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Sustainability Evaluation of Woven Geotextiles in Geotechnical Engineering using Eco-friendly Bitumen Embossing with Synthetic Resin and Copper Sulfate

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Abstract

The sustainability of woven jute geotextiles treated with varying amounts of bitumen emulsion in geotechnical engineering is examined in this article. Several methods are being used to improve the serviceability of jute geotextiles. Natural jute fibres provide environmental benefits; however, bitumen emulsion treatment is being studied for its ability to enhance geotechnical properties. JGT1, JGT2, JGT3 and JGT4 were the four samples that underwent treatment and analysis. In certain instances, JGT3 samples provide positive FTIR and tensile strength values. The study assesses biodegradability and water absorption percentage. The results show how bitumen emulsion concentrations impact jute geotextile performance, which could aid in the design of long-lasting and environmentally responsible infrastructure. The consequences of bitumen coating chemical treatment are examined in this article.

Keywords: Jute textiles; Jute geotextile; Biodegradable; Rot-resistant; Soil burial test

Introduction

Lignin (12–14%), hemicellulose (21–25%), cellulose (58–60%), and lipids and waxes (0.4–1.0%) are the primary components of jute. Jute also contains trace amounts of minerals, proteins or nitrogenous substances, pectin, and colors. Jute geotextile is considered an important building material with environmentally favorable qualities, despite its limited resistance to biodegradation (Thakur et al., 2019). Their main purpose is to foster the establishment of vegetation, which gives soils mechanical strength to prevent erosion and sliding (Saha et al., 2012). As a potential replacement for dangerous synthetic fibres, natural fibres help reduce greenhouse gas emissions and other negative environmental effects (Senthilrajan and Venkateshwaran, 2023). Jute geotextiles, which are made of natural fibres, have gained popularity in geotechnical engineering because of their ability to fortify soil and promote sustainable growth (Chakravarthy et al., 2021). To address this issue, researchers have examined a number of treatment methods to extend the lifespan of jute geotextiles. One way to treat the geotextiles is with an alkali-activated binder (AAB) made of fly ash, sodium silicate, and sodium hydroxide (Thakur et al., 2019). Jute geotextiles are commonly used in agriculture, river bank protection, soil erosion prevention, and other fields. It has been found that the AAB treatment hardens and enhances the jute geotextiles' resilience to exposure to various contaminants (Saha et al., 2016). According to reports, synthetic geo textiles have a number of drawbacks, including the fact that their surfaces can become rough and fractured and change color when exposed to UV light. It indicates that synthetic geotextiles are degrading on the surface, which is why soil temperatures are rising by 1 to 20 degrees Celsius. We discovered that jute geo textiles had many greater qualities than synthetic ones, including being more practical and environmentally beneficial. Because of its fertilizing effect, low stretchability, non-slip properties, and lack of metal composition, jute geo textiles can be useful in a variety of industries. It is necessary to understand the sustainable aspects of jute geo textiles since jute has hydrophobic properties that allow it to readily retain watery liquids.

Das et al. (2017) reported that geotextiles are widely utilized in the civil, building, and agricultural industries for a variety of purposes, including purification process, strengthening, discharge, and segregation. In certain applications, such as drainage, bank erosion management, land reclamation from the sea, separation, etc., jute fibre, which is typically coarse, is readily incorporated. Depending on the kind of soil, moisture level, bacteria, UV radiation, and oxygen availability, jute fibres can disintegrate by 60–80% in 6–18 months when exposed to dampness (Midha et al., 2017). Despite their relative advantages, geotextiles composed of natural fibres are rarely utilized in engineering projects because of their relatively low tensile strengths and susceptibility to physical, chemical, and biological deteriorations (Saha et al., 2012). According to Gupta et al. (2018), jute geotextile treated with antimicrobial agents prolongs the life of jute and replaces artificial geo-synthetics. Two different methods were employed in the creation of new JGT fabrics in order to increase the useful life of jute geotextiles (JGTs) for use in transportation: (a) making all of the fabric rot-proof and (b) creating blended JGT fabrics composed of jute and polypropylene (Ghosh et al., 2019). However, a number of operations can extend their lifespan by as much as 20 years. As a result, customized biodegradable jute geotextiles with different levels of tenacity, porosity, permeability, and transmissibility can be made according to site-specific specifications. Despite being less durable than synthetic geotextiles, jute geotextiles have certain advantages over synthetic ones in particular applications, such as agro-mulching and other regions requiring quick consolidation. Additionally, as jute geotextiles break down, lignomass is produced, which improves the soil's organic matter, fertility, and texture. Additionally, by stabilizing and consolidating the soil, it encourages vegetative growth (Kumar and Sreedhar, 2022).

