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Comprehensive Review of Strength Enhancement of Clay Soils Using Nylon Fiber,Fly Ash, Jute and Waste Materials

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Abstract*— Clay soil provides substantial problems with geotechnical engineering because of its strong flexibility and susceptibility to volume fluctuations. This review paper examines the problems with clay soil and provides methods for managing and stabilizing it effectively, with an emphasis on environmentally friendly and sustainable practices. For improving the performance and strength of clay soil, the integration of elements such as nylon fiber, jute, fly ash, and waste products is investigated. Because it increases the capacity of the soil to support more weight, fortifies the soil, lessens settling problems, and is in line with environmental sustainability, soil stabilization is essential for assuring the longevity, safety, and cost-effectiveness of infrastructure projects. This review provides insightful information on improving clay soil by synthesizing existing knowledge, evaluating material performance, identifying best practices, and taking environmental effects into account.

***Keywords*— Clay Soil, Soil Stabilization, Nylon Fiber, Jute Fiber, Fly Ash, Waste Materials, Geotechnical Engineering, Sustainability, Environmental Impact.**

I. INTRODUCTION

Clay soil presents a variety of difficulties in geotechnical engineering and construction due to its small particles and strong plasticity. Due to its tendency to significantly change in volume in response to changing moisture levels, poor drainage properties, low natural bearing capacity, susceptibility to shear failure, and seasonal variability, it is not the best material to use as a foundation material for large structures. Construction activities are made more difficult by compaction issues, and volume variations may be made worse by the presence of expanding clay minerals [1]. Additionally, the investigation of eco-friendly and sustainable alternatives is necessary due to the environmental impact of current stabilization techniques. In particular, when taking into account incorporating of raw materials like nylon fiber, jute, fly ash, and waste materials for improving the soil's durability and effectiveness, which is addressed in this review paper, comprehending these challenges is crucial for developing efficient techniques for clay soil management and stabilization.

Because soil stabilization is crucial to guaranteeing the durability, safety, and economic viability of numerous infrastructure projects, it plays a crucial role in civil engineering, geotechnical engineering, and construction. First off, it greatly increases the soil's capacity for carrying loads, enabling it to effectively support the weight of buildings, roads, bridges, and other essential elements of the built environment. As stabilization protects the structural integrity of projects, this is especially important in areas with weak or subpar natural soil conditions [2]. Furthermore, soil stabilization techniques significantly increase the strength and stability of the soil, whether they involve mechanical compaction, chemical additions, or the introduction of reinforcing components like fibers or waste products. This successfully reduces problems with soil deformation, settling, and failure, protecting the long-term functionality of built assets. Beyond structural factors, economic savings are another benefit of soil stabilization. It decreases both initial building costs and continuing maintenance costs by removing the need for substantial excavation and the replacement of subpar soil [3]. Finally, there is a rising focus on sustainable stabilization methods that are also environmentally beneficial. These techniques, which incorporate the utilization of waste products or bio-based additives, not only enhance soil functionality but also adhere to ecological principles by minimizing the negative effects of construction activities on the environment. In conclusion, soil stabilization is essential to the accomplishment, durability, and environmental friendliness of infrastructure projects, making it a pillar of contemporary engineering techniques [4]. The review's goals are to evaluate material performance, identify best practices, and take environmental effects into account while synthesizing current information on clay soil augmentation using nylon fiber, jute, fly ash, and waste materials.

II. ROLE OF NYLON FIBER, JUTE, FLY ASH, AND WASTE MATERIALS

In soil stabilization and building techniques, the use of nylon fiber, jute, fly ash, and waste materials is essential. Jute and nylon fiber are used as reinforcement materials to increase the tensile strength and stiffness of clay soil, lowering the likelihood of structural failure and cracking. [5] Fly ash is a valuable addition to geotechnical projects because of its potent pozzolanic qualities, which are used to increase soil stability and strength. Additionally, several waste products [6] are reused to improve soil qualities, adding to sustainability and cost-effectiveness [8], such as rice husk ash, sugarcane bagasse ash, plastic waste, coir pith, and others [7]. Together, these resources address the issues raised by clayey soils, providing practical answers for soil enhancement and environmentally friendly building techniques [9].

