Filtration properties of staple fibre thermo-bonded nonwoven fabrics

D Kalaivani, S Arun Karthick & N Gobi[a]

Department of Textile Technology, Anna University, Chennai 600 025, India

Thermal bonded polyester staple fibre nonwoven fabrics have been produced, considering different proportions of binder fibres, directions of web laid as variables, and bonding time and bonding temperature as constant. The influence of process variables on fabric properties, such as bursting strength, air permeability, bubble point diameter, mean flow pore diameter and filtration efficiency with three different particle (1, 0.5, and 0.3μ) along with the overall filtration efficiency have been tested and the results are compared with spun laced nonwoven fabrics. The fibres are oriented in cross and parallel directions, this arrangement of fibres leads to increase in bursting strength. The trend in air permeability of cross-laid web fabrics is found similar to spunlaced fabrics. The pore sizes of the thermal bonded fabrics have been minimized by laying the web in cross direction and increasing the binder fibre proportion; it has minimum variation with spunlaced fabrics. Aerosols of different particles are fed to the upstream of the filters with the face velocity of 16.6 cm/s which is then maintained as constant. The maximum filtration efficiency achieved is found to be 93.13% which is around 13% higher than that of the spunlaced fabric. For 80g/m^2 fabrics with 0.3μ particles, the filtration efficiency of spun laced fabric is only 38% which is around one and a half time lesser than 80 g/m^2 of thermal bonded fabric; 90g/m^2 fabrics show equal and better properties than 100g/m^2 fabrics.

Keywords: Air permeability, Binder fibres, Filtration efficiency, Pore size, Spunlaced fabrics, Thermal bonded fabrics, Web laying direction

1 Introduction

Highly porous fabrics are widely used for filtration which can be defined as the process of separation of particles from a dispersing medium[1,2]. Filtration efficiency is generally defined as the ratio of weight of particles removed and weight of particles fed to the filters expressed in percentage[3]. Textile fibrous materials are widely used for filtration application and are classified as woven and nonwoven filter fabrics. Higher air permeability controlled pores per unit area and higher filtration efficiency are the advantages of nonwoven filters than woven filters[4]. For hygiene work environment the air quality is very important as per the new standards and scientific approach. The air quality can be further improved by using effective filtration medium. The woven filtration media is widely used for filtration of more than one micron particles. Depending on the type of nonwoven fabric and bonding technique, the porosity and pore size distribution change and this variation influences the filtration efficiency of the air filter[5].

Needle-punched nonwoven fabric has an advantage of longer flow path due to bulky structural nature[3,6].

The single layered needle-punched nonwoven fabric has the disadvantages such as non-uniformity of the web, and the distribution of pore size results in poor dust loading capacity in the direction of airflow. Thermal bonded and spun bonded nonwoven fabrics are also used for filtration application due to its minimal pore size and its distribution[7]. Thermal bonded nonwoven filter samples made from staple fibres have multiple filtration layers of inter connected pores and tortures pore paths through the fabric thickness[7,8]. Thermal bonded fabric may have either an area bonding process or point bonding process. The area thermal bonded process is mainly used for webs containing binder fibres[9]. Polypropylene is found to be a suitable binder fibre to produce staple fibre thermal bonded nonwoven fabric[10,11]. Cellulosic fibres are also blended with polypropylene and then calendared for producing nonwoven fabric[12]. Hemp and polypropylene are also blended to produce nonwoven fabrics for different applications[13].

The porosity and pore size of the nonwoven fabric and its physical properties can be modified by bonding temperature, bonding time, and pressure applied[8,14]. Higher bonding temperature reduces the mean flow pore diameter and also its physical

———————
[a]Corresponding author.
E-mail: gobsnn@gmail.com

properties[14]. As per the mechanism of filtration, less than 0.1 micron particles are filtered by Brownian diffusion but less than one micron particles are filtered by intercepted and more than one micron particles are filtered by inertial impaction[15].

Spun bonded nonwoven fabrics are generally produced by extrusion and bonding process. The laying of filaments cannot be altered easily to change the porous nature of the fabric. The random arrangement of fibres in nonwoven provides favourable conditions for trapping and precipitation of particles[16]. The continuous filament tends to have more order within the cross-section, as opposed to the staple fibres which are random throughout the fabric. Staple fibres generally provide a much tighter pore structure than continuous filament[9]. The arrangement of web in different directions influences the pore size and pore size distribution of the fabric. So far, limited literatures are available with respect to staple fibre area bonded nonwoven with different web laying directions. The orientation of fibres in cross and parallel directions in the web influences the formation of pores and its distribution.

