



Effect of process parameters on properties of polypropylene and kenaf fibres needle-punched nonwoven geotextiles

Cyrus Tshifularo^{1,2}, Rajesh Anandjiwala^{1,2,a} & Asis Patnaik^{1,2,3}

¹CSIR Materials Science and Manufacturing, Polymers and Composites Competence Area, Nonwovens and Composites Group, Port Elizabeth, South Africa

²Department of Textile Science, Faculty of Science, Nelson Mandela University, Port Elizabeth, South Africa

³Department of Clothing and Textile Technology, Faculty of Engineering and the Built Environment, Cape Peninsula University of Technology, Bellville Campus, Cape Town 7535, South Africa

Received 11 June 2019; revised received and accepted 19 November 2019

Effects of stroke frequency, depth of needle penetration and mass per unit area on properties of needle-punched nonwoven fabrics produced from polypropylene (PP), 50/50 PP/kenaf and kenaf fibres have been studied. Properties of fabrics, such as tensile strength, puncture resistance, pore size, water permeability and transmissivity are analysed. Results obtained show that the higher tensile strength and puncture resistance are achieved in fabrics produced from kenaf fibres at higher stroke frequency, depth of needle penetration and mass per unit area. Fabrics produced from kenaf fibres can be employed in geotextile applications, since they also possess bigger pore size and higher water permeability.

Keywords: Geotextiles, Kenaf, Needle-punched nonwoven, Permeability, Polypropylene, Puncture resistance, Stroke frequency, Tensile strength, Transmissivity

1 Introduction

Recently, during the past few decades nonwoven geotextiles produced from natural fibres have witnessed increased usage. This increase in the use of natural fibres in geotextile applications was attributed to non-renewable materials produced from petroleum-based products, growing environmental concern, government regulation, cleaner and safer environment¹⁻⁴. Natural fibres have been used in geotextile applications, such as filtration, separation, reinforcement and drainage, where the geotextile is expected to perform one or more functions⁵. Ghosh *et al.*⁴ have reported that the fibres can be utilized in geotextile applications if they possess better mechanical properties. The use of natural fibres was attributed to their better tensile strength, environmental friendliness, biodegradability, lower density, carbon dioxide sequestration, higher toughness and availability at lower cost⁴⁻⁹. Coir, jute, flax, sisal, abaca, pineapple, hemp, bamboo, cotton, sugarcane bagasse and kenaf are the examples of natural fibres^{1, 4, 5, 10-12}. Kenaf is a strong, hard and tough plant with shorter plantation cycle. It is grown

in subtropical and tropical parts of both Africa and Asia with lower amount of pesticides required during cultivation. Kenaf fibres are extracted from a kenaf plant mostly using water-retting process. However, both chemical and mechanical retting processes can also be utilized. Kenaf fibres are categorized into three groups, namely bast, core and pitch constitutes. Amount of both bast and core raw materials is higher to that of pitch and hence they provide more kenaf fibres. Bast and core are differentiated by their chemical compositions. Advantages of using kenaf fibres include better mechanical properties, low density, abrasion resistance, environmental friendliness and biodegradability^{7, 8, 13}. Paridah *et al.*⁷ have reported that kenaf fibres produced from bast are longer with better mechanical properties. Similarly, like other natural fibres, disadvantages of kenaf fibres are that their properties, such as length, aspect ratio, cross-section, diameter and tensile strength of the fibres, are influenced by place of origin, type of climate, harvesting date, cultivation and steam explosion treatment. These properties influence physical and mechanical properties of kenaf fibres^{2, 8, 14, 15}. In addition, the quality of the fibres produced from bast plant is affected by the duration of the retting process, which is between 14 days and

^a Corresponding author.

E-mail: Rajesh.anandjiwala@mandela.ac.za

28 days⁷. Furthermore, needle-punched nonwoven fabrics produced from kenaf fibres are expected to pose processing problems, such as lower entanglement of coarser fibres particularly at lower depth of needle penetration and fibre breakages during carding and needle-punching process^{6, 11, 12}. These problems can be minimised by blending both kenaf and polypropylene (PP) fibres together^{6, 16}. The products produced using kenaf fibres are used in the automotive and sports industries, food packaging, ropes, papermaking, nonwoven textile and furniture^{7, 8, 13, 17, 18}.

Most of the previously reported research work are carried out on the use of natural fibres in slope stabilisation, river bank protection, prevention of soil erosion, vertical drains and increasing plant growth^{1, 3-6, 9-11, 16, 18, 19}. However, studies are scanty on the use of kenaf fibres in geotextile applications. The aim of this work is, therefore, to study the effect of process parameters on the needle-punched nonwoven fabrics produced from different fibres and their blends, namely 100 % PP, a blend of 50/50 % PP/kenaf and 100 % kenaf in order to either minimise or replace currently utilized synthetic fibres in the geotextile applications.

2 Materials and Methods

Needle-punched nonwoven fabrics were produced from different fibres and their blends, namely 100 % polypropylene (PP), a blend of 50/50 PP/kenaf and 100 % kenaf. The length and fineness of PP fibres were 40 mm and 2.2 decitex respectively. Kenaf fibres were opened and cleaned to remove dirt, such as plant debris, dust and wax on a Temafa cottonization line before subjecting to a carding process. In addition, the cottonizer improves the fibres fineness and shorten the fibre length. The length and fineness of kenaf fibres were measured on Optical Fibre Diameter Analyzer (OFDA) according to ASTM D1440 – 96 standards and the measured values were 120 mm and 5.1 decitex before cottonization, and 76 mm and 3.3 decitex after cottonization respectively.

Nonwoven fabrics were produced on a pilot plant equipped with card, cross-lapper and needle-punching machine. The fibres were transported to the carding machine by a chute feeding system. PP fibres were carded at a feed rate of 0.6 m/min and output speed of 0.9 m/min; 50/50 PP/kenaf were carded at a feed rate of 0.7 m/min and output speed of 1.3 m/min; and a feed rate of 0.6 m/min and output speed of 1.2 m/min were utilised when kenaf fibres were carded.

The Groz-Beckert felting needles with a technical specification of 15×18×32×3 R333 G3027 and composed of 6000 needles on a needle board and board width of 60 cm were utilized to needle-punch the fibrous web to produce 27 samples of the nonwoven fabrics. These results in a total of 81 fabrics produced from PP, 50/50 PP/kenaf and kenaf fibres. The cross-lapped web was transported on a conveyor through the needle loom for pre-needling. The nominal mass per unit area of the web was 300 g/m², therefore, two and three layers of the web were combined to achieve the mass per unit area of 600 and 900 g/m² respectively. The web composed of one, two and three layers was needle-punched at different stroke frequencies and depth of needle penetrations to achieve desired consolidation and density of the fabric.

2.1 Fabric Preparation

Nonwoven fabrics were conditioned for 24 h at a standard testing atmosphere of 21 ± 2 °C and 65 ± 2 % relative humidity before any test was performed. Samples were cut randomly along length and width directions of the fabrics. The produced needle-punched nonwoven fabrics were analysed according to the standard test method to determine mass per unit area (ASTM D3776 – 09), thickness (WSP120.6 – 05), tensile strength (ASTM D5034 – 09), puncture resistance (EN ISO12236), pore size and pore size distribution (ASTM F316 – 11), water permeability (EN ISO11058 – 10) and transmissivity (ASTM D4716 -14).

2.2 Test Methods

2.2.1 Mass per Unit Area

The mass per unit area of each sample was determined according to the ASTM D3776 – 09 standard. Five pieces of 20 cm × 20 cm size were cut randomly from each fabric and weighed individually on a Mettler balance in grams. The average weight was recorded in g/m².