A. Properties and Characteristics

Fly ash is a pozzolanic substance that, when combined with calcium hydroxide and water, yields cementitious

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compounds. Fly ash is filler used in hot mix asphalt applications, and because of its spherical shape and particle size dispersion, it enhances the fluidity of permissible fill and grout. The investigation conducted by Senol et al. [11] to stabilize four different types of soft subgrades from separate road sites in Wisconsin, USA, used various types of self-cementing fly ashes (without any other activators). By combining fly ash in various concentrations with changing amounts of water, stabilized soil samples were created. In order to stabilize the expanding soil, Kumar and Harika [12] employed waste materials like fly ash as an additive to blend with the soil. The experimental findings show a decrease in the Atterberg limits, Plasticity Index, and Free Swell Index with the addition of fly ash to the Black Cotton Soil at a rate of 0% to 20%. Untreated soil has a CBR value of 2.189%, whereas treated soil with fly ash has a maximum CBR value of 2.33% (10% fly ash), which is an increase of 6.0% from the value that was originally measured. Unconfined compressive strength (UCC) of soil without treatment is 0.1688 N/mm2, and when treated with fly ash, it increases to a value of 0.333 N/mm2 (10% fly ash), which is a 49.30% increase from the initial value. Additional down drift is seen in both CBR and UCC values. According to Tastan et al. [13], the CaO concentration and CaO/SiO2 ratio [or CaO/(SiO2+Al2O3) ratio] of fly ash are important properties that influence the increase in unconfined compressive strength and resilient modulus. Organic content in the soil is harmful for stability. The strength of the soil-fly ash mixture weakens rapidly as soil organic content rises.

Table 1. Physical and chemical properties of flyash

Property	Description
Physical Properties	
Color	Typically gray or tan, but can vary depending on the source of the fly ash.
Particle Size	Fine, powdery consistency, with particles ranging from micrometers to sub-millimeters in size.
Density	Typically ranges from 1.9 to 2.4 g/cm^3, depending on the type and source of fly ash.
Specific Gravity	Generally ranges between 2.0 and 2.8.
Fineness	Most fly ashes are finer than Portland cement and contribute to improved workability in concrete mixes.
Chemical Properties	
Silica Content (SiO_2)	Predominantly composed of amorphous silica, typically ranging from 40% to 90% or more.
Alumina Content (Al_2O_3)	Contains aluminum oxide, usually in the range of 10% to 35%, depending on the type of fly ash.
Calcium Oxide (CaO)	Typically contains varying amounts of calcium oxide, which contributes to pozzolanic reactivity.
Iron Oxide (Fe_2O_3)	Contains iron oxide, usually ranging from 5% to 20%, affecting the color and reactivity of the fly ash.
Loss on Ignition (LOI)	Measures the unburned carbon content; lower LOI indicates higher combustion efficiency.
Chemical Composition Variability	Fly ash properties can vary widely depending on its source, combustion conditions, and type (Class C or F).

Unconfined compressive strength and resilient modulus rose as fly ash content was raised for the majority of the soil-fly ash combinations evaluated. Fly ash, a crucial component in construction and geotechnical engineering, has a wide range of physical and chemical characteristics that are detailed in Table 1 An extensive variety of particle sizes are often present in fly ash, which has a fine, powdery consistency. Fly ash's physical characteristics, such as color, density, specific gravity, and fineness, differ depending on the material's origin and nature. Fly ash is mostly made up of silica (SiO2), with different amounts of alumina (Al2O3), calcium oxide (CaO), and iron oxide (Fe2O3), according to its chemical composition. The unburned carbon content and combustion efficiency are measured using the loss on ignition (LOI) method. It's necessary to take into account the unique qualities of the fly ash source when incorporating it into construction materials and projects because the chemical composition of fly ash can vary greatly.

B. Enhancing Tensile Strength Using Nylon Fiber

The process of fixing soil makes use of nylon fibers' extraordinary qualities. These synthetic fibers have remarkable tensile durability and strength. These nylon strands are painstakingly integrated into the soil during construction when used as soil reinforcement. This calls for evenly mixing the fibers with the soil surrounding them to obtain a consistent dispersion. The nylon fibers that are incorporated into the soil mixture form a structural network in the soil matrix. By acting as a reinforcing system, this structure raises the soil's natural resistance to tensile stress as well as its capacity to withstand it. Numerous variables, including changes in the moisture content or the usage of loads, which are frequently observed in construction and construction-related tasks, could be contributing factors of these forces. This reinforcement considerably improves the material's tension strength, reducing the likelihood of erosion and fracture formation, particularly in locations with severe weather patterns or high traffic. The use of nylon fibers aids in ensuring the long-term stability and integrity of the construction project in addition to fortifying the soil. A reduction in fracture occurrence, which ensures that structural integrity of elements like pavements, is one of the many advantages of this technique. The enhanced tensile strength of the soil results in improved durability, which also lengthens the usable life of built-up infrastructure. Additionally, the soil reinforced with nylon fibers is more resistant to erosion, which makes it beneficial in locations with frequent heavy rains or water exposure. Furthermore, employing nylon fibers throughout soil stabilization can be more cost-effective than using other methods, making it a viable option for a range of civil construction and architectural purposes.