In this study, polyester staple fibre thermal bonded nonwoven fabric has been produced with different web laying directions, and polypropylene is used as a binder fibre. The performance of fabric in filtration is compared with spun laced fabric.

2 Materials and Methods

2.1 Materials

Thermal bonded nonwoven fabrics, composed of polyester and polypropylene fibres, were used for this study. Polyester staple fibre (2.5 den) with 51 mm length was taken as carrier fibre and the bundle fibre strength was kept as 7.71N. Polypropylene staple fibre (2.8 den) with 38 mm of length was taken as binder fibre and its bundle fibre strength was kept as 11.08 N. Twelve samples were produced by changing the process variables, such as binder fibre percentage and web laying direction, and then tested for the filtration efficiency.

2.2 Web Preparation for Nonwoven Fabric Development

Nonwoven fabric samples were prepared by thermal bonding process. The web of required areal density was prepared by miniature carding machine and the laying of web in machine and cross direction was carried out to produce the samples. The prepared web was bonded by a laboratory model thermal bonding machine, and bonding roller temperature and

speed were maintained at 170° C and 5RPM respectively. The details of twelve developed thermal bonded samples and three commercially procured spunlaced samples, prepared from same raw material, are given in Table 1. The properties of developed thermal bonded samples and spun laced samples are tested and compared.

2.3 Fabric Testing

2.3.1 Fabric Areal Density

ASTM D6242 was followed to measure the mass per unit area of nonwoven fabrics. The specimens of the size 10.2×10.2 cm were cut randomly from different places and weighed in electronic balance with an accuracy of 0.01 g and the average readings were taken.

2.3.2 Thickness Measurement

Nonwoven fabrics are highly compressible; a high pressure would give an inaccurate value of its thickness. As per EN ISO 9073-2(1996) standard, the thicknesses of the nonwoven fabrics were measured using Digital thickness tester under 0.5 kPa of applied pressure with a pressure foot diameter of 25 mm. Average readings over various positions of nonwoven fabrics were taken.

2.3.3 Air Permeability

The air permeability was tested using TEXTEST FX3300 air permeability tester. The applied pressure was selected at 125 Pa as the fabrics were measured with an area of 38 cm^2 ring according to ASTM D737-04 test method. Average readings were taken over various positions of nonwoven fabrics.

2.3.4 Bursting Strength

Bursting strength of the fabric was measured as per ASTM D 3786-13 method using hydraulic bursting strength tester. The opening of the lower clamp of the instrument has diameter of 30.5 mm, rate of fluid displacement of 95cm^2/min, and test fluid used is glycerine.

2.3.5 Fabric Pore Size Determination

Pore size and distribution were measured using capillary flow porometer as per the test ASTM E 1294. The liquid extrusion technique was used for the evaluation of pore size in nonwovens. In this technique, a wetting liquid Galwik (surface tension 15.9 dynes/cm²) fills the pores of the sample and pressurized gas removes the liquid from the pores. Differential gas pressure and flow rates through wet and dry samples were measured to calculate pore diameters.

2.4 Filtration Efficiency Testing

Figure 1 shows the experimental setup used for measuring the filtration efficiency. During the experiment the required amount of air was obtained from compressor coupled with a pre-filter. Two controllable precision air regulators were used to obtain calculated flow of air from compressor to aerosol generator and aerosol mixing chamber. NaCl was used as the challenge aerosol. The aerosol particles of 0.3-1 micron were generated by an aerosol generator. Then the aerosol generator output passes through aerosol neutralizer (P-210) to reach the Boltzmann equilibrium charged state before mixing up with aerosol mixing chamber (to make up required air flow velocity). The face velocity was maintained as 16.66 cm/s throughout the process to measure the filtration efficiency. The developed thermal bonded and spunlaced nonwoven filter fabrics were then tested for various properties. The pressure drops across the filters were measured using differential pressure gauge. Laser particle counter was used to measure number of aerosol concentration at filter upstream and downstream. As the aerosol charge was neutralized, the filtration mechanism was purely mechanical in nature. Filtration efficiency was calculated using the following equation:

$$\text{Filtration efficiency} = \frac{\begin{array}{c}\text{No. of particles} \\ \text{feed}\end{array} - \begin{array}{c}\text{No. of particles received} \\ \text{after filtration}\end{array}}{\text{No. of particles feed}} \times 100$$

