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# Effects of processing condition on the filtration performances of nonwovens for bag filter media

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The needle punching and thermal bonding combination process is a useful method for manufacturing of bag filter media. We prepared needle punched and thermal bonded nonwovens using a nonwoven pilot plant in KITECH, and studied the various manufacturing conditions to prepare the bag filter media. The differential pressure of the bag filter media was decreased, and the collection efficiency was increased with increasing main-needling strokes, respectively. The most of made filter media were perfectly filtrated to standard test dust having above 2 $\mu$m diameter. The increase in needling strokes resulted in the increase of average pore size, and the average value of all the samples was about 40 $\mu$m. In the result of the mechanical properties test, the web formation was randomized with increase the main-needling strokes. Finally, we evaluated the lifetime durability of the products according to the reliability assessment standard RS K 0001. The arriving time up to 100 cycle of the prepared media with 1200 main-needling was longer than that of the other media. It revealed that many needling strokes resulted in lower differential pressure and longer lifetime of filter. 

## 1. Introduction

Recently, various air filtration systems have been installed in many fields such as manufacturing factories, offices, buildings, and houses, and various types of filtration materials [1–5] were practically used. Particularly, bag filters, used in a dust collector, are in the market. In present, the bag filter media can be manufactured by natural fibers (cotton or wool) or synthetic fibers (polyester, polyamide, or polypropylene), occasionally manufactured with glass fiber or natural fiber. Woven fabrics are used in reverse-flow bag filter media, while nonwovens, more simply prepared, are often used in reverse-pulse filter media. The production methods of nonwoven for bag filter media were spunbonding, stitching, needle punching, and etc. [6–9]. Among those, the needle punched nonwoven, which prepared from polyester, polyamide, and polyolefin, was in general superior to the other bag filter media as point of price competition and filtration performance.

The filtration performance of bag filter was generally divided by collection efficiency and differential pressure [3, 4]. The differential pressure of filtering has to be minimized at the maximal possible collection efficiency of the bag filter. The collection efficiency and the differential pressure are directly related to the durability of bag filter media. For estimation of accuracy lifetime of manufactured filters, the bag filter media must be objectively analyzed by a reliability assessment method. Reliability meant that the product maintains its properties under a given condition for specialized period of time without any failure, which it called Mean-Time-To-Failure (MTTF). The assessment standard of reliability is very important to advancement of manufacturing technology and competitive goods.

In this work, we made bag filter media using a nonwoven plant coupled with needle-punching and thermal bonding processes. The combined manufacture method, needle punching and thermal bonding process, is a very effective one for manufacturing the bag filter media. We studied the effects of processing condition on the filtration performances of nonwovens for bag filter media. Finally, we evaluate the filtration performances of the prepared bag filter media according to the reliability assessment standard method, RS K 0001, Bag filter media for environmental cleaning dust collector, which known as a method to assess the lifetime durability of bag filter media [10].

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TABLE I The characteristics of raw materials

| Properties | Regular polyester | Low-melting polyester |
|---|---|---|
| Density (g/cc) | 1.38 | 1.38 |
| Linear density (denier) | 3.2 | 4.3 |
| Length (mm) | 50.5 | 50.5 |
| Melting point (°C) | 265 | 110 |
| Strength (g/d) | 5.8 | 3.5 |
| Elongation (%) | 32.0 | 48.0 |
| Crimp degree (%) | 17.5 | 13.0 |

