A Review on The Utilization of Geosynthetics and Natural Fibers in Enhancing the Pavement Subgrade Strength

Upeksha Divyangani
Department of Civil Engineering
SLTC Research University
Padukka, Sri Lanka
upekshad@sltc.ac.lk

Chamod Hettiarachchi
Department of Civil Engineering
SLTC Research University
Padukka, Sri Lanka
chamodh@sltc.ac.lk

***Abstract*—The practice of reinforcing subgrade soil to improve its strength, a technique with roots dating back centuries, remains a crucial engineering endeavor, particularly in regions plagued by weak subgrades and challenging soils like expansive silts and clays with high swelling-shrinkage characteristics and low-bearing capacity. The conventional method of subgrade modification through excavation and replacement, marked by its exorbitant costs and time-consuming nature, has given way to alternative solutions, prominently natural and synthetic reinforcement methods. Geosynthetics including polypropylene fibers (PP), polyethylene fibers (PE), polyester fibers (PET), glass fibers, nylon fibers, steel fibers, and polyvinyl alcohol fibers (PVA), are widely employed for this purpose. Additionally, eco-friendly and cost-effective natural fibers like coir, sisal, palm, jute, hemp, bamboo, and kenaf fibers are gaining attraction. These fibers, their lengths, compositions (typically within the range of 0.2% to 1.5% of soil weight), and arrangements within soil samples have been subjected to extensive experimentation. Through laboratory analysis and testing, including sieve analysis, sedimentation analysis, Atterberg limits, and Standard Penetration Cone (SPC) tests, researchers have consistently demonstrated that reinforced soils exhibit improvement in shear strength, axial strain due to failure, load-bearing capacity, and California Bearing Ratio (CBR) strength. These findings underscore the potential for efficiently stabilizing problematic soils for road pavement construction using both natural and synthetic fibers, ultimately enhancing subgrade performance. This comprehensive review highlights the value of stabilizing problematic soils for constructing road pavements using natural and synthetic fibers.**

Keywords—Subgrade modification, geosynthetic, natural fiber, reinforcement, pavements

I. Introduction

A. The Significance of Soil Reinforcement

The construction and maintenance of pavements are considered a vital infrastructure component. It is stated that the soil can be classified into four types: gravel, sand, silt and clay. Certain soils have low shear and tensile strengths, and their other properties also rely on the surrounding environmental factors [1]. Another efficient and dependable method in improving the technical attributes of soil is the incorporation of reinforcing inclusions [2].

Stabilization is a technique of improving the engineering attributes of soil by utilizing different compounds to guarantee that it is appropriate for construction [3]. Numerous techniques have been developed over time, particularly for ground improvement and soil stability. These techniques can be roughly categorized into three different kinds: mechanical, chemical, and physical [4]

B. Methods of Soil Reinforcement

Soil reinforcement can be done in three ways; physical, chemical, and mechanical. Reinforcement can further be divided into two main groups: preferably inextensible inclusions which are metal strips and bars and ideally extensible inclusions known to be natural and synthetic fibers[4]. When soil reinforcement first began, the weak soil layer was removed and replaced with a more acceptable soil layer. However, this method is tedious and costly. Therefore, engineers' resort to the use of geosynthetics such as geotextiles, geogrids, geomembranes, and geo-composites [5].

II. Reinforcement of Soil by Fibers

A. Alternatives to Traditional Methods of Reinforcement

Natural fibers are readily available, often nonabrasive, and absorb nitrogen and phosphorus from the soil as well as carbon dioxide from the air at a very high rate [6]. Alternatives such as using natural and synthetic fibers are becoming popular nowadays. Research conducted has shown desirable effects on the engineering properties of soil once it has been incorporated with fiber [7] A variety of natural fibers, also known as "eco-composites", including bamboo, sisal, jute, flax, barely straw, and coconut coir, have been investigated as stabilizers to improve the qualities of soil [8]. Whereas types of synthetic (man-made) fibers [9] include polypropylene fibers (PP)[10][4], polyethylene fibers (PE), glass fibers[11], nylon fibers, steel fibers, polyester fibers (PET) and polyvinyl alcohol fibers (PVA). The distribution of fiber orientation greatly affects how the fibers causes changes to the strength and failure of fiber-reinforced soil [7].

