Application of nanofiber nonwoven fabrics *via* mass production electrospinning

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Abstract

Nanofibers via electrospinning can be used in a variety of applications such as filtering membranes, functional coating, breathable fabrics and medical devices. The purpose of this study is to analyze the mechanical properties of nanofiber nonwoven fabrics as a lining cloth for outdoor wear and air filter media. The specimens are three kinds of PU (polyurethane) nanofiber nonwoven fabrics for breathable fabric and nonwoven fabric coated by nanofiber. To investigate the characteristic as a breathable fabric, waterproof function and air permeability were measured. In addition, pore size and fiber diameter, which were related to vapor permeability and air permeability, were observed in a scanning electron microscope (SEM). Correlation between the pore size and the permeability has been examined. Tensile property, which was important factor as a lining cloth, was also tested. All mechanical properties were compared with Gore-tex's mechanical properties. To evaluate air filter, air permeability, pressure drop and efficiency were tested. As a result, it could be known that the nanofiber nonwoven fabrics had suitable condition as a lining cloth and air filter. Especially, the air permeability was very well. This study indicated some feasibility that nanofiber nonwoven fabric can be used in lining cloth and air filter, instead of conventional breathable fabric or air filter.

Keywords: elstrospinning, nanofiber, breathable fabric, nonwoven fabric, air filter

1. Introduction

Recently, nanofiber web has gained great attention due to their lower diameter than that of the fibers fabricated by conventional other spinning techniques, high surface areas per unit volume, and small pore structure, etc. Generally, nanofiber can be made by electrically driven jet, using known method called electro-spinning. The basic principle involves applying electrostatic forces between the capillary tip and collector by a high voltage power source. The nanofiber *via* electrospinning technique, have huge potential applications in filters, tissue engineering scaffolds, wound dressing, drug delivery material, biomimetic materials, composite reinforcement, protective clothing like a military uniform, lining clothing for outdoor wear and many others [1, 2, 3]. In spite of their huge potential application, nanofiber nonwoven fabric had been produced on only lab scale because of technical problem like production speed. Even if the production speed was incresed, there were still many other technical problems for mass production such as beads existence, low uniformity and so on. However, recently, some company was successful in mass production of nanofiber nonwoven fabric *via* electrospinning. It was meant that many potential applications of nanofiber will be realized. Hence, we focused on breathable fabric as lining clothing and air filter media in the many applications. To be applied as breathable fabric, it should be investigated suitability of nanofiber nonwoven fabric. It could not be found that any standard mechanical data about nanofiber nonwoven fabric because there was no commercialized production hitherto.

The purpose of this study is to investigate mechanical properties of nanofiber nonwoven fabrics that were manufactured *via* mass production eletrospinning for its application. To observe pore structure and fibers, surface of fabric and cross section of fabric were observed in a scanning electron microscope, basically. To evaluate nanofiber nonwoven fabric as lining clothing, the mechanical properties such as waterproofness, air permeability and tensile property were measured. In addition, for evaluation of air filter media, air permeability, pressure drop and efficiency were also tested. Finally, to investigate feasibility of nanofiber nonwoven fabric as a breathable fabric, it was compared with property of conventional product such as Gore-tex, ultra low penetrating air filter (ULPA) and high efficiency particulate air filter (HEPA).

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2. Experimental

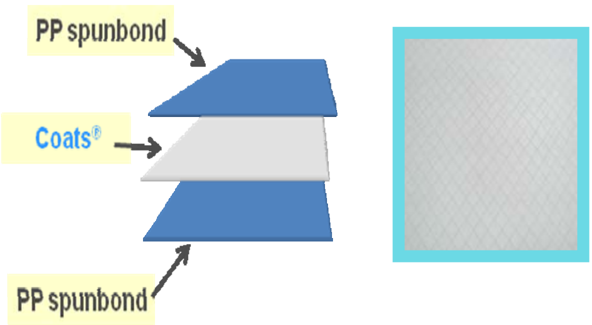
2.1 Samples

Three kinds of nanofiber nonwoven fabrics that were manufactured *via* mass production eletrospinning were prepared as breathable fabric. Material of all fabrics was polyurethane (FINETEX TECHNOLOGY Inc., USA). These were different thickness as a polymer jet speed. Table 1 shows thickness and polymer jet amount per unit area of each sample.

Table 1. Characteristics of samples

Sample	A	B	C
Polymer jet amount per unit area(g/m^2)	4	6	7
Thickness( )	15	30	42

For filter test, ULPA, HEPA and nanofiber filter with three layer structure were prepared. The three layer structure nanofiber filter is shown in Fig. l. Both sides were PP spunbond and only the center of filter was nanofiber matrix, like sandwich structure, in shown as Fig. 1(a). The nanofiber matrix coated with nylon 6 nanofibers *via* mass production eletrospinning [4]. Fig. 1(b) is commercialized nanofiber filter product.