The greater the lignin concentration, the more resistant the fibres are to microbial attack-induced rotting (Ghosh et al., 2014). At increasing temperatures, the lignin included in jute geotextiles starts to disintegrate. Sustainability is the primary concern since jute geotextiles lose tensile strength as a result of depolymerisation at higher temperatures. Natural fibres can be treated with antimicrobial chemicals, plant-derived oils, acetylation, and bitumen coating to increase their durability; however, these procedures can be costly and cause leaching (Chakravarthy et al., 2021). Jute's quick biodegradation and limited microbiological resistance, particularly in damp soil settings, are disadvantages despite its total biodegradability (Ghosh et al., 2014). Bitumen emulsion is a dispersed liquid consisting of three ingredients: bitumen, water, and emulsion. Strong anti-stripping, anti-rutting, and anti-microbial properties found in bitumen emulsion help prevent jute from deteriorating in soil, increasing the durability and longevity of the fibres (Akter et al., 2020). Asphalt's inherent viscoelasticity causes it to harden and stiffen after drying, increasing the elasticity of jute textiles. Despite the widespread availability of jute geotextiles, synthetic commercial geotextiles are nevertheless often used (Abid and Rathod, 2022). Reports state that bitumen-coated jute retains 30% of its tensile strength even after one and a half years. Bitumen-coated jute geotextiles were able to retain strength 85.17% in the warp direction and 91.23% in the weft direction. When utilized for road surfaces, bitumen-treated jute has a 59.85% resistance to punctures (Chakravarthy et al., 2021).

The treatment of jute fabrics with different ratios of bitumen emulsion and polyester (PE) resin was examined by Akter et al. (2018). Tensile strength increased significantly in the treated samples, with the sample treated with 10% bitumen emulsion and 20% PE resin showing the largest increase. Tests of soil degradation conducted over a period of ninety days showed that the treated fabrics were more durable than the untreated ones. The enhanced physico-mechanical characteristics and decreased biodegradability of the treated jute fabrics were validated by other tests, such as moisture recovery, water uptake, and scanning electron microscopy (SEM) (Akter et al., 2018). Moreover, bitumen treatment has a detrimental effect on the pliability and malleability of geotextiles (Saha et al., 2012). Jute fiber-based geotextile should be carefully cared for in order to improve and extend its durability, since the lifespan of any sort of JGT is highly desirable in terms of its serviceability and performance standards (Ghosh et al., 2014). The jute geotextile sheet employed in this study reduces the direction of water flow on paved roads by absorbing asphalt and serving as a waterproofing layer. Jute geo textiles come in three primary varieties: knitted, non-woven, and woven. Two sets of parallel yarns or threads emerge, which is a characteristic of woven geotextiles. Weft is the thread that is perpendicular to the length, while warp is the yarn that flows along it. It is possible to make non-woven geotextiles using both short staple fibres and continuous filament yarn. The fibres are fused together using one or more of the following techniques: mechanical, chemical, thermal, or a mix of these. Non-woven geotextiles are produced by mechanically interlocking threads or filaments or by chemical or thermally joining them. Yarn loops are joined together to create knitted geotextiles. Knitted geotextiles are rarely manufactured in large quantities.

