrial by products such as fly ash, ground granulated blast furnace slag (GGBS), or similar waste materials offer significant potential for soil improvement while addressing industrial waste disposal and environmental pollution issues. The use of hybrid reinforcement, combining natural fibers with industrial by products, provides a sustainable approach to subgrade stabilization by leveraging the complementary properties of both materials. Jute fibers improve ductility and reduce brittleness, while industrial by products enhance strength, reduce plasticity, and improve long-term performance of the stabilized soil. This integrated method contributes to environmentally responsible pavement construction and supports the concept of circular economy. The present project titled “Experimental Evaluation of Eco-Friendly Hybrid Reinforcement by Using Jute and Industrial By products for Pavement Subgrade Stabilization” focuses on evaluating the effectiveness of this hybrid stabilization technique through laboratory experimentation. The study aims to assess improvements in engineering properties of subgrade soil and to explore the feasibility of adopting eco-friendly materials as alternatives to conventional stabilization methods.

A.Problem statement

- Weak subgrade soil: Many road pavements fail prematurely due to weak and low-bearing-capacity subgrade soils that cannot withstand repeated traffic loads.
- High construction costs: Conventional soil stabilization methods using cement, lime, or synthetic materials are costly and increase project expenses.
- Environmental concerns: Traditional stabilizers (cement, lime, chemicals) contribute to carbon emissions and environmental degradation.
- Many pavement failures occur due to weak and poorly performing subgrade soils, which lead to excessive deformation, cracking, and reduced service life of flexible pavements.
- Conventional subgrade stabilization methods commonly use cement, lime, or chemical additives.

B. Scope of the Work

- Collection and characterization of locally available subgrade soil.
- Selection and preparation of jute fibres and suitable industrial by products for stabilization.
- Preparation of soil samples with varying proportions of jute fiber and industrial by products.
- Conducting laboratory tests such as Atterberg limits, Standard/Modified Proctor test, CBR test, and shear strength tests to evaluate soil performance

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- Analysis and comparison of test results to identify the optimum combination of hybrid reinforcement.
- Evaluation of environmental and economic benefits of using eco-friendly stabilization materials.

C. Objectives

- To study the engineering properties of natural subgrade soil used for pavement construction.
- To evaluate the suitability of jute fiber as a natural reinforcement material for subgrade stabilization.
- To assess the effect of selected industrial by products on the strength and stability of subgrade soil.
- To investigate the combined effect of hybrid reinforcement (jute + industrial by products) on subgrade performance.
- To determine improvements in key parameters such as California Bearing Ratio (CBR), compaction characteristics, shear strength, and deformation behavior.
- To compare the performance of untreated soil with stabilized soil mixes.

2-LITERATURE SURVEY

"Application of Jute Fiber for the Improvement of Subgrade Characteristics"

Author(s):KamrulHasan
Publication year: 2015

This study focuses on the use of jute fibre to improve the engineering properties of subgrade soil. Jute fibre acts as a natural reinforcing material that can improve soil resistance to deformation and enhance its load-bearing behaviour. The effectiveness of reinforcement depends on factors such as fibre content, fibre dimensions and soil characteristics. The study is relevant to the present research because it establishes the potential of jute fibre as an eco-friendly material for improving pavement subgrade performance.

"A Review on Stabilization of Indian Soils for Road Construction by Using Jute Fiber"
Author(s): Vijinder Singh and Vinod Kumar Sonthwal

This review examines the application of jute fibre for stabilizing Indian soils used in road construction. It discusses the potential of natural fibre reinforcement as an alternative approach to improving soil engineering properties. Jute fibre can help reinforce the soil matrix and improve its resistance to deformation. The study provides background for investigating natural fibres as sustainable materials in pavement construction.

"A Study on Soil Stabilization with Jute and Coir in Highway Sub-Grade"

Author(s): Uzma Farooq, Kamal Preet Kaur and NeerajKumar
Publication year: 2021

This study addresses the use of jute and coir fibres for highway subgrade stabilization. Natural fibres are considered as reinforcement materials because of their availability and potential to improve the mechanical behaviour of soil. Their effectiveness depends on the fibre proportions, soil type and mixing conditions. This research is relevant to evaluating jute fibre as a sustainable reinforcement material for pavement subgrades.