B. Natural Fibers–Various Treatment Methods

1) Physical Treatments: Studies on the morphology of coir fibers reveal the lignin sheath that surrounds the cellulose fibers. Usually, removing this lignin layer from the surface yields a better and more stable matrix. Understanding the characteristics of the cell wall segments and how they relate to fiber characteristics is crucial to realizing how fibers of lignocellulosic can be used in high-performance industrial applications [12]. Natural fibers carry amorphous regions, other polar groups as well as hydroxyl compounds that increase its ability to absorb moisture while leading to a descending manner in the mechanical properties of the fiber, which ultimately leads to biodegradation [13]. Physical techniques improve fiber-matrix cohesiveness by altering surface qualities rather than the structural makeup of the fibers. Corona, plasma, ultraviolet (UV), fiber pounding, and heat therapy are examples of physical treatment methods. These methods are only used to alter the characteristics of natural fibers surfaces [14]. Many natural fibers' surfaces have been effectively modified via plasma treatment. Mechanical characteristics of natural fibers were found to greatly improve after plasma treatment. Similar to plasma treatment, surface etching caused by it may increase surface roughness and produce a better interface[12]. The UV treatment approach improves the polarization of the fiber surface, improving fiber moisture adsorbtion and boosting overall strength [15]. An increase in the resilience of natural fibers by 10% can be achieved by using the fiber-beating method, increasing the surface area, defibrillating the fibers, and mechanical interlocking. In heat treatment, heat is applied to fibers to a degree slightly below the point at which they break down. This situation affects the fibers' mechanical, chemical, and degree of polymerization as well as their chemistry, strength, and water content [12], [13].

2) Chemical Treatments: The adhesion between the matrix and natural fibers is strengthened by chemical processes[16]. Usually natural fibers can be treated chemically by means of alkali (mercerization), silane treatment, peroxide treatment, etc. It has been shown that with an alkali treatment, where the fiber is treated with sodium hydroxide (NaOH), the mechanical properties can be improved significantly by modifying its crystalline structure and removing hemicellulose and lignin from its structure [13] In order to enhance the chemical interactions between natural fibers and the polymeric matrix, silanes are a favourable and adaptable class of coupling agents [12], [16].

III. Existing Literature on Natural and Synthetic Fibers on Soil Reinforcement

A. Case Studies on Subgrade Improvement by Natural Fibers

With the abundance of natural fibers in several countries, engineers have paid a fair amount of interest in the application of natural fibers on soil reinforcement. The vitality of natural fibers in the contemporary construction industry is defined by the term "eco-composite.". Many studies have been conducted to evaluate the improvement of subgrade strength by the combination of fibers with the problematic soil in question.

1) Coconut (coir) Fibers: The coconut tree, *Cocos nucifera* (L.) (Arecaceae), is made up of the drupe, or edible fruit, which has a fibrous husk covering it. (mesocarp). This mesocarp is available in two types; namely brown fiber and white fiber, where the brown fiber is the more mature and dried-up fiber from the husk that is used to produce several household and industrial placement items such as geotextiles. In a study conducted by [17] uses brown–washed coir in percentages of 0% to 1% with an increment of 0.25% of 20mm length, added in a discrete arrangement. A California Bearing Ratio (CBR) test was conducted on the parent soil sample and the reinforced sample, and it was concluded that the strength of the soil improve with the increasing number of reinforcement layers (specifically at a depth of 1/3 of soil). In another study conducted on problematic soil mixing four types of fiber; including coir fiber, were also added in percentages of (0.5% to 1%) with a gradiation of 0.25% of the weight of the soil. An extreme learning machine (ELM) approach was used in this study and it showed that the use of coir fiber increased the soil-fiber density, further increasing the strength of the subgrade [8] [18] has incorporated coir fiber geotextiles in the process of improving the subgrade soil and has found out that the bearing capacity improved with the reinforcement by 1.83 times, the soaked California Bearing Ratio (CBR) value was improved and that the durability of a coir geotextile was about four to six years depending on the chemical and physical properties of the soil. [19] conducted research on the use of coir fiber as well as thermoplastic waste in subgrade modification where they found out that the tensile strength and flexural strength of the soil improved with the fraction of fiber used between 20%-30% of its total weight of soil. Another research conducted by [20]showed that the use of coir fiber (CF) in clay soil improved the subgrade by increasing its CBR value with the inclusion of CF. Another study conducted by [21] used fiber content of 0.2% to 1% with an increment of 0.2% by weight of soil. The results showed that the CBR strength of the soil sample increased by 4.6 times. A study conducted with the use of coir fiber showed that the CBR strength of soil yields higher strength with the addition of 0.3% fiber into the soil mixture [22].

