Indian Journal of Fibre & Textile Research
Vol. 44, June 2019, pp. 148-154

Effect of fibre composition on essential properties of needle-punched nonwoven fabrics as secondary layer for composite wound dressings

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Received 23 October 2017; revised received and accepted 15 December 2017

Suitability of viscose, bamboo, cotton and polyester fibres as a secondary layer for wound dressing application has been analysed. The needle-punched nonwovens of the selected fibres in seven different combinations, namely 100% viscose, 70/30 viscose/bamboo, 70/30 viscose/cotton, 70/30 viscose/polyester, 30/70 viscose/bamboo, 30/70 viscose/cotton and 30/70 viscose/polyester have been used for the study. These nonwovens are compared for their properties like mass per unit area, thickness, air permeability, tensile strength, elongation, water vapor transmission rate, rate of absorption, absorbency, vertical wicking, dehydration rate, and antibacterial efficacy against *S.aureus* and *E.coli*. From the obtained results, based on the importance of wound dressing characteristics, 70/30 viscose/bamboo needle-punched nonwoven is found to be more useful as a secondary layer for wound dressing. The dressings maintain the suitable moisture conditions around the wound surface, preventing the desiccation. The usage of developed nonwovens aids in rapid uptake and retention of wound fluid, which creates an optimum environment for rapid healing and inhibition of bacterial growth.

Keywords: Antibacterial properties, Bamboo, Cotton, Composite, Needle punching, Nonwoven, Physical properties, Viscose, Wound dressing

1 Introduction

Wound dressings with moist healing environment, barrier to microorganisms, gaseous transfer, absorbency, removal of exudates, non-toxicity, non allergic property, easy removal from wound, non adherent, antimicrobial property against wound pathogenic bacteria are termed as ideal wound dressings[1,2]. Wound dressings are classified into three categories based on their material, namely biologic, synthetic and biologic-synthetic. Biologic dressings include alloskin and pigskin, but they have poor adhesiveness, high anti-genicity and risk of cross contamination. Synthetic dressings have long shelf life with minimal inflammatory reaction and can be used without any risk of pathogen transmission. Biologic-synthetic dressings mostly have bi-layered structure with high polymer and biologic material incorporated[3].

Nonwoven, as a medium plays a vital role in the wound dressing as a secondary layer. Compared with conventional woven gauze, nonwoven fabrics are claimed to provide improved absorbent capacity, conformability, bulk and softness, and lower linting. One significant advantage of nonwoven fabrics is their ability to manage fluid in three dimensions where it may be necessary to distribute liquid uniformly, to transport liquid faster in specific directions, or to impair liquid transport completely in specific directions[4]. Owing to the comparative performance benefits and the inherent versatility of manufacturing technology, nonwoven fabrics are increasingly incorporated into wound-care products[5]. The advantages of nonwoven fabric over existing fabric is their 3D structure, finer interlocking, higher resilience performance than other material, inexpensive and flexible production system[6]. Lou *et al.*[7] developed a tencel/cotton nonwoven fabric coated with chitosan for wound dressing application. In their analysis, it is mentioned that the developed nonwoven-chitosan membrane controls evaporative water loss, promotes fluid drainage ability and inhibits exogenous microorganism invasion.

Liu and Huang[8] proposed a novel wound dressing using nonwoven fabric coated with herbal extract and chitosan membrane. By covering the wound with the dressing, epithelialization and reconstruction of wound was achieved. Viscose is one of the most common fibres used in wound dressing manufacturing due to its higher absorbency, breathability and softness[9,10]. Hence, the blending of other potential fibre material

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along with the viscose may develop economic product[11,12]. Bamboo is known for its antimicrobial ability and generally used in the form of fabric by several researchers[13,14]. The cotton and polyester fibres are selected based on their availability, good functional properties like strong wrinkle, dirt, and microbial attacks resistance. This will not only increase the performance but also satisfy the increasing requirements from the customer side[15,16].

