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Technical note

Interface shear characteristics of jute/polypropylene hybrid nonwoven geotextiles and sand using large size direct shear test

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ABSTRACT

In this study, large-size direct shear tests were conducted to determine the interfacial shear characteristics of sand–geotextile under three different normal stresses. The geotextiles used in the present study were hybrid needlepunched nonwovens containing defined weight proportions of jute and polypropylene fibers. Subsequently, the interfacial shear characteristics of hybrid and that of a nonwoven geotextile consisting of solely polypropylene fibers with sand were compared and analyzed under different normal stresses. Initial higher shear stiffness of sand-polypropylene geotextiles was observed corresponding to sand-hybrid geotextiles specifically under higher normal stresses. Nevertheless, the contact efficiency of sand-hybrid nonwovens was similar to that of sand-polypropylene geotextiles. The surface morphology of sand particles has been investigated based on the images obtained from scanning electron microscopy (SEM) and quantitatively analyzed by means of Wadell roundness and degree of angularity methods.

1. Introduction

Geotextiles have successfully replaced metal strips for various reinforcement applications in order to overcome the weakness of soil against tension. The popular use of geotextiles in reinforcement applications is not only due to their low stiffness that makes them compatible with soil in terms of deformability but they increase shear strength, ductility and provide smaller loss of post-peak strength compared to unreinforced soil (Gray and Ohashi, 1983; Haeri et al., 2000). The analysis of interaction of soil-geotextile is of paramount importance for the design and performance of reinforced soil structures (Palmeira, 2009). The interaction between the soil and the geotextile is complex and it depends on various factors including geotextile properties (type of constituent fibers and their properties, fiber orientation, pore dimensions, mass per unit area, thickness, extensibility, surface roughness, anchor length), soil properties (size, shape, density, saturation conditions), loading conditions (normal stress component), rate of deformation and method of testing (Athanasopoulos, 1993; Bakeer et al., 1998; Bouazza and Djafer-Khodja, 1994; Farrag et al., 1993; Fourie and Fabian, 1987; Haeri et al., 2000; Mogahzy et al., 1994; Rawal et al. 2010; Yogarajah and Yeo, 1994; Zhai et al., 1996). One of the most important and commonly used methods to understand the soil-geotextile interaction is carried out by direct shear test in which the soil is strained against the geotextile. The direct shear method has been particularly useful in determining the frictional behaviour of soil-geotextile interface (Anubhav and Basudhar, 2010). A typical uniform shear mechanism generated at the interface of soil-geotextile can cause the interlocking of soil particles in the pores of the geotextiles depending upon the geometrical properties of soil particles and the surface characteristics of the geotextile (Palmeira, 2009).

In the past, nonwoven geotextiles have been successfully used for reinforcing different types of soils under various conditions due to their rough surface characteristics and higher extensibility (Hufenus et al., 2006; Tatsuoka and Yamauchi, 1986; Tuna and Altun, 2012). In general, nonwoven geotextiles can be prepared from synthetic and natural fibers, both of the fiber types offer their own advantages and demerits for geotechnical engineering applications. Natural fibers are environment friendly, biodegradable, non-abrasive, less costly, exhibit high initial modulus and high moisture absorption but they have non-uniformity in their physical and mechanical properties. Alternatively, the synthetic fibers have dominated the geotextile industry due to minimal variation in mechanical properties but they can be hazardous to the environment. The hybrid nonwoven geotextiles consisting of optimal level of synthetic and natural fibers content can complement each other

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Table 1
Physical properties of fibers used in the production of nonwoven geotextiles.

Type of fiber	Staple length (mm)	Linear density (dtex)	Diameter (μm)	Tensile strength (MPa)	Modulus (GPa)	Breaking Strain (%)
Jute	51	28.1 ± 0.24	53.38 ± 5.93	369 ± 97	38.92 ± 10.52	1.18 ± 0.30
Polypropylene	60	6.6 ± 0.01	25.24 ± 0.04	548 ± 66	1.30 ± 0.30	30.00 ± 4.43

demerits. Recently, we have successfully prepared jute/polypropylene hybrid needlepunched nonwoven geotextiles and optimized some of their physical and the mechanical properties (Rawal and Sayeed, 2013). The main objectives of this study is to compare and analyze the interface shear characteristics of sand-jute/polypropylene and sand-polypropylene needlepunched nonwoven geotextiles. This study would demonstrate the potential of replacement of 100% polypropylene based nonwoven geotextiles by jute/polypropylene nonwoven geotextiles specifically for temporary structure applications. Furthermore, the effect of sand particle shapes on the interface friction properties of sand–geotextiles has also been analyzed.

2. Experimental work

Tossa jute of grade BTC (Bangla Tossa C) and polypropylene (PP) staple fibers were mixed in defined weight proportions for preparing Jute/PP hybrid needlepunched nonwoven geotextiles. The constituent fiber properties are given in Table 1.