The long-term effects of copper sulfate on the chemical and physical characteristics of jute geotextiles are the subject of relatively few studies. Comprehensive research on the ecological impacts of copper sulfate in jute geotextiles, particularly in soil and groundwater, is lacking. The effects of copper sulfate on the mechanical strength, longevity and rates of degradation of jute geotextiles under various environmental circumstances may not have been well investigated in previous studies. Research is required to compare the effects of copper sulfate on jute geotextiles with those of other treatments or additions. There is a knowledge gap about the performance of copper sulfate in practical applications because the majority of research may be carried out in controlled laboratory environments. Rani et al. (2017) investigated the effects of chemical treatments, including copper sulfate, on jute geotextiles' performance in unpaved roads. They highlighted degradation issues and the need for more research on long-term effects under different environmental conditions. Shohan and Talukder (2021) provided insights into jute geotextiles but did not specifically address copper sulfate's effects. Comparative studies could provide valuable insights into copper sulfate's use in jute geotextiles. In order to create geosynthetics, the knitting process is combined with another technique, such as weaving, to create each knitted geotextile. As far as our thorough investigation is concerned, there is no literature on bitumen emulsion, bitumen emulsion with adhesive glue, or bitumen emulsion with copper sulfate applied to jute geo textile. A soil burial test, water uptake analysis, tensile test, and FTIR test were conducted as part of this investigation into the sustainability of jute fabrics.

Materials and Methods

The pilot plant and processing section provided raw jute fabric (1×1 plain weave, 16 EPI, and 10 PPI). For experimental purposes, woven jute of grade 460–500g/m^2 was utilized as a geotextile. Brush, GSM cutter, Bitumen Emulsion (BE), and synthetic resin. Without any purification, all of the chemicals and reagents were used after being gathered as laboratory-grade. In atmospheric conditions, a copper sulphate mixture (0.02Kg/m^2) is also utilized in direct sunshine.

Table 1. Properties of jute geo textiles

Test parameter	Untreated JGT 1	Treated (JGT 2, JGT 3, JGT 4)
Fabric construction	1x1 plain weave design	1x1 plain weave design
Mass per unit area (g/m^2).	460	470-480
Thickness (mm) at 2kpa	2.40	2.50

Preparation of the specimen

The raw jute fibres were cured using bitumen emulsion. The jute fabric was submerged in the solution for 20 to 15min, then brushed with a roller and left to air dry for a full day. Samples for JGT1 (untreated or raw jute), JGT2 (30% bitumen emulsion), and JGT3 (35% bitumen emulsion and 5% synthetic resin) were prepared using the method employed in this investigation. In the current investigation, the bitumen emulsion was applied to the woven type jute geotextile at different rates (0.2 to 0.5 kg/m^2) using JGT4 (25% bitumen emulsion and copper sulfate). Visual inspection revealed that the jute geotextile surface area was more effectively covered by application rates of 0.3 and 0.4 kg/m^2 than by 0.2 and 0.6 kg/m^2 (Fig. 3). In the first step, a sample of compost was made by mixing rich garden soil with leaf litter in a 10:1 ratio. Therefore, the produced compost mixture was evenly applied to the untreated and BET (Bitumen Emulsion Treated) sides of the materials to guarantee that the surface area of the jute geotextile is nicely coated throughout.

Tensile test

A little piece of geotextile tensile strength is measured using a testing device made by Goodbrand Company Ltd. The measured length and width of a tested sample are 40cm and 7cm, respectively. The 35cm grip length is still maintained. Maintaining the tensile loading at a deformation rate of 100mm/min yields the thin strip tensile strength. Ten specimens of each type of geotextile are used in a machine-directed evaluation process, and the average tensile strength of each sample is given.

