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Development of Nonwoven Fabrics for Clothing Applications

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Abstract

The apparel fabric manufacturing is a growing sector of the global textile industry and the fabrics used in this market are mainly produced by the conventional methods such as weaving and knitting processes. These methods of making apparel fabrics are length and costly. However, because of the advancements in nonwoven technology, nonwoven fabrics are finding a niche market in the clothing industry because of its cost effectiveness and high speeds of nonwoven production processes. We have carried out an extensive study on the development of apparel-like nonwoven fabrics. The resultant fabric showed improved drape, hand, durability and thermophysiological comfort characteristics than the reference samples for apparel applications. Results of the study also showed that the developed nonwoven fabrics showed nearly 200% higher tensile strength than the reference nonwoven fabrics. Furthermore, it also showed improved air permeability, for example, the resultant nonwoven fabric exhibited 500% higher air permeability value as compared with the Evolon fabric at 100 Pa pressure. Thus the results of the study indicate that the resultant nonwoven fabrics may be used in a wide range of apparel applications, which can lead to additional benefits in terms of cost and time.

Keywords: Fabric; Textile; Apparel; Fibres; Market competition

Introduction

The conventional methods of producing apparel fabrics are lengthy and costly. These methods involve a series of complex processes; starting from the ginning process to ring spinning for yarn manufacturing and then only after weaving or knitting the fabric becomes available for garment manufacture. Therefore, the production of apparel fabric using the conventional routes requires a considerable amount of investment in the infrastructure, labour, and energy. The complexity and material processing requirements of these methods also have detrimental effect on the environment.

In contrast, the fabric produce through the nonwoven methods are more efficient and cost-effective because in this case the fabric is produced directly from the fibres, avoiding the costly and tedious yarn making process. Nonwoven fabrics have commonly been disadvantaged when it is compared with the conventional fabric in terms of their aesthetic and mechanical properties like softness, durability, stretchability, drapability and surface abrasion. The nonwoven fabrics must exhibit such characteristics if they are going to be suitable for the production of garments. The apparel industry in terms of garment manufacturing is rapidly growing and the growth rate of the apparel production in the world is estimated at 8.2% for the period of 2011-2017 [1].

Because of the tough market competition, many manufacturers and research organisations are trying to adopt new technologies and materials in order to sustain their market share. Furthermore, development and introduction of innovative products in the apparel market will allow companies to capture a larger share of the market. Because of the competitive pressures, researchers are trying to explore the non-conventional approaches to develop fabrics for apparel applications in order to innovate and reduce costs.

It is known that conventional nonwovens have been used as auxiliary materials in the apparel industry like; they are being used as fusible interlinings and reinforcements for collars and cuffs. It was assumed that nonwovens are disposable and relatively rigid structures and they do not have the attributes that can promote them in the apparel industry as the outer fabrics. However, because of the improvements in technology and materials, the perception of disposable and rigidness of the nonwovens has changed in recent years with the development of the commercially nonwoven fabric "Evolon". Evolon is one of the best high-tech nonwovens that are being used as apparel outer fabric. It was made through spun laying and hydroentanglement processes by using island in the sea splitable bi-component PET and PA filament fibres [2].

Besides Evolon, there are other commercial nonwoven fabrics that have entered the clothing industry and the most well-known are "Miratec" from PGI (the U.S.) and "Inova" from DuPont (the U.S.). "Miratech" nonwoven fabric is used in the Nike's undershirts and it was also used by Futon fabric [3].

The appearance of commercially nonwoven fabric is not like that of a woven structure because the filaments are scattered randomly in diverse orders, which results in uncharacteristic appearance of the fabric and secondly the hand feel is little harsh. It was because; Evolon is made by microfilament that affects the aesthetical and thermal properties of the fabric, which could be uncomfortable for the wearer.

There are other nonwoven fabrics, such as, Tyvek by DuPont that are made by thermal bonding of spunbonded PE. This type of nonwoven fabrics can be used only for protective clothing purpose but they are not suitable as outer fabric next to the skin. Therefore, there is good scope to develop different kind of unconventional nonwoven, which can be suitable for garment production and can be used as outer fabrics, worn next to the skin for casual wear.

In 1968, Scott Paper launched disposable paper garments but because of poor aesthetical and mechanical properties could not capture

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the market [4]. Toray Industries (1970) developed the world's first ultra-micro nonwoven fabric known as Ultrasuede®. Ultrasuede® was made by using the micro fibres known as "island in the sea", through a series of processes including needlepunching and other complex processes, such as ironing, curling, cutting, etc. The nonwoven fabric was used in apparel, automotive, industrial and interior design applications [5]. Ultrasuede® is used mainly in leather-textured products in the automotive industry. Because of its suede structure, the fabric is not suitable for clothing purposes in casual wear.

