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Jute Geotextile as a Sustainable Soil Reinforcement Material: Mechanisms, Engineering Performance, and Environmental Relevance

[1]**Pandya A. A.**
(Associate Professor, Department of Applied Mechanics, SSEC, Bhavnagar, Gujarat, India)
[2]**Sarvaiya H. K.**
(Assistant Professor, Department of Applied Mechanics, SSEC, Bhavnagar, Gujarat, India)

Abstract:
This review paper systematically examines the role of Jute Geotextile (JGT) as a sustainable alternative to synthetic geotextiles in geotechnical engineering. Through a critical synthesis of existing literature, the paper evaluates the mechanical, hydraulic, and environmental impacts of JGT on soil reinforcement, erosion control, and soil improvement. Key findings indicate that JGT significantly enhances soil properties such as California Bearing Ratio (CBR), shear strength, and consolidation rate, while also promoting vegetation growth and soil fertility through biodegradation [1], [2]. A comparative analysis with synthetic and other natural geotextiles highlights JGT's suitability for temporary and eco-sensitive applications [3], [4]. The paper concludes with recommendations for future research, including lifespan extension treatments and large-scale field validations, to facilitate wider adoption of JGT in sustainable geotechnical practices.

Keywords: Jute Geotextile, Soil Reinforcement, Biodegradable Geotextiles, Sustainable Geotechnics, Erosion Control, Soil Stabilization, Natural Fiber Geotextiles.

1. Introduction

The growing emphasis on sustainable development in civil engineering has spurred interest in eco-friendly materials that minimize environmental impact while maintaining functional performance. Geotextiles, widely used for soil stabilization, filtration, drainage, and reinforcement, have traditionally been manufactured from synthetic polymers such as polypropylene and polyester. Although these materials offer high tensile strength and durability, their non-biodegradable nature poses significant environmental challenges, including long-term pollution and carbon-intensive production.

In response, Natural Fiber Geotextiles (NFGs) have emerged as viable alternatives, with Jute Geotextile (JGT) being one of the most promising due to its renewable source, rapid biodegradability, and favorable engineering properties [1]. Jute (*Corchorus species*) is a fast-growing, low-cost crop cultivated extensively in tropical regions. When processed into geotextiles, it provides temporary mechanical reinforcement, enhances soil moisture retention, and eventually decomposes into organic matter, enriching the soil [5].

This paper aims to provide a comprehensive review of the influence of JGT on soil engineering properties. It consolidates and compares experimental and field data on unreinforced versus JGT-reinforced soils, analyzes the underlying reinforcement mechanisms, and positions JGT within the broader context of geotextile materials [6]. The review also identifies research gaps and proposes directions for future work to optimize JGT applications in geotechnical engineering.

2. Properties and Mechanisms of Jute Geotextile

2.1 Physical and Mechanical Characteristics

Jute fibers possess a multicellular structure with high cellulose content (approximately 60–70%), which contributes to their initial tensile strength (up to 25 kN/m) and low elongation at break [5]. These properties enable JGT to mobilize reinforcement quickly under small strains, making it effective for restraining soil deformation. The natural roughness and high drapability of JGT ensure excellent conformity to soil surfaces, enhancing interfacial friction and load distribution [7].

2.2 Hydraulic and Environmental Behavior

JGT exhibits high water absorption capacity (moisture regain up to 13.75%), which aids in maintaining soil moisture and supporting vegetation establishment [8]. Its permeable structure facilitates efficient drainage, reducing pore water pressure and accelerating consolidation in cohesive soils [2]. Unlike synthetic geotextiles, JGT is fully biodegradable, typically degrading within 1–2 years under field conditions. The degradation process releases organic compounds that improve soil structure, porosity, and nutrient content [9].

2.3 Reinforcement Mechanisms

JGT reinforces soil through three primary mechanisms:

1. Tensile Reinforcement: JGT layers act as tensile elements that redistribute vertical loads laterally [1].
2. Frictional Interlock: The rough texture of jute fibers increases shear resistance at the soil–geotextile interface [7].
3. Drainage Enhancement: By providing horizontal drainage paths, JGT accelerates dissipation of excess pore water, increasing effective stress and soil strength [2].

3. Comparative Analysis of Soil Properties: Unreinforced vs. JGT-Reinforced

3.1 Mechanical Strength Improvements

- California Bearing Ratio (CBR): Multiple studies report CBR increases of 30–100% in JGT-reinforced soil, depending on soil type, moisture content, and JGT layering configuration [1], [10].
- Shear Strength Parameters: Direct shear and triaxial tests show notable increases in cohesion (c) and angle of internal friction (φ) due to interfacial friction and confinement [7].