The present experimental work focuses on the suitability of viscose, bamboo, cotton and polyester fibres for the development of secondary layer in wound dressings. Since the application is focused on wound dressings, the fibre blends and nonwoven structure have been selected by considering the major requirement for wound dressings, such as moisture management properties (like water vapor permeability, absorbency, wicking), air permeability and antibacterial properties[17,18]. Hence, the above-said fibres are combined with viscose in a particular ratio and studied. For the selection of needle-punched nonwovens, the characteristic advantage like high absorbency, higher productivity, lower production costs and shorter production cycles are the major motivations[19]. Hence, different blend proportions are selected to combine the effect of different fibre properties and nonwoven structure towards the requirement of endues.

2 Materials and Methods

2.1 Materials

Following seven different fibre compositions of the needle-punched nonwoven fabrics were compared for their properties:

(i) 100% viscose,
(ii) 70/30 viscose/bamboo (V/B)
(iii) 70/30 viscose/cotton (V/C)
(iv) 70/30 viscose/polyester (V/P)
(v) 30/70 viscose/bamboo (V/B)
(vi) 30/70 viscose/cotton (V/C)
(vii) 30/70 viscose/polyester (V/P)

The samples were conditioned for 48 h in 65% relative humidity and 21°C temperature. Then the samples were cut as per required size and used for the evaluation. Lenzing viscose® fibre (2.8dtex; 38mm cut length) was procured from Lenzing AG - India Branch Office, Coimbatore, Tamilnadu. Polyester fibre (1.2 denier; 38mm) and cotton fibres (1.2 denier; 28 mm staple length), were procured from R.G. Spinning Mills, Tamil Nadu and bamboo fibres (38 mm fibre length; 1.4 dtex), from JG Spinning Mills, Tamil Nadu. Sodium bicarbonate, sodium chloride and calcium chloride dehydrate were purchased from HI-PURE Chem Industries, (Chennai, India). The deionized water was obtained from the Institute, which was prepared by EDI method (electro-deionization). The bacterial cultures of *Staphylococcus aureus* (*S.aureus*) (MTCC 737) and *Escherichia coli* (*E.coli*) (MTCC 1687) were obtained from MTCC, IMTech, Chandigarh.

2.2 Nonwoven Preparation Method

The fibres were processed in a miniature card, web processing machine to obtain web in specified ratios. Four layers of webs were prepared for a single combination to produce needle-punched nonwoven fabrics. All the four layers of webs produced from miniature card machine were overlapped together. Then they were processed through a DILO CBF-6 needle-punching machine to develop the desired needle-punched nonwoven. The needle loom consists of 6000 needles with a stroke rate of 1200/min and needle penetration of 10 mm. The working width of the machine is 8000-10000 mm. The in-feed speed of the machine is 0.31m/min, and the draw-off speed is 0.40 m/min, with a stroke frequency of 121strokes/min. The fabric was reversed and punched on both the sides.

2.3 Evaluation of Needle-punched Nonwovens

2.3.1 Physical Properties

The prepared nonwoven samples were conditioned as per ASTM D 1776-04 in a controlled atmosphere for 8 h in 65% relative humidity and 21°C temperature. 20 samples were taken for each test, and the average values were considered for analysis.

Mass per unit area of the nonwoven sample was measured as per the standard ASTM D3776-97. An SDL digital thickness gauge was used to measure the thickness as per ASTM D5729-97, prior to all the tests.

Air permeability of the samples was measured as per the standard ASTM D737-99. Instron universal testing instrument was used in the measurement of tensile strength and percent elongation with a 2 kg load cell (Model 4206, Instron Ltd., USA). The experiment was carried out as per ASTM D 882-12 standard.

2.3.2 Fluid Handling Properties

Water Vapor Transmission Rate

Desiccant method was used to measure the water vapor transmission rate as per the standard ASTM

E96-95. Rate of absorption of wound fluid was analyzed by dropping the test solution onto the sample using an eye dropper, and time (in seconds) to fully absorb the fluid drops was noted down. 20 drops were dropped onto each sample, and the mean was calculated[20].