In the early nineties, Kimberly-Clark introduced a new product with the name of "Demique". It was an elastic nonwoven fabric, which was produced by using thermoplastic micro fibre based on co-polyether esters. The elastic nonwoven fabric was used in various personal care applications such as diapers and feminine hygiene products [6]. The fabric was also used in stretchable bed sheets as a composite with cotton/polyester woven fabric. Because of its elastic nature, poor breathability and thermophysiological properties, this fabric is not suitable for apparel applications.

DuPont has developed a range of strong nonwoven products under the trademark of Tyvek®. The products are in the forms of paper, film and fabric and are made from thermal bonding of spunbonded polyethylene nonwoven fabric. Tyvek® possesses high abrasion and puncture resistance, smooth surface, high tearing strength, lightweight and good dimension stability. The fabric is mainly used in the construction and medical sectors as protective clothing and protective cover applications [7]. Because of Tyvek's finishing properties like water and wind proof, the fabric is also used in many consumer applications as a protective material. A good example is the use of the fabric by American Apparel Company in Tyvek jacket (Figure 1), which is an outerwear and has received a very impressive response from the customers [8]. However, the heat bonded fabric made of non-absorbent polyethylene does not absorb moisture and therefore it is not used in direct skin contact garment applications.

Figure 1: Tyvek Day Jacket by American Apparel.

Canesis Network Ltd was established in 1961 by The Wool Research Organisation of New Zealand (WRONZ). They have developed a lightweight apparel nonwoven fabric made from wool and after some finishing, it showed unique properties and the fabric was fit for fashion apparel applications as shown in Figure 2 [9].

Figure 2: Nonwoven wool garments by Canesis Network Ltd.

University of Leeds [10] also constructed some fashion designed garments by using different nonwoven fabrics. These fabrics were supplied from different nonwoven manufacturers like Freudenberg Nonwovens, Mogul, Fibreweb, Colbond, Tredegar Film Products etc. These garments are shown in Figure 3.

Figure 3: Nonwoven garments designed by University of Leeds.

The purpose of this study was to investigate the limitations in the current nonwoven fabrics used for the apparel applications and to realise the functional properties of the fabrics that are suitable for apparel applications. After evaluating the current limitations in the available nonwoven fabrics and the properties required for apparel purposes, a production model was developed based on the selection of materials, manufacturing processes and testing procedures. After completion of this research, a very unique and innovative hydroentangled nonwoven fabric was developed, which exhibited good characteristics for apparel applications in term of the outer garments for single and multi uses.

Materials and Methods

In this study, hydroentangled nonwoven fabrics were developed by using specific ratio of blend of two different fibers, Fibrillated Tencel (1.4 dtex, 38 mm length) and bi-component sheath/core PE/PET (2.2 dtex, 40 mm length). The blended materials were carded (parallel) and pre-needled prior to hydroentanglement process. Five samples were prepared with nominal area density of 150 ± 5 gm^{-2}. The details of the developed hydroentangled nonwoven, commercial nonwoven and the woven fabrics are given in Table 1.

Results and Discussion

Bending rigidity

Bending rigidity (BR) values of all the developed fabrics were determined by using BS 3356:1990 testing standard. Bending behaviour is an important factor, which affects the clothing properties such as handle and drape. Bending rigidity introduces the damping ability to the fabric and it affects the handling, deformation, crease resistance and buckling behaviour [11]. Figure 4 shows that the bending rigidity of the fabric (H) was better than the commercial fabric (E) and the values were close to that of the plain woven fabric (W) in the machine and cross directions. Unidirectional strands of developed fabric (H) smooth surface of Tencel fibres and the spaces between the fibres facilitate the fabric to show better flexural rigidity behaviour in machine and cross directions.

Komori et al. concluded in their research that the fibres' arrangement in the fabric structure has a major effect on the bending properties of a fabric. Scattered filament structure in Evolon fabric resisted to give better drape in machine and cross direction. The lower flexural rigidity values of the woven fabric (W), give better drape and easy deformation of fabric [12]. It was because of its set pattern of unidirectional weave and the high degree of freedom of individual fibre motion during bending, the crimped nature and slippage of the fibres.