2.2.2 Thickness

Thickness of each sample was analysed according to the WSP120.6 – 05 standard. A constant pressure of 1 kPa was applied with the help of a round metal disc of 50 mm diameter and 170g weight. Five round samples (50 mm diameter) were cut randomly from each fabric for testing and the average value of thickness was recorded in mm.

2.2.3 Tensile Strength (Grab Test)

The tensile strength of each sample was tested on an Instron 3369 universal tester according to the ASTM

D5034 - 96 standard. A gauge length of 75 mm, load cell of 5000 N and constant rate of extension of 300 mm/min were used during the test. Five random samples (50 mm wide and 200 mm in length) were cut in both cross and machine directions and tested. The average value for each sample was recorded in kN/m.

2.2.4 Puncture Resistance

Puncture resistance of each sample was tested according to the EN ISO12236 standard. Rectangular samples (230 mm×250 mm) were cut for each test. Each tested sample was clamped between two steel rings. A plunger with a diameter of 50 mm and weight of 2500 g was used to puncture the sample in the perpendicular direction at a constant rate of 50 ± 5 mm/min and force of 5 kN. Five random samples from each fabric were tested and an average value was recorded in N.

2.2.5 Pore Size and Pore Size Distribution

Fabric pore size was analysed on a capillary flow porometer (CFP-1100-AEXCC) according to the ASTM F316 -11 standards. The capillary flow porometer is a liquid extrusion technique which measures differential gas pressure and flow rate through wet and dry samples. Galwick liquid with a surface tension of 15.9 dynes/cm was used to wet the sample. After the sample was dipped in Galwick liquid and fully saturated, it was placed inside a sample holder with diameter ranges between 55 mm and 60 mm. The liquid inside pores was emptied using pressurized non-reacting gas. Bigger pores were emptied first as they require lower pressure in comparison to smaller pores which require higher pressure. Pores that were emptied first or at lower pressure were taken as largest pore diameters (bubble point). In addition, the variations in pressure and gas flow rate through dry and wet samples were measured and utilized to determine pore size distribution. The flow rate increases with an increase in gas pressure in a dry sample. However, in a wet sample no gas flow was apparent in the beginning as pores were completely filled with liquid. The increase in gas pressure emptied the pores filled with liquid until all pores were empty and the flow rates through both wet and dry samples were the same. Five random samples from each fabric were tested and the minimum, the largest and the mean flow pore diameters were calculated automatically by the capillary flow porometry instrument. The average value of pore size was calculated manually and recorded in μm .

2.2.6 Water Permeability

Water permeability of the fabric was analysed using GE-TE-FLOW-K permeameter according to the EN ISO11058-10 standard. The GE-TE-FLOW-K permeameter measures water permeability based on the principle of falling hydraulic head with a hydraulic difference height of $0 < H < 540$ mm. In the falling head method, water was transported to the fabric plane that results in a laminar flow through the fabric. Distilled water was used to analyse water permeability and the temperature of water during the test was kept at 20 °C.

Sample with a diameter of 75 mm was placed in the sample holder, fastened and inserted in the testing instrument. The change in pressure and the flow rate of water against time were used to measure fabric permeability. Five random samples from each fabric were tested and the average value was recorded in m/s.

2.2.7 Transmissivity

The transmissivity of the fabric was analysed using hydraulic transmissivity device and CEN/ISO drain tester, according to the ASTM D4716 - 14 standard. The rectangular tank was filled with test water closer to 305 mm height. The square samples of 305 mm × 305 mm were cut and placed in the sample holder to measure the flow rate under normal stress of 5000 kPa. Water from the rectangular tank flows through the tested sample and fill a smaller tank. A container was used to collect the water flowing from the smaller tank. The duration it takes for the water to reach the quantity of 4 litres was recorded using a stopwatch. Three random samples from each fabric were analysed and the average transmissivity value was recorded in L^2/s .

The statistical analysis (ANOVA) was conducted to establish the suitable process parameters to produce the fabrics. A full factorial design was used and the analyses were conducted at 5 % significant level using SPSS 23 and Statistica 12 programs. The Tukey test was applied at 95 % confidence level to compare group means.

3 Results and Discussion

Comparison among the properties of needle-punched nonwoven fabrics produced from different fibres and their blends, namely 100 % PP, a blend of 50/50 % PP/kenaf and 100 % kenaf, is shown in Table 1 and Figs 1 – 6. In addition, A_1 , A_2 and A_3 represent fabrics produced from PP; B_1 , B_2 and B_3

Table 1 — Fabric weight, thickness and density of needle-punched nonwoven fabrics

Sample ID	Depth of needle penetration, mm	Stroke frequency strokes/min	Actual fabric weight, g/m ²			Fabric thickness, mm			Fabric density, kg/m ³		
			PP	50/50 PP/kenaf	Kenaf	PP	50/50 kenaf PP/kenaf	kenaf	PP	50/50 kenaf PP/kenaf	kenaf
1	4	250	300 (355)	300 (320)	300 (310)	5.9	6.7	9.1	1504.2	1194.0	851.6
2	7	250	300 (343)	300 (270)	300 (290)	5.1	4.4	9.8	1681.3	1534.1	739.7
3	10	250	300 (290)	300 (310)	300 (352)	4.4	5.6	6.7	1647.7	1383.9	1313.4
4	4	350	300 (318)	300 (290)	300 (340)	3.9	6.5	4.8	2038.4	1115.3	1770.8
5	7	350	300 (310)	300 (340)	300 (320)	3.2	5.2	5.6	2421.9	1634.6	1428.5
6	10	350	300(280)	300 (320)	300 (330)	3.5	4.9	6.0	2000.0	1632.6	1375.0
7	4	450	300 (320)	300 (288)	300 (295)	4.2	6.1	4.9	1904.7	1180.3	1505.1
8	7	450	300(325)	300 (260)	300 (333)	3.5	4.4	3.7	2321.4	1477.2	2250
9	10	450	300 (315)	300 (342)	300 (255)	3.9	5.3	4.4	2019.2	1613.2	1448.8
10	4	250	600 (590)	600 (590)	600 (590)	6.8	8.0	9.1	2169.1	1843.7	1620.8
11	7	250	600 (573)	600 (653)	600 (650)	7.1	9.3	8.0	2017.6	1755.3	2031.2
12	10	250	600 (620)	600 (610)	600 (580)	7.8	7.9	6.2	1987.2	1930.3	2338.7
13	4	350	600 (630)	600(573)	600 (595)	8.4	8.5	7.4	1875.0	1685.2	2010.1
14	7	350	600 (660)	600 (660)	600 (610)	7.2	5.9	6.7	2291.6	2796.6	2276.1
15	10	350	600 (650)	600 (620)	600 (630)	9.6	6.9	8.1	1692.7	2246.3	1944.4
16	4	450	600 (605)	600 (550)	600 (520)	8.4	7.2	5.3	1800.6	1909.7	2452.8
17	7	450	600 (592)	600 (492)	600 (570)	6.9	5.5	4.8	2144.9	2236.3	2968.7
18	10	450	600 (610)	600 (580)	600 (565)	7.6	6.4	6.6	2006.5	2265.6	2140.2
19	4	250	900 (920)	900 (930)	900 (890)	11.7	8.5	9.6	1965.8	2735.2	2317.7
20	7	250	900 (895)	900 (890)	900 (910)	10.8	10.6	11.1	2071.7	2099.1	2049.5
21	10	250	900 (950)	900 (920)	900 (930)	12.5	8.1	12.7	1900.0	2839.5	1830.7
22	4	350	900 (918)	900 (850)	900 (800)	11.2	9.6	10.2	2049.1	2213.5	1960.7
23	7	350	900 (910)	900 (880)	900 (918)	10.1	10.3	10.4	2252.4	2135.9	2206.7
24	10	350	900 (930)	900 (950)	900 (780)	11.3	13.1	7.3	2057.5	1812.9	2671.2
25	4	450	900 (870)	900 (912)	900 (790)	12.1	11.8	9.1	1797.5	1932.2	2170.3
26	7	450	900 (857)	900 (787)	900 (740)	10.5	9.1	7.8	2040.4	2162.1	2371.7
27	10	450	900 (905)	900 (833)	900 (840)	11.3	10.7	8.2	2002.2	1946.2	2560.9

Values in parentheses show actual mass per unit area.

represent fabrics produced from 50/50 PP/kenaf and C₁, C₂ and C₃ represent fabrics produced from kenaf fibres. However, A₁, B₁ and C₁ constitute fabrics produced at a depth of needle penetration 4 mm; A₂, B₂ and C₂ constitute fabrics produced at a depth of needle penetration 7 mm; and A₃, B₃ and C₃ constitute fabrics produced at a depth of needle penetration 10 mm.