Absorbency

The absorbency of nonwoven samples was determined by using SMTL test standard BS EN 13726-1:2002 section 3.2 - free swell absorptive capacities, which is common for fibrous dressings in wound dressing evaluation. For this test, solution was prepared by adding 2.298g sodium chloride and 0.368g calcium chloride dihydrate together to 1 litre of de-ionised water.

Vertical Wicking

Vertical wicking was carried out by adding Eosin B to the test solution and test samples of 15 mm×100 mm were prepared. Then the samples were immersed into the prepared solution slowly and vertically up to 10mm length. It was then left for 60 s, and the vertical wicking height was noted down[21].

Dehydration

Dehydration measurement was performed by drying the test sample in an incubator for 24 h at 37±1°C and weighed. Then, for 30 min, the specimens were submerged in an excess volume of test solution at 37±1°C. The specimens were then drained for 30 s, re-weighed and kept into petri dishes. Then the samples were kept in an incubator for 24 h at 37±1°C. Dehydration rate was calculated as

$$\text{Dehydration rate (g/min)} = (W\text{-}D)/\ T$$

where W is the wet mass of samples in gram; D, the dry mass of samples in grams; and T, the test period in minute[22].

2.3.3 In vitro Antibacterial Activity Assessment

Antimicrobial activity of the samples was assessed by agar diffusion qualitative method as per SN 195920 standard, against *Staphylococcus aureus* and *Escherichia coli.*

3. Results and Discussion

3.1 Effect of Fibre Composition on Basic Structural Properties of Nonwoven Fabrics

Effort has been made in maintaining the thickness in the range of 160-180 GSM during the needle-punched nonwoven manufacturing process. Table 1 shows the nonwoven fabric weight in gram per square meter (GSM). The mass per unit area of the fabrics ranges between 168 GSM and 172 GSM and thickness of the fabrics ranges between 3.4 mm and 3.8 mm. It is found that 30/70 V/C fabrics exhibit higher mass per unit area of 178 GSM and higher thickness of 3.796 mm. 30/70 V/P shows lower mass per unit area of 167 GSM and medium thickness of 3.65mm. But lower thickness value of 3.433 mm and medium weight of 176 GSM are attributed to 30/70 V/B fabric. In case of 70/30 V/B, both thickness and weight values appear to be medium as 3.515 mm and 170 GSM respectively.

The deviations are attributed to the difference in the type of fibres and linear density of fibres. The thickness of the fabric increases with an increase in fabric weight[23]. Even though, the weight of the V/B sample is comparable with other samples; it shows reduced thickness comparatively, which shows the compressibility nature of bamboo fibres[24]. High bending rigidity and low packing density of polyester fibre lead to bulkier fabrics in case of V/P samples[25].

3.2 Effect of Fibre Composition on Air Permeability of Nonwoven Fabrics

It is clear from the Table 1 that fabric composition has a significant impact on the air permeability of the

Table 1 — Properties of needle-punched nonwoven fabrics

Fabric	Mass per unit area, GSM	Thickness mm	Air permeability $cm^3/cm^2/s$	Tensile strength N	Elongation %	Dehydration rate, g/min	WVTR g/m^2/day	Vertical wicking mm	Absorbency g/g	Rate of absorption s
100 % V	176±0.04	3.505±0.36	118.1	65.54	26.28	0.0283	40.44	3.97	11.362	4
70/30 V/B	170±0.07	3.515±0.38	127.2	49.58	30.06	0.0334	59.44	4.52	14.548	3.9
70/30 V/C	172±0.05	3.544±0.35	104.1	75.24	25.12	0.0187	34.83	3.79	10.758	5
70/30 V/P	177±0.05	3.678±0.37	140	40.3	18.37	0.0338	23.34	2.94	8.343	6.5
30/70 V/B	176±0.07	3.433±0.41	132.2	44.82	32.25	0.0372	51.25	3.95	13.89	3.3
30/70 V/C	178±0.04	3.769±0.30	98.1	78.39	27.04	0.0123	28.14	3.63	8.809	4.5
30/70 V/P	167±0.05	3.65±0.40	145	37.48	21.05	0.0282	19.58	3.65	7.239	7.1

WVTR – Water vapour transmission rate. V–viscose, C–Cotton, B–Bamboo, and P–Polyester.

prepared nonwoven samples. Air permeability of 100% viscose is found as 118.1cm^3/cm^2/s and it is increased with the addition of polyester.