2) Sisal Fibers: Agave sisalana, a succulent plant of the *Agave genus*, produces the leaves that are used to make sisal, a natural fiber. In arid or semi-arid locations, like sections of Africa, South America, and Asia, sisal plants are largely grown. A study used a random inclusion of 0.25% to 1.0% of sisal fiber by weight of subgrade soil. The fiber was used at a desired length of 30mm. The prepared subgrade samples were soaked to cause capillary rise. According to the test results, the capillarity impact caused the tensile and compressive strengths of 10 kPa and 20 kPa pre-compressed specimen to drop from an average of 1.48 MPa to 0.98 MPa when compared to non-capillary specimen. Without capillary effects, a strength gain of 12.21% and 63% would be comparable. Compared to un-pre compressed specimens evaluated under tension, 11 were recorded for pre-compressed specimens at 10 kPa and 20 kPa.

The test results were obtained by conducting a splitting tensile strength (STS) test [23]. Another study done by [24] on black cotton soil by the inclusion of sisal fiber in 0.25% to 1.50% with a gradation of 0.25% of the weight of soil. The soil was further mixed with rice husk ash in equal amounts and the test was concluded showing that a percentage of 0.75% of fiber provides a maximum value of 7.22 (being 4.24 times greater than the control sample) in terms of CBR strength. For fiber lengths of 10, 15, and 20 mm, varied percentages of sisal fibers were utilized to evaluate various compaction metrics, including California bearing ratio (CBR), and unconfined compression strength tests (UCS). According to the literature used, the maximum density (MDD) of soil mixed with fiber somewhat dropped as fiber content and length increased, although the ideal moisture content (OMC) slightly increased. With increasing fiber length and content, the California bearing ratio (CBR) and unconfined compressive strength (UCS) both rose remarkably; this rise was evident at 15 mm fiber length and fiber content of 1.5% [25].

3) Palm Fibers: A study was conducted on the effects of adding palm fiber with lengths between 30 and 35 mm and percentages between 0.1% and 1.0% by weight of soil on the strength of subgrade soil. A number of laboratory experiments, such as compaction, an unconfined compression test, and a 4-day soak California bearing ratio test, were performed on it. According to the findings, the maximum density reduced as the fiber content improved while the ideal moisture content increased. The maximum soaking CBR value for palm fiber inclusion was 14%, and the unconfined compression value was 352 kPa. These peak values were found at 0.2% fiber, which is the ideal fiber content [26].

4) Jute Fibers: A natural plant-based fiber known as jute,

Corchorus Olitorius, and *Corchorus capsularis*, is harvested from the plant's stem. In countries with tropical climates, such as India, Bangladesh, and other areas of Southeast Asia, jute is largely farmed. Two types of clayey soil were used in the study. The soil was mixed with 0.25 to 1.25 percent jute fiber, with increments of 0.25 percent and length variations of 0.5 to 1.5 centimeters. The samples underwent optimum moisture content tests, unconfined compression (UCC) tests – to obtain the shear strength parameters of cohesive soils, unconfined compressive tests (UCS) – to determine the soil failure point in compression at a given load per unit area, and California Bearing Ratio (CBR) tests to evaluate their strength improvement in relation to its control sample. Results showed that the 1cm fiber with a percentage of 0.75% fiber content showed an increase in both UCS and CBR values, providing evidence that jute fiber is a good reinforcement material for problematic soils [27]. A research conducted by [28] where jute fiber of 25mm length was mixed with the soft soil by percentages varying from 0.25% to 1.0% by weight of soil. then its fundamental characteristics were identified, including compaction characteristics, unconfined compressive strength, and California bearing ratio in both soaked and unsoaked circumstances. The results showed that with the addition of the jute fiber, the CBR strength of the sample was increased from 2.8% to 6.5% under soaked conditions. A study conducted on clayey soil with a variation of jute fiber percentages from 0.3% to 0.9% was also done. The addition of jute fiber with a 0.6% content and a length of 6 mm to soft soil specimens arranged at the maximum density and ideal moisture content produced the most effective fiber-reinforcing effects [29].