2.5 Quality Factor and Ranking Method

Since filtration efficiency is important for the fabric properties such as air permeability, pressure
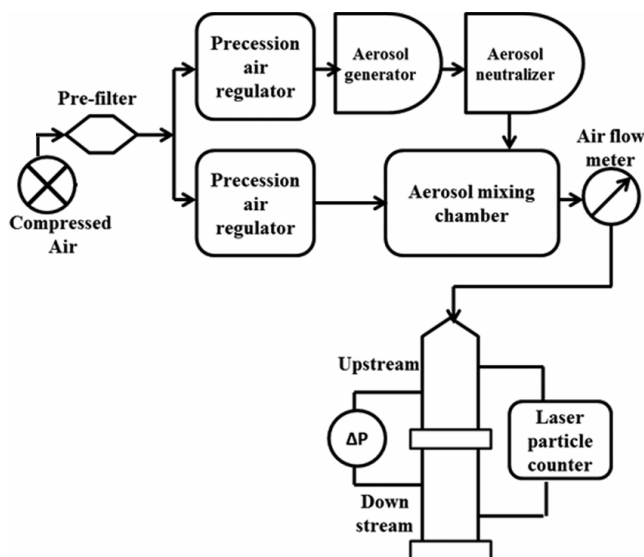

Fig. 1—Schematic diagram of filtration efficiency tester

drop and bursting strength are required for attaining the quality of filter. To evaluate the quality of filter, these proportions need to be considered. Hence, quality factor is desired for all samples by considering the important properties. The weightage of the property can also be given, depending on its influence on quality of filter[17], as shown below:

$$Q = 0.6a + 0.15\, b + (0.15/c) + 0.1\, d \qquad \dots (1)$$

when Q is the Quality factor; a, the filtration efficiency; b, the air permeability; c, the pressure drop; and d, the bursting strength.

3 Results and Discussion

In this study, the bonding temperature, pressure applied and bonding time are to be maintained as constants and the influence of other parameters on properties is discussed. Areal density and thickness of samples have been tested and there is no significant difference found within the same areal density, but a significant difference is observed between the areal density of the samples. Bursting strength is an indication of the pressure endurance capacity of the filter, while dust loading onto the fabrics results in blocking of pores, thus leading to increase of pressure in inlet stream. The bursting strength results of all samples are given in Table 1. Areal density and binder fibre proportions are directly proportional to bursting strength of fabric. The cross and parallel laying fibre arrangement in cross laid web leads to significant increase in bursting strength due to distribution of loads to all fibres in the structure of fabric. Spun laced fabrics shows lower bursting strength due to intermingling of fibres without bonding.

Nonwoven filters show higher air permeability and reduced pressure drop, by suitable medium selection we can attain improved filtration efficiency. The areal density, direction of web laying and proportion of binder fibre are linearly related to the air permeability of the fabric. The results of air permeability are given in Table 1. The direction of web laying is influenced more with the change in air permeability than that with the change in percentage of binding fibre. The air permeability reduces while changing the direction of the web arrangement from machine direction to cross direction. While crossing the web, due to the intermingling of fibres, blocking of the flow path leads to reduction of air permeability. The concept of production of spun lace is the intermingling of fibres by air/water jet and its orientation is also partially cross laid and parallel laid, hence it also follows the same trend.

Table 1—Properties of developed thermal bonded nonwoven and commercial spun laced fabrics

