Mechanical Properties of Hybrid Needlepunched Nonwoven Geotextiles

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Abstract
Needlepunched nonwoven geotextiles (both natural and synthetic fibre based) are widely used for various civil engineering applications. In this preliminary research work, the wide width tensile (both virgin and damaged at the centre), puncture resistance and compression properties of hybrid geotextiles were analysed. These hybrid geotextiles have been produced from the blend of jute/polypropylene fibres in defined weight proportions (0%, 20%, 40% and 60%). Subsequently, a comparison has been made between various physical and mechanical properties of needlepunched nonwoven geotextiles. In this research work, it was found that hybrid geotextiles made of jute (40 wt.%) showed better performance amongst the hybrid jute/polypropylene nonwoven geotextiles.

Key Words: **Hybrid Geotextiles, Tensile, Puncture, Needlepunched nonwoven, Porosity**

1. INTRODUCTION

Geotextiles can be made from synthetic and natural fibres but the synthetic fibres are widely used in civil engineering applications primarily due to their superior mechanical properties and long-term durability [1]. Natural fibre based geotextiles are environment friendly, less costly, easily available, and biodegradable as they are easily degraded within the soil [2]. Several researchers have reported the use of natural fibres including jute, flax, coir, hemp, wood and bamboo in various applications of geotextiles such as soil erosion control, vertical drains, road bases, bank protection and slope stabilisation [3-5]. However, the overall objective of the present work is to compare and analyse the mechanical properties of hybrid needlepunched nonwoven geotextiles produced from jute and polypropylene fibres that can be effectively used for reinforcement applications.

Table 1: Physical properties of fibres used in the production of nonwoven geotextiles

Type of fibre	Staple length (mm)	Linear density (dtex)	Diameter (µm)	Tenacity (N/tex)	Tensile strength (MPa)	Modulus (GPa)	Extension at break%
Jute	51	28.1	53.38	0.294	369	38.92	1.18
Polypropylene	60	6.6	25.24	0.415	548	1.30	30.00

2. MATERIALS AND METHODS

Tossa jute of grade BTC (Bangla Tossa C) and polypropylene staple fibres (supplied by Zenith fibres, India) were used for fabrication of needlepunched nonwoven geotextiles. The constituent fibre properties are given in Table 1 and the typical stress-strain curves of jute and polypropylene fibres are shown in Figure 1.

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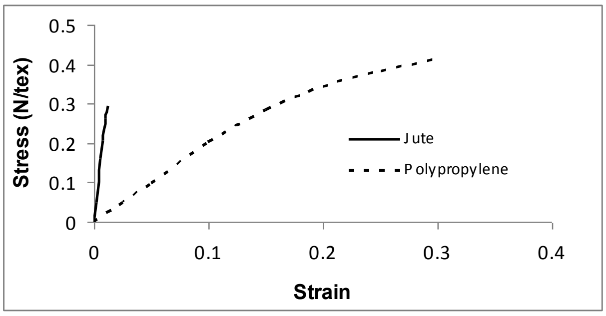

Figure 1: Typical stress-strain curves of jute and polypropylene fibres

Fabrication of Needlepunched nonwoven geotextiles

Taguchi's full factorial experimental design was employed by varying the punch density (150,180 and 225/cm^2) and depth of needle penetration (8, 10 and 12 mm) to optimise the process parameters for the production of hybrid jute/polypropylene needlepunched nonwoven geotextiles. The optimised process parameters found through the experimental design are punch density of 150/cm^2 and depth of needle penetration of 12 mm. Following the optimization of process parameters, four samples of hybrid jute/polypropylene (jute/PP) needlepunched nonwoven geotextiles have been prepared from polypropylene fibres after blending with jute staple fibres in defined Jute/PP proportions, i.e., 0/100, 20/80, 40/60 and 60/40. These hybrid needlepunched nonwoven geotextiles have nominal fabric area density of 400 g/m^2 and were prepared using DILO needlepunching nonwoven line based at IIT Delhi. It must be noted that the process parameters were kept constant for all the four geotextile samples. Subsequently, the hybrid needlepunched nonwovens were tested for various mechanical properties including wide width tensile test in the machine and cross-machine directions (ASTM D4595-09), CBR puncture resistance (ASTM D6241-04) and compression properties. Furthermore, a circular hole is artificially induced at the centre of specimen so as to create the damage and the tensile properties of hybrid needlepunched nonwovens were determined both in the machine and cross-machine directions.

3. RESULTS AND DISCUSSION

3.1 Tensile properties of hybrid needlepunched nonwoven geotextiles

Table 2 shows a comparison between the tensile properties of hybrid needlepunched nonwoven geotextiles for both virgin/undamaged and damaged at centre in the cross machine and machine directions.