3.1 Fabric Weight, Density and Thickness of Nonwoven Fabric

Table 1 shows that, in general, density, thickness and nominal weight of the needle-punched nonwoven fabrics are related to each other and influenced by stroke frequency, depth of needle penetration and feed rate of the needle-punching process. For example, when comparing the fabrics produced from PP fibres at area weights of 300, 600, 900 g/m² but fixed stroke frequency of 350 /min and fixed depth of needle

penetration of 10 mm, the thickness and density of the fabrics increased by 69 % and 2.8 % respectively, with an increase in mass per unit area from 300 to 900 g/m². Obviously, the increase in nominal weight of the fabrics also increases thickness of the fabrics. The thickness of the fabrics produced from 100 % PP fibres is higher than those of the fabrics produced from a blend of 50/50 % PP/kenaf and 100 % kenaf fibres. This is expected due to uniformity of PP fibres, which results in uniform web and better interlocking of the fibres. However, in general, the thickness of the fabrics decreases with an increase in depth of needle penetration due to increased interlocking and entanglement of the fibres. This is attributed to the barbs of the needles carrying higher number of fibres at higher depth of needle penetration, resulting in more compact fabric. The density of the fabrics increases with an increase in fabric compactness but

decreases with an increase in depth of needle penetration above optimum level due to excessive breakages and reorientation of fibres¹¹.

3.2 Tensile Strengths of Fabrics

The tensile strengths of the fabrics in both machine (MD) and cross-machine (CD) directions have been studied. In general, the tensile strength in CD is higher in comparison to that in MD for all the fabrics as shown in Figs 1 and 2. This is attributed to the fact that majority of the fibres are oriented in the cross-machine direction due to cross-lapping process. The ratios of tensile strengths in MD to CD for majority of the fabrics, excepting in two cases, are found less than 1, which implies that the nonwoven fabrics are anisotropic. However, the values of this ratio of the tensile strengths of the fabrics produced from PP fibres and one produced from kenaf fibres are close to 1 (Samples 2 and 10), which implies that the tensile strengths in the MD and CD are nearly same.

The tensile strengths of the fabrics produced from different fibres and their blends are expected to increase with an increase in mass per unit area, stroke

frequency and depth of needle penetration. In Fig. 1 (A₂), the CD tensile strengths of the fabrics produced from 100 % PP fibres at fixed area weight of 600 g/m² and fixed depth of needle penetration of 7 mm and stroke frequencies of 250, 350 and 450/min, the tensile strengths of the fabrics increase with an increase in stroke frequency from 250 to 450/min (P = 0.0829). The increase in tensile strength is attributed to an increase in fabric compactness resulted from better interlocking and entanglement of the fibres at a higher stroke frequency²⁰. The CD tensile strengths of the fabrics produced from PP, 50/50 PP/kenaf and kenaf fibres do not follow any specific trend with an increase in stroke frequency at certain fixed mass per unit area and fixed depth of needle penetration. For example, as seen in Fig. 1 (B₁), comparing CD tensile strengths of the fabrics produced from 50/50 PP/kenaf fibres at fixed area weight of 300 g/m² and depth of needle penetration of 4 mm and stroke frequencies of 250, 350 and 450 /min, the CD tensile strength of the fabrics decreases with an increase in stroke frequency from 250/min to 350/min (P = 0.0001); however, it increases with an increase in stroke frequency from

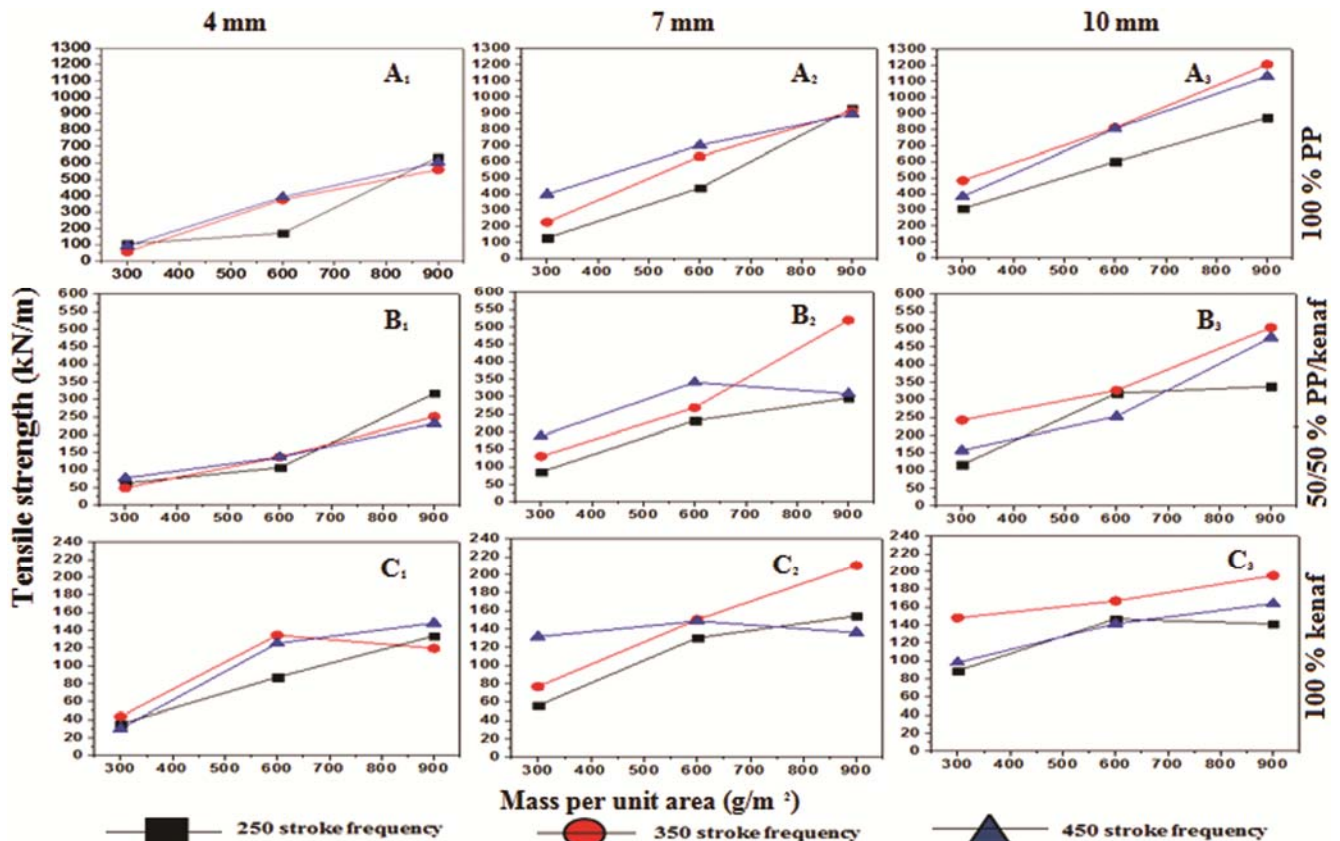


Fig. 1 — Effect of stroke frequency and mass per unit area on CD tensile strength of different nonwoven fabrics (PP, 50/50 PP/kenaf and kenaf) at different depths of needle penetration

350/min to 450/min ($P = 1.0000$). The variations in the tensile strengths of the fabrics produced from 50/50 PP/kenaf fibres are attributed to the disparities in the properties of PP and kenaf fibres, such as crimp, cross-section, fineness and length, which influence uniformity of the fibrous web, thickness and areal density of the fabrics as well as degree of fibre entanglement. Adanur and Tianyi²¹ have reported that the fibre crimp distribution influences the shape of the stress-strain curve of the fabric.

