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Study on Filtration Performance of Various Multi-layered Fabrics

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Abstract. The single-layered needle-punched nonwovens and multi-layered needle-punched composite fabrics were prepared in this paper, which were made by polyester fibers under proper parameters. The filtration performance of fabrics was evaluated through the analyses of filtration efficiency, filtration resistance, pore sizes, air permeability and porosity. The mechanical properties of fabrics were also studied. The results show that the filtration efficiency of multi-layered needle-punched composite fabrics increases by about 20% and the filtration resistance drops by about 200% when compared with those of single-layered needle-punched nonwovens. The tensile strength of multi-layered needle-punched composite fabrics goes up obviously. However, the difference between horizontal and vertical strength is visible and the stability is also poor. Compared to the composite fabrics with woven textiles, the composite fabrics with knitted textiles are better in filtration performance, but worse in mechanical properties.

Introduction

Nowadays, nonwovens for dry filtration make up a growing percentage. On the other side, although low pressure drop and high filtration efficiency are good points of nonwoven filters, loose and unstable structure leads to short service life which makes users change filter media frequently.

The obvious characters of woven fabrics are good mechanical properties and stable structure. The pore size is large while the porosity is small. Under the same condition, the filtration efficiency is much lower than that of nonwovens. Knitted fabrics are good in tensile strength. Due to loop structure, dimensional stability is poor. Generally, the pore size is also large and pore channel is tortuous. Only knitting raising fabrics can be used for dry filtration.

To some degree, the development of composite filter cloth solves the problems of the filter media mentioned above. Among them, needle-felt is a kind of three-dimension structure with high porosity and even pore distribution. It can make full use of mechanisms, such as direct separation, inertial deposition, direct interception and particle diffusion. The high filtration efficiency, low pressure drop and good air permeability ensure that it is energy-saving and emission reduction when used in dry filtration[1-2]. However, it is complicated to produce those composite fabrics and its structure is unitary.

Some papers[3-4] show most researchers in filtration industry make their efforts to employ new raw materials and new productive technology to develop filtration media with excellent properties. However, it is a good idea to prepare air filtration media with good performance through changing their structures. In light of limitations of single-layered filter cloth for air filtration, multi-layered fabrics were prepared in this paper.

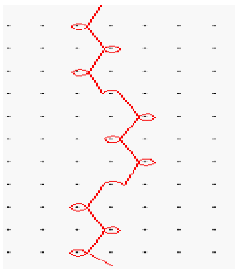
Sample preparation

Fiber selection. The polyester fibers are chosen as the raw materials of nonwovens. The length of the polyester fibers used in this paper is 51mm and the fineness is 2.6D.

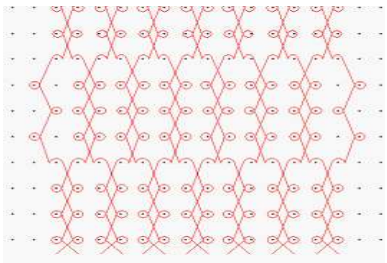
Base cloth selection. The structure of two kinds of woven fabrics is plain weaving and that of knitted fabrics is six-eye network hole. The specifications of them are shown in Table 1 and the schematics of the knitted fabrics are shown in Fig. 1.

Table 1 Specifications of base cloth

Sample	Woven A#	Woven B#	Knitted C#	Knitted D#
Yarn（PET）structure	Staple yarn	Mono-filament	Multi-filament	Multi-filament
Yarn fineness	474D	29D	66D/25f	331D/25f
Twist[t/m]/twist direction	359.84/s	0	0	0
Warp density [ends/5cm]	66	168	52	29
Weft density [picks/5cm]	22	168	40	24
Surface density [M/(g/m^2)]	112	24	38	131
Thickness [δ/(mm)]	0.67	0.09	0.29	0.74



(a) Mat yarn motion map (the flat + the satin)



(b)B:1-0/1-2/1-0/1-2/2-3/2-1/2-3/2-1
F:3-4/3-2/3-4/3-2/2-1/2-3/2-1/2-3

Fig. 1 Schematic of the structure of knitted fabrics

Preparation of single-layered needle-punched nonwovens. The processing machinery is nonwoven acupuncture production line. And the processing workflows are as follows; spiked apron⟶opening⟶pressure cotton box⟶roller feeder⟶roller carding⟶web formation⟶cross layering⟶pre-needle punching⟶needle punching. The layer number of web is 40; total pre-needling density is 168 s/cm^2;total needling density is 300 s/cm^2.

Preparation of needle-punching composite fabrics. Given the bond strength and the damage to fibers and textiles, the layer number of composite fabrics is 3. Specifically, the middle layer is woven or knitted fabrics and the other two sides are composed of needle-punched nonwovens. The direction of needle-punched nonwovens and base cloth is the same when they are compounded.

The specifications of needle-punched nonwovens are shown in Table 2.

Table 2 Specifications of needle-punched composite fabrics

Samples	Compound Specification	Compound Technology
Woven Composite 1#	Nonwovens —Woven A#—Nonwovens	Total needling density:
Woven Composite 2#	Nonwovens —Woven B#—Nonwovens	200 s/cm^2
Knitted Composite 3#	Nonwovens —Knitted C#—Nonwovens	(pros(100) and
Knitted Composite 4#	Nonwovens —Knitted D#—Nonwovens	cons(100))

Study on the filtration performance of fabrics

Measurement instruments and methods. Fabric pore size was tested by GY2 according to bubble point method and fabric air permeability was tested by YG461D according to the national standard GB/T13764-1992. The filtration efficiency and filtration resistance were measured by SX-L1050.