Demsie et al.'s [14] investigation into subgrade soil stabilization and nylon synthetic fiber (NSF) compromises. Fibers with a longer fiber length and lower fiber content have been used in some investigations in the past, but the contrary has also been true in other studies. However, this study's design was special in that it took into account the right fiber length (10 mm and 20 mm) and content (0.5%, 1%, 1.5%, and 2.5%) to stabilize poor subgrade soil. Natural soil had wet CBR and CBR swell values of 1.80% and 8.95%, respectively. In comparison to natural soil, the percentage increase in the soaking CBR value due to reinforcement is 265.3, 310.0, 282.8, and 342.2 for aspect ratios of 33.33, 66.67, 25, and 50, accordingly. Additionally, there have been a 34.7, 52.75, 43.55, and 36.9 percent reduction in swelling, respectively.

The findings of an experiment into how fiber affected both the consolidation and shear strength characteristics of a clay soil reinforced adding nylon fibers are presented by Estabragh et al. in [15]. Samples of unreinforced and reinforced clay with various amounts of randomly scattered nylon fibers underwent a series of one dimension rather consolidation and triaxial tests. By mixing recycled polyethylene terephthalate (PET) fibers with fly ash in the subgrade soil, Mishra and Gupta [16] investigated the impact of soil engineering features. PET fibers make up the proportions ranging from 0% to 1.6% by weight of the soil with an increase of 0.4%, whereas Fly Ash makes up the proportions ranging from 0% to 20% by weight of the soil with an increase of 5%. The optimal amount was determined to be 1.2% recycled PET fiber and 15% fly ash by weight of soil, which increased the subgrade soil's strength metrics. Glass fibers are being used as discrete random reinforcement in expansive subgrade soil by Rabab'ah et al. [17] to increase the strength of the soil for use in pavement construction. By weight of dry soil, the fiber content ranged between 0.25 and 1 percent. 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. Glass fibers may be an appropriate reinforcement for the subgrade layer in the construction of pavement, according to MEPDG analysis. The addition of glass fibers to subgrade stabilization can significantly reduce pavement thickness.

According to Pallavi and Poorey [18], an effort has been made to use waste from factories as stabilizing agents, including fly ash and nylon fibers. It has been investigated how fly ash and nylon fibers affect clayey soil's liquid limit, plastic limit, plasticity index, dry density, and CBR (Soaked). Study the cumulative impact of different percentages of the appropriate quantity of fly ash and the optimal quantity of Nylon fiber at a variety of aspect ratios on the properties of black cotton soil. First, investigation that combined impacts of ranging percentage of fly ash (10%, 20%, 30%, 40%) and that differ percentage of Nylon Fibre (0.25, 0.50, 0.75, 1, 1.25, 1.50) at varying aspect ratios (20, 40, 60, 80).

The exploratory findings from testing on organic soil reinforced with nylon fibers that were scattered at random and stabilized with RHA are represented by Brahmachary et al. [19]. Standard proctor compaction, unconfined compressive strength (UCS), unsoaked and soaked CBR tests were first performed on soil samples that had been partially substituted by RHA with doses of 0%, 5%, 10%, 15%, and 20%, and then on soil plus the ideal percent of RHA and various contents of nylon fiber (0.3%, 0.5%, 0.7%, 1%, and 1.2%). The results of the investigation show that adding various doses of RHA and nylon fiber to organic soil raises its ideal moisture content while lowering its maximum dry density.