It is also observed that the CD tensile strengths of the fabrics produced from kenaf fibres were fluctuating with an increase in stroke frequency at certain fixed mass per unit area and fixed depth of needle penetration as shown in Fig. 1 (C_1 , C_2 and C_3). For example, in Fig 1 (C_3) at fixed area weight of 900 g/m^2 and depth of needle penetration of 10 mm and stroke frequencies of 250, 350 and 450 /min, the CD tensile strength of fabrics produced from kenaf fibres increases with an increase of stroke frequency from 250 /min to 350 /min ($P = 0.0001$); however, it decreases with an increase in stroke frequency above 350/min ($P = 0.0001$). The variations in the tensile

strengths of the fabrics produced from kenaf fibres is attributed to the increase in punch density and depth of needle penetration above the optimal level, which results in higher breakages and reorientation of the fibres as observed by others²².

The MD tensile strengths of the fabrics PP, 50/50 PP/kenaf and kenaf have also been analysed as shown in Fig. 2 above. Results obtained are found mostly influenced by majority of the fibres that are oriented in the cross-machine direction because of cross-lapping process²³.

The tensile strengths of the needle-punched nonwoven fabrics produced from PP fibres are comparatively higher than that of the fabrics produced from 50/50 PP/kenaf fibres and kenaf fibres; which is attributed to the properties of PP fibres, such as flexibility, high extensibility, better tensile strength, elastic recovery and lesser fibre deformation during needle-punching process.

The three-way ANOVA has been performed to determine the interaction effects of the stroke frequency, depth of needle penetration and mass per unit area on the CD and MD tensile strength of the

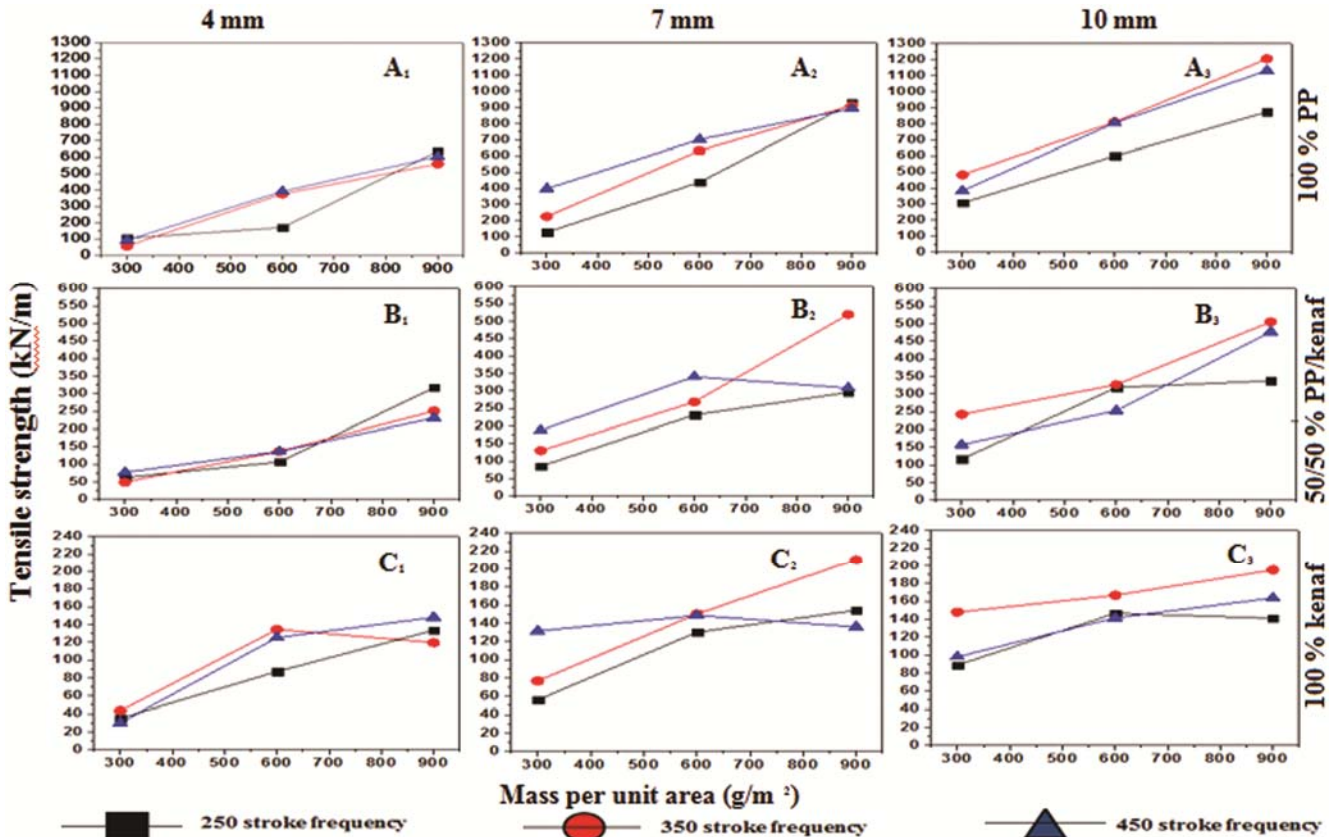


Fig. 2 — Effect of stroke frequency and mass per unit area on MD tensile strength of different nonwoven fabrics (PP, 50/50 PP/kenaf and kenaf) at different depths of needle penetration

nonwoven fabrics produced from PP, 50/50 PP/kenaf and kenaf fibres. The test of significance is carried out at confidence level of 95 % ($p \leq 0.05$); if the P-value is less than 0.05; the effect is significant and vice versa. Three-way ANOVA shows that all the parameters and their two-way (mass per unit area \times stroke frequency; mass per unit area \times needle depth of penetration; stroke frequency \times needle depth of penetration) and three-way interactions (mass per unit area \times stroke frequency \times needle depth of penetration) on the tensile strength of the fabrics is statistically significant as the P – values are less than 0.05.

3.3 Puncture Resistance

The puncture resistance of the fabrics follows a similar trend to the tensile strength. Both increase with an increase in mass per unit area of the nonwoven fabrics^{24, 25}. Lower puncture resistance values are achieved in the fabrics produced from PP, 50/50 PP/kenaf and kenaf fibres at the lowest values of depth of needle penetration, stroke frequency and mass per unit area in comparison to that produced at the highest values of depth of needle penetration, stroke frequency and mass per unit area, as shown in

Fig. 3 (A_1, B_1 and C_1). These lowest values of puncture resistance are attributed to the barbs of the needles carrying fewer number of fibres at the lowest values of both depth of needle penetration and mass per unit area; which results in poor interlocking and entanglement of the fibres, therefore, a less compact fabric with higher thickness is produced. There is a similarity on the results obtained on puncture resistance of the fabrics to that of tensile strength, as mentioned earlier. For example, in Fig 3 (A_3, B_2 and C_3), the puncture resistance values increase with an increase in stroke frequency at a certain fixed mass per unit area and fixed depth of needle penetration.