## 2. Experimental

### 2.1. Preparation of nonwovens

For nonwoven manufacturing two polyester staple fibers used in this study, which were supplied by Huvis Co., LTD., Korea. One fiber was regular polyester staple fiber (RSF-U®) and the other fiber was low-melting polyester staple fiber (LMF-U®). The characteristics of materials were shown in Table I. Fig. 1 shows schematic diagram of nonwoven manufacturing process. Those fibers were opened and dosed by a bale opener and a fine opener. After opening, the fiber blend made with 70 wt.% regular polyester and 30 wt.% low-melting polyester in mix tank. In process of web forming, the blended fibers were carded using two 60 inch Kyowakikai roller carding machines. For the randomizing orientation, the fibrous web was perpendicularly laid against movement direction by two cross lappers coupled with horizontal carriage laying machine. The two laid webs from two cross lappers were united by delivery conveyors and then needled by two needle-punch machines. The frequency of the pre-needling was 300 strokes per one minute and the main-needling was 0, 400, 800, and 1,200 strokes, respectively. All the needles used in this study were felting needles (FPD-2H3, 40S) made by Organ Needle Co., LTD. The needling density of the pre-needling was 2,500 piece/m$^2$ and main-needling was 5,000 piece/m$^2$. The needled web was thermo-bonded by a flat-bed laminator at 180°C. The overall working speed was 2 m/min, the width of the produced nonwoven was 1000 mm, and the weight was about 300 g/m$^2$.

### 2.2. Measurements of the filtration performances

The differential pressure and the collection efficiency were measured by testing system for air filter (PAF 113, TOPAS) with standard test dust of ISO 12103-1. The differential pressure was measured at 100–600 m$^3$/h of air flow and, the collection efficiency was measured with the test dust of 0.2–110 $\mu$m size under condition of standard laboratory. The pore size and the pore size distribution of the as-made filter media were measured with a porometry (CFP-1200-AEL, Porous Materials Inc.) according to ASTM F316, and Porewick® used as a wetting agent. The pore size distribution was calculated with the obtained results under wet state and dry state at 0.8 psi. The calculation equation of the pore size distribution is follows;

$$\textit{Pore Size Distribution} = \frac{\textit{Filter Flow}_{\text{current}}\,(\%) - \textit{Filter Flow}_{\text{previous}}\,(\%)}{\textit{Diameter}_{\text{previous}} - \textit{Diameter}_{\text{current}}}$$

The air permeability measurement of the bag filter media was conducted using a permeability tester (FX 3300, TEXTEST) at 100 Pa. The specimen size used in this test was prepared to 17 × 17 cm then it was measured according to KS K 0570.

$$\textit{Air Permeability}\,(\text{cm}^3/\text{cm}^2/\text{sec}) = \frac{\textit{Flow volume}\,(\text{cm}^3)\cdot g\,(1/\text{hr}) \times 0.2777}{\textit{Area of suction head}\,(\text{cm}^2)}$$

### 2.3. Measurements of the physical properties

For the shrinkage ratio test of the filter media, the specimen size was prepared to 20 × 20 cm and was heated in normal dry oven at 150°C during 2 h then cooled

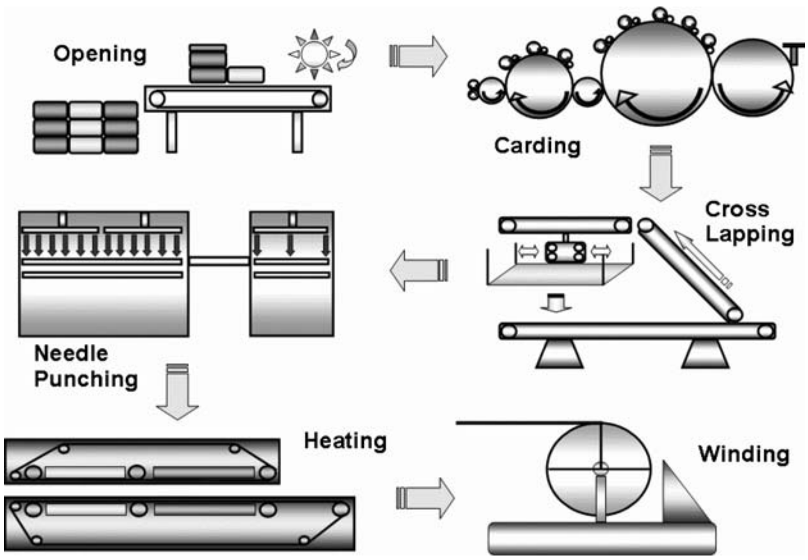


*Figure 1* Schematic diagram of manufacturing process of the bag filter media.