(a) (b)

Fig. 1 (a)structure of nanofiber matrix type filter and (b)appearance

2.2 SEM image observation

A cross section image and surface image were observed using a SEM (scanning electron microscope, KEYNECE VE-8800, Japan), after Pd coating for 120 seconds (Hitachi, Ltd., Japan). It was took 10 parts from each sample, randomly, and then observed on 8000 magnification, 10000 magnification and 15000 magnification. To obtain the average fiber diameter and pore size, it was measured 50 spots on each sample, randomly, using an image analyzer.

2.3 Waterproofness

Waterproofness was tested by on the JIS-L1092 using high-pressure type water resistance tester (DAIEI Kagaku Seiki Co., WP-1000k, Japan). The size of sample is 150mm×150mm. It was experimented 5 pieces of each sample and obtained average waterproof function.

2.4 Air permeability

Air permeability was tested by on the JIS-L1018, Frazier method (TOYO Seiki Co., Japan). The size of sample is 200mm×200mm. It was also tested 5 pieces of each sample and obtained average air permeability.

2.5 Tensile property

To measure tensile property, it was tested by on the JIS-L1908. Generally, the size of sample is 50mm×200mm, on the JIS-L1908. However, it exceeded measurement limit because of nanofiber' mechanical characteristic. So, the size was adjusted with 10mm ×100mm. It was tested 15 times by 50mm/min rate extension at room temperature.

3. Results and discussion

3.1 SEM image observation

Each sample's SEM image was shown in Fig. 2. It was observed nanofiber on 400nm~1200nm. The average diameter of nanofiber on each sample was 670nm~700nm, as shown in Table 2. It could be known their diameter size was similar to each sample. Using image analysis, total pore size was measured, and then average pore size was calculated. It was 0.6 ^{2}. There was no difference among the samples. From the Fig. 2(d), structure of nanofiber nonwoven fabric composed multi-layers. On previous research, multi-layer structure of nanofiber web was only assumed theoretically [5]. However, it could be verified in this SEM image. The average pore size was 0.6 ^{2}, but because of its multi-layer structure, it could be known smaller size in actual nanofiber web. It was one of the reasons of that nanofiber nonwoven fabric has high waterproofness.

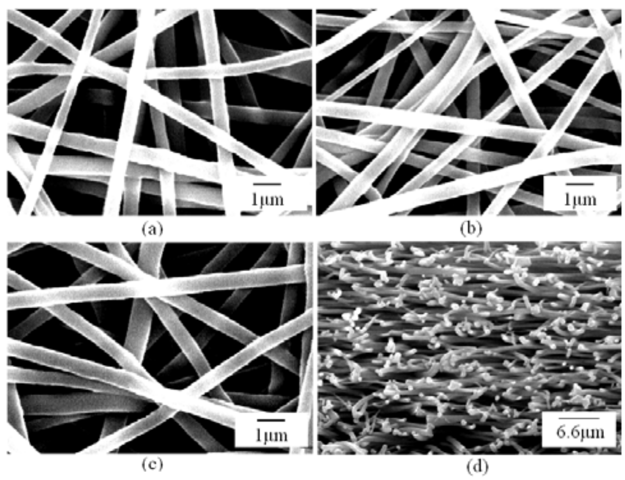


Fig. 2 SEM Images (a)surface of sample A, (b)surface of sample B, (c)surface of sample C, (d)cross-section of sample B

Table.2 Fiber diameter and pore size

Sample	A	B	C
Average diameter of fiber (nm)	665	703	667
Average pore size (^{2})	0.6	0.55	0.57

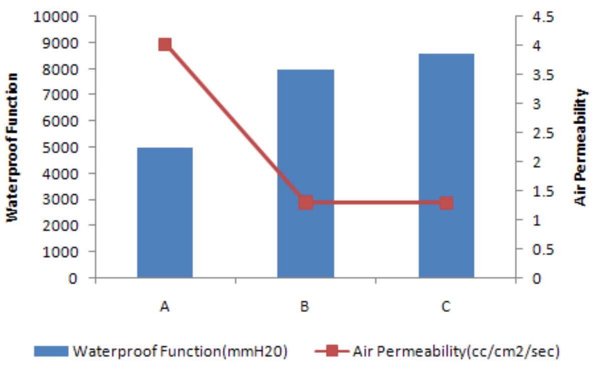


Fig. 3 Waterproof function and air permeability

3.2 Waterproofness and air permeability

Breathable waterproof fabric should have the pore bigger than vapor's size (4nm) and smaller than rain drop's size (2000-3000). The ideal breathable waterproof fabric has 0.2 -10 pore. In this ideal breathable waterproof fabric, only the vapor was passed, but water was not passed. Regarding to the structural properties, nanofiber nonwoven fabric could be known high waterproofness and high vapor permeability.