C. Sustainable Reinforcement with Jute

Jute fibers have the ability to improve soil characteristics in geotechnical and building applications, and sustainable reinforcing using jute is a method that promotes environmental friendliness. Being a natural and biodegradable fabric made from plants, jute offers a number of attractive benefits. Jute fibers interlace inside the soil matrix when added into soil, enhancing its cohesion and general stability. This reinforcement increases the soil's resistance to structural failures, lowers the likelihood of landslides, and helps avoid soil erosion. In addition, jute's moisture-retentive properties are especially useful in areas with arid or semi-arid climates, where they aid in maintaining ideal soil moisture levels for plant growth and guard against soil drying out and cracking. When working with expansive soils susceptible to volume fluctuations due to differences in moisture content, jute fibers can help lower the plasticity of highly plastic clay soils, making them more appropriate for construction. Jute fibers biodegrade spontaneously over time, leaving behind soil with improved characteristics without introducing long-lasting foreign materials into the environment, which makes this process particularly sustainable. Additionally, jute reinforcement is frequently inexpensive, which makes it a desirable option for soil stability and is in line with green building techniques. In conclusion, jute is a useful material for sustainable reinforcement in geotechnical engineering, helping to improve soil quality and protect the environment.

The goal of Gupta et al. [20] is to create a fly ash-based treatment method that is affordable, environmentally safe, and greatly enhances jute's engineering and strength capabilities as a geotextile. Alkali-activated binders (AAB) are becoming more and more used in engineering applications. It is created through the reaction of an alkali activator solution and an aluminosilicate precursor (most commonly Class F fly ash and/or slag). Jute geotextile that has undergone AAB treatment demonstrates an increase in load-bearing capability of about 27%.

According to Lal et al. [21], adding a Jute fiber strip to soil can improve its properties. On unreinforced jute fiber soil and normal soil, a series of triaxial and CBR experiments were conducted. The progression of subgrade strength of roads reinforced with alkali activated binder (AAB) treated jute geotextile is understood by Komaravolu, V.P. (2021). Testing for CBR, bearing capacity, on unreinforced soils, untreated jute reinforced

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soils, and treated jute reinforced soils revealed a significant increase in CBR, bearing values in treated jute geotextiles.

Table 2. Comparative Summary of Soil Stabilization and Reinforcement Materials

	Fly Ash	Nylon Fiber	Jute Fiber
Pozzolanic Properties	Acts as a pozzolanic material.	Synthetic nylon fibers with high tensile strength.	Natural and biodegradable jute fibers.
Use in Soil Stabilization	Stabilizes subgrades and soft soils.	Enhances soil tensile strength.	Reinforces soil and prevents erosion.
Influence on Soil Properties	Reduces Atterberg limits, Plasticity Index, Free Swell Index.	Increases soil tensile strength and resistance to tensile forces.	Enhances cohesion, prevents erosion, and reduces plasticity.
Impact on CBR (California Bearing Ratio)	Increases CBR values, improving load-bearing capacity.	Significantly improves CBR values.	Increases CBR values, enhancing soil strength.
Unconfined Compressive Strength (UCS)	Increases UCS, enhancing overall soil strength.	Enhances UCS, reducing cracks and erosion susceptibility	Contributes to improved soil cohesion and stability.
Key Factors Affecting Effectiveness	CaO content and CaO/SiO2 ratio.	Fiber length and content.	Natural fiber interlacing and moisture retention.
Environmental Considerations	Utilizes waste fly ash material.	Synthetic material, but enhances soil durability and longevity.	Natural and biodegradable fibers, eco-friendly solution.
Cost-Effectiveness	Can be cost-effective compared to other soil improvement methods.	Offers cost-effective soil reinforcement.	Often cost-effective while promoting sustainability.

The unique qualities and effects of fly ash, nylon fiber, and jute fiber as soil reinforcing and stability materials are highlighted in Table 2. Fly ash is a good choice for subgrade stabilization since it has improved soil strength and load-bearing capacity thanks to its pozzolanic qualities. Jute fiber provides sustainable reinforcement, fostering eco-friendliness and cost effectiveness, while nylon fiber greatly increases tensile strength while lowering the susceptibility to fractures and erosion. The choice of material relies on the particular project requirements and environmental factors, as each material has distinct advantages and can meet a variety of geotechnical engineering objectives

III. CONCLUSION

This review study emphasizes the need for efficient stabilization techniques while highlighting the numerous difficulties that clay soil presents in geotechnical engineering and construction. In order to increase soil strength, decrease settling issues, and promote sustainability in construction projects, soil stabilization is crucial. Promising answers to these problems can be found in the use of materials including nylon fiber, jute, fly ash, and waste products. Fly ash, which has pozzolanic characteristics, increases soil strength, and jute and nylon fiber reinforcement reduce the likelihood of erosion and fissures. These materials have distinctive qualities that make them appropriate for use in a variety of geotechnical engineering applications. Environmental factors and project-specific requirements influence the material selection. Overall, this research offers important insights into improving clay soil and offers a thorough understanding of environmentally acceptable and sustainable soil stabilization techniques.

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