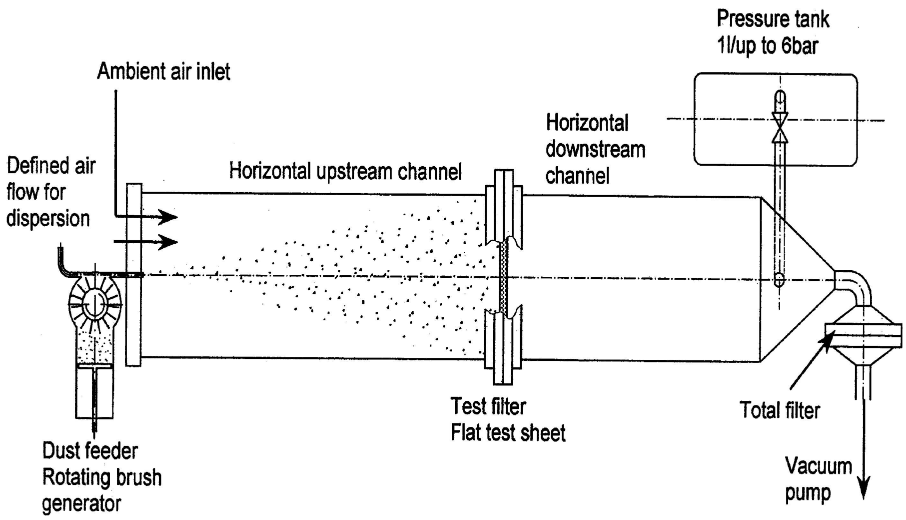


*Figure 2* A scheme of reliability testing system of bag filter media.

down to room temperature. After cooling, specimens length of both the machine direction and the cross direction were precisely measured and calculated by follow equation.

$$Ratio\ of\ Shrinkage\ (\%) = \frac{length_{\text{before test}} - length_{\text{after test}}}{length_{\text{before test}}} \times 100$$

The tensile strength and the elongation of the filter media were measured using universal testing machine (Hounsfield H100KS®) according to KS K 0520. This test was conducted with 2.5 kN of load cell, 50 mm/min of elongation speed, and 75 mm of gauge length. For the observation of the filter media surface, we used to scanning electron microscopy (JSM-6400, JEOL) at 20 kV.

### 2.4. Reliability assessment of bag filter media

The bag filter media for environmental cleaning dust collector were selected among of the prepared nonwovens, their reliability were assessed to according to the method of Reliability Standard, RS K 0001 which was created by Agency for Technology and Standards, Korea. The differential pressure of the as-made filter media at time cycle were measured using the cleanable filters under operational conditions (MMTC-2000®, PALAS) according to VDI 3926 type 2. Fig. 2 shows the scheme of reliability testing system of bag filter media used in this experiment. In this measurement, filter face velocity was 180 m/h, dust concentration at the filter face was 5 g/m$^3$, pressure loss before cleaning was 1200 Pa, number of filtration cycles was 100, and the test dust was aluminum oxide.

## 3. Results and discussion

### 3.1. The effects of processing condition on the filtration performances

Fig. 3 shows differential pressure of the filter media against time at 180 m/h when filtration cycles are 100