Water absorbency

First, the 5x5 cm samples were weighed and condition treated. The samples were then immersed in distilled water at 25°C for a whole day. After a predetermined period of time, the samples were removed from the immersion, and tissue paper was used to wipe away any remaining water. The water absorbency test was conducted in accordance with British Standard 3449 (Akter et al., 2020). The water absorption or uptake was calculated as:

$$\text{water absorption } \% = \frac{\text{mass of water absorbed}}{\text{original mass}} \text{ x}100$$

Digging of the soil

Using tools like a shovel, a hoe, and an iron crow bar, among others, the site's natural soil is first excavated to the required depth. To guarantee a well-compacted surface, the earth is securely packed with a soil compactor after levelling. The digging site is where the geo-emulsified jute fabric is found. This layer of geo-jute fabric is primarily used to reduce the soil's capacity to absorb water. To meet the needs of the experiment, the thickness of this geo-jute is fixed between 1.5 and 3.5mm.

Fourier Transform Infrared (FTIR) Spectroscopy

The Shimadzu IRSpirit-X 00154 model, serial number A230861, spectrophotometer at BJRI, was utilized to perform FTIR spectroscopy. A transmittance range of 650 to 4000cm^{-1} was used for the scan. The spectra were obtained using the attenuated total reflectance (ATR) mode.

Results and discussion

Tensile strength/ elongation test

Two instances of the jute geotextile were subjected to strip tensile strength/elongation tests. Initially, an experiment was carried out on untreated jute geotextile (Fig. 1). Tests were performed both before and after soil degradation in the second BET scenario, which involved applying bitumen emulsion to jute geotextile at two application rates of 0.4 and 0.5Kg/m^2 (Fig. 1). The mechanical integrity of jute geo-textiles is diminished by soil deterioration (Fig. 1). In terms of tensile strength, both prior to and following degradation, warp threads routinely perform better than weft threads. Higher residual strength is maintained by treated jute fabrics, particularly JGT-2 and JGT-3, suggesting that treatments (such as bitumen or $CuSO_4$) increase durability. The JGT3 sample yields the best strength analysis results.

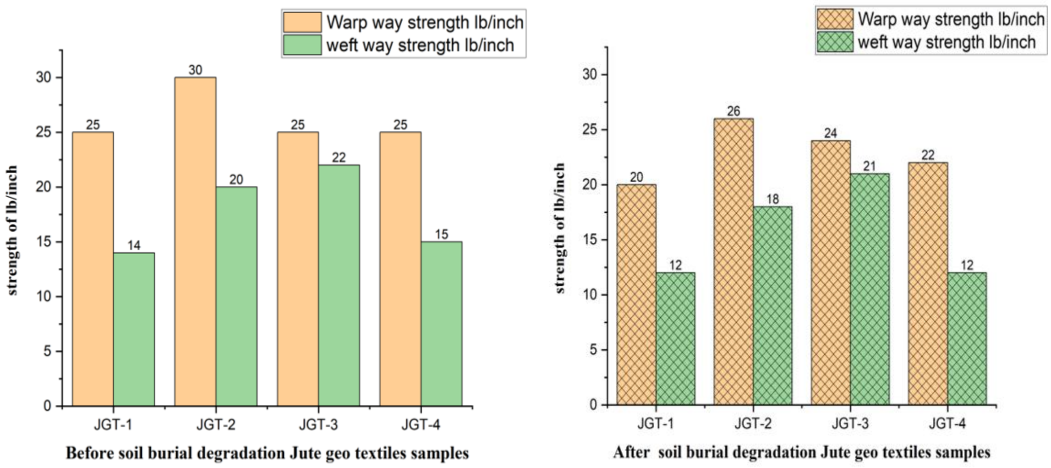


Fig. 1. Tensile strength test of geotextile – (A) before soil burial degradation (B) after soil burial degradation of geo textiles

Water amount of geo textile

To evaluate water affinity, geotextile samples measuring 110 mm by 110 mm were immersed in distilled water for a whole day. After that, the weight of the absorbed water was determined and given as a percentage of the dry weight of the original sample. These figures show that JGT1, JGT2, and JGT4 absorbed 195.52%, 244%, and 240.3%, 200% of water, respectively, based on their initial dry weight (Fig. 2). Following the chemical treatment, the materials appear to become less hydrophilic; the fiber level treatment is more successful than the fabric level treatment.