5) Hemp Fibers: Hemp fiber is a natural fiber derived from the stalks of the hemp plant (*Cannabis sativa*) [30] To evaluate the strength parameters of clay with hemp fiber reinforcement, a study was conducted with a specimen of control clay sample mixed with fiber percentages which vary from 0.5% to 1.5% with a gradation of 0.25%. The length of hemp fibers was kept constant at 4cm. The samples then underwent a series of tests to evaluate their undrained shear strength characteristics and were successful in providing that the strength of fiber-reinforced clay indeed improved from 0.5% to 1.25% and then decreased from then onwards. The optimum fiber content was determined to be 1.25% [31]. Further research on the effectiveness was done by [32] where they included a mixture of hemp fiber and coir fiber in percentages of 0.1% to 0.4% by mass of black cotton soil treated with alkali-activated binder. The length of the fiber was kept at 25mm. the results concluded that it increased the resilience of soil fibers to freeze-thaw cycles. The strength-bearing ratio was considerably enhanced in terms of CBR performance by the formation of active cementitious bonding and interfacial friction along the exterior of fiber and clay particles. A further investigation was done on a soft soil subgrade that was combined with an alkali-activated binder and included 0.2% to 0.8% of fiber by weight of the soil. This was an extension of the research done by [32]and[33].

6) Bamboo Fibers: Bamboo fiber is yet another natural fiber that is currently being used in the modification of subgrade strength. Many researchers did study on a soil sample by reinforcing it with bamboo fiber at varied percentages from 0.2% to 1.4% with an increase of 0.2%, as the strength characteristics of the subgrade mostly depend on the CBR value of the reinforced soil sample. The length of the fibers was selected to be 10mm and 20mm. The CBR value of common soil is raised and ductility behavior is improved by the combination of fiber with soil. According to the test results, soil's CBR value when and wet rises as bamboo fibers are longer and bigger in diameter. Additionally, it was discovered that adding more bamboo fiber raises the CBR value of reinforced soil; this increase becomes significant at 1.2% of the total amount of fiber. The thickness of the pavement will decrease due to this significant increase in CBR value [34]. To investigate further the effectiveness of using bamboo fiber, [35] added a ratio of 1% to 5% of fiber percentages to a problematic soil and found out that there was a tendency of all specimens compressive stresses to rise as the amount of bamboo fiber in them rose. Bamboo fiber content of 0%, 1%, 3%, and 5% had maximum compressive stresses of 115, 108, 130, and 152 kN/m2, respectively.

7) Kenaf Fiber: Research conducted by [6] investigates the effectiveness of the engineering behavior of clayey soil with the inclusion of kenaf fiber. The kenaf fiber was used in varying percentages of 0.25%, 0.50%, and 0.75% of the weight of the soil sample. An advantage of kenaf fibers in terms of volume change was found to be that they decreased the specimen's initial constriction (up to 34%) and the subsequent dilation (up to 40%). The relationship between fiber mixed clay contents and the variation of the brittleness index showed that fibers had a stronger impact on improving soil mixture ductility than clay content did. Additionally, when the proportion of fiber in the mixture rises, the shear strength parameters, which are internal friction angle and cohesion, dramatically improved by 15% and 13%, respectively.

B. Case Studies on Subgrade Improvement by Synthetic Fibers

An alternative to natural fibers, in geotechnical engineering, short synthetic fiber soil composites have garnered increased attention lately. In geotechnical projects, they are still a relatively new method. Several different kinds of synthetic fibers, including those made of polypropylene, polyester, polyethylene, nylon, steel, and glass, are currently in use.

