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Technical note

Nonwoven geotextiles from nettle and poly(lactic acid) fibers for slope stabilization using bioengineering approach

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ABSTRACT

This article deals with needle-punched nonwoven geotextiles prepared from nettle and poly(lactic acid) fibers in different weight proportions for potential slope stabilization application using bioengineering approach. The geotextiles were tested for tensile strength, biodegradability, and enhancement of soil fertility. The tensile strength of the geotextiles was found to decrease with addition of stronger nettle fibers. This apparently surprising behavior was explained in the light of theoretical tensile mechanics of nonwovens. Further, the nettle fibers displayed higher biodegradability than the poly(lactic acid) fibers, and when buried under soil, all the geotextiles exhibited a loss in tensile strength. Interestingly, the fertility of the soil was remarkably improved after biodegradation of poly(lactic acid) fibers. Overall, the nonwoven geotextiles prepared in this work were found to be promising for slope stabilization application.

1. Introduction

The stabilization of slopes in a constructional project work is always critical as there is every possibility that the structures might collapse if the slopes are found to be unstable. The potential causes for instability of slopes are ranging from deep-seated failure (landslide) to surface erosion by wind or water. Nowadays, there are many techniques available for stabilization of slopes such as mechanical, earthwork, and bioengineering (Lay et al., 2012). The mechanical technique utilizes nonliving components such as rock, concrete, steel pins, gabion baskets, geosynthetics to reinforce slopes. The earthwork technique does reshaping of surface slopes by several methods such as creating terraces or benches, flattening oversteppened slopes, soil roughening, and land forming. The bioengineering technique includes installation of a geotextile followed by seeding and plantation of saplings. This facilitates the vegetation to grow, as a result, after some days the roots of the vegetation take care of the soil that ultimately protects the slope from erosion. This technique has been found very effective for stabilization of different kinds of slopes, for example, road embankment, flood embankment, hilly slope, over burden dump of mine spoil, to name a few (Choudhary et al., 2008).

The nonwoven geotextiles are already proven to be efficient for stabilization of slopes. There are many case studies available where nonwoven geotextiles were successfully used for slope stabilization applications (Tatsuoka and Yamauchi, 1986; Ahn et al., 2002; Lekha, 2004; Vishnudas et al., 2006; Mwasha, 2009). Today there are various types of geotextiles available in the market for this application. They are developed by using either natural fibers such as jute, coir, and sisal or synthetic fibers such as polyester and polypropylene. With the increase of environmental consciousness and demand of legislative authorities, the geotextiles prepared from synthetic fibers are being considered more critically and they are less preferred to those prepared from natural fibers or biofibers from renewable sources. Many attempts were made in the past to develop biodegradable geotextiles from natural fibers for slope stabilization and erosion control applications (Datye and Gore, 1994; Ranganathan, 1994; Ahn et al., 2002; Bieak and George, 2003; George et al., 2003; Lekha, 2004; Rao et al., 2005; Lekha and Kavitha, 2006; Rawal and Anandjiwala, 2007; Choudhary et al., 2008; Ram et al., 2009; Ghosh et al., 2009; Carvaho et al., 2011; Mizal-Azzmi et al., 2011; Erdogan and Erdem, 2011; Senthil and Devi, 2011; Artidteang et al., 2015). In these studies, a myriad of natural fibers namely jute, coir, sisal, flax, kenaf, bamboo, peanut shell, turkey feather were used. The coir based geotextiles were found to be very much suitable for stabilizing slopes using bioengineering approach. Nevertheless, there is one more natural fiber - nettle - which is not yet used in geotextiles. As known, nettle is a cellulosic plant fiber which is abundantly available in the tropical wasteland areas around the world. The nettle family, *Urticaceace*, contains around 500 species. Of them, *Girardinia diversifolia* produces nettle fiber. This fiber is very strong, but rigid and inextensible (Dreyer and Edom, 2005). Its usage is so far restricted to handmade textile products only. As this fiber is reported to be very strong, the geotextile made up of this fiber is expected to be

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strong too which is a prerequisite for slope stabilization and soil erosion control. Further, this fiber may be blended with poly(lactic acid) fibers for manufacturing of geotextiles as the latter was reported to increase the nutrient level of the soil after degradation (Farrington et al., 2005). It is therefore expected that a geotextile prepared from nettle and poly (lactic acid) fibers would not only be strong enough to provide excellent reinforcement to the soil but also help in vegetation, thus providing better stabilization of slopes and better control of erosion. Here, an attempt is made to develop, characterize, and evaluate a series of nonwoven geotextiles prepared by using nettle and poly(lactic acid) fibers in different weight proportions and employing needle-punching nonwoven technology.

2. Materials and methods

2.1. Materials

In this work, the Himalayan nettle (*Girardinia diversifolia*) filaments of 1 m–2 m length, procured from Uttarakhand Bamboo & Fiber Development Board in India, were used. Poly(lactic acid) fibers of 55 mm cut length and 6 denier fineness were also used. Further, easily obtainable EMPARTA® Sodium hydroxide pellets (low chloride) with assay (NaOH) more than 97% were used for alkali treatment on nettle fibers.