"Enhancing Soil Subgrade Strength with Eco-Friendly Materials"

Author(s): Zen Pravin Raut, Manendra Pratap Verma and Sapana Madan

This study focuses on improving subgrade strength using environmentally friendly materials. The use of alternative stabilizing materials can reduce dependence on conventional soil treatment methods and support sustainable road construction. The research topic is relevant to the present investigation, which evaluates natural jute fibre and fly ash as materials for improving the strength and stability of weak subgrade soil.

"Subgrade Soil Stabilization Using Jute Fibre as a Reinforcing Material"

Author(s): Anzar Hamid and Huda Shafiq
Publication year: 2017

This study investigates the use of jute fibre as a reinforcing material for subgrade soil stabilization. Natural fibres can improve the interaction between soil particles and provide resistance against deformation. The effectiveness of jute fibre depends on its proportion and distribution within the soil. This study is relevant to the present work because it considers the mechanical reinforcement of weak soil using a renewable material.

3-METHEDOLOGY

A. Materials Used

The experimental investigation was conducted to evaluate the effectiveness of hybrid reinforcement using jute fibre and fly ash for pavement subgrade stabilization. The materials used in the study were locally available subgrade soil, Class F fly ash, jute fibres, and potable water.

1) Subgrade Soil: Soil was collected from the Doddaballapur region. The collected soil was air-dried, pulverized, and passed through a 4.75 mm sieve to remove larger particles and impurities. The soil was characterized through laboratory tests to determine its basic geotechnical properties. The reported specific gravity was 2.67, and the liquid limit was 40%.

2) Fly Ash: Class F fly ash, obtained as an industrial by-product of coal combustion in thermal power plants, was

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selected as the stabilizing material. It contains silica, alumina, and iron oxide, which contribute to the potential for pozzolanic reactions under suitable conditions. The reported specific gravity was 2.28, and the combined content of silicon dioxide, aluminium oxide, and iron oxide was 88.7%.

3) Jute Fibre: Natural jute fibre was used as a biodegradable reinforcement material. The fibres were cut into short lengths to facilitate uniform mixing with the soil. The mix-design section of the report specifies a fibre length of 10–20 mm. Jute fibres provide mechanical reinforcement and are intended to improve ductility and resistance to crack propagation.

4) Water: Clean potable water was used to prepare the soil mixtures and achieve the required moisture content during compaction.

B. Characterization of Soil and Materials

Preliminary laboratory investigations were carried out to establish the properties of the untreated soil and selected stabilizing materials. The soil tests included specific gravity, grain-size distribution, natural moisture content, Atterberg limits, compaction characteristics, and permeability. The California Bearing Ratio (CBR) and unconfined compressive strength (UCS) were used to evaluate the bearing capacity and strength of the soil.

The liquid limit was reported as 40%, while the untreated soil had a maximum dry density (MDD) of approximately 1.80 g/cm³ and an optimum moisture content (OMC) of approximately 14%. The reported coefficient of permeability before stabilization was 0.096 cm/s. These properties were used as reference values for comparison with the stabilized mixtures.

C. Mix Proportions

Different combinations of soil, fly ash, and jute fibre were considered to investigate the influence of hybrid reinforcement on subgrade performance. The principal mix proportions reported in the study are presented in Table I.

Table i. Mix proportions used in the study

Mix ID	Soil (%)	Fly Ash (%)	Jute Fibre (%)
M1 – Control	100	0	0
M2	95	5	0.5
M3	90	10	0.5
M4	85	15	0.5

The fly ash content was varied from 0% to 15%, while the jute fibre content was maintained at 0.5% in the main hybrid mix series. The untreated soil was used as the control specimen. The proportions were examined to identify a combination that provided improved strength and bearing capacity.

D. Preparation of Soil Mixtures

The soil was first air-dried, pulverized, and sieved. The required quantity of fly ash was then added to the soil according to the selected mix proportion. The materials were mixed thoroughly to obtain a reasonably uniform distribution of fly ash. The pre-cut jute fibres were gradually incorporated into the mixture, taking care to minimize fibre clustering and uneven distribution.

Potable water was added gradually to achieve the moisture content required for compaction. The report indicates an OMC of approximately 14% for the untreated soil; the appropriate moisture content for each stabilized mix was to be determined from its compaction characteristics. The prepared mixtures were then used for the relevant laboratory investigations.