Sample No.	Sample ID	Thickness mm	Bursting strength kg/cm^2	Air permeability Cm^3/cm^2/s	Bubble point diameter μ	Mean flow pore diameter μ	Δp mm (in water)	Filtration efficiency, %			Overall filtration efficiency %	Quality factor Q	Rank
								0.3 μ	0.5 μ	1 μ			
S1	80-MD-95/5	0.746	7.564	177.5	143.29	40.69	1.5	63.48	70.99	71.48	82.54	77.0	5
S2	80-MD-85/15	0.75	7.81	160.5	71.29	36.15	2.5	79.55	84.95	84.76	86.58	76.9	6
S3	80-CD-95/5	0.75	8.076	155.5	68.94	33.69	1	75.44	82.33	82.11	84.52	75.0	12
S4	80-CD-85/15	0.792	8.462	148.3	72.67	31.08	3.5	84.47	86.31	92.04	87.79	75.8	10
S5	90-MD-95/5	0.764	8.393	157.8	81.49	36.34	1.5	70.77	78.67	84.36	87.45	77.1	4
S6	90-MD-85/15	0.762	8.652	152.5	75.41	31.08	3.5	88.21	87.78	93.17	91.59	78.7	1
S7	90-CD-95/5	0.744	8.698	147.3	66.52	31.83	2	86.86	91.06	93.56	90.32	77.2	3
S8	90-CD-85/15	0.76	8.779	142.5	67.64	30.45	4	89.79	92.07	94.66	93.18	78.2	2
S9	100-MD-95/5	0.928	8.949	145.5	102.49	35.89	2.5	76.65	79.22	83.42	87.52	75.3	11
S10	100-MD-85/15	0.94	9.7618	141.5	96.31	33.74	3	87.33	86.63	88.45	89.78	76.1	9
S11	100-CD-95/5	0.788	9.206	136.5	93.54	35.81	4	86.72	90.47	92.73	91.26	76.2	8
S12	100-CD-85/15	0.876	10.121	130	68.97	29.83	4.5	90.48	93.51	96.73	93.03	76.4	7
S13	80-Spunlace	0.51	5.124	134.5	147.23	37.65	3	38.08	59.19	59.10	72.65	64.3	14
S14	90-Spunlace	0.574	6.022	130	97.35	35.15	3.5	56.88	70.097	83.80	77.57	66.7	13
S15	100-Spunlace	0.714	7.288	89	79.42	31.44	4	84.73	86.08	88.04	82.59	63.7	15

Pore size and pore size distribution decide the filtration efficiency and pressure drop of fabrics during filtration. By the thermal bonding process, the pore size has been minimized and pore size distribution improves. The bubble point diameter and mean flow pore diameter in microns of the samples are given in Table 1. The pore size of the samples is influenced by both the proportion of binder fibre and also the direction of web laying. For 80 g/m^2 fabrics, the pore size is minimized by changing the web laying direction. Random distribution of fibres and its effective melting leads to minimize the pore size. This is due to melting ratio of fibres in the structure of the fabric and also the higher flow viscosity of the molten solution which leads to minimizing the pore size. In case of 90 g/m^2 fabric, it is observed that web laying direction significantly reduces the pore size of the samples when the proportion of binder fibre is lower. The increase in binder fibre proportion and change in web laying direction equally contribute to reduce the pore size when areal density of fabric increases from 80 g/m^2 to 90 g/m^2. The same trend has been followed by the 100 g/m^2 fabrics. Without binding the fibres due to the random distribution in the structure of fabric, the pore size can be reduced in case of spun laced fabrics. The mean flow pore diameter and bubble point diameter show that the process parameters such as bonding roller speed and binder to

fibre proportion are effective for 90 g/m^2 fabrics than that for 80 g/m^2 and 100g/m^2 fabrics.

The thickness of the samples has been slightly reduced when the binder to fibre proportion increases. The aerosol particles of three different sizes, such as 1, 0.5, and 0.3μ have been generated by aerosol generator and then diluted in aerosol chamber. The aerosol particles are fed to the upstream of the tester by the air flow rate of 50 liters per min and the face velocity is maintained at 16.6 cm/s.

The filtration efficiency of samples with different particle size and overall filtration efficiency are given in Table 1. The web laying direction and higher binder fibre proportion increases the filtration efficiency, the samples S9 and S10 show lower filtration efficiency than samples S6, S7 and S8 even though the areal density is higher. The maximum filtration efficiency (93.13%) is achieved by sample S12, which is around 13% higher than that of the spun laced (100 g/m^2), that is equal to sample S8. It shows that 90 g/m^2 fabrics are well bonded by the binder fibres. The effective interaction of binder fibres and web laying direction shows higher filtration efficiency for all particles sizes. Sample S12 shows better filtration efficiency for the particle sizes 0.3, 0.5, and 1 μ, and at the same time the pressure drop is comparatively higher than other samples. The difference in filtration efficiencies of samples S12, S8

and S6 observed between the particle sizes of minimum and maximum is only around 5 %. Hence, higher rank samples execute better performance relating to all particle sizes. In this case, the filtration efficiency of the spun laced samples is found to be lower than that of the thermal bonded fabrics; for example, the filtration efficiency of the 80 g/m^2 spun laced fabric is only 38% for 0.3 μ particle size. The pressure difference is also higher for spun laced fabrics due to random distribution of fibres and the particles cannot be filtered by the fabric due to interlacement without bonding. The pressure developed on the spun laced fabric due to the interlacement of fibres drives the particles through the air stream and this result in poor filtration efficiency as compared to the thermal bonded fabric under similar conditions.