1) Polypropylene Fibers: The thermoplastic polymer polypropylene is used to create the synthetic fiber known as polypropylene fiber (PP fiber). It has a nice mix of stiffness and impact strength and is lightweight, strong, and water-resistant. Additionally, PP fiber is unaffected by insects or mildew and is resistant to most of acids and alkalis. In a research conducted by [36], the mechanical properties and strength of silty sand reinforced with short resinous Polypropylene (PP) fibers arranged at random were examined in laboratory uniaxial compression experiments. The fibers were of percentages; 0.25% to 0.75% of the weight of soil and in lengths of 1.5cm, 2cm, and 3cm. It was found that the fibers of length 1.5cm showed a drastic improvement in the strength of the reinforced soil. Another research conducted on single fiber pull-out tests assessed the parameters influencing the interfacial strength properties of soil reinforced with polypropylene fiber (PP-fiber) [3]. Four different fiber content percentages (0.25%, 0.50%, 0.75%, and 1.0%) and three different fiber lengths (6 mm, 12 mm, and 20 mm) of reinforced stabilized soil specimens were established in order to conduct additional studies on the efficacy of this fiber. After seven and twenty-eight days of curing, tests for unconfined compressive and split tensile strength were conducted. The maximum values for strength were found to contain between 0.5% and 0.75% of the 12 mm-long fibers. [37] A study conducted by [4] showed that a fiber ratio of 0.4% to 0.8% of weight of soil proved maximum strength within a varying ratio of 0% to 1%.

2) Polyester Fibers: A synthetic fiber created from petroleum products is called polyester fiber. One of the most widely used fibers worldwide, it can be discovered in many different products, including clothing, household goods, and industrial products. A study focused on the impact of the subgrade soil's technical attributeswhen recycled polyethylene terephthalate (PET) fibers were incorporated with fly ash. Shear strength, shear modulus, California Bearing Ratio (CBR), indirect tensile strength, and Atterberg limits using clayey soil were the technical attributesthat were specifically investigated. The usage of variables ranging from 0% to 1.6% by the weight of the soil with a gradation of 0.4% for PET fibers resulted in an improvement in shear strength, a decrease in plasticity index, and a CBR value. The ideal proportion was found to be 1.2% recycled PET fiber and 15% fly ash by soil weight, which enhanced the strength metrics of the subgrade soil [38]. Another research conducted by [39] to determine the impact of polyester fiber content on the strength behavior of the tested soil, Unconfined compressive strength tests (UC) and consolidated undrained (CU) triaxial compression tests were conducted on clayey soil specimens that were compacted, untreated, and treated with lime and cement. The specimens were reinforced with varying percentages of polyester fiber (i.e., 0%, 0.05%, 0.1%, and 0.2% by weight). According to test results, adding lime or cement significantly increased strength and strength metrics. The application of fiber contents from 0% to 0.2% was found to enhance strength by a factor in the range of 2.3 to 4.6.

3) Polyethylene Fibers: Polyethylene, a thermoplastic polymer, is used to create synthetic polyethylene fibers, which are high-performance materials. A study was conducted to find the effectiveness of using polyethylene terephthalate (PET) fibers in subgrade improvement with proportions ranging from 0% to 1.6% of fiber with the weight of soil. The experimental studies' findings show that using fiber increased the shear strength, CBR value, and plasticity index. The most suitable amount was determined to be 1.2% recycled PET fiber and 15% fly ash by soil weight, increasing the strength parameters of the subgrade soil [38].

4) Glass Fibers: Glass fiber, sometimes referred to as fiberglass, is a strong, lightweight material manufactured from incredibly tiny glass strands. These strands are frequently woven into fabrics or utilized in a variety of composites as a reinforcing material. Researchers used random and discrete fiberglass reinforcement to study the effects of expanding subgrade. The fiber content used in this study was within the percentage range of 0.25% to 1.0% by weight of soil. On unreinforced and reinforced expansive soil specimens, many tests were carried out, including those for free swell, unconfined compressive strength (UCS), indirect tensile strength (ITS), and California bearing ratio (CBR). According to the test results, adding glass fibers to subgrade soil dramatically raises the UCS, ITS, and CBR values while lowering the free swell values [11]. In another study conducted by [40], fiberglass with percentages from 1% to 6% was used on the soil selected to provide a uniform blend. Then the specimen was tested under several tests for its strength characteristics. The findings demonstrated a 2.4 improvement in tensile strength at soil reinforced with 3% to 5% fiber glass.