Table 2: Tensile test results (virgin and damaged at centre) and puncture resistance of hybrid Jute/PP needlepunched nonwoven geotextiles

Sample ID	Cross machine direction			Machine direction			Puncture resistance (kN)
	Tenacity (N/tex)	Breaking strain (%)	Secant Modulus at 10% Strain (N/tex)	Tenacity (N/tex)	Breaking strain (%)	Secant Modulus at 10% Strain (N/tex)	
Virgin							
100% PP	0.075	105.94±3.03	0.023	0.028	186.63±7.49	0.006	3.23 ± 0.08
20/80 Jute/PP	0.059	106.87±2.34	0.026	0.023	182.80±10.22	0.007	2.16 ± 0.15
40/60 Jute/PP	0.066	96.91±1.75	0.050	0.022	177.22±4.10	0.010	2.31± 0.17
60/40 Jute/PP	0.038	94.48±6.55	0.048	0.017	168.92±5.66	0.012	1.86 ± 0.11
Damaged at centre							
100% PP	0.055 (0.73)*	104.34±4.50	0.020	0.022(0.79)*	175.67±6.53	0.0055	-----
20/80 Jute/PP	0.048 (0.81)*	102.72±6.10	0.024	0.019(0.83)*	169.18±1.86	0.0060	
40/60 Jute/PP	0.050 (0.76)*	100.74±1.51	0.045	0.020(0.91)*	174.43±5.01	0.0097	
60/40 Jute/PP	0.033 (0.86)*	91.09±8.19	0.050	0.010(0.58)*	167.02±8.02	0.0090	

***Indicates the ratio of tenacity between damaged at centre and virgin samples.**

Table 3: Compression properties of hybrid needlepunched nonwoven geotextiles

Samples ID	Fabric mass/unit area (g/m^2)	Thickness (mm)			Porosity			Percentage change in porosity	
		2 kPa	20kPa	200kPa	2 kPa	20 kPa	200 kPa	2-20kPa	2-200kPa
100% PP	390	4.12 (0.12)*	3.68 (0.044)	1.62 (0.059)*	0.90	0.88	0.74	2.22	17.77
20/80 Jute/PP	394	4.01 (0.12)*	3.37 (0.051)	1.75 (0.117)*	0.90	0.88	0.77	2.22	14.44
40/60 Jute/PP	405	3.85 (0.10)	3.26 (0.095)	1.80 (0.044)*	0.90	0.89	0.79	1.11	12.22
60/40 Jute/PP	410	3.60 (0.13)*	3.08 (0.187)*	1.65 (0.210)*	0.90	0.89	0.79	1.11	12.22

***Parentheses indicate the standard deviations of thickness values.**

It is seen that the tensile properties in the cross-machine direction in both the geotextile samples of virgin and damaged at centre is higher than the corresponding tensile properties in the machine direction because the fibres are preferentially oriented in the cross-machine direction. From Table 2, it can be observed that 40/60 Jute/PP hybrid geotextiles have resulted in higher tenacity and secant modulus amongst the hybrid geotextiles both in the cross machine direction and machine directions. It may be due to the fact that 40/60 Jute/PP has a compact structure, as shown in Table 3 and the changes in the thickness under defined pressure ranges are minimal. Increasing the jute proportion is expected to increase the secant modulus of hybrid nonwoven as the initial modulus of jute fibres is significantly higher than the polypropylene fibres (see Table 1). Similar trends are also found in this hybrid geotextile for both virgin and damaged samples. Breaking strains are also found to decrease with increasing jute fibres content in the hybrid needlepunched nonwoven geotextiles.

Furthermore, the effect of circular damage was analysed by computing the ratio of tensile strength before and after damage as shown in Table 2. It was observed that jute content of 40-60 wt % is able to preserve their tensile properties in the range of 76-86% after the circular damage is induced in the hybrid nonwoven. Figure 2 illustrates the typical stress-strain characteristics of 40/60 Jute/PP and 60/40 jute/PP virgin (V) and damaged (D) samples in the cross-machine and machine directions.

