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Durability studies of surface-modified coir geotextiles

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ABSTRACT

Coir *(Cocos nucifera)* is a natural fibre known to retain its strength and resist biodegradation far better than other industrial natural fibres. However, systematic studies in this discipline are scarce. Geotextiles are usually exposed to diverse pH, salinity, moisture, and microbial association conditions. In the present work, specific surface modifications of coir geotextiles using a natural agent (cashew nut shell liquid) have been carried out to enhance their long-term performance depending on the end applications. The modified and unmodified geotextiles were subjected to acidic, alkaline, and neutral pH conditions, saline conditions, alternate wetting and drying cycles, and thermal cycles for the assessment of their durability, measured in terms of tensile strength. In situ soil burial studies in a tropical climate were conducted in specially prepared soil to follow the biodegradation behaviour of geotextiles at various depths. The surface-modified geotextiles were found to resist adverse chemical, physical, and biological conditions much better than the unmodified geotextiles. Alkaline conditions marginally accelerated the degradation rates when compared to acidic environments. The saline conditions, as well as alternate wetting and drying conditions, resulted in marginal loss of tensile strength (< 7%). The surface-modified geotextiles buried within lower depths of soil under field conditions retained 70–80% of their initial tensile strength after 12 months, whereas the unmodified geotextiles lost 88% strength in four months. The positive impact of surface modification on durability is confirmed by scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis. The results indicate the excellent potential of suitably surface-modified coir geotextiles for long-term use in adverse conditions.

1. Introduction

The performance of geosynthetics in relation to the environment in engineering applications is highly sustainable when compared to that of conventional construction materials (Raja et al., 2015; Dixon et al., 2017). Replacing synthetic geotextiles by natural geotextiles further reduces carbon emission into the environment during their life cycles (Kiffle et al., 2017). Natural fibres and geotextiles have great potential for solving various geotechnical problems (Rawal and Sayeed, 2013; Mishra et al., 2017). Short-term applications such as drainage (Nguyen and Indraratna, 2017; Broda et al., 2017), reinforcement (Subaida et al., 2009; Maheshwari et al., 2012), slope protection (Lekha and Kavitha, 2006; Kumar and Das, 2018), and heavy metal containment (Rupakheti and Bhatia, 2017) have been successfully addressed using natural fibres or geotextiles made of coir, jute, nettle, and wool.

Among the various lignocellulosic fibres, coir has the highest lignin content (Rajan et al., 2005). This accounts for the high rigidity, strength retention, and resistance to microbial degradation of coir geotextiles in comparison with other natural geotextiles. Specific characteristics such as drapability and the ability to withstand sudden shock/pull make coir geotextiles a better choice over other natural geotextiles in erosion control and slope protection applications (Pritchard et al., 2000). Coir has a tendency to absorb moisture due to its rough texture with numerous fine pores on the surface. The moisture absorption capacity of coir further increases with the advancement in degradation (Vishnudas et al., 2012). Moisture penetrates through the fine pores and cracks on the fibre surface and causes the fibre to swell. This weakens the cell wall and allows microbial attack under ambient pH, temperature, and nutrient conditions. Based on earlier reports of various field studies carried out across the world, natural geotextiles including coir geotextiles have been found to lose tensile strength over time. The tensile strength of coir geotextiles has been reported to drop by nearly 80% of its original value in the first year of installation under tropical climatic conditions (Schurholz, 1992; Balan, 1995; Lekha, 2004; Marques et al., 2014.

The degradation of lignocellulosic fibres is thus a highly complex and contradictory process that is accelerated by the perfect combination of numerous factors (Sarsby, 2007). The long-term degradation

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behaviour of geotextiles and geomembranes of synthetic origins has been largely discussed (Veylon et al., 2016; Koerner et al., 2017; Tian et al., 2018), and their degradation mechanism is entirely different from that of their natural counterparts. Hence, the degradation behaviour of natural geotextiles needs to be addressed separately.

Surface modification of natural geotextiles is a suitable option to prevent moisture intake and extend its useful life (Sanyal and Chakraborty, 1994; Sinha and Chakraborty, 2004). Jute geotextiles that have been transesterified using a mixture of natural and synthetic products resist degradation and exhibit high erosion-control properties (Saha et al., 2012; Midha et al., 2014). Kenaf geotextiles coated with polyurethane have been successfully implemented in the short-term reinforcement of embankments (Chaiyaput et al., 2014). The impregnation of natural fibres with nanoparticles is a recent approach in this field (Anggraini et al., 2016). The efficiency of surface-modified coir geotextiles using cashew nut shell liquid (CNSL) towards controlling microbial attacks has been recently investigated (Sumi et al., 2016). In the present study, the degradation behaviour of unmodified and surface-modified coir geotextiles under active chemical, physical, and biological environments is analysed in detail.

