Hsing Wen-Hao,
***Kao Kuo-Ting,**
***Lin Jia-Horng,**
****Shu Yi-Ting**

Department of Textile Engineering, Chinese Culture University,
Taipei 11192, Taiwan, R.O.C
E-mail: hsing@faculty.pccu.edu.tw

***Laboratory of Fibre Application and Manufacturing, Graduated Institute of Textile Engineering, Feng Chia University,**
Taichung 40724, Taiwan, R.O.C
E-mail: p9126306@fcu.edu.tw

****Institute of Biomedical Engineering, Chung Yuan Christian University,**
Chung-Li 32023, Taiwan, R.O.C

Investigation of Nonwoven Carding Process with the Application of Static Electricity to Various Fibres and Process Parameters

Abstract
This paper is one of a series of studies on the carded-web forming process with the application of static electricity to carded nonwoven fabric process. Electrostatic carding technology was used to apply static electricity to the worker-roller of the carding machine, in which the electrostatic application could change the fibre transformation, to improve the fibre loading of carding and then increase the carding performance and fibre web uniformity. Furthermore, the fibre load of the carding element, the surface potential on the roller and the uniformity and nep count of the fibre web would be measured to investigate the effect of the applied static electricity on the carding performance of different types of fibres at various process parameters. The results showed that there was a relationship between the applied static electricity and the fibre loading of carding roller. It signified that the electrostatic method affected the uniformity of nonwoven fabric. In addition, it was found that the change of fibre loading on the worker-roller depended on the polarities in those tribo-electrification process, as well as those that the static electricity was applied to.

Key words: *static electricity, carded nonwoven fabric, fibre web, carding performance.*

Introduction

The manufacturing processes for nonwoven fabrics invariably consist of two distinct phases, web formation and subsequent bonding. All nonwoven fabrics are based on fibrous webs. Therefore, the characteristics of the web determine the physical properties of the final product. A satisfactory web for nonwoven fabric production of a specific weight is produced with minimum weight variation along its length or across its width, and hence it is difficult to discuss nonwoven fabrics without reference to this essential process. Of all the fibre web-forming methods, the carding method is regarded as a conventional fibre web forming system; however, the carded web process faces a challenge from the high production of new methods of web forming. Thus, it is more important to improve the web quality and production for the carded web process.

Carding is a basic process in the production of yarns and fibre webs of nonwoven fabrics to disentangle fibre stock into individual fibres with minimum fibre breakage and parallelisation distribution, and then convert the fibres into the form of a web. Carding action is the most important kind of mating surface interaction in the carding machine. To have a carding interaction, the teeth of both the mating surfaces must be in a hold state relative to the fibre load. The result is a disaggregation of fibre tufts with a portion of the fibre claimed by both surfaces. Fibre distributions (fibre loading) on carding elements continue to interest researchers because their distribution and translation will affect fibre openness, mixing, and web quality, etc. [1, 2]. Additionally, over the last 30 years numerous developments in the design and working conditions of carding machines have taken place. These include high-speed carding, modified feed systems, multiple take-in rollers, additional carding segments, improved wire clothing, and so on [3].

This work proposes a technical innovation for carding technology achieved by applying the static electricity to the carding element for a roller card. Although as everyone knows static electricity cause great damage in our life and during industrial production , it also has many applications in the textile industry, such as flocking products, filters, etc. In several research works [4-7], static electricity was used to control the fibre movement in the fibre web, sliver and composite forming. Thus, we expect to utilise the characteristics of static electricity to manufacture carded-web nonwoven fabrics and improve the carding action and web quality. In previous studies [8, 9], we attempted to apply static electricity to the carding machine to improve the carding efficacy. The results of previous studies seemed to show a relationship between the measured surface potential of the worker-roller, the fibre loading, and the uniformity of the fibre web. In this study, the feasibility investigation of the electrostatic method, which was applied on the carding process to improve the uniformity of the carded web, was further applied to different types and fineness of fibres. To understand the mechanism of the aid of static electricity in the carding action, the fibre loading and surface potential of the roller clothing; the uniformity of the fibre web image were also measured for various fibre types and process parameters (e.g. the relative speeds and settings of the carding elements), and the correlations between these data were also considered.

Experimental

Materials

The characteristics of the three original staple fibres used in this study are listed

Table 1. The physical properties of staple fibres used in this study.

Fibres	Fineness, dtex	Length, mm	Tenacity, cN/dtex	Elongation, %	Crimp no., n/cm	O.P.U., %
PET	0.89	38	0.73	21	11.1	0.21
PET	2.22	51	0.49	46	11.2	0.16
Nylon 6	2.22	51	0.42	68	4.7	0.45

Table 2. Triboelectric series.