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- Bearing Capacity and Settlement: JGT reduces settlement by up to 40% in soft subgrades and increases ultimate bearing capacity, making it suitable for embankments and low-volume roads [11].

3.2 Hydraulic and Consolidation Behavior

- Consolidation Acceleration: JGT reduces the time for 90% consolidation (t_{90}) by acting as horizontal drainage layers, particularly beneficial in clayey soils [2].
- Erosion Control: JGT effectively reduces soil erosion by dissipating raindrop energy, reducing surface runoff velocity, and stabilizing soil particles. Field studies indicate erosion reduction rates of 50–80% on slopes [3], [12].

Table 1: Summary of Key Soil Property Enhancements with JGT Reinforcement

Soil Property	Unreinforced Soil	JGT-Reinforced Soil	Primary Mechanism
CBR Value	Low	Significantly Increased	Confinement & Load Distribution [1]
Shear Strength	Moderate	Enhanced	Frictional Interlock [7]
Consolidation Time	Long	Reduced	Horizontal Drainage [2]
Erosion Rate	High	Substantially Reduced	Surface Protection [3]
Organic Content	Low/Stable	Increased Over Time	Biodegradation [9]

4. Comparison with Other Geotextiles

4.1 JGT vs. Synthetic Geotextiles

Synthetic geotextiles offer superior long-term strength and durability (50+ years) but are non-biodegradable and derived from fossil fuels [13]. JGT, while lower in ultimate tensile strength, provides adequate performance for short- to medium-term applications and offers clear environmental benefits, including soil enrichment and reduced carbon footprint [14].

4.2 JGT vs. Other Natural Geotextiles (Coir, Sisal)

Coir geotextiles, with higher lignin content, degrade slower (3–5 years) and are preferable for longer temporary stabilization [4]. Sisal offers higher tensile strength but lower drapability. JGT strikes a balance between biodegradability, drapability, and cost, making it ideal for erosion control and vegetative establishment projects [15].

Table 2: Comparison of Geotextile Types

Feature	Jute Geotextile	Coir Geotextile	Synthetic Geotextile
Tensile Strength	Moderate	Moderate	High [13]
Degradation Period	1–2 years [9]	3–5 years [4]	>50 years [13]
Environmental Impact	Biodegradable, soil-enriching [9]	Biodegradable, slower decay [4]	Non-biodegradable, polluting [14]
Primary Use	Erosion control, vegetation support [3]	Slope stabilization, longer-term reinforcement [4]	Permanent structures, high-load applications [13]

5. Case Studies and Field Applications

Several field applications demonstrate the efficacy of JGT:

- Slope Stabilization in Hilly Regions: JGT reduced soil loss by over 70% on embankment slopes in Assam, India [3].
- Road Subgrade Reinforcement: In Bangladesh, JGT-improved subgrades showed CBR improvements of 85% and reduced construction costs by 20% compared to synthetic alternatives [10].
- Erosion Control in Riverbanks: JGT mats successfully stabilized eroding riverbanks while promoting native vegetation growth [12].

6. Challenges and Limitations

Despite its advantages, JGT faces certain limitations:

- Limited durability under prolonged UV exposure and high pH conditions [16].
- Variability in mechanical properties due to natural fiber inconsistency [5].
- Lack of standardized long-term performance data in diverse climatic zones [17].

7. Future Research Directions

To enhance JGT's applicability and performance, future studies should focus on:

1. Chemical and Physical Treatments: To prolong functional life without compromising biodegradability [16].
2. Hybrid Geotextiles: Combining jute with other natural/synthetic fibers to optimize strength and durability [18].
3. Large-Scale Field Monitoring: Long-term studies under varied environmental and loading conditions [17].
4. Life Cycle Assessment (LCA): Comprehensive environmental and economic analysis compared to synthetic geotextiles [14].
5. Standardization and Guidelines: Development of codes and specifications for JGT use in geotechnical projects [6].

Conclusion

Jute Geotextile represents a sustainable, effective, and economically viable material for soil improvement, erosion control, and temporary reinforcement [1], [9]. Its ability to enhance soil engineering properties while contributing to long-term soil health through biodegradation aligns with global sustainability goals [14]. With further research and standardization, JGT can play a pivotal role in green geotechnical engineering, particularly in regions where jute is locally available and environmental sensitivity is paramount [6].

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