Still in Fig. 3 (A_3) at a fixed area weight of 600 g/m^2 , puncture resistance of the fabrics produced from PP fibres increases with an increase in stroke frequency from 250 /min to 450 /min ($P = 0.4065$). The increase in puncture resistance of the fabrics is attributed to barbs of the needles carrying higher number of fibres at higher depth of needle penetration and mass per unit area, which results in deeper interlocking and entanglement of the fibres, a compact fabric is produced with lower thickness and higher density²⁶. However, the puncture resistance

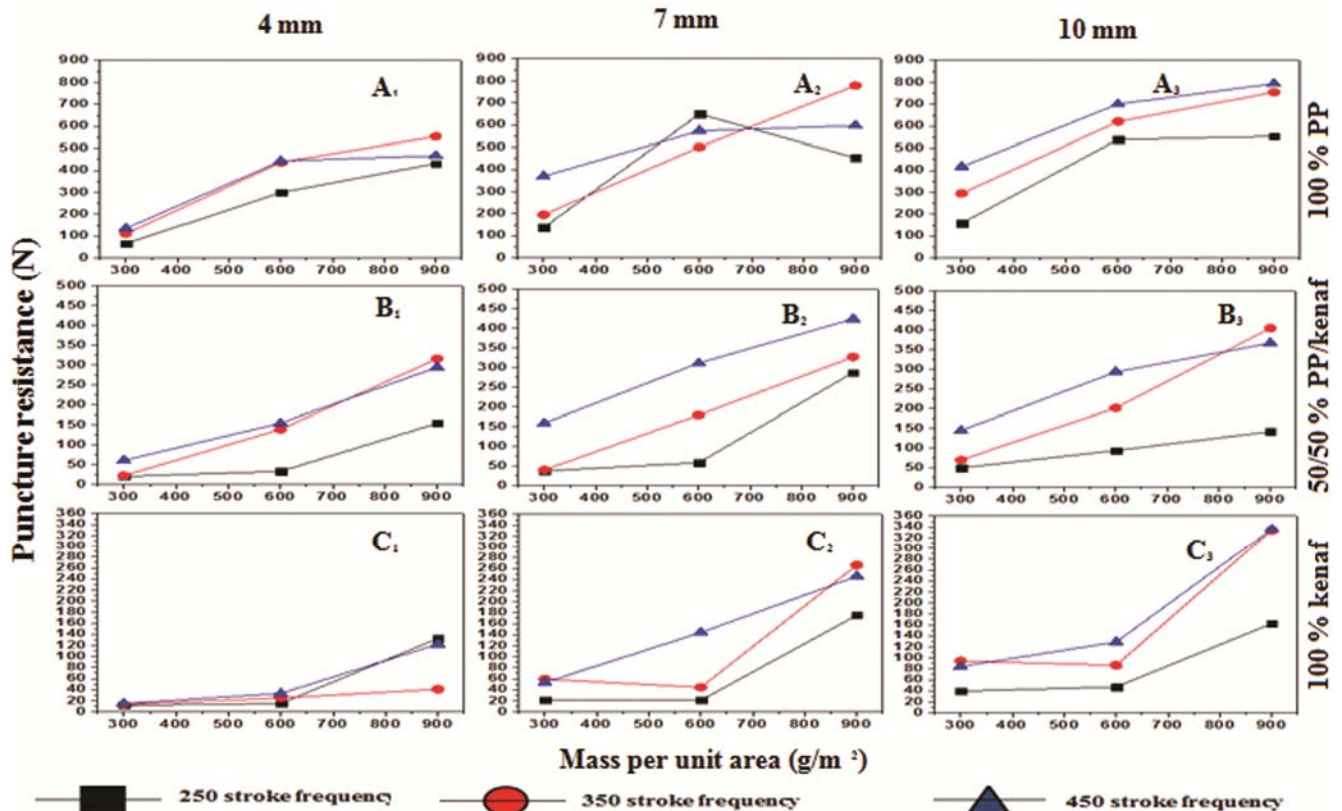


Fig. 3 — Effect of stroke frequency and mass per unit area on puncture resistance of different nonwoven fabrics (PP, 50/50 PP/kenaf and kenaf) at different depths of needle penetration

values of the fabrics are varying with an increase in stroke frequency at a certain fixed mass per unit area and fixed depth of needle penetration, as shown in Fig. 3 (A₂, B₃ and C₂). In Fig. 3(C₂) at fixed area weight of 900 g/m², the puncture resistance values of fabrics produced from 100% kenaf fibres increase with an increase in stroke frequency from 250 /min to 350 /min (P = 0.0001). However, it decreases with an increase in stroke frequency above 350 /min (P = 0.3886). The variations in the puncture resistance values of the fabrics produced from kenaf fibres are attributed to the increase in stroke frequency up to an optimal level. However, it decreases with further increase in stroke frequency above optimum level due to breakage of mostly longer fibres to shorter fibres.

Shorter fibres result in higher area weight but poor interlocking of the fibres. The puncture resistance values of the fabrics produced from 50/50 PP/kenaf fibres are influenced by lower bending rigidity of the PP fibres in comparison to that of kenaf fibres. More PP fibres were transported in the thickness direction which might influence fabric areal density²⁷. Rawal *et al.*²⁸ have reported that the puncture resistance of the fabrics is influenced mainly by the web areal density

in comparison to depth of needle penetration.

Statistical analysis similar to that reported in the tensile strength is also conducted on the results of puncture resistance of fabrics produced from PP, 50/50 PP/kenaf and kenaf fibres. All the tested parameters and their two-way and three-way interactions show statistically significant effects on the puncture resistance of all the fabrics. However, only interaction between mass per unit area and depth of needle penetration on the puncture resistance of the fabrics produced from PP fibres is found statistically not significant, (P = 0.326); this is attributed to reorientation and breakages of the fibres at higher depth of needle penetration which promote variations in areal density, thereby affecting the puncture resistance.

3.4 Pore Size

The pore sizes of the nonwoven fabrics produced from PP, 50/50 PP/kenaf and kenaf fibres with an increase in stroke frequency at fixed values of depth of needle penetration and mass per unit area, as shown in Fig. 4 (A₁, B₃ and C₂). In Fig. 4 (A₁), at fixed area weight of 300 g/m², the pore sizes of the