5) Steel Fibers: Steel fibers are short, small-diameter metallic fibers typically composed of a variety of steels, such as stainless and carbon steel. A study was done to assess the efficiency of Fly Ash and/or Cement-modified, Steel Fiber-reinforced Marginal Soil (Clayey Sand). These qualities for the goal of subgrade construction, strengthened with steel fiber, Marginal Soil Modified with Cement and/or Fly Ash was investigated in order to increase CBR value. In the current study, steel fibers with a diameter of 0.5 mm and lengths of 1 to 2 cm were employed. A 4% by-volume addition of steel fibers was made to the marginal soil which increased it's strength parameters [41].

IV. Future Works

It is important to highlight that the true behavior of fiber-reinforced soils is still poorly understood due to lack of research on the effects of scale effects and soil and fiber engineering features on the stress-strain-strength characteristics of fiber-reinforced soils. As a result, additional research, particularly large-scale tests by means of using physical models representing natural conditions, are required to comprehend the behavior of fiber-reinforced soils. More information on its effectiveness of using synthetic fibers is needed in terms of durability.

V. Conclusion

This review paper examines the idea of employing short fiber soil composites, or discrete randomly distributed fibers in soil. In this manner, the currently utilized natural and synthetic soil reinforcement fibers (coir, sisal, palm, jute, bamboo) as well as glass and steel were examined. Fibers are added at a dose rate of roughly 0.2–4% by weight to silt, clay, sand, or soil that has been stabilized with lime and cement in a simple process. All of the aforementioned publications have typically demonstrated that fiber reinforcing improves the strength and stiffness of composite soil. We may draw the conclusion that the claimed improvement in strength and stiffness was a result of the soil, fiber, and testing circumstances. Technical benefits of using fibers in soil reinforcement include reducing the occurrence of tensile cracks, raising hydraulic conductivity and liquefaction strength, lowering thermal conductivity and weight of building materials, lowering the propensity of expansive soils to swell, and lowering soil brittleness. It is emphasized that the use of natural fibers is more effective in strength gained than the use of synthetic fibers due to their economical availability and renewability.

TABLE 1 Summary of Existing Literature

Author/Date	**Aim of Study**	**Variables**	**Main findings**
D. Kaushik and Sitesh Kumar Singh 2021	Effectiveness on the geotechnical properties of soil.	Brown washed coir 0% - 1% with an increment of 0.25% of 20mm in discrete arrangement	Increase of strength with the increasing number of layers
N. Karthi, K. Kumaresan, S. Sathish, S. Gokulkumar, L. Prabhu, and N. Vigneshkumar 2019	Improving the strength of the subgrade.	four types of fiber; including coir fiber, were also added with a step of 0.25% of the soil's weight in percentages ranging from 0.5% to 1% ELM approach	Bearing capacity improved with the reinforcement by 1.83 times. CBR value was improved. Durability of a coir geo textile was about four to six years.
D. P. Ferreira, J. Cruz, and R. Fangueiro 2018	Subgrade modification.	Coir fiber and thermoplastic between 20%-30% of its total weight of soil.	Textile and flexural strengths of the soil improved with the fraction of fiber used in between 20% - 30% of its total weight of soil.
R. Mello, Maria Virginia Gelfuso, and D. Thomazini 2015	Subgrade soil improvement in terms of CBR strength.	Coir fiber in clay soil	Improved the subgrade by increasing its CBR with the addition of coir fiber.
Mehdi Valipour, Piltan Tabatabaie Shourijeh, and Alireza Mohammadinia 2021	Subgrade soil improvement in terms of CBR strength.	0.2% to 1% fiber content, increased by 0.2% based on the weight of the soil.	CBR strength of the soil sample increased by 4.6 times.
S. O. Amiandamhen, M. Meincken, and L. Tyhoda 2020	Subgrade soil improvement in terms of CBR strength.	Coir fiber of 0.3% into the soil mixture in discrete arrangement.	CBR strength of soils yields higher strength with the addition of 0.3% fiber into the soil mixture.
Aliakbar Gholampour and Togay Ozbakkaloglu 2020	Effects on the tensile and compressive strengths of soil by STS test.	Random inclusion of 0.25% to 1.0% of sisal fiber of 30mm by the weight of subgrade soil.	Capillarity impact caused the tensile and compressive strengths of 10 kPa and 20 kPa pre-compressed specimens to drop from an average of 1.48 MPa to 0.98 MPa.
Mazahir M.M. Taha, Cheng Pei Feng, and	Impact of sisal fiber addition on the CBR	inclusion of sisal fiber in 0.25% to	0.75% of fiber provides a maximum