Moisture management

The developed fabric (H) (24.48 g.cm and 14.56 g.cm) exhibited higher wicking results than commercial nonwoven (E) and woven (W) fabric (1.34 g.cm and 1.10 g.cm) both in machine and cross machine directions.

Porous fabric structure, parallel formation of strands in the fabric structure enabled the developed fabric (H) to show higher wicking properties than commercial (E) and woven (W) fabrics. Because of fibril structure of Tencel fibers, it created very fine capillaries or tubes in the fabric structure during hydroentanglement process, which helps to move the moisture from the body to environment and also within the structure of the fabric (Figure 5).

Tensile properties

Developed hydroentangled fabric (H) showed maximum tensile strength in the machine direction as shown in Figure 6. It was 0.074 N/tex, which were almost 200% higher than the commercial hydroentangled (E) fabric and 30% higher than the conventional woven fabric in machine direction. It was because of the unique structure of the H fabric, which consisted of micro staple fibres, thus imparting higher entangling points in per unit area of the fabric. Furthermore, the higher wet and dry tenacity of Tencel fibres as compared to the cotton and polyamide fibres used in woven and Evolon references samples, respectively. Evolon (E) nonwoven fabric showed higher extensibility in machine direction as compared to the other samples, it was because of the polyamide 6 filaments present in the fabric structure. Woven fabric showed minimum extensibility in the machine direction due to its weave structure. Plain compact weave did not allow the fibres to move in the fabric structure due to which the woven fabric showed lower extensibility in the machine direction.

Fabric Type	Manufacturing Process	Contents	Area Density (gm^{-2})	Thickness (mm)	Bulk Density (gcm^{-3})
H	Hybrid process of pre-needled and hydroentanglement	Fibril Tencel and bi-component (sheath/core) PE/PET	145	0.88	0.17
E	Spunlaid and hydroentanglement	Splitable bi-component (isle-land-in-sea) PET/PA6 filament	140	0.43	0.32
W	Plain weave	Cotton and PET	144	0.50	0.29

Table 1: Physical properties of developed hydroentangled nonwoven (H), commercial nonwoven (E)) and woven (W) fabrics.

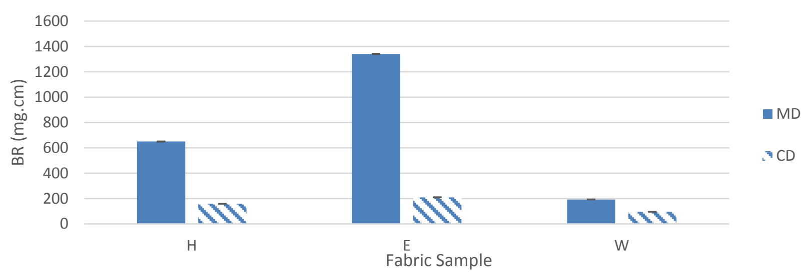

Figure 4: Bending Properties comparison of developed fabrics (H) with Evolon 100PK (E) and woven fabric (W).

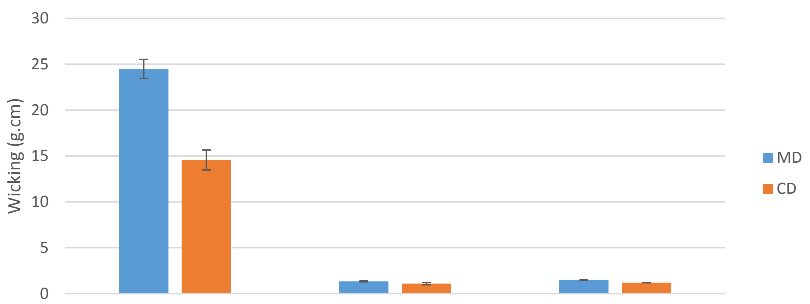

Figure 5: Wicking of the developed hydroentangled (H), commercial nonwoven (E) and woven (W) fabrics.

Air permeability

The fabric (H) showed higher air permeability values than the other fabrics. It showed air permeability value of 448 mm/sec that is 85% higher than the commercial hydroentangled nonwoven fabric (E) and this value was very close to that of the woven fabric (W) as shown in Figure 7.

The pore structure of the fabric has a direct effect on its air permeability. The air permeability increases as the pore size increases, which depend on different parameters, such as fibre fineness, bonding techniques and finishing processes [13]. Figure 8 demonstrated that woven fabric (C) possessed more prominent and regular pore structure than the developed nonwoven (B) and commercial nonwoven (A) fabrics. On the other hand, developed hydroentangled structure showed more loose structure than the commercial nonwoven fabric. The lower value of air permeability of the commercial nonwoven fabric was because of its compact structure. There were not enough spaces between the micro filaments in the fabric structure for allowing the air to pass through.