2.1. *Preparation and testing of needlepunched nonwoven geotextiles*

Three samples of hybrid needlepunched nonwoven geotextiles have been prepared in Jute/PP weight proportions, i.e., 20/80, 40/60 and 60/40. In addition, a needlepunched nonwoven geotextile made from 100% polypropylene fibers was also fabricated and accordingly, this sample was designated as 00/100 Jute/PP. The methodology of preparation of these geotextiles is provided in our previous work (Rawal and Sayeed, 2013). These geotextiles were cross-laid needlepunched nonwovens consisting of majority of fibers oriented in the cross-machine direction. Various physical and mechanical properties of these hybrid needlepunched nonwovens were tested according to the standard test methods. Table 2 shows the physical and tensile properties of needlepunched nonwoven geotextiles. The pore size distribution of nonwoven geotextiles was determined using capillary flow porometer according to ASTM D6767, as shown in Fig. 1.

2.2. *Sand characteristics*

Locally available sand known as Badarpur sand was used in the present study. Fig. 1 shows the grain size distribution of Badarpur sand. The sand is classified as a poorly graded (SP) according to the Unified Soil Classification System (USCS). The properties of sand particles are: average grain size, $D_{50} = 0.45$ mm; effective grain size, $D_{10} = 0.246$ mm; uniformity coefficient, $C_u = 1.93$; coefficient of curvature, $C_c = 0.97$; maximum dry density, $\gamma_{\max} = 16.28$ kN/m^3 and minimum dry density, $\gamma_{\min} = 13.97$ kN/m^3. The qualitative analysis of shape of sand particles was carried out using scanning electron microscopy (SEM) and it has been observed that the particles are angular in nature with sharp edges as illustrated in Fig. 2. Furthermore, the shape of the particles was quantitatively analyzed in terms of Wadell roundness and degree of angularity methods (Wadell, 1932; Lees, 1964). In Wadell roundness method, a circle of maximum diameter is inscribed in a projected two-dimensional sand particle shape and simultaneously, a circle of maximum diameter is also inscribed at each corner. Hence, the average roundness (R) for sand particle shapes can be computed as shown below.

$$R = \frac{\left(\sum_{k=1}^{n} D_k\right) \Big/ n}{D_i} \tag{1}$$

where D_k is the diameter of circles fitted at the corners, n is the number of the corners and D_i is the diameter of the inscribed circle.

The average roundness ranges between 0 and 1 indicating non-circular and complete circular shapes, respectively. In this study, the average roundness of 152 sand particles was determined by capturing the particle images using low magnification optical microscope and subsequently, these images were analyzed using image analysis software (Leica Qwin®). The average roundness of sand particles was found to be 0.3 indicating a high degree of non-circularity. Furthermore, the degree of angularity was determined based on the methodology developed by Lees (1964). Here, the degree of angularity (A) is quantified in terms of the bounding edge angles (α) and the distance of the edges from the centre of the particle (x) having the largest inscribed circle of radius (r) in a defined plane. Hence,

$$A = (180^\circ - \alpha)\frac{x}{r} \tag{2}$$

It should be noted that the total degree of angularity (A) is the sum of the magnitudes of all the corners measured in three mutually perpendicular planes.

Table 2
Physical and tensile properties of Jute/PP hybrid needlepunched nonwoven geotextiles.

Sample ID	Physical properties				Wide width tensile test, ASTM D4595					
					Cross-machine direction			Machine direction		
	Mass/unit area (g/m^2), ASTM D6242	Thickness at 2 kPa (mm), ASTM D5729	Pore size, O_{95} (μm), ASTM D6767	O_{95}/D_{50}	Tensile strength (kN/m)	Secant modulus at 10% strain (kN/m)	Breaking strain (%)	Tensile strength (kN/m)	Secant modulus at 10% strain (kN/m)	Breaking strain (%)
00/100 Jute/PP	390 (10.07)	4.12 (0.12)	174.10	0.39	29.36 (0.68)	8.93 (0.87)	84.35 (3.03)	10.77 (0.55)	2.32 (0.18)	160.3 (7.49)
20/80 Jute/PP	394 (7.27)	4.01 (0.12)	185.56	0.41	23.10 (1.20)	10.15 (0.49)	89.78 (2.34)	9.12 (0.41)	2.81 (0.12)	154.67 (3.30)
40/60 Jute/PP	405 (6.68)	3.85 (0.10)	187.63	0.42	26.81 (0.58)	20.21 (0.69)	86.19 (1.75)	8.74 (0.29)	4.07 (0.19)	155.13 (4.10)
60/40 Jute/PP	410 (10.04)	3.60 (0.13)	185.13	0.41	15.74 (0.46)	19.92 (2.80)	75.42 (6.55)	6.99 (0.37)	5.00 (0.31)	137.50 (5.66)

Figures in parenthesis illustrate the standard deviation obtained in five tests.