Sara H.S. Ahmed 2020	strength of black cotton soil.	1.50% with an increment of 0.25% of the weight of soil.	value of 7.22 (being 4.24 times greater than the control sample) in terms of CBR strength.
A. Garg, Sanandam Bordoloi, S. Mondal, Jun Jun Ni, and S. Sreedeep 2020	To evaluate various compaction metrics, including California bearing ratio (CBR), and unconfined compression strength tests (UCS) on subgrade soil.	fibers with 10, 15, and 20 mm lengths.	With increasing fiber length and content, the California bearing ratio (CBR) and unconfined compressive strength (UCS) both rose significantly; at 15 mm fiber length and 1.5% fiber content.
N. Das and Shashi Kant Singh 2019	improving the subgrade soil strength.	Inclusion of palm fiber with lengths of 30mm to 35mm and percentages of 0.1% to 1.0% by the weight of soil.	Maximum density decreased as the fiber content increased while the ideal moisture content increased. With palm fiber inclusion, the maximum soaking CBR value was 14%, and the unconfined compression value was 352 kPa. These maximum values were discovered at the ideal 0.2% fiber content.
Nima EsmaeilpourShirvani, Abbasali TaghaviGhalesari, Mohammadreza Khaleghnejad Tabari, and Asskar Janalizadeh Choobbasti 2019	Aim of study was to evaluate the strength of subgrade of two types of clayey soil by adding jute fibers.	0.25% to 1.25% of jute fiber with an increment of 0.25% and a length variation of 0.5cm to 1.5cm.	Fiber of length of 1 cm with 0.75% fiber content showed an increase in both UCS and CBR values.

M. Olgun 2013	Fundamental characteristics were identified, including compaction characteristics, unconfined compressive strength, and California bearing ratio in both soaked as well as unsoaked circumstances.	The soft soil was combined with 25 mm long jute fiber in percentages ranging from 0.25% to 1.0% by weight of soil.	CBR strength of the sample was increased from 2.8% to 6.5% under soaked conditions.
C. Tang, B. Shi, W. Gao, F. Chen, and Y. Cai 2007	Improving the subgrade soil strength.	clayey soil with a range of 0.3% to 0.9% for jute fiber at a 6mm length.	Soft soil specimens with a length of 6 mm and a 0.6% fiber content demonstrated efficacy.
V.Saravana Selvam, M. Sivaraja, K. Raja, K.S. Navaneethan, and G.Dheeran Amarapathi 2016	To assess the hemp fiber-infused clay's strength parameters.	Clay sample mixed with fiber percentages varying from 0.5% to 1.5% with an increment of 0.25%. The length of hemp fibers was kept constant at 4cm.	undrained shear strength characteristics and were successful in providing that the strength of fiber-reinforced clay indeed increased from 0.5% to 1.25% and then decreased from then onwards.
Chao Sheng Tang, B. Shi, and Li Zheng Zhao 2010	To assess the black cotton soil's strength parameters using hemp fiber.	Hemp fiber and coir fiber in percentages of 0.1% to 0.4% by mass of black cotton soil treated with alkali-activated binder. Fiber was kept at 25mm.	Increased the resilience of soil fibers to freeze-thaw cycles.
Samer Rabab'ah, Omar Al Hattamleh, Hussein Aldeeky, and Bilal Abu Alfoul 2021	To assess the black cotton soil's strength parameters using hemp fiber.	Expansive soil subgrade incorporated with alkali-activated binder with the inclusion of fiber with percentages of 0.2% to 0.8%	Significant increase in CBR value was found.
Shahriar Shahrokhabadi and Najme Nazeryzadeh	Impact of bamboo fiber on clayey subgrade soil's CBR strength.	Bamboo fiber with varying percentages from 0.2% to 1.4% with an increment of	Thickness of the pavement will decrease due to this significant