Thermophysiological properties

Thermal comfort properties of a fabric are the basic requirements

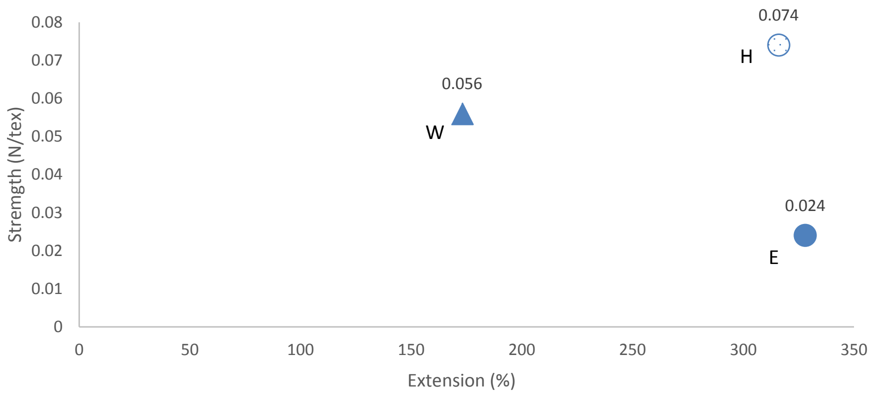

Figure 6: Comparisons of tensile strength in MD of hydroentangled nonwoven fabric (H) with commercial hydroentangled (E) and woven fabrics (W).

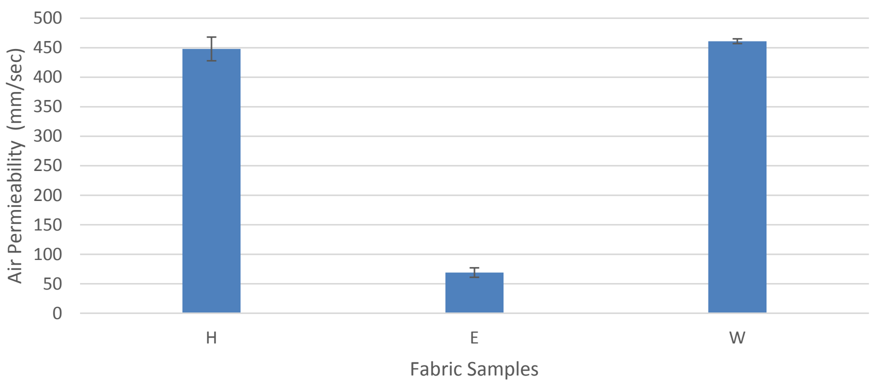

Figure 7: Comparison of air permeability values of developed hydroentangled nonwoven fabric (H) with commercial hydroentangled (E) and woven fabric (W).

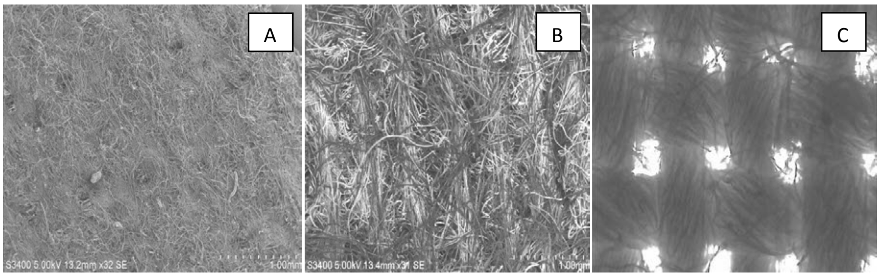

Figure 8: SEM of commercial hydroentangled (A), developed hydroentangled (B) and woven (C) fabric structures.

for the wearer. One of the basic functions of the fabric is to maintain the body temperature against external elements or weather conditions. In this research, three basics tests were carried out and the fabrics were evaluated according to the standards. These tests were thermal absorption (dry, wet); thermal resistance and water vapour resistance.

Thermal absorption test concluded that the developed hydroentangled fabric (H) gave lower value of thermal absorption in the dry state as shown in Table 1 and this will provide warm feeling to the wearer and wearer would feel uncomfortable. This is because of fabric's thick and porous structure that contained dead air in the fabric structure, which provide the resistance to transfer the heat from body to environment. It was observed by Frydrych et al. that the heat diffusion depends on the thickness of the fabric, because the heat waves spend more time in a thicker fabric than in a thinner fabric structure [14].