Air permeability also depends on the fineness of fibres and fabric weight. The finer the fibre, the more is inter-fibre closeness, which reduces the air permeation[26]. The increase in fabric weight also reduces the air permeability, as the fibre occupation increases per unit area of the fabric[27]. In general, the air permeability decreases in needle-punched nonwovens with increase in fabric density and thickness[28].

The air permeability of the fabric increases with the increase in ratio of polyester fibre. The lower density of polyester fibre contributes to the higher thickness with bulky fabric when compared to viscose fabrics of equal mass per unit area[25]. Addition of one natural and other synthetic fibre together creates the chances for increased amount of pores with higher surface areas in the structure. Along with that, the range of different denier fibres and random distribution of fibres in the fabric are also the main reason behind the increment in the air permeability value[29].

Air permeability of V/B samples is also in the higher side, where 70/30 V/B sample shows the air permeability value of 127.2cm^3/cm^2/s, and 30/70 V/B shows 132.2cm^3/cm^2/s air permeability. This can be explained by the fact that the breathable nature of bamboo fibre enhances the rate of air flow in the structure[30]. This statement is controversial when compared with bamboo woven fabric. The increase in bamboo content decreases the air permeability[31].

3.3 Effect of Fibre Composition on Mechanical Properties of Nonwoven Fabrics

Tensile strength of the needle-punched nonwovens is measured as per ASTM D 882-12 (Table 1). The results reveal that the tensile strength of the samples is in the range of 40-80 N. The tensile strength of 70/30 V/C is 75 N, and that of 30/70 V/C is 78 N, which is higher than that of other fibre compositions. This may be due to the compact structure and high inter-fibre cohesion[32]. The tensile strength decreases with an increase in polyester content.

Tensile strength values of the fabric increases with the weight of the fabric. These results are in line with the previous findings of Adanur and Liao[33]. Bamboo and viscose fibres exhibit a lower dry and wet tenacity as compared to cotton, which is also reflected in the tensile strength of nonwovens also. But the elongation value of bamboo is higher than cotton and other nonwovens. It can be explained by the fact that bamboo fibre has got good elongation at break value than any other fibres[34]. An increase in the amount of polyester in the fabric leads to decrease in tensile strength, and the elongation of the fabric is increased by increasing polyester content[35]. However, the highest tensile strength is noticed for V/C blends.

3.4 Effect of Fabric Composition on Fluid Handling Properties of Nonwoven Fabrics

3.4.1 Water Vapor Transmission Rate

The water vapor transmission (WVTR) for nonwoven samples are in the range of 480-1440 g/m^2/day, which show their suitability to be used as a wound dressing to facilitate the natural aeration of the skin[36] (Table 1). The 70/30 V/B and 30/70 V/B show higher value of water vapor transmission rate of 59.14 and 51.25 g/m^2/h.

The water vapor transmission of 100% viscose, V/B and V/C fabrics shows higher values as compared to V/P fabrics, due to the hydrophilic nature of fibres. It is due to the characteristics of bamboo fibre, which is filled with many micro gaps and micro holes. It has better moisture absorption and excellent wicking ability that pulls the moisture away from the source. The capillary effect of normal polyester fabric is comparatively less than hydrophilic natural fibres like bamboo and micro denier polyester fibres[37]. Moisture vapor mechanism explains the process of water vapor transmission through a textile material using two processes, namely diffusion and sorption-desorption. Das *et al.*[38] mentioned that the water vapor diffusion may be of simple diffusion through the air spaces between the fibres, which depends on the water vapor diffusivity of the fibre and the porosity of the textile material. Hence, the moisture regain value of the fabric causes proportional changes in the diffusivity[39]. Sorption and desorption process can be explained by the hygroscopicity of the material, which has a positive impact on vapor transmission. The transfer of water vapor from the skin to the dry air is more in case of hygroscopic fabrics[40]. Fabrics prepared with polyester fibres are characterized by low water vapor transmission rate fabrics than other compositions. V/P fabric results in the water vapor transmission rate in the range of 480-550 g/m^2/day. Also, water vapor transmission decreases with an increase in polyester content. These results are in support with Abou-Okeil *et al.*[29] that due to an increase in the polyester content the hydrophobicity content increases, thereby decreasing water vapor transmission rate.