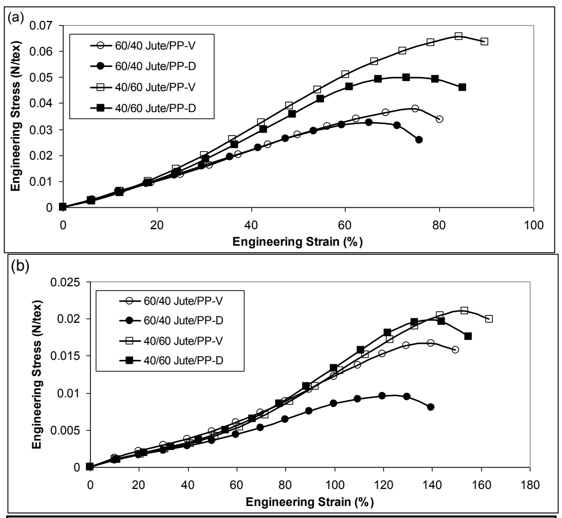

Figure 2: Typical stress-strain curves of virgin (V) and damaged (D) needlepunched nonwoven geotextiles (40/60 Jute/PP and 60/40 PP/Jute) (a) cross-machine direction (CD) and (b) machine direction (MD)

3.2 Puncture properties of hybrid needlepunched nonwoven geotextiles

Geotextiles are extensively used for the protection of geomembranes against sharp objects such as gravel, stones etc. as the former acts as cushioning under various soil conditions. These soil conditions including subgrade surface irregularities can impart concentrated forces perpendicular to the plane of geotextile leading to the puncture failure of the geotextile material [7]. Puncture resistance is a commonly used index test method to simulate the force required to penetrate the geotextile by objects such as stones, gravels, etc. In this study, 40/60 Jute/PP has shown the maximum puncture resistance in comparison to the other hybrid nonwoven geotextiles. These results have a good correlation with the compactness of hybrid nonwovens and in-plane tensile properties. In the past, the puncture resistance of needlepunched nonwovens were related with their in-plane tensile properties as demonstrated by Ghosh [7]. Figure 3 depicts the relationship between puncture resistance and tensile strength in the cross machine and machine directions. It can be seen that there is a good correlation between puncture resistance and tensile strength in the machine direction. Similar results were observed in predicting the puncture properties of hybrid needlepunched nonwovens fabricated from polypropylene and viscose fibres based on the tensile properties in the machine direction [8]. It was found that the proportions of fibres in the machine direction and the ratio of fibres aligned in the through-thickness direction are almost same manifesting a good correlation between the puncture and tensile properties in the machine direction. When a force is being applied in the through-thickness direction, the fibres, which are oriented in the thickness direction, will resist and contribute towards the puncture force.

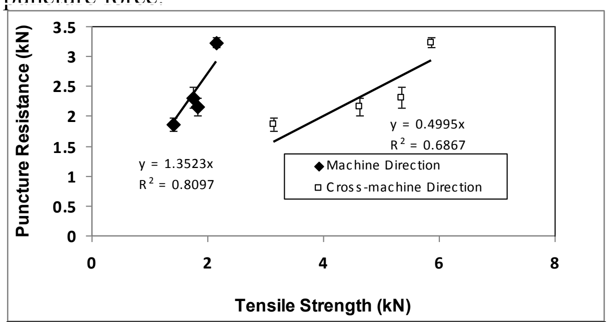

Figure 3: Relationship between puncture resistance and tensile strength in cross-machine directions (here error bar indicates standard deviation for puncture resistance)

3.3 Compression properties of hybrid needlepunched nonwoven geotextiles

Table 3 shows a comparison between the compression properties of hybrid jute/PP needlepunched nonwoven geotextiles. Here, the porosity is calculated by determining the geotextile thickness at the pressures of 2, 20 and 200 kPa. The minimum reduction in porosity was found in the jute content of 40-60 wt % specifically under higher level of compressive stresses.

4. CONCLUSIONS

Hybrid needlepunched nonwoven geotextiles were successfully produced from polypropylene and jute fibres in different weight proportions of mass per unit area of 400 g/m^2. A comparison is made between the mechanical properties of these hybrid jute/PP needlepunched nonwoven geotextiles and 100% polypropylene based geotextile. From the preliminary research work, it may be concluded that that jute content of 40 wt% has a compact structure with minimum changes in the porosities under a range of compressive stresses. 40/60 Jute/PP has amongst the highest tensile strength, secant modulus and puncture resistance in hybrid needlepunched nonwoven geotextiles. Interestingly, 40/60 Jute/PP has a moderate loss of tensile strength when damage such as a circular hole was artificially induced in the hybrid nonwoven, Thus, the research work of hybrid needlepunched nonwoven geotextiles has clearly depicted that the natural fibre such as jute in combination with polypropylene can be potentially used for reinforcement applications.

It is suggested that increasing the weight content of jute fibres, i.e. more than 60% may not help in obtaining the 'right' structural and mechanical characteristics of hybrid nonwovens as the jute fibres have low extensibility. Future work will focus on enhancing the mechanical characteristics of hybrid needlepunched nonwoven geotextiles by chemically treating the jute fibres. Furthermore, the other geometrical and mechanical characteristics such as pore size distribution and shear resistance would need to be investigated.

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