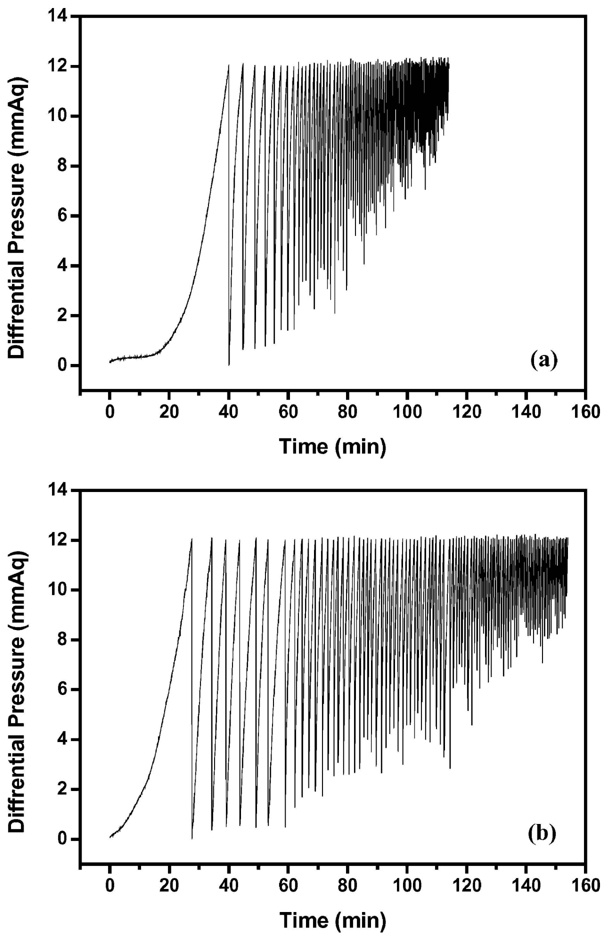


*Figure 3* The differential pressure against time; main-needling strokes (a) 0 and (b) 1200.

and Fig. 4 shows that against air flow volume. The axis of ordinate is the differential pressure between front and back of the total filter in the Fig. 2. The differential pressure of filter is high then collection efficiency is low, that is, the two parameters are inverse proportion. The bag filter media have to proper the differential pressure and the collection efficiency for end use. According to the RS K 0001, the differential pressure must be below 120 mmAq when filter face velocity is 180 m/h. All the

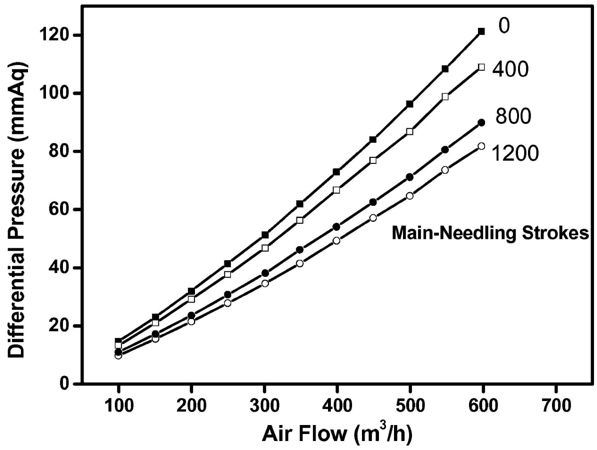


*Figure 4* The differential pressure of the bag filter media during increase main-needling strokes against test airflow.

differential pressure of the prepared bag filter media was smaller than the standard. In the Fig. 4, the differential pressures of the prepared filters were increased with the air flow volume but they were decreased with increasing the frequency of main-needling. It was implied that the fibers interlocking in web was increased with addition the needling then the web was oriented at random. The collection efficiency of the prepared bag filter media was shown in Fig. 5. According to standard, the collection efficiency at 0.9 $\mu$m must be above 50%, and that of the specimen are high values, 95–99%. All the specimens showed generally similar collection behavior and they showed perfect collection activity above 99% when dust size was above 2 $\mu$m diameter.