3.4.2 Rate of Absorption and Absorbency of Nonwoven Fabrics

Absorbency of a needle-punched nonwoven fabric depends on a number of factors like fibre composition, geometrical fibre alignment, constituent fibre properties, contact point between fibres in the fabric, porosity of the fabric and inter-fibre cohesion. Nonwovens used for wound dressings should have good absorbency towards wound fluid. Table 1 also shows that absorbency of viscose/bamboo fabric is greater for 70/30 V/B (14.5 g/g) and 30/70 V/B (13.8 g/g) fabrics as compared to the other fabrics.

This can be explained by the fact that both viscose and bamboo are natural fibres, and bamboo has good absorbency in fibre stage because of its microstructure. The bamboo fibre cross-section is filled with micro-gaps and micro-holes that lead to higher moisture absorption and ventilation[41]. Interaction of water molecules and fibre molecules is higher due to the hydrophilicity of the material in both cases because of the absorption by fibre molecules and moisture fill-up in inter-fibre pores of the material[42]. In present study, all the samples are produced by needle-punching with no significant variation in areal density. Hence, by considering the water entrapment in pores as constant, the high absorption value of viscose and bamboo can be explained by the higher absorption of water molecules due to the hygroscopic nature of fibres. The absorbency of cotton fabrics is attributed to its lower contact angle, and hence the viscose/polyester exhibits the lowest absorbency value. When the absorbency of nonwoven fabric is high, the rate of absorption is low for the fabric. 70/30 V/P and 30/70 V/P fabrics show rate of absorption of 6.5 s and 7.1 s respectively. The fabric with low absorption takes more time to absorb the fluid and so the high absorption rate. The increase in polyester content increases the rate of absorption significantly.

3.4.3 Vertical Wicking of Nonwoven Fabrics

Wicking height exhibits an irregular pattern. The highest value of 4.52 mm is attributed to 70/30 (V/B) and the value gradually reduces when the bamboo content is increased. The behavior of vertical wicking cannot be explained by the single factor of fabric composition with the tested time of 1 min. Wickability depends on the following four factors, viz wicking without fibre diffusion, wicking combined with diffusion into the fibre, fibre adsorption and wicking by fibre adsorption & diffusion[43]. The wicking time of viscose, viscose/bamboo and viscose/polyester shows higher values compared to viscose/cotton. It does not show any relationship with absorbency of the samples, in contrast to the statement of Uzun *et al.*[44] who mentioned that higher absorbency values show lower wicking rate because of the travelling of water molecules along the length happens, which is only after increasing the fibre diameter in the specified point.

Higher wicking height of 3.6 mm is observed from the result for 30/70 V/P fabrics than 70/30 V/P fabrics. This can be explained by the fact that the movement of water through the hydrophobic synthetic fibre fabric is more rapid as compared to hydrophilic fibre fabric[45].

3.4.4 Dehydration Rate of Nonwoven Fabrics

Dehydration, in general, delays the wound healing process. A warm, damp environment is ideal for the growth of new tissue, and a lack of moisture to the affected area can halt cellular development and migration. This dehydration reduces the movement of the epithelial cells across the wound, which ultimately repairs the damaged tissues by cellular development. This interrupts the creation of new tissue and leaves the wound open and susceptible to harmful bacteria that can cause infection. The dehydration properties of the nonwoven fabrics are given in the Table 1. Dehydration rates of 70V/30B and 30/70V/B show higher values of 0.033 and 0.037 g/min respectively. V/C samples show minimum dehydration rate compared to other samples. 70V/30C and 30V/70 C exhibit lowest dehydration rates of 0.0187 and 0.0123 g/min respectively.