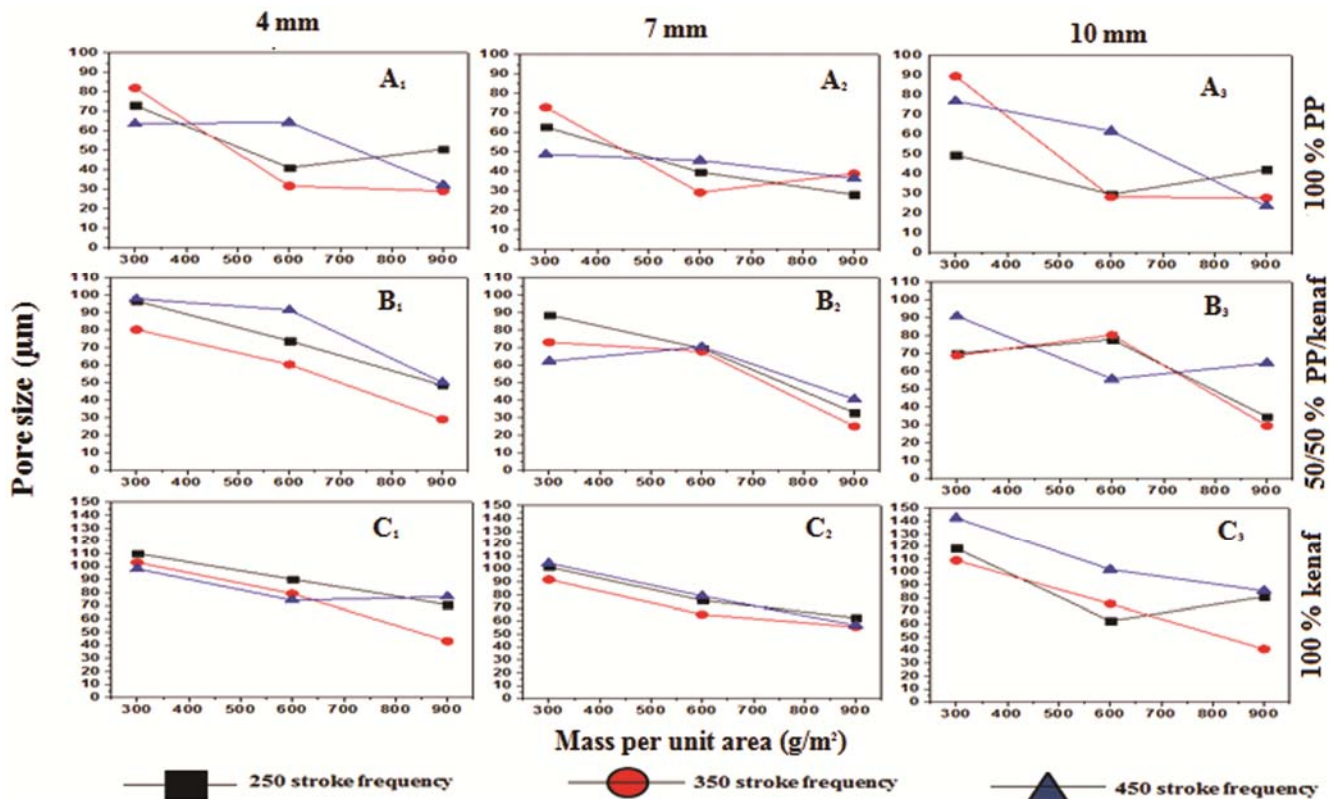


Fig. 4 — Effect of stroke frequency and mass per unit area on pore size of different nonwoven fabrics (PP, 50/50 PP/kenaf and kenaf) at different depths of needle penetration.

fabrics produced from PP fibres increases with an increase in stroke frequency from 250/min to stroke frequency of 350 /min ($P = 0.00001$). However, it decreases with an increase in stroke frequency above 350/min ($P = 0.00001$). The variations in the pore sizes of the fabrics produced from PP fibres is attributed to lower fibre-to-fibre friction and lesser bending resistance of PP fibres at lower punch density and mass per unit area, which influence fibre entanglement, uniformity of mass per unit area and thickness of fabrics.

The variations in the pore size of the fabrics produced from 50/50 PP/kenaf fibres are attributed to differences in the properties of PP and kenaf fibres which may influence pore size and pore size distribution. The differences in the properties of PP and kenaf fibres might influence orientation of the fibres. Rawal *et al.*²⁹ have reported that the fibres oriented in a preferential direction in the fabric results in smaller pore size in comparison to randomly oriented fibres. Therefore, an increase in the number of fibres oriented in a preferential direction minimises fibre-fibre contacts and results in smaller pore size.

In Fig. 4 (C_2) at fixed area weight of 600 g/m², the pore sizes of the fabrics produced from kenaf fibres decrease with an increase in stroke frequency from 250/min to 350 /min ($P = 0.9995$). However, it increases with an increase in stroke frequency above 350 /min ($P = 0.2392$). The fluctuations in the pore size of the fabrics produced from kenaf fibres is attributed to variations in the fineness, length and diameter of kenaf fibres, which might promote variations in elementary layers within fabric on which pore sizes depend³⁰. The pore size of the fabrics produced from kenaf fibres is composed of different diameters, as the diameter of the pore changes along pore path. This is attributed to variations in the properties of kenaf fibres, which promote irregularity in pore diameters³¹.

The pore sizes of the fabrics produced from kenaf fibres are found bigger in comparison to those produced from 50/50 PP/kenaf and PP fibres. This is attributed to variations in fibre fineness and fibre length as well as higher bending rigidity of kenaf fibres. However, the smaller pores in the fabrics produced from PP fibres, as shown in Fig. 4, are attributed to the fineness and lower breakages of PP fibres during needle-punching.

Similar statistical analysis, as in the case of puncture resistance of nonwoven fabrics, is also conducted on data for pore size of the fabrics

produced from PP, 50/50 PP/kenaf and 100 kenaf fibres. All the tested parameters, their two-way and three-way interactions show significant effects on the pore size of the nonwoven fabrics. However, the interaction between mass per unit area and depth of needle penetration on the pore size of fabrics produced from 50/50 PP/kenaf fibres is not found significant, ($P = 0.099$). This non-significance is attributed to excessive breakages of coarser kenaf fibres at higher depth of needle penetration as well as shorter fibres, which are preferentially aligned to cross-machine direction during the needle-punching process.

3.5 Water Permeability

In Fig. 5 (A_1 , B_1 and C_1), water permeability values of the fabrics produced from PP, 50/50 PP/kenaf and kenaf fibres decrease with an increase in stroke frequency at certain fixed depth of needle penetration and mass per unit area. As shown in Fig. 5 (C_1) at fixed area weight of 600 g/m², water permeability values of the fabrics produced from kenaf fibres decrease with an increase in stroke frequency from 250/min to 450/min ($P = 0.00001$). The decrease in water permeability is attributed to the increase in the number of fibres per unit area of the fabrics as well as barbs of the needles carrying higher number of fibres, which results in a consolidated fibrous web with smaller pores. The increase in the number of fibres per unit area of the fabric decreases the average pore size¹⁹. However, water permeability of the fabrics does not follow any specific trend with an increase in stroke frequency at certain fixed depth of needle penetration and mass per unit area, as shown in Fig. 5 (A_3 , B_3 and C_3).

Variation in water permeability of the fabrics produced from PP fibres is influenced by lower fibre-to-fibre friction and bending resistance of PP fibres, which affect web uniformity and entanglement of the fibres, thus promoting fabric anisotropies. Rawal *et al.*³² have reported that water permeability is influenced by preferential flow of water due to structural heterogeneities as well as fabric anisotropies.

Still in Fig. 5 (B_3) at fixed area weight of 300 g/m², water permeability of the fabrics produced from 50/50 PP/kenaf fibres decreases with an increase in stroke frequency from 250/min to 350/min ($P = 0.9998$); however, it increases with an increase in stroke frequency from 350/min to 450/min ($P = 0.6223$). The variation in water permeability of fabrics produced from 50/50 PP/kenaf fibres is influenced by the