## 3.2. The effects of processing condition on the structure and surface

The pore size was measured with a capillary flow porosity tester. Fig. 6 shows (a) pore size distribution and (b) average pore sizes of the prepared bag filter media. The pores in all the samples were mainly distributed over 10–80 $\mu$m without correlation of the main-needling strokes. The average pore size and the pore size at bubble point of all the samples were about 36 and 85 $\mu$m, respectively, and those slightly decreased with increase of main-needling strokes. The bubble point means generally the maximum pore diameter in the filter media. It was revealed that the width of pore size distribution for the prepared nonwoven by higher needling strokes was smaller than that of the other filter media. Air permeability of the prepared bag filter media was shown in Fig. 7. The air permeability is one of important properties in bag filter media and in proportion to main-needling strokes. In the result of thermal shrinkage test, the shrinkage ratios of all the samples were lower than 0.5% against machine direction and cross direction. Fig. 8 shows microphotographs of the thermally bonded nonwovens at 180°C. Though the nonwovens were thermal bonded at 180°C, the temperature was slightly low to perfectly melt for the bag filters.

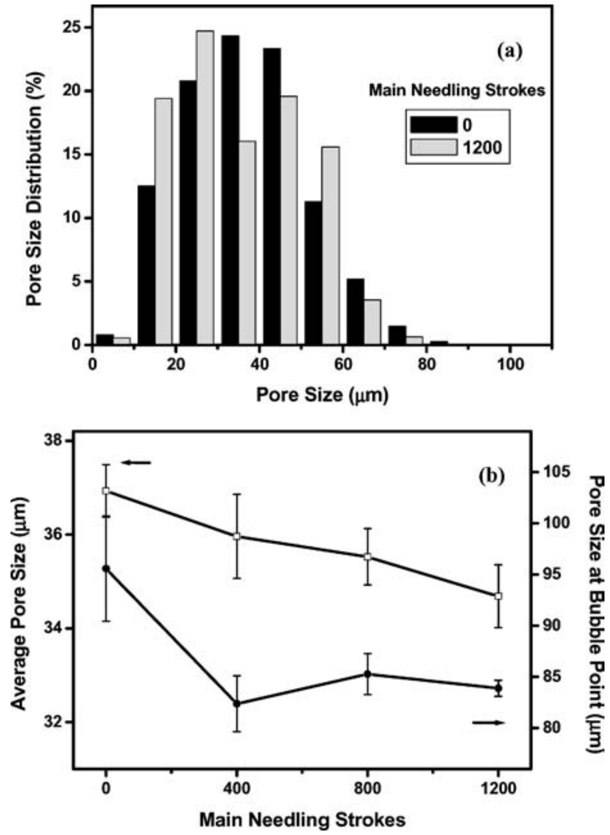


*Figure 6* (a) The pore size distribution and (b) the changes of pore size (left) and bubble point (right) according to the main-needling strokes.

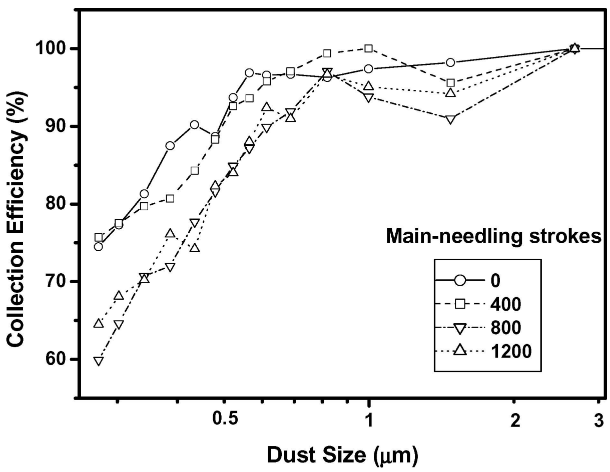


*Figure 5* Change of collection efficiency with increase main-needling strokes.

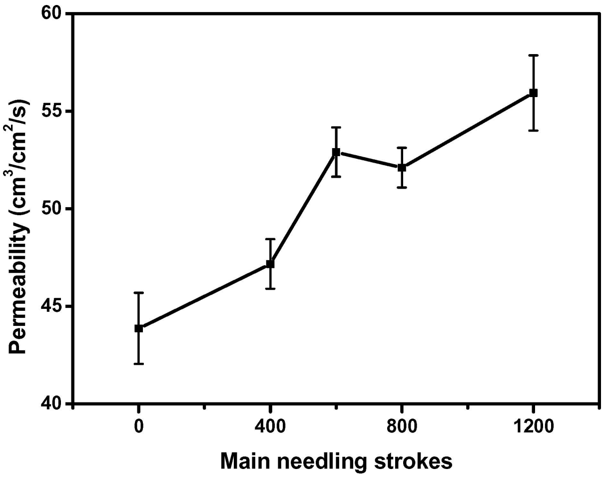


*Figure 7* Air permeability with increase main-needling strokes per minute.