The specimen shows considerable difference in dehydration rate, since dehydration rate has inverse dependence to the thickness of the nonwoven[46]. However, it can be noted that the results are in contradiction to the expectation. Even though the mass per unit area is high for blends viscose/cotton (30/70) the dehydration rate is very low, due to the inherent nature of the cotton fibre. The bamboo blends show higher dehydration rate than the cotton blends, though the mass per unit area of the sample is less. The influence of polyester is found to be negligible in both the combinations.

3.5 Antimicrobial Activity

The zone of inhibition of all nonwoven samples against Gram positive bacteria *S.aureus* and Gram negative bacteria *E.coli* shows positive results in agar disc diffusion technique (Fig. 1). All the samples

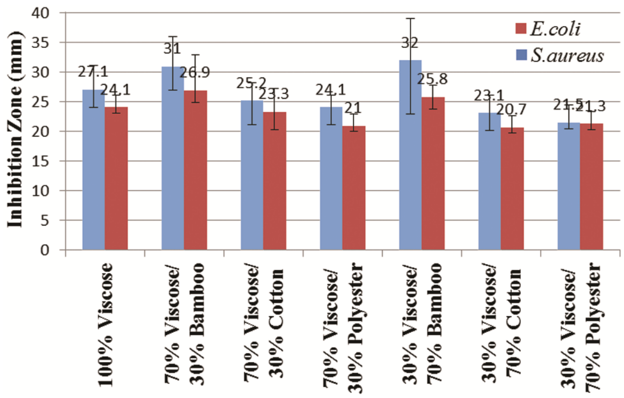

Fig. 1 — Zone of inhibition of samples against *S.aureus* and *E.coli*

exhibit antibacterial activity against both the bacteria, which may be due to the presence of viscose. However, 30 viscose/70 bamboo sample shows higher bacterial inhibition zone of 32 mm against *S.aureus*, and 70 viscose/30 bamboo shows inhibition zone of 26 mm against *E.coli* as compared to other samples. The performance of the bamboo and viscose blends (in both blend ratios) is noted higher than the other fibre blends. This can be explained by the inherent antimicrobial property of both bamboo and viscose. The bamboo absorbs and evaporates water rapidly due to its structure, and hence the environment in bamboo is not suitable for bacterial growth[47]. Figure 1 shows the zone of inhibition values of the developed nonwoven fabric.

In the overall analysis, it can be noted that the air permeability of the developed nonwoven fabric is high for the blends with polyester. The water vapor transmission rate of the nonwoven fabric largely depends upon the bamboo fibre content. As similar to the water vapour transmission rate, the absorption and rate of absorbency values are also found high in the case of bamboo blends. The vertical wicking behavior of the nonwoven samples largely depends upon the viscose fibre content. The maximum wicking value is found in viscose/bamboo (70/30) blends, than in 100% pure viscose. With respect to the dehydration rate, the lowest dehydration occurs with the viscose/cotton nonwoven blends. The bamboo blends of viscose possess higher antibacterial activity than the other fibre blends. With respect to the mechanical behavior, the highest tearing value is found for cotton/viscose blends and the elongation percentage is found higher for bamboo/viscose blends. Elongation is also important in the area of application, where more weightage is given to the elongation property than to tearing strength of the material. From these findings, it can be noted that most of the essential properties, like moisture vapour transmission, absorption rate, absorption percentage, wicking and antibacterial ability and elongation percentage are high in the case of viscose/bamboo blended nonwoven material than in other blends.

4 Conclusion

The results of the experimental study reveal that the viscose/bamboo blended needle-punched nonwoven meets the quality requirements of nonwovens to be used as a secondary layer for wound dressings. Among the blended fabrics, this sample shows optimum results in tensile strength, and higher elongation, air permeability and fluid handling properties. This blend also exhibits higher resistance to common wound infecting bacteria like *S.aureus* and *E.coli* due to the nature of the combined effect of both viscose and bamboo fibres, which is the most important property of a wound dressing. Hence, the 70/30 V/B (70%viscose/30% bamboo) needle-punched nonwoven is recommended to be used as a potential secondary layer for wound dressings.

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