The results given in Table 2 show that the woven (W) fabric exhibited the highest dry thermal absorptivity value because of its systematic fabric weave and a lower thickness value. The commercial nonwoven (E) exhibited a thermal absorptivity value of 104 $w.m^{-2}.S^{1/2}.K^{-1}$, which was higher than the developed nonwoven (H) fabric (77 $w.m^{-2}.S^{1/2}.K^{-1}$) and lower than the reference woven (W) sample (130 $w.m^{-2}.S^{1/2}.K^{-1}$).

The thermal properties of the developed hydroentangled nonwoven fabric can be enhanced after thermal bonding process. During thermal bonding process, the low melt sheath part of bi-component fibre "PE" would be melted and will create thermal bonding with its surrounding fibres. Thus the thermal bonding process will eliminate the trapped air in the fabric structure, which will result in better thermal absorption value of the nonwoven fabric.

Garment development

In order to show the potential of the developed nonwoven fabric (H) for producing garments, the fabric was dyed and a standard garment making procedure was applied. Firstly, the fabric was dyed by using reactive dyes by the batch dyeing method. The details of the dying process are given below:

Fabric weight: 177 g

Dye (30% of Wt.): 54 ml

Salt (30% of Wt.): 54 g

Dyeing: Batch method

Temperature: 70°C

Time: Machine run for 45 min at 70°C

It was observed that the fabric maintained its integrity during and after the dying process. The fabric skewness was checked by using the ISO 13015:2013 test method and it was found that after the washing and dyeing the fabric was not skewed and only 2% shrinkage observed.

The fabric was cut after the drying process and it was observed that during the cutting process the fabric behaved like a normal woven fabric. The fabric was then subjected to the stitching process and two main machines were involved in stitching of the garment. The first one was lock stitch machine and the second was overlock machine. It was noted that during the stitching process there were no needle marks on the fabric and because of the fabric flexibility the stitching operation was smooth and easy to perform (Figure 9).

It is believed that until the recent past, nonwoven fabrics were not suitable for apparel applications as they lacked the functionalities required for garment manufacture. However, in view of the development of new materials and nonwoven processes it is now quite plausible to think that nonwovens will play an increasingly important role in the apparel sector. There are already commercial nonwoven

S#	Fabrics	Thickness @ 5 g/cm^2 (mm)	Wt. g/m^2	Density g/cm^3	DRY		WET		% of loss in warmth to touch	% of recovery after 4 min wetting
					b ($w.m^{-2}.S^{1/2}.K^{-1}$)	r ($K.m^2.W^{-1}$)	b ($w.m^{-2}.S^{1/2}.K^{-1}$)	r ($K.m^2.W^{-1}$)		
1	H1	0.86	150	0.174	77	23.7	494	9.8	541%	44.58%
2	E1	0.43	140	0.325	104	20.9	484	7.7	365%	36.8%
3	W1	0.48	144	0.300	130	20.4	437	7.0	226%	34.31%

Table 2: Thermal absorptivity of developed fabric (H) commercial nonwoven (E) and woven (W) fabrics in wet and dry state.

Figure 9: Shirt produced from the developed nonwoven fabric (H) showing types of stitches used.

fabrics available that may be used in specialised apparel applications, however, with further improvements, nonwoven fabrics will be available that are durable, flexible, soft and comfortable. Furthermore, the future nonwovens could also have the dimensionally stability and launderablilty, which is comparable to the conventional woven fabrics.

Conclusion

In this study, different mechanical and aesthetical properties of the developed hydroentangled fabrics were evaluated and compared with the commercial nonwoven and woven fabrics for apparel applications. It was observed that the unique structure of the developed hydroentangled fabric showed better results as compared to the commercial nonwoven fabric. It was noticed that the aligned placement of fibres and frictional twisting of micro fibres with the surrounding fibres in the fabric structure improved the tensile properties of the developed hydroentangled fabric. Because of the hydrophilic nature of Tencel fibres and the micro structure of the bi-component fibres an enhancement in the moisture management properties of the developed hydroentangled fabric was obtained. Furthermore, the porous structure improved the air permeability property of the developed fabric. The stitching behaviour of the developed fabric was very similar to that of a woven fabric and there were no stitching faults observed during the stitching operations and the stitched garment was very comfortable to the wear. This study shows it is possible to produce nonwoven fabrics that are suitable for many outer garment applications in the apparel industry.

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