Surface density, thickness and porosity. The results of surface density, thickness and calculations of porosity are shown in Table 3.

Table 3 Surface weight , thickness and porosity

Samples	nonwovens	Woven Composite 1#	Woven Composite 2#	Knitted Composite 3#	Knitted Composite 4#
Surface density M/(g/m^2)	289	634	599	536	696
Thickness δ/(mm)	2.91	4.27	4.10	3.75	4.31
Porosity n/(%)	92.75	89.16	89.34	89.57	88.21

Pore size. The liquid used is absolute ethyl alcohol. The surface tension is 0.0228 N/m and the wetting angle is 0° .The results of average and maximum pore sizes are shown in Fig. 2.

Air permeability. Air permeability has a direct effect on fluid resistance, cleanness of ashes and consumption of energy[5]. The results are shown in Fig. 3.

Filtration efficiency and filtration resistance. The formula of filtration efficiency is identified as Formula 1 and the filtration resistance as Formula 2.

$$\text{filtration efficiency}=\frac{\text{particles arrested by filtration media}}{\text{partiles before filtration}} \quad . \qquad (1)$$

$$\Delta P = P_1 - P_2 . \qquad (2)$$

Where, $\triangle P$ is filtration resistance; P_1 is pressure before filtration; P_2 is pressure after filtration; The results of filtration efficiency and filtration resistance are shown in Fig. 4.

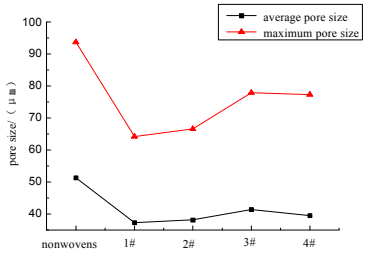


Fig. 2 Average pore size and maximum pore size

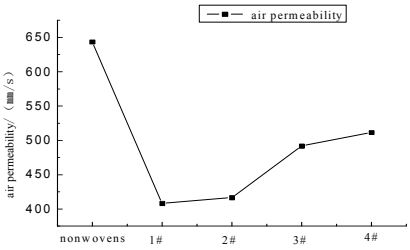


Fig. 3 Air permeability

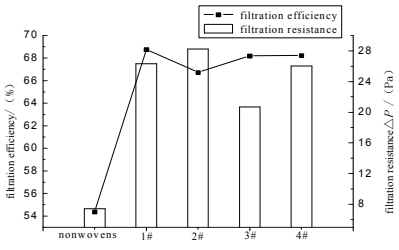


Fig.4 Filtration efficiency and filtration resistance

It can be seen that porosity, average and maximum pore sizes of needle-punched nonwovens are relatively high and the air permeability is good. The pressure drop is quite low. However, the filtration efficiency is also low.

The reduction of air permeability of composite fabrics is mainly decided by the increase of thickness, surface weight and the decrease of pore sizes. Generally, air permeability has a determing effect on the filtration resistance. However, the more complex pore channels increase the filtration efficiency.

The differences between composite fabrics with woven fabrics and those with knitted fabrics result from different base cloth. The compound technology also has different effects on structures of composite fabrics with various base cloth.

Study on the mechanic properties of fabrics

The tensile property was tested by YG065H according to FZ/T60005-91.The results are shown in Fig. 5 and Fig. 6.

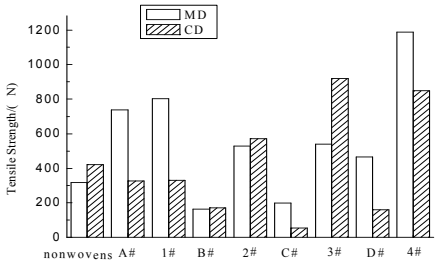


Fig. 5 Tensile strength of fabrics

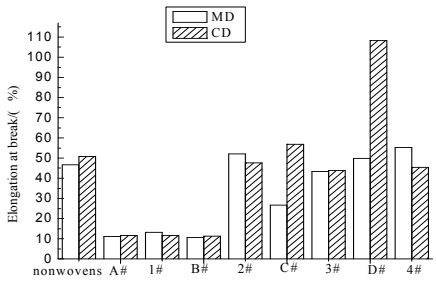


Fig. 6 Elongation at break of fabrics

On the whole, the tensile strength of composite fabrics is equal to or greater than that of needle-punched nonwovens or the corresponding base cloth, but the anisotropic property becomes more obvious; Elongation at break of woven composite fabrics is less than or equal to that of needle-punched nonwovens and dimensional stability becomes much better. However, elongation at break of knitted composite fabrics is greater than or equal to that of needle-punched nonwovens and dimensional stability is not improved. The differences between woven composite fabrics and knitted fabrics are mainly decided by different base cloth. Due to different base cloth, the entanglement among fibers or between fibers and yarns is also not the same.

Conclusion

Compared with needle-punched nonwovens, the porosity, average and maximum pore sizes of composite fabrics are smaller and the air permeability is worse. The filtration efficiency is increased above 20% and the filtration resistance rises by 200% above. There are few differences between the two woven composite fabrics in filtration performance and so do the two knitted composite fabrics. For filtration efficiency and filtration resistance, knitted composite fabrics are better than woven composite fabrics. Just for tensile strength and elongation at break, woven composite fabrics are superior to knitted composite fabrics.

Acknowledgements

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