E. Compaction Test

Compaction testing was carried out to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the soil mixtures. The prepared soil was mixed with measured quantities of water and placed in a compaction mould in layers. Each layer was compacted using the rammer and procedure specified for the selected Proctor compaction test. The compacted mould was weighed, and the moisture content was determined.

The procedure was repeated at different moisture contents. Dry density was calculated for each moisture content, and a dry-density-versus-moisture-content curve was used to identify the MDD and OMC. These parameters were used to guide the preparation of specimens for strength testing.

F. California Bearing Ratio (CBR) Test

The CBR test was used to evaluate the bearing capacity of the untreated and stabilized soil mixtures. The prepared soil was placed and compacted in a CBR mould according to the selected test procedure. Where required by the adopted procedure, specimens were subjected to soaking before testing. A penetration plunger was then applied at a controlled rate, and the corresponding loads were recorded at specified penetration values.

The CBR value was calculated from the measured load and the corresponding standard load. The values obtained for the untreated and stabilized mixtures were compared to assess the influence of fly ash and jute fibre on pavement subgrade performance.

G. Unconfined Compressive Strength (UCS) Test

The unconfined compressive strength test was used to assess the compressive strength of the prepared soil mixtures. Specimens were prepared from the selected mixtures and subjected to axial loading without lateral confinement. The applied load and deformation were recorded during testing until failure or the applicable termination criterion was reached.

The maximum compressive stress was used to determine the UCS of each specimen. The UCS values of the stabilized mixtures were compared with those of the untreated soil to evaluate the improvement in strength due to hybrid reinforcement.

H. Permeability Evaluation

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Permeability was evaluated to examine the movement of water through the soil before and after stabilization. The report describes a field permeability procedure in which a permeability ring was inserted into the soil, water was maintained at a specified head, and the volume of infiltrated water was measured over a known time interval. The coefficient of permeability was calculated using the relevant test relationship.

The reported permeability decreased from 0.096 cm/s before stabilization to approximately 0.065 cm/s after stabilization. This reduction indicates lower water infiltration in the stabilized soil under the reported test conditions.

I. Comparison and Identification of the Optimum Mix

The results of the compaction, CBR, UCS, and permeability investigations were compared to assess the performance of the different mixtures. The untreated soil served as the reference, and the effects of increasing fly ash content in the presence of jute fibre were evaluated using the reported test results.

The study identified the mixture containing 10% fly ash and 0.5% jute fibre as the optimum combination among the reported mixes. This mixture achieved a reported UCS of 265 kPa and a CBR value of 8%, compared with a UCS of 110 kPa and a reported CBR value of approximately 3% for the untreated soil. At 15% fly ash, the reported strength values decreased slightly, indicating that increasing the stabilizer content beyond the optimum level did not provide further improvement.

The methodology therefore provides an experimental basis for evaluating the use of natural jute fibre and industrial fly ash in pavement subgrade stabilization, with particular emphasis on strength, bearing capacity, compaction behaviour, and permeability.

4-RESULTS AND DISCUSSION

A. Effect of Hybrid Stabilization on Strength Properties

The experimental results indicate that the addition of fly ash and jute fibre improved the strength characteristics of the subgrade soil. The untreated soil exhibited a low unconfined compressive strength (UCS) of 110 kPa and a California Bearing Ratio (CBR) of approximately 3%. With the incorporation of fly ash and 0.5% jute fibre, both UCS and CBR increased. The maximum reported values were obtained at 10% fly ash and 0.5% jute fibre.

Table ii. Strength characteristics of different mixtures

Mix ID	Fly Ash (%)	Jute Fibre (%)	UCS (kPa)	CBR (%)
M1	0	0	110	3
M2	5	0.5	185	5
M3	10	0.5	265	8
M4	15	0.5	240	7

The UCS increased from 110 kPa for untreated soil to 265 kPa for the mixture containing 10% fly ash and 0.5% jute fibre, representing an increase of approximately 141%. Similarly, the CBR increased from 3% to 8%, indicating an improvement in bearing capacity. These results suggest that the combined use of fly ash and jute fibre enhanced the load-bearing performance of the soil under the reported test conditions.

B. Influence of Fly Ash Content

The strength values increased as the fly ash content increased from 0% to 10%, while the jute fibre content was maintained at 0.5%. At 5% fly ash, the UCS and CBR reached 185 kPa and 5%, respectively. Increasing the fly ash content to 10% further improved the UCS to 265 kPa and the CBR to 8%.