Most positive (+)	
Human hands, skin	+++
Asbestos	
Rabbit fur	
Acetate	
Glass	
Mica	
Human hair	
Nylon	
Wool	
Cat fur	
Lead	
Silk	
Aluminium	
Paper	+
Cotton	Zero
Steel	-
Wood	
Amber	
Sealing wax	
Hard rubber	
Mylar	
Nickel, copper	
Silver	
Brass	
Gold, platinum	
Sulphur	
Acetate, rayon	
Polyester	
Celluloid	
Polystyrene	
Orlon	
Acrylic	
Polyvinylidene chloride (Saran)	
Polyurethane	
Polyethylene	
Polypropylene	
Polyvinylchloride (vinyl)	
Kel-F (PCTFE)	
Silicon	
Teflon	
Silicone rubber	- - -
Most negative (-)	

in Table 1. PET staple fibres of two different finenesses (from the Far Eastern Textile Ltd., Taipei, Taiwan, R.O.C) were selected to investigate the influence of electrostatic action on different fineness of fibres. In addition, Nylon 6 staple fibre (Chiang Long Chemical Co., Ltd., Taichung, Taiwan, R.O.C) was also used in this study to in order compare their different electrical properties with those of PET fibres. These fibres are the materials of nonwoven or fibre web. Table 2 is a triboelectric series [10] that provides an indication of the ordering of some common materials.

Methods and procedure

The single doffer card (Ta-You Machinery, Taoyuan, Taiwan, R.O.C) was used to produce the fibre web after electrostatic action. The electrostatic induction devices were installed to the worker-roller, and the experimental procedure is shown in Figure 1. The fibre materials are first opened and mixed by the experimental opener, and then the opened feed mat is fed into the carding machine to form a uniform single-layer fibre web. The experimental conditions are listed in Table 3. The influence of the changing electrostatic voltage of the worker-roller and cylinder speed on the fibre loading, surface potential on the worker-roller, and the analysis of the fibre web are investigated.

Carding processing with the aid of static electricity

The principle of carding is a mechanical action in which the fibres are held by one surface while the other surface combs the fibres, causing individual fibre separation. The static electricity is applied to the worker-roller to improve the fibre web uniformity of the fibre web made by the carding process (Figure 2). Between the worker-roller and the cylinder of the roller card, electrifying the worker-roller that was insulated by the body of the machine produced the electrostatic field. Thus, the polarisation for fibres would form when they passed through the carding area. The electrostatic force of the worker wire could change the fibres remaining on the cylinder to increase the carding action of the clothing wire. Afterwards, the fibre load, the surface electrical potential on the worker-roller, and the grey value of the fibre web after the electrostatic carding process are estimated with the general carding method.

Measuring the fibre loading on the worker-roller

The fibre loading has been known to affect the degree of openness. Since the test carried out did not have any established standards, in order to understand the change of fibre loading on the worker-roller for obtaining a base of web uniformity during carding with electrostatic action, we measure the weight of fibre

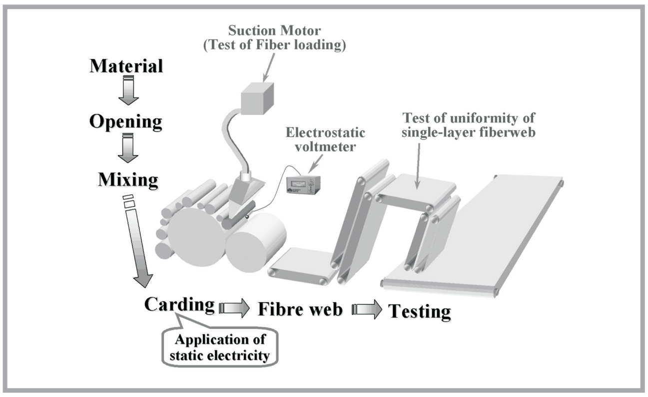

Figure 1. *Flow chart of experimental procedures.*

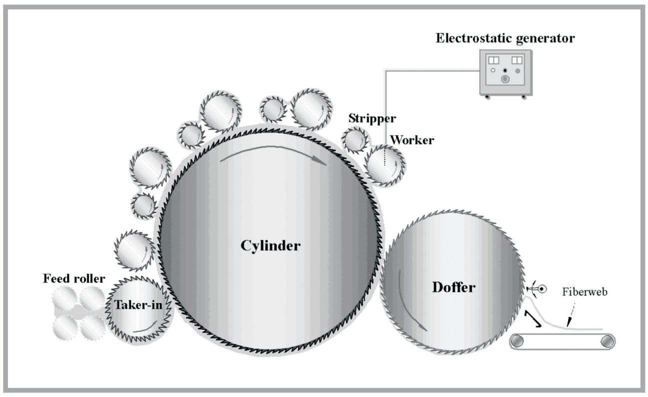

Figure 2. *The diagram of experimental mechanism.*

Table 3. *Conditions of experimental parameters on the carding machine.*

Components	Diameter, cm, in	Speed, rpm	Tooth density, teeth/cm², teeth/in²	Components	Setting, in/10³
Feed roller	7.6, 3.0	1.9 (0.45 m/min)	-	Cylinder to 1st worker wire	12
Taker-in	21.6, 8.5	438	16.1, 104	Cylinder to 2nd worker wire	10
Cylinder	76.2, 30.0	300, 400, 500	61.2, 395	Cylinder to 3rd worker wire	9
Doffer	53.3, 21.0	11.1	47.3, 305	Cylinder to 4th worker wire	5, 7, 12
Worker-roller	14.0, 5.5	17.0	47.3, 305	Stripper to worker wire	12
Stripper	8.9, 3.5	432	20.9, 135	Cylinder to stripper wire	24

amount on the 4th worker-roller by suction. The fibres on the worker-roller are sucked for 30 seconds, and then collected for weighing.