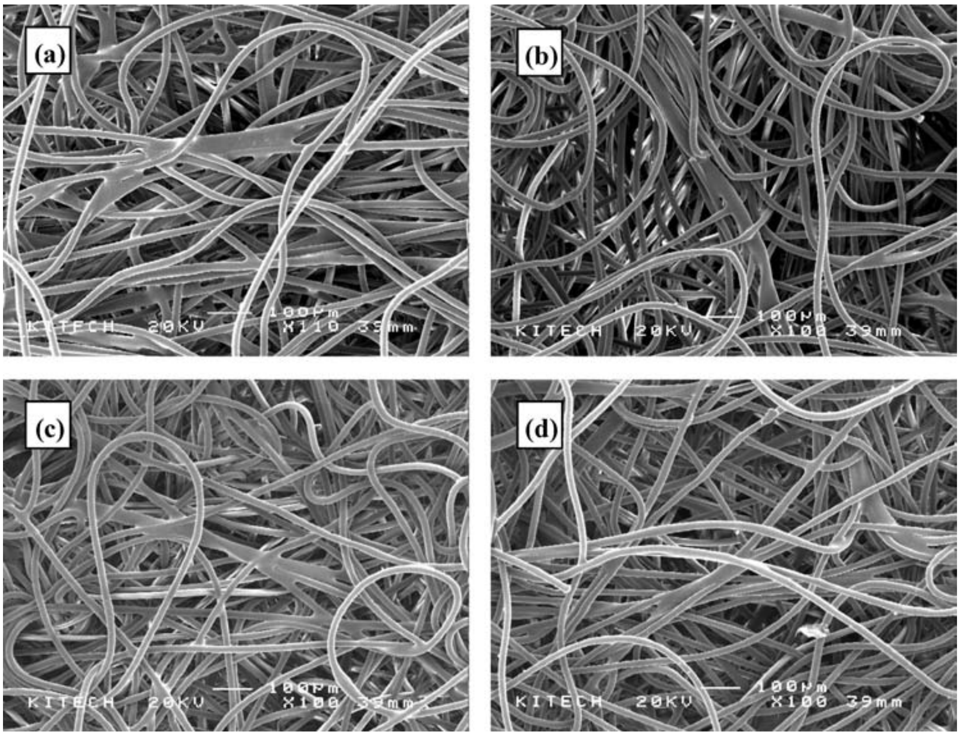


*Figure 8* SEM images of the bag filter media with increase main-needling strokes (a) 0, (b) 400, (c) 800, and (d) 1200.

## 3.3. The effects of processing condition on the tensile properties

Ordinary needle punched nonwovens are physically bound web to form a fabric by puncturing the web with an array of barbed needles. So, the mechanical properties of the needle punched nonwovens with the porosities are very important and closely a relationship with process conditions and parameters, such as speed and depth of needle strokes, speed of web transfer, binding ratio, and temperature at thermal bonding. Fig. 9 shows the tensile properties of the prepared bag filter media by a universal tester. In the results of tensile test, the tensile strength of the prepared specimen without the main-needling had big difference between values against the machine direction and the cross direction. The tensile strength increased to the machine direction and decreased to the cross direction with increase the main-needling strokes, respectively. In other words, the strength gap of machine and cross direction continuously decreased as increase the main-needling strokes. This phenomenon revealed that the orientation of web was randomized with increase the main-needling strokes. In this needle punching with randomizing mechanisms, the fibers in the web have a non-emphasized position under ideal conditions, that is, random orientation. The elongation of the bag filter media were appeared similar behavior with the result of strength. For irregular filtration performance of bag filter, it needs perfect random web forming and high interlock ratio, that is, many needling strokes require during the nonwoven manufacturing.