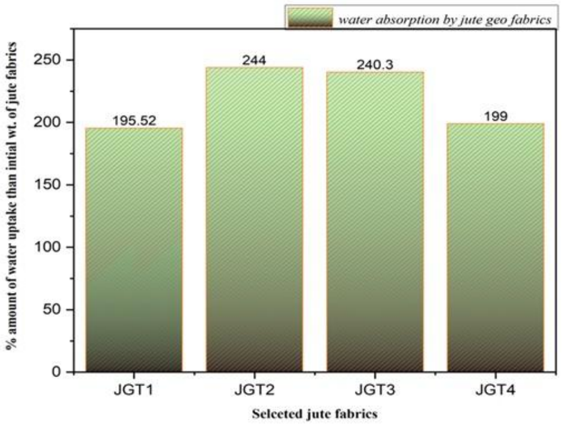
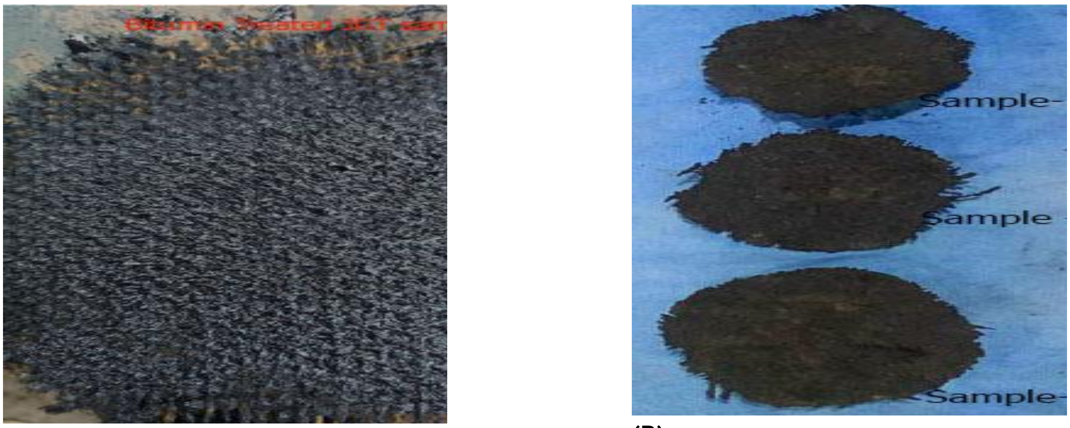


Fig. 2. Water absorption by jute geo fabrics

Soil burial degradation

Fig. 3 displays the results of the soil burial degradation test. Both treated and untreated fabrics were buried in the ground for up to 120 days. After 120 days, the materials were carefully taken out of the ground, rinsed with distilled water, and left to air dry at room temperature for a full day (Akter et al., 2020). Jute has a high attraction for water and is a hydrophilic, biodegradable fibre due to the presence of -OH groups in its polymer chain. The breakdown process is accelerated when jute fibre is buried in soil because water enters it. Degradation by microbes may also occur. As a result, the tensile strength drastically decreases. However, as the breakdown period grows, the coating weakens and degrades more slowly since the polymers are biodegradable (Akter et al., 2020).



(A) **(B)**

Fig. 3. Soil burial degradation test- (A) Before burial jute geo textiles treated with bitumen emulsion; (B) after burial under soil after 120 days

Acid-alkali treatment

To demonstrate the fabrics' tolerance to both acids and alkalis, they are submerged in acetic acid and NaOH. Following testing, it was found that the weight of the geotextile fabrics had decreased (Fig. 4). In practically every application of geotechnical engineering, geotextiles are exposed to diluted solutions of dissolved oxygen, acids, or alkalis. Therefore, jute's resistance to acid and alkaline attack is another crucial durability trait. In this experiment, 2.5g/L of NaOH and 1M acetic acid were used to create alkaline and acidic solutions, respectively. The treated and untreated jute samples were stored in acidic and alkaline solutions at room temperature for 3, 6, and 9 days, respectively. To get rid of any extra acid and alkali deposits from the sample surface, the samples were meticulously cleaned with water and dried after the conclusion of their individual exposure intervals. We found that the samples had deteriorated after this testing.