2013		0.2%. the length of the fibers was selected to be 10mm and 20mm.	increase in CBR value
Sayyed Mahdi Hejazi, M. Sheikhzadeh, Sayyed Mahdi Abtahi, and A. Zadhoush 2012	Effect of bamboo fiber on CBR strength of clayey subgrade soil.	1% to 5% of fiber percentages to a problematic soil.	a tendency of all specimen compressive stresses to rise as the amount of bamboo fiber in them rose. Bamboo fiber content of 0%, 1%, 3%, and 5% had maximum compressive stresses of 115, 108, 130, and 152 kN/m2
M. Syed, Anasua GuhaRay, and D. Goel - 2022	The efficiency of incorporating kenaf fiber into clayey soil to improve its engineering behavior.	Percentages representing 0.25%, 0.50%, and 0.75% of the soil sample's weight.	Fibers had a stronger impact on improving soil mixture ductility than clay content did.
Pradip Kumar Pradhan, Rabindra Kumar Kar, and A. Naik 2012	Strength and mechanical properties of silty sand reinforced with short resinous Polypropylene (PP) fibers arranged at random.	Fibers of percentages; 0.25% to 0.75% of the weight of soil and in lengths of 1.5cm, 2cm, and 3cm.	The strength of the reinforced soil significantly increased with the addition of 1.5 cm fibers.
Prasad Dhammika Dharmaratne, Harsha Galabada, R. Jayasinghe, Renuka Nilmini, and Rangika Umesh Halwatura 2021	Improving the subgrade soil strength by the addition of PP fibers.	fiber lengths (6 mm, 12 mm, and 20 mm) and fiber content percentages (0.25%, 0.50%, 0.75%, and 1.0%).	For the 12 mm-long fibers, the highest strength values were obtained with a content of 0.5%–0.75%.
B. Mishra and Mohit Kumar Gupta - 2018	Improving the subgrade soil strength by the addition of PP fibers.	A fiber ratio of 0.4% to 0.8%	Proved maximum strength within a varying ratio of 0% to 1%.
R. P. Munirwan, Munirwansyah, Marwan, P. J. Ramadhansyah, and V. Kamchoom 2020	Effectiveness on the subgrade soil's technical attributeswhen recycled polyethylene terephthalate (PET) fibers were incorporated with fly ash.	proportions by soil weight that range from 0% to 1.6% with a 0.4% increase.	produced a CBR value, a reduction in the plasticity index, and an increase in shear strength. It was discovered that 1.2% recycled PET fiber was the ideal quantity.
L. Peter, P. K. Jayasree, K. Balan, and S. Alaka Raj 2016	To ascertain how the strength behavior of clayey soil is affected by the polyester fiber content.	A set of unconfined compressive strength tests (UC) and consolidated undrained (CU) triaxial compression tests conducted on compacted, untreated, lime-treated, and cement-treated clayey soil specimens reinforced with varying weights of polyester fibers (i.e., 0%, 0.05%, 0.1%, and 0.2% by weight).	Found an increase in strength within the fiber contents from 0% to 0.2% by a factor between 2.3 to 4.6.
Sridhar Rajagopalaiah - 2019	To ascertain how the strength behavior of clayey soil is affected by the glass fiber content.	Random and discrete fiber glass with a percentage range of 0.25% to 1.0%.	Glass fibers significantly increase the UCS, and CBR values in subgrade soil while decreasing the free swell values.
Oğuzhan Yavuz Bayraktar and Kastamonu Üniversitesi 2020	To determine the effectiveness of Steel Fiber-reinforced Fly Ash and/or Cement-modified Marginal Soil (Clayey Sand).	Steel fibers with a diameter of 0.5 mm and lengths of 1 to 2 cm were employed.	4% by-volume addition of steel fibers was made to the marginal soil which increased its strength parameters.

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