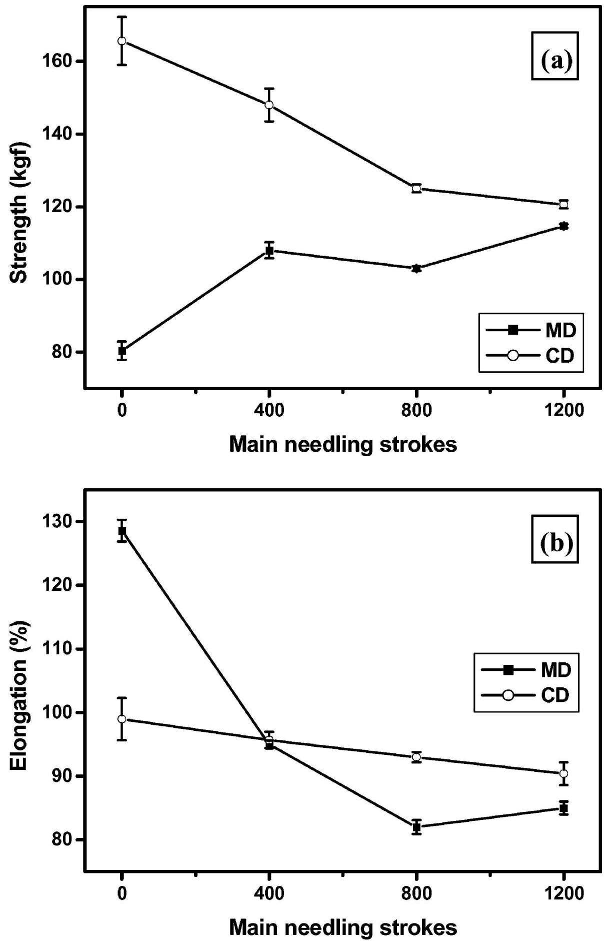


*Figure 9* Tensile strength and elongation at break of the bag filter media.

## 3.4. The assessments of the lifetime durability according to the reliability standard

In the Fig. 3, the filtration cycling time is very important and it is closely related lifetime of bag filter. In this machine, the shake method was air pulse jet type. Increasing at a given pressure, the specimen was carried out one shake, that is, one filtration cycle. The arriving time at 100 filtration cycles was closely related with Mean-Time-To-Failure (MTTF). MTTF is average value of operating time from initial state to breakdown of a product or a system, that is, it is equal to the lifetime durability. In the testing of filter media for cleanable filters under operational conditions, the finished time at 100 filtration cycles of the as-made bag filter without main-needling was 114 min and that of the made bag filter by 1,200 main-needling strokes was 154 min (Fig. 3). It was revealed that the lifetime of the many interlocked and randomized filter media by needling was longer than the other filter media.

## 4. Conclusion

We made the bag filter media utilizing a nonwoven pilot plant coupled with needle punching and thermal bonding combination processes. The prepared filter media were evaluated for the bag filter media for environmental cleaning dust collector by the reliability assessment standard (RS K 0001). Most of the made filters were satisfied with the various standard which comprised of the filtration performances for cleanable filters under operational conditions, the air permeability, the pore size and distribution, the shrinkage of textiles, the nonwovens determination of breaking strength. Increasing the main-needling, the durability and the air permeability increased, but the differential pressure and the average pore size decreased, and also the web forming in the filter media were randomized by high interlocks. According to the result of the reliability assessment, the lifetime durability of the as-made filter media with high needling strokes was superior to that of the other filter media. Therefore, for the bag filter media including good quality, optimum manufacturing condition is following; the ratio of low-melt fiber is 30%, the main-needling stroke is 1200/min, the process speed is 2 m/min, and the thermal bonding temperature is 180°C.

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