Results of waterproofness test and air permeability test were in shown as Fig. 3. Waterproofness was increased according to thickness of nonwoven fabric. In case of air permeability, it was decreased according to the sample's thickness. However, results of between sample B and sample C were not so much different. It concerned density of fiber and thickness. To investigate the relation between thickness of fabric and waterproofness, the apparent density was calculated by the equation (1).

$$\frac{jetted\ \ polymer\ \ amount}{volum\ of\ \ fabric} = apparent\ \ density \qquad (1)$$

Apparent density was shown in Table 3. Even though sample C had most thickness, the apparent density was similar to sample B. It was considered the apparent density affected on waterproofness. Namely, the apparent density was a reason of that sample B and sample C were not so much different in waterproofness results. Hence, it assumed that if thickness of nanofiber web is decreased over 30 , waterproofness is ineffective. In case of sample A, there was low waterproofness, in comparison of other samples. It was caused by thickness, not apparent density. The apparent density was proper, but it was quite thin. So, it was considered that resistance about water was increased.

Table 3. Apparent density of sample

Sample	A	B	C
Thickness ( )	15	30	42
Apparent density (g/cm^3)	0.27	0.20	0.17

From the results of air permeability, sample B and sample C were quite similar to each other. It was considered same reason of waterproofness. Namely, on structure of nanofiber fabric, it was concerned thickness and density. However, air permeability between the sample B and sample C was not so much different, in comparison with waterproofness. It was almost same value. That was meant air permeability was more affected from apparent density. In other words, waterproofness concern not only apparent density but also thickness. But, the case of air permeability was only affected from apparent density.

Generally, it was known that Gore-tex is most useful breathable waterproof fabric. For the evaluation of suitability on nanofiber nonwoven fabric as a breathable waterproof fabric, it was necessary to compare with Gore-tex. Table 4. shows air permeability and waterproofness of Gore-tex.

Table4. Properties of Gore-tex

Waterproof function (mmH_20)	20000
Air permeability ($cc/cm^2/sec$)	0.5-0.6

Gore-tex has a quite high waterproof function. Even though sample C has good waterproofness, there is no doubt the nanofiber nonwoven fabric was not enough for regular lining material. However, the Gore-tex has three-layer structure. Only, the center layer is Gore-tex film and it is protected by other fabric. Definitionally, it should be high waterproof function because its mechanical properties and thickness were increased. If the nanfiber web has multi layer, and then is tested as multi-layer state, it will be expected to have more high waterproofness. On account of multi-layer structure of Gore-tex, its air permeability is very low, less than 10% of nanofiber web. Waterproofness of general fabric for the tent is $2000mmH_2O$. This value means life waterproofness level. It was also expected nanofiber web's waterproofness would be improved by change of thickness and apparent density

3.3 Tensile property

In the field of clothing material, tenacity of fabric is needed to some degree. It was most related on internal structure. The more intersection point of fiber, the stronger tenacity. It is owing to stable structure. Namely, apparent density is affected on tensile property. Sample B and sample C has quite similar tenacity due to apparent density is similar. However, the tenacity of sample A was too low to use lining clothing. It was considered that thickness of sample A was very thin, so it could not be resisted by load. That is, apparent density as well as thickness is affected on tensile property.

Table 5. Comparison of air filtration

	Air permeability ($cc/cm^2/sec$)	Pressure drop (mmAq)	Efficiency (%)
HEPA	3.2	20.7	99.991
ULPA	1.97	34.6	99.999
*Matrix coated with nanofibers	14.5	5.9	99.994
**Matrix coated with nanofibers	10.7	7.4	99.999

*Coating weight: 0.15 g/m^2, **Coating weight: 0.3 g/m^2

3.4 Evaluation of filtration

The filtration properties of three types were determined and their results are in Table 5. Air permeability among the three filters, nanofiber matrix type filter shows the highest filtration efficiency with the lowest pressure drop. The nanofiber matrix type filter has same efficiency filtration of ULPA. However, the nanofiber matrix type filter coated 0.3(g/m^2) nylon 6. This mean that production cost is very low, in comparison with ULPA. It was considered nanofiber matrix type filter benefit to filter market.

4. Conclusion

In this study, the mechanical properties of nanofiber nonwoven fabrics *via* mass production eletrospinning technique investigated for evaluation of suitability as lining clothing material. First of all, pore structure and fiber diameter were observed using a scanning electron microscope. In addition, to examine breathable fabric, air permeability and waterprofness were measured. It was found that waterproofness and air permeability were affected from apparent density and thickness. Especially, air permeability was very high in comparison with commercial breathable fabric, Gore-tex. And waterproofness can be possible to improve by adjustment of apparent density and thickness. It was also investigated suitability of nanofiber nonwoven fabric as a lining clothing. It was known that nanofiber web has the tenacity for lining clothing material. In addition, nanofiber matrix type filter has not only high filtration efficiency but also cost efficiency. It was considered nanofiber matrix type filter has competitive power in filter market.

From the results, it was found that nanofiber nonwoven fabric had the suitable conditions as a breathable fabric in lining clothing and filter field. We could be convinced that nanofiber nonwoven fabric will be commercialized, instead of existing breathable fabric as a next new material.

Acknowledgements

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