The quality factor and ranking for all samples are given in Table 1. Since, the application area of the fabrics is filtration; the filtration efficiency contributes more in the quality factor equation. The air permeability, pressure drop and bursting strength are considered next to the filtration efficiency. The quality factor is considered to obtain the best sample and it is identified that sample S6 satisfies all quality factor requirements. Among the samples produced and procured, the nonwoven fabric with 90 g/m^2 having 15% binder fibre and machine direction laid is considered as the best samples for filtering 0.3-1 μ particles.

4 Conclusion

Twelve thermal bonded samples have been produced in this study and three spun laced samples have been procured for comparison. The various areal density, direction of laying of web and binder fibre percentage have been used to produce the samples. Bursting strength of the fabric increases with increase in mass per unit area, and proportion of binder fibre influences directly over the bursting strength of the fabric. The bursting strength increases from 4.39 % to 11.5 % by changing the web laying direction and increases from 1.45 % to 7.7 % by changing the binder fibre proportion. Air permeability and pore size distribution of the fabric decrease while increasing the mass per unit area and binder fibre proportion. The air permeability decreases from 8.1 % to 6.5 % by increasing the binder fibre proportion and decreases from 10.65 % to 9.69 % by changing the web laying direction. Filtration efficiency of the fabric increases while increasing the mass per unit area, binder fibre proportion and web laying direction. For lower mass per unit area of fabrics, the proportion

of binder fibre influences more than the direction of web laid. For filtering 0.5 micron and 1micron particles, the direction of web laying influences the filtration efficiency; cross laid web shows higher filtration efficiency. For filtering 0.3 micron particles, the proportion of binder fibre influences more on filtration efficiency. By increasing the proportion of binder fibre, the filtration efficiency increases from 15.28% to 24.84%, and by changing the web laying direction the filtration efficiency increases from 1.75% to 5.82%. The quality factor is used to identify the best sample and the sample S6 has been identified as the best sample. Hence, it is concluded that the filtration efficiency of the thermal bonded staple fibre nonwoven fabric is better than the spun laced fabric and the thermal bonded fabrics show better performance pertaining to all properties than the spun laced fabrics.

References
1   Das A, Alagirusamy R & Rajan Nagendra K, *Indian J Fibre Text Res*, 34 (2009) 253.
2   Heinrich Jackob, *Indian J Fibre Text Res*, 19 (1994) 216.
3   Rajesh D, Anandjiwala & Lydia Boguslavsky, *Text Res J*, 78 (7) (2008) 614.
4   Kothari V K, Das A & Singh S, *Indian J Fibre Text Res*, 32 (2007) 214.
5   Rakesh Patel, Devarshi Shah, Bhupendra G, Prajapti & Manisha Patel, *Indian J Sci Technol*, 3 (2010) 1121.
6   Thangadurai K, Thilagavathi G & Amitava Bhattacharyya, *J Text Institute*, 105 (2014) 1319.
7   Wang X Y & Gong R H, *J Appl Polym Sci,* 102 (2006) 2264.
8   Stephen Michielsen, Behnam Pourdehimi & Prashant Desai, *J Appl Polym Sci*, 109 (2006) 2489.
9   Bhatia S K & Smith J L, *Geosynth Int*, 3 (1996) 85.
10   Subhash Chand, Gajanan S Bhat, Joshep E & Spuruiell Malkan, *Elsevier Sci*, 367 (2001) 155.
11   Gajanan S Bhat, Praveen K Jangala & Joshep E Spuruiell, *J Appl Polym Sci*, 92 (2004) 3593.
12   Desai A N & Balasubramanian N, *Indian J Fibre Text Res*, 19 (1994) 209.
13   Tanveer Malik & Ajay S Joshi, *Colourage.* 59 (4) April (2012) 83.
14   Wang X Y & Gong R H, *J Appl Polm Sci*, 101 (2006) 2689.
15   Julien Payen, Philippe Vroman, Maryline Lewandowski, Anne Perwuelz, Sandrine Calle-Chazelet & Dominique Thomas, *Text Res J*, 82 (19) (2012) 1948.
16   Boguslavsky L & Tsehloane, *Proceedings*, *2nd CSIR Biennial Conference* (CSIR International Convention Centre Pretoria), 2008, 1.
17   Gobi N, Thangavelu R, Venkatachalam R & Rajagoundar P, *Mater Res*, 14 (4) (2011) 552.