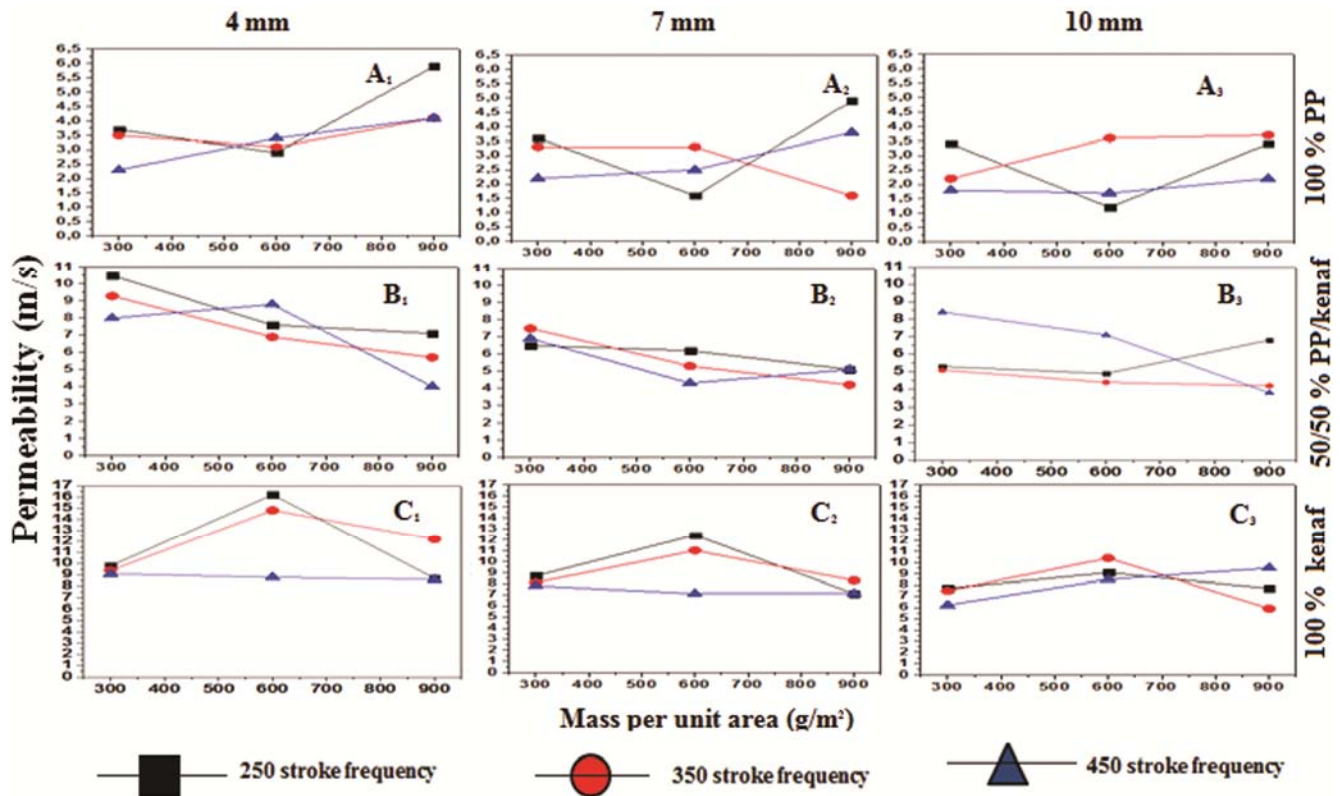


Fig. 5 — Effect of stroke frequency and mass per unit area on water permeability of different nonwoven fabrics (PP, 50/50 PP/kenaf and kenaf) at different depths of needle penetration

possibility of intra and inter fibre contacts of PP and kenaf fibres³³; these influence the width and depth of pores on which water permeability depends.

The statistical analysis similar to that reported in the pore size is also conducted on the results of water permeability of the nonwoven fabrics produced from PP, 50/50 PP/kenaf and kenaf fibres. All the tested parameters, their two-way and three-way interactions, as discussed earlier, show significant effects on water permeability of the fabrics, as the P values being less than 0.05.

3.6 Transmissivity

The transmissivity of the fabrics produced from PP fibres varies with an increase in stroke frequency at certain fixed depth of needle penetration and mass per unit area, as shown in Fig. 6 (A₁ and A₃). Fig. 6 (A₁) at fixed area weight of 900 g/m², the transmissivity of the fabrics produced from PP fibres increases with an increase in stroke frequency from 250/min to 350/min ($P = 0.0055$); however, it decreases with an increase in stroke frequency from 350/min to 450/min ($P = 0.3740$). The variation in transmissivity of the fabrics produced from PP fibres is attributed to the increases

in stroke frequency and depth of needle penetration, which may interlock and entangle fibres to an optimal level. However, breakages of fibres and breakdown of loop structure occur at above optimal level. This results in fabric anisotropies that might influence flow of water^{11,32}. However, the transmissivity of the fabric increases with the increase in stroke frequency at an area weight of 900 g/m² and depth of needle penetration of 7 mm, as shown in Fig. 6 (A₂) due to the increase in number of finer fibres in multi-layered needle-punched nonwoven fabric³⁴.

As shown in Fig. 6 (B₁ to B₃), it is observed that the transmissivity of the fabrics produced from 50/50 PP/kenaf fibres resembles to that of the fabrics produced from PP fibres, as it also varies with an increase in stroke frequency at certain fixed depth of needle penetration and mass per unit area. The variations in the transmissivity of the fabrics produced from 50/50 PP/kenaf fibres is influenced by differences in the properties of PP and kenaf fibres and fibre arrangement in each elementary layer within the fabric. Adams and Rebenfeld³⁵ have reported that the transmissivity of multi-layered fabric is attributed to the degree of anisotropy and orientation of the

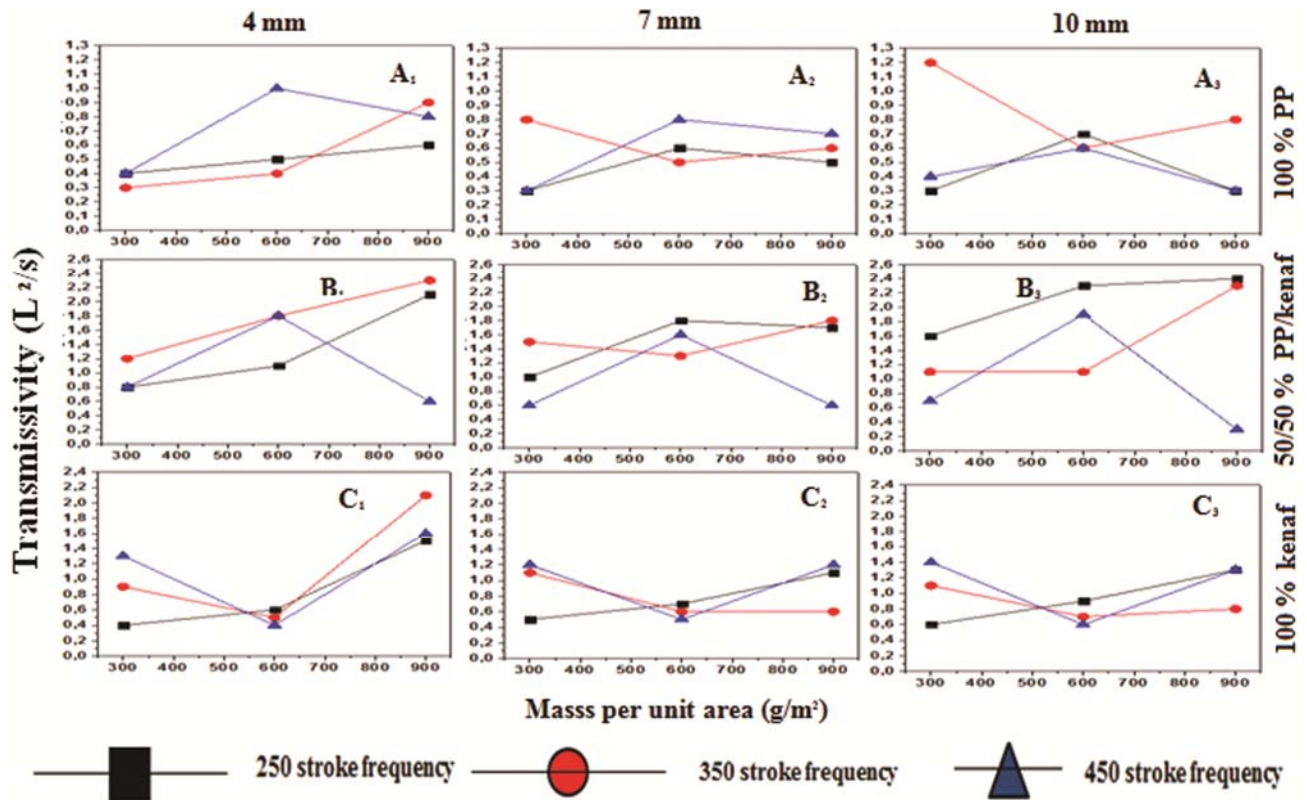


Fig. 6 — Effect of stroke frequency and mass per unit area on transmissivity of different nonwoven fabrics (PP, 50/50 PP/kenaf and kenaf) at different depths of needle penetration

fibres in the fabric structure. Layers with lower permeability also influence transmissivity of multi-layered fabrics³⁵.