2.2. Methods

2.2.1. Alkali treatment on nettle fibers

The nettle filaments as procured were cut into staple fibers of 55 mm ± 1 mm length, followed by cleaning mechanically and sorting manually. Afterwards, an attempt was made to process them on a laboratory-based miniature carding machine (Make: Trytex, India) for preparation of fibrewebs. But, this attempt was not successful as it resulted in significant fiber breakage. This was probably associated to high stiffness and low extensibility of nettle fibers as reported by Dreyer and Edom (2005). In order to make the nettle fibers processable on the carding machine, it was necessary to improve the mechanical properties of nettle fibers. As alkali treatment was known to improve the flexibility and extensibility of nettle fibers (Kumar and Das, 2016a), it was carried out by treating the cleaned staple nettle fibers with alkaline (NaOH) solution in a laboratory-based batch process. The optimum alkali treatment conditions, reported elsewhere (Kumar and Das, 2016b), were followed for alkali treatment. In one batch, 40 g of cleaned nettle fibers were immersed into 2000 ml of alkaline solution with an alkali concentration of 10%. The fibers were treated at 61.5 °C temperature for 0.5 h. The treated fibers were extracted from the solution, squeezed, washed with distilled water and neutralized with 10% acetic acid. The fibers were then washed with distilled water and squeezed to remove excess water. Afterwards, they were manually opened to single fiber stage. This was followed by drying in a hot air oven at a temperature of 30 °C for 48 h. The dried fibers were kept under standard testing atmospheric conditions as stipulated in ASTM D1776–04 standard.

2.2.2. Development of nonwoven geotextiles

The alkali-treated nettle fibers were blended with poly(lactic acid) fibers as homogeneously as possible manually in five different blend proportions (w/w) (0/100, 25/75, 50/50, 75/25, 100/0). The fiber blends were fed to a laboratory-based miniature carding machine. The machine had a feed roll running at angular speed of 1.04 rpm (revolution per minute), cylinder at 300 rpm, and doffer at 2.07 rpm. It delivered parallel-laid fiberwebs consisting of nettle and poly(lactic acid) fibers with five different blend proportions. Afterwards, the fiberwebs were processed through a needlepunching machine (Make: Dilo, Germany) so as to bond the fibers mechanically. While needle-punching, the punch density was kept at 225 punches/cm^2 and the depth of needle penetration was maintained at 12 mm. In this way, a series of needle-punched nonwoven geotextiles was prepared from nettle and poly(lactic acid) fibers with five different blend proportions.

2.2.3. Characterization of fibers

The untreated as well as alkali-treated nettle fibers and poly(lactic acid) fibers were tested for fineness, tensile properties, and fiber-to-fiber friction. The alkali-treated nettle fibers were also tested for density.

The density of alkali-treated nettle fibers was determined using Archimedes method in accordance with ASTM Standard D3800 (1999). A weighed quantity of fibers was fully immersed in water and the volumetric displacement of water was observed. The density of fiber was determined by the ratio of the weight of fiber to the volume of water displaced.

In order to measure the fineness of untreated as well as alkali-treated nettle fibers, the single fiber weighing method, as stated in ASTM Standard D1577 (2007), was followed. For this purpose, nettle fibers of 100 mm staple length were weighed individually using an electronic micro-weighing balance (Model: AND GR-201). An average of fifty readings was taken each for untreated nettle fibers and alkali-treated nettle fibers. The fineness of poly(lactic acid) fibers was determined in accordance with fiber bundle weighing method, as stated in ASTM Standard D1577 (2007). For this purpose, a bundle of poly(lactic acid) fibers, each of 55 mm cut length, was weighed using the electronic micro-weighing balance stated earlier and the number of fibers was counted to determine the fineness of poly(lactic acid) fibers. Here, an average of ten readings was taken.

The untreated as well as alkali-treated nettle fibers and poly(lactic acid) fibers were tested for tensile properties using Instron tensile tester (Model: 4301) according to single fiber tensile test as prescribed by ASTM Standard D3822 (2007). The gauge length was kept constant at 25 mm and the crosshead speed was also maintained constant at 2.5 mm/min. Fifty untreated nettle fibers, fifty alkali-treated nettle fibers, and fifty poly(lactic acid) fibers, each of 55 mm cut length, were randomly selected for tensile test. Each fiber was first weighed using the above-mentioned electronic micro-weighing balance. Then, each fiber was attached to a paper window and subsequently to the jaws of the tensile tester. An average of fifty readings was taken to determine the mean tensile strength, mean breaking elongation, and mean initial modulus.

The fiber-to-fiber friction of untreated as well as alkali-treated nettle fibers and poly(lactic acid) fibers was determined following a method reported by Kumar et al. (2005). According to this method, two fiber fringes of 5 mg/cm^2 weight were placed one over another and a known weight of 40 g was placed on them. The upper fringe was attached to the load cell of Instron tensile tester (Model: 4301) by an inextensible cord through a friction less pulley and the lower fringe was clamped on a base plate. The crosshead speed was kept at 10 mm/min and the maximum draw force developed between the fiber fringes at the point of slippage was recorded by the tensile tester under the applied known weight. From the recorded value of draw force, the coefficient of fiber-to-fiber friction was determined using Amonton's law. Here, an average of five readings was taken to calculate the mean coefficient of fiber-to-fiber friction.

2.2.4. Characterization of nonwoven geotextiles

The nonwoven geotextiles were tested for basis weight, thickness, fiber orientation, and tensile properties. The basis weight and thickness were determined in accordance with ASTM Standard D5261 (2010) and ASTM Standard D5199 (2011), respectively. To measure the basis weight of each of the five geotextiles, five samples each of 100 mm × 100 mm size were weighed using a weighing balance (Make: Afcoset, Model: FX300) and the average of five readings was taken. To measure the thickness of each of the five geotextiles, five samples were tested on a thickness tester (Make: Essdiel) and the average of five readings was calculated. To determine the orientation of