However, when the fly ash content increased to 15%, the UCS decreased to 240 kPa and the CBR decreased to 7%. This reduction suggests that excessive fly ash may not provide additional strength improvement under the conditions investigated. The results therefore identify 10% fly ash, combined with 0.5% jute fibre, as the optimum mixture among the proportions reported in this study.

C. Role of Jute Fibre in Soil Reinforcement

Jute fibre provides mechanical reinforcement within the soil matrix. Its presence can help bridge developing cracks, redistribute stresses, and improve resistance to deformation. The report describes the stabilized soil as exhibiting more gradual failure and better crack control than untreated soil.

Fly ash and jute fibre serve complementary functions: fly ash contributes to particle bonding and stabilization, while jute fibre provides reinforcement and helps improve ductility. Their combined use offers a potential means of improving both the strength and deformation behaviour of pavement subgrade soil. However, the individual contribution of jute fibre cannot be quantified independently from the reported hybrid-mixture results alone.

D. Compaction and Moisture Characteristics

The untreated soil had a reported maximum dry density (MDD) of approximately 1.80 g/cm³ and an optimum moisture content (OMC) of approximately 14%. The report indicates that the addition of fly ash and jute fibre improved compaction behaviour, although the exact MDD and OMC values for each stabilized mixture are not provided in the comparative results.

Fly ash may influence particle packing and the moisture requirements of the soil mixture, while the distribution of jute fibres can affect the compacted soil structure. Therefore, the compaction characteristics of each mixture should be considered when preparing specimens and applying the stabilization method in the field.

E. Permeability Behaviour

The reported coefficient of permeability decreased from 0.096 cm/s for untreated soil to approximately 0.065 cm/s after stabilization. This represents a reduction of approximately 32.3%.

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The lower reported permeability indicates reduced water movement through the stabilized soil under the test conditions. Improved particle packing and bonding may contribute to this behaviour. Reduced infiltration can be beneficial for subgrade performance; however, further testing under different moisture conditions and repeated wetting and drying would be required to establish long-term durability.

F. Identification of the Optimum Mixture

Considering the reported UCS, CBR, and permeability results, the mixture containing 10% fly ash and 0.5% jute fibre provided the best overall performance among the investigated hybrid mixtures. It achieved a UCS of 265 kPa and a CBR of 8%, compared with 110 kPa and 3%, respectively, for the untreated soil.

The decrease in UCS and CBR at 15% fly ash further indicates that increasing the fly ash content beyond the optimum level did not improve strength. Based on these findings, the combination of 10% fly ash and 0.5% jute fibre is identified as the preferred mixture within the scope of the reported experimental investigation.

Overall, the results support the potential application of jute fibre and fly ash as hybrid stabilizing materials for pavement subgrade improvement. Further investigations involving replicate specimens, detailed compaction results, controlled curing periods, and long-term durability testing would strengthen the assessment of its practical suitability.

5-CONCLUSION

The present study investigated the effectiveness of hybrid soil stabilization using fly ash and jute fibre to improve the engineering properties of soil for pavement subgrade applications. The experimental results showed that the combination of fly ash and jute fibre improved the strength characteristics of the soil compared with untreated soil. Among the mixtures investigated, the mixture containing 10% fly ash and 0.5% jute fibre exhibited the best performance, with the unconfined compressive strength increasing from 110 kPa to 265 kPa, representing an improvement of approximately 141%. The California Bearing Ratio (CBR) also increased from 3% to 8%, indicating improved resistance to penetration and potential suitability for pavement subgrade applications. However, increasing the fly ash content to 15% resulted in a reduction in both UCS and CBR, suggesting that excessive fly ash did not provide additional strength improvement under the tested conditions. The permeability decreased from approximately 0.096 cm/s to 0.065 cm/s, representing a reduction of about 32.3%. The combined use of fly ash and jute fibre therefore shows potential for improving selected engineering properties of pavement subgrade soil while utilizing an industrial by-product and a natural reinforcing material. Based on the mixtures evaluated, 10% fly ash with 0.5% jute fibre was identified as the optimum combination. Further studies on durability, wet–dry cycles, repeated testing, and field performance are recommended to validate the long-term suitability of this stabilization technique.

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