The transmissivity of the fabrics produced from kenaf fibres decreases with an increase in stroke frequency at an area weight of 600 g/m² and depth of needle penetration of 7 mm, as shown in Fig. 6 (C₂) due to stroke frequency, which might reorient higher number of fibres from horizontal to vertical (thickness) direction³⁶.

A similar statistical analysis, as reported on water permeability, is also carried out on transmissivity data of the nonwoven fabrics produced from PP, 50/50 PP/kenaf and kenaf fibres. The tested parameters, namely mass per unit area and stroke frequency as well as their two-way and three-way interactions show significant effects on the transmissivity properties of fabrics produced from PP fibres. However, the effect of depth of needle penetration of the fabrics is not found significant ($P = 0.572$), which is attributed to variations in areal density, fibre orientation and fibre distribution.

Only the interaction between mass per unit area and depth of needle penetration on the fabrics

produced from 50/50 PP/kenaf fibres is not found significant ($P = 0.541$), which could be attributed to an increase in depth of needle penetration, which might reorient fibres from horizontal direction to vertical (thickness) direction.

The effect of depth of needle penetration on the fabrics produced from kenaf fibres is also not found significant ($P = 0.108$), which is attributed to preferential alignment of short fibres in the cross-machine direction during needle punching, thereby affecting the thickness and mass per unit area of the nonwoven fabrics.

4 Conclusion

It is inferred that the fabrics produced from 50/50 PP/kenaf fibres achieve better values of tensile strength and puncture resistance in comparison to that produced from kenaf fibres; however, lower than those for the fabrics produced from PP fibres. In addition, the fabrics produced from 50/50 PP/kenaf fibres achieve bigger pore sizes and higher water permeability in comparison to that produced from PP fibres; however, comparatively lower than those for the fabrics produced from kenaf fibres. Therefore, it is

reasonable to suggest that the nonwoven fabrics produced from 50/50 PP/kenaf fibres can fulfil majority of performance requirements in geotextile applications, such as filtration, separation, reinforcement and drainage. In addition, results show that the properties of needle-punched nonwoven fabrics are influenced by stroke frequency, depth of needle penetration and mass per unit area. However, it is not expected that the properties of the fabrics will always follow the same trend particularly with an increase in stroke frequency at certain fixed mass per unit area and fixed depth of needle penetration. Further work on field trial is needed to ascertain the application of the study.

References

- 1 Lekha K R, *Geotext Geomembranes*, 22 (5) (2004) 399.
- 2 Thomason J L, Carruthers J, Kelly J & Johnson G, *Compos Sci Technol*, 71 (7) (2011) 1008.
- 3 Subaida E A, Chandrakaran S & Sankar N, *Geotext Geomembranes*, 26 (5) (2008) 384.
- 4 Ghosh M, Choudhury P K & Sanyal T, *IGC Geotide*, (2009) 497 - 501.
- 5 Methacanon P, Weerawatsophon U, Sumransin N, Prahsarn C & Bergado D T, *Carbohydrate Polym*, 82 (4) (2010) 1090.
- 6 English B, Biobased, biodegradable geotextiles: USDA Forest Service research update. In Steiner PR, comp, *Proceedings, the 2nd Pacific Rim Bio-Based Composites Symposium*, (1994) 6 - 9.
- 7 Paridah M T, Basher A B, Saifulazry S & Ahmed Z, *BioResources*, 6 (4) (2011) 5260.
- 8 Saba N, Paridah M T & Jawaid M, *Construction Building Materials*, 76 (2015) 87.
- 9 Sarsby R W, *Geotext Geomembranes*, 25 (4-5) (2007) 302.
- 10 Prabakar J & Sridhar R S, *Construction Building Materials*, 16 (2) (2002) 123.
- 11 Roy A N & Ray P, *J Natural Fibres*, 6 (4) (2009) 303.
- 12 Sengupta S, Ray P & Majumdar P K, *Indian J of Fibre Text Res* 33 (2008) 411.
- 13 Blackburn R S, *Biodegradable and Sustainable Fibres* (Taylor & Francis, US) 2005.
- 14 Müssig J & Martens R, *J Industrial Hemp*, 8 (1) (2003) 11.
- 15 Steve C & Mussig J, *Industrial Applications of Natural Fibres: Structure, Properties and Technical Applications* (John Wiley and Sons, UK) 2010.
- 16 Basu G, Roy A N, Bhattacharyya S K & Ghosh S K, *Geotext Geomembranes*, 27 (6) (2009) 506.
- 17 Anuar H & Zuraida A, *Composites Part B: Eng* 42 (3) (2011) 462.
- 18 Rawal A & Anandjiwala R, *Geotext Geomembranes*, 25 (1) (2007) 61.
- 19 Debnath S & Madhusoothanan M, *J Industrial Text*, 39 (3) (2010) 215.
- 20 Midha V K & Mukhopadyay A, *Indian J Fibre Text Res*, 30 (2005) 218.
- 21 Adanur S & Tianyi L, *Text Res J*, 69 (1999) 816.
- 22 Debnath S & Madhusoothanan M, *J Industrial Text*, 39 (2010) 215.
- 23 Russell S J, *Handbook of Nonwovens* (Woodhead Publishing, Cambridge) 2006.
- 24 Wojtasik D, *Land Reclamation*, 40 (2008) 115.
- 25 Fangueiro R, Carvalho R & Soutinho F, *Proceedings, the International Conference on Engineering UBI2011*, Covilha, Portugal, 2011, 1 - 7.
- 26 Anandjiwala R D & Boguslavsky L, *Text Res J*, 78 (2008) 614.
- 27 Rawal A & Sayeed M M A, *Geotext Geomembranes*, 37 (2013) 54.
- 28 Rawal A, Anand S & Shah T, *J Industrial Text*, 37 (2008) 341.
- 29 Rawal A, Kameswara Rao P V, Russell S & Jeganathan A, *J Appl Polym Sci*, 118 (2010b) 2668.
- 30 Simmonds G E, Bomberger J D & Bryner M A, *J Eng Fibers Fabrics*, 2 (2007) 1.
- 31 Jena A & Gupta K, *Fluid/Particle Separation J*, 14 (2002) 227.
- 32 Rawal A, Shah T & Anand S, *Text Prog*, 42 (2010) 181.
- 33 Rawal A & Saraswat H, *Geotext Geomembranes*, 29 (2011) 363.
- 34 Hwang G S, Lu C K, Lin M F, Hwu B L & Hsing W H, *Text Res J*, 69 (1999)
- 35 Adams K L & Rebenfeld, L, *Text Res J*, 57 (1987) 647.
- 36 Rawal A & Anandjiwala R, *J Industrial Text*, 35 (2006) 271.