2. Experimental procedure

Durability studies were carried out on simple Panama weave-type coir geotextiles with an area density of 1390 g/m^2 and short-term tensile strength of 22 ± 5 kN/m (machine direction). The chemical composition of the coir fibres used in this study is listed in Table 1. The surface modification of the coir geotextiles was carried out as per the procedure outlined by Sumi et al. (2017). Pre-treatment of the alkali-cleaned coir was performed using copper sulphate solution (1%), and coating was provided using Technical CNSL solution with kerosene as solvent and nitric acid (1% by weight of CNSL) as precursor. Unmodified geotextiles were used as control samples. Two different concentrations of CNSL (20% and 40%) were selected for durability studies. The unmodified geotextiles, geotextiles modified with 20% CNSL, and those modified with 40% CNSL were named UM, C20, and C40, respectively. The geotextiles were subjected to various chemical, physical, and biological degradation conditions as outlined in Table 2. The degradation of the geotextiles was determined in terms of their tensile strength. The wide width strip tensile strength was determined on 200 mm × 200 mm samples as per IS 13162 Part 5, 1992. The tests were carried out in the machine direction using a universal testing machine (UTM) specifically designed for coir geotextiles and yarn (Model: A.S.I., New Delhi, India, Capacity 50 kN). The microbial growth in different depths of soil was studied by the dilution plating method (Schmidt, 1967). SEM and XRD analyses were conducted on the fibre samples to investigate the possible changes in morphology and structure. The coir fibres were pulled out from the geotextiles, cleaned by ultrasonication, and vacuum-dried prior to SEM and XRD analysis. The surface morphology was studied using SEM (Make: JOEL JSM-5600, Japan) at an accelerating voltage of 15 V. The crystallinity achieved by the coir upon coating and after degradation was determined by XRD analysis using PANalytical XpertPRO. The samples were analysed in powder form at a 2θ operating range from 10° to 80°. The crystallinity index (Cr) was estimated using the relation $C_r = (I_{22.5} - I_{18.5}) \times 100/I_{22.5}$, where $I_{22.5}$ and $I_{18.5}$ represent the maximum intensities at 2θ = 22.5° and 18.5°, respectively (Saha et al., 2012).

Table 1
Chemical composition of coir fibres.

Component	% by weight	Testing standard
Lignin	41.5	AOAC 932.01, 2012
Cellulose	45	AOAC 973.18, 2012
Hemicellulose	11.5	ASTM D 1104-56, 1978
Pectin	0.95	IS 15929, 2012

Table 2
Degradation conditions of the study.

Degradation condition		
Chemical	Physical	Biological
pH (5,7,9), salinity	Wetting and drying cycles, Thermal cycles	Soil burial (at depths of 25 cm, 50 cm and 75 cm for 12 months)

2.1. Chemical degradation studies

The geotextile samples were weighed accurately and immersed separately in aqueous solutions of acidic (pH 5.0), alkaline (pH 9.0), and neutral (pH 7.0) pH at room temperature (27 ± 1 °C). The geotextile to solution ratio of 1:10 (by weight) was maintained to ensure the complete immersion of the geotextiles in the solution during the test period of 12 months. The immersion containers (50 L) were closed and fitted with a small vent for the escape of gases. The acidity was adjusted by the addition of hydrochloric acid (HCl), and the alkalinity was maintained by the addition of sodium hydroxide (NaOH) solution. The pH of all the solutions was monitored on a weekly basis and corrected accordingly. Any loss by evaporation was compensated by supplementing pure water to maintain the initial volume of immersion. To study the effect of salinity on the geotextiles, the samples were immersed in an aqueous saline solution with 3% by weight of NaCl (Saha et al., 2012). The tensile strength of the samples was determined at the end of every month.

2.2. Physical degradation studies

Alternate wetting-drying conditions were applied as per the conditions outlined by Balan (1995). The geotextiles were first fully immersed in water (pH 7 ± 0.2) at room temperature (27 ± 1 °C) for seven days, maintaining the geotextile to solution ratio of 1:10 (by weight). The specimens were then removed and placed on a stainless steel strainer for 30 min to drain the excess water. Afterwards, the geotextiles were dried by exposure to direct sunlight (average maximum daily temperature measured over 12 months: 29 ± 1 °C) for seven days. Considering seven days of wetting and seven days of drying as one cycle, the tensile strength of each set of samples was determined at the end of two cycles (28 days). The experiment was carried out for 26 cycles, i.e., 364 days. To study the effect of freeze-thaw cycles on the durability of geotextiles and the stability of the coating composition, a thermal cycling study was conducted as per ASTM D6944–15, 2015. Each cycle consisted of freezing at −14 ± 3 °C for 17 h followed by thawing at 50 ± 3 °C for 7 h. The studies were conducted for 30 cycles.

2.3. Biological degradation studies

The biological degradation of the geotextiles was examined by conducting a soil burial test as per IS 1623, 1992. The test soil was prepared by mixing garden soil, cow dung, and sand in a 2:1:1 ratio. The geotextiles were buried in the prepared soil (pH 6.75–6.85) at depths of 25 cm (top layer), 50 cm (middle layer), and 75 cm (bottom layer) inside fibre-reinforced plastic tanks (1.5 m × 1 m × 1 m) that were open at the top. The tanks were kept in a field and were subjected to natural weather conditions. The geotextile samples were carefully exhumed, cleaned, and dried at the end of every month for the determination of the tensile strength.