FTIR analysis of jute geo-textiles

The image's FTIR spectra (Fig. 5) demonstrates the structural traits and alterations in jute fibres treated with bitumen, glue, and $CuSO_4$ both prior to and following soil degradation. The functional groups found in each sample are displayed by plotting the transmittance values against the wavenumber (cm^{-1}). A broad band caused by hydroxyl groups, which are common in natural fibres like cellulose and hemicellulose, was seen in the 3770 cm^{-1} (O-H stretching) peaks. This band is noticeable in all samples, although its intensity varies, particularly in damaged samples that show cellulose breakdown. In contrast, alkane C-H stretching vibrations, which are frequently observed in cellulose and lignin, were discovered in 2934 cm^{-1} (C-H stretching) peaks. This peak is less noticeable after degradation and more noticeable in fabrics that have been untreated and treated with $CuSO_4$.

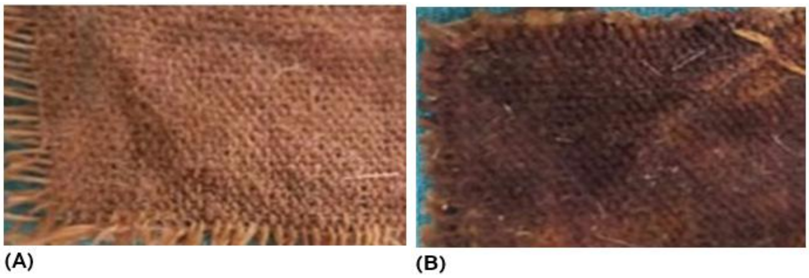


Fig. 4. Acid alkali treatment on jute geo textile fabrics – (A) treatment with acetic acid; (B) treatment with sodium hydroxide

The bitumen-treated samples exhibit changes here, indicating the interaction of aromatic compounds in bitumen. 1579 cm^{-1} (C=C or COO^- stretching) peaks were discovered as a result of aromatic C=C stretching or carboxylate groups. All samples showed the characteristic 1039 cm^{-1} (C-O-C and C-O stretching) peaks of polysaccharides such as cellulose and hemicellulose, which show partial breakdown of polysaccharide components. Untreated jute textiles exhibit all of the distinctive peaks of natural cellulose and hemicellulose in FTIR analysis, and strong O-H and C-H absorption suggests the presence of unmodified jute constituents. In contrast, the profile of $CuSO_4$-treated jute was comparable to that of untreated jute, with slightly decreased peaks, especially at 3770 and 1039 cm^{-1}. This suggests that $CuSO_4$ may function as a moderate preservative, gently altering the molecular vibrations. However, in samples that were bitumen and adhesive treated (prior to deterioration), the peaks at 1579 and 1039 cm^{-1} were more noticeable, maybe as a result of the interaction with synthetic substances. This indicates that bitumen and adhesives were successfully coated or bonded with jute fibre. Conversely, a discernible decrease in the O-H and C-O-C peaks was noted in bitumen and adhesive-treated (after degradation) samples. This suggests that the bitumen has broken down or partially detached from the fibres following soil exposure, as well as changes at 1579 cm^{-1} (Fig. 5). Natural fibre peaks are obscured by bitumen and adhesive treatment, which lowers transmittance. The peaks, however, become weaker (e.g., 1039 cm^{-1}) as the soil deteriorates, indicating that the protective layer has partially disintegrated. These results show how treatments impact jute geo-fabrics' structure and how they impact the environment.

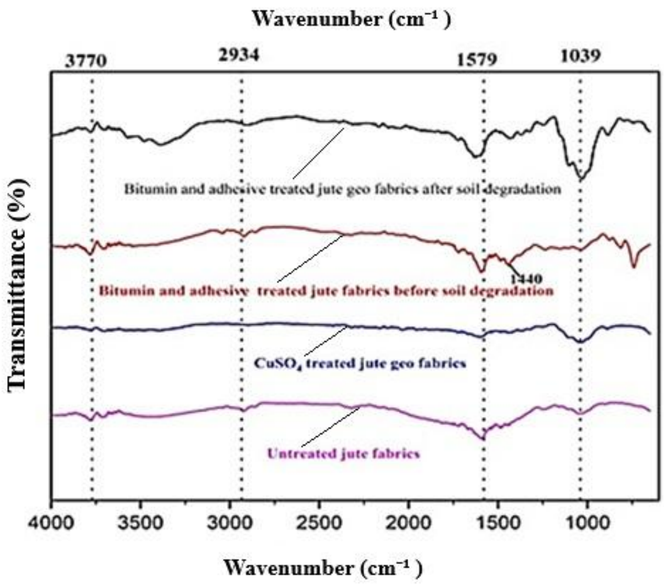


Fig. 5. FTIR analysis of jute geo textiles by untreated and treated samples

Samples such as JGT-2 and JGT-3 exhibit greater tensile strength, particularly in the warp direction, and more of their molecular structure (as determined by FTIR). Bitumen-treated fabric (JGT-2) has clear FTIR signals before and after deterioration, which correlate with the maximum tensile strength retention and suggest that the bitumen coating provides good protection. Small FTIR shifts and high residual strength, on the other hand, indicate that $CuSO_4$ treatment (JGT-3) fabrics offer moderate protection, possibly due to mild cross-linking or antimicrobial activities. Conversely, untreated samples (JGT-1, JGT-4) exhibit the most loss in tensile strength and severe FTIR degradation, with noticeably weaker peaks at ~1039cm^{-1} (C–O–C bonds in cellulose).

Conclusion

Bitumen combined with the right chemical recipe may be one of the most affordable and technically viable solutions for certain technical end-use applications. When utilized as a raw material to create geotextiles in the presence of soil and water, jute's biodegradability is generally questioned. By lowering common issues such as moisture sensitivity and quick biodegradation, the current study demonstrates that bitumen emulsion treatment of jute is a novel approach to increase its tensile strength. Rot-proofing jute geo textiles has helped them last a little longer. The combination of copper sulfate, bitumen and resin in jute geotextiles enhances their resistance to biological degradation, water infiltration, erosion, chemical stability, and mechanical performance. This environmentally friendly approach aligns with sustainable engineering practices and offers an economical solution for geotechnical applications. Jute, a low-cost material, can be effectively enhanced with these additives for various applications. The treatment increased the crystallinity of the fibre. The treated textiles exhibited reduced hydrophilicity and increased resilience to deterioration. Additionally, the treatment had no effect on the materials' tensile strength, flexibility, or filtering capabilities. The untreated jute was shown to have more erosion than the treated jute. Following chemical treatments and soil deterioration, FTIR analysis verifies structural alterations in jute fibres. Although bitumen and glue offer some resistance to deterioration, alterations in the distinctive cellulose peaks (such as those at 1039 and 3770 cm^{-1}) show that breakdown still happens. Without causing significant structural changes, $CuSO_4$ provides slight chemical modifications that could serve as a preservative. The molecular evidence of degradation provided by FTIR is in good agreement with the mechanical strength reduction. Under soil circumstances, bitumen and $CuSO_4$ treatments support the preservation of tensile strength and chemical integrity. The significance of chemical protection techniques for geotextiles made of natural fibres in applications exposed to soil is highlighted by this correlation. After 90 days of being buried in soil and compost, it was discovered that the untreated jute strands were brittle and broke easily. After 60 days of testing, the same treatment showed the least amount of weight loss for exposure to alkali, acid, and soil burial. Numerous chemical and physical alterations have been made to improve jute geotextiles. Together, this research shows that bitumen emulsion, synthetic resins, and copper sulfate are environmentally benign ways to treat woven jute geotextiles, which can greatly improve their mechanical qualities and biodegradation resistance. In geotechnical engineering applications, these treatments enhance the durability and efficacy of jute geotextiles.

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MAI, ZA and MK conceived the concept, wrote and approved the manuscript.

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