Measuring the surface electrical potential on the worker-roller

To establish the relationship between the fibre amount and tribo-electricity, we use an on-line and non-contacting electrostatic voltmeter (Model 542 from Trek, Inc., USA) to measure the surface electrical potential on the worker-roller at a distance of 5.5 cm for 2 - 3 minutes. The data is collected at a rate of 7 - 14 scans/sec.

Basis weight and image analysis of fibre web

After carding, the fibres form a single-layer fibre web. This is carefully cut into a fixed sample size. Then, a CCD camera (CV-M40, JAI Corporation, Japan) is used to capture the image of the fibre web under conditions of constant illumination. These images are analysed to obtain the grey value distribution, and its average and standard deviation are calculated. Finally, the fibre web is weighed using a precision balance and its weight per unit area is calculated. In Figure 3, web weight, determined gravimetrically, for a given fibre web section, is plotted versus the grey value of fibre web image for PET 0.89 dtex, and 2.22 dtex, and Nylon 6 2.22 dtex fibres.

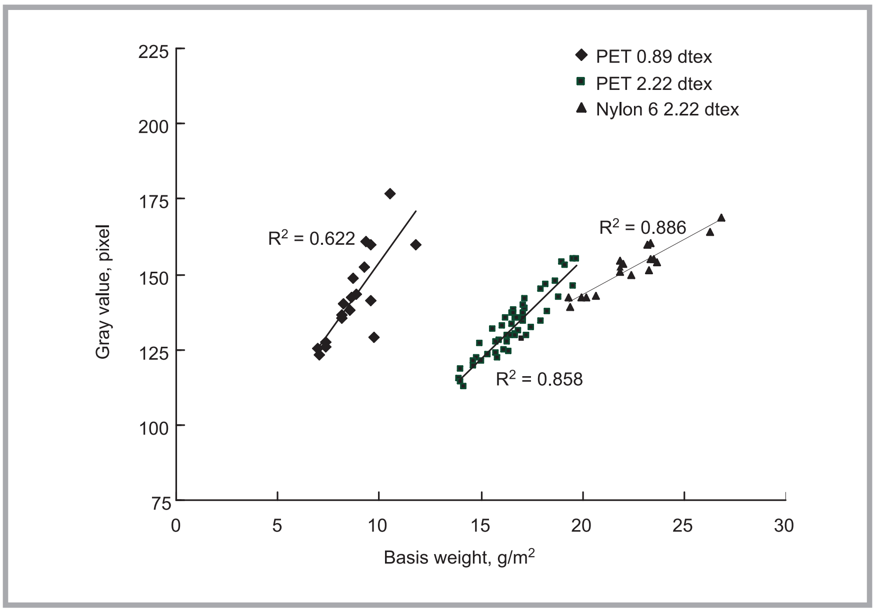

Figure 3. The grey value of image vs. the basis weight of carded web for different fibres.

Nep counting

The nep count is measured according to the test method of the College of Textiles, North Carolina State University [11]. Three samples of fibre web per run were collected on board while the card was running without damaging the fibre orientation. For each sample, neps were counted equally in three sections across the card. They were counted using a template with 20 holes, each 2.8 cm in diameter. For each experimental run, an average nep count was calculated from the sum of the left, middle, and right sections. The average nep count in a section was expressed in neps/g and calculated as follows:

$$Neps/g = 10^4 \times \frac{n}{N} \times \frac{1}{S} \times \frac{1}{W}$$

where:

n - total number of neps on a template

N - the number of holes on a template, 20

S - the area of a hole, 6.16 cm^2

W - web basis weight (g/m^2).

Results and discussion

Analysis of different types of fibres

The data summarising the measured properties related to fibre loading on the worker-roller at various applied voltages for PET 0.89 dtex, 2.22 dtex, and Nylon 6 2.22 dtex fibres are given in Figure 4. For PET 0.89 dtex and 2.22 dtex fibres, the fibre loading decreases slightly with the increase in applied voltage, with the exception of PET 0.89 dtex fibre at application of 2 kV. This shows that the applied static electricity of the worker-roller may decrease the numbers of PET fibres on it. For Nylon 6 2.22 dtex fibre, the result displays a trend that increases at -1 kV, then decreases with a further increase in applied voltage, and finally increases again when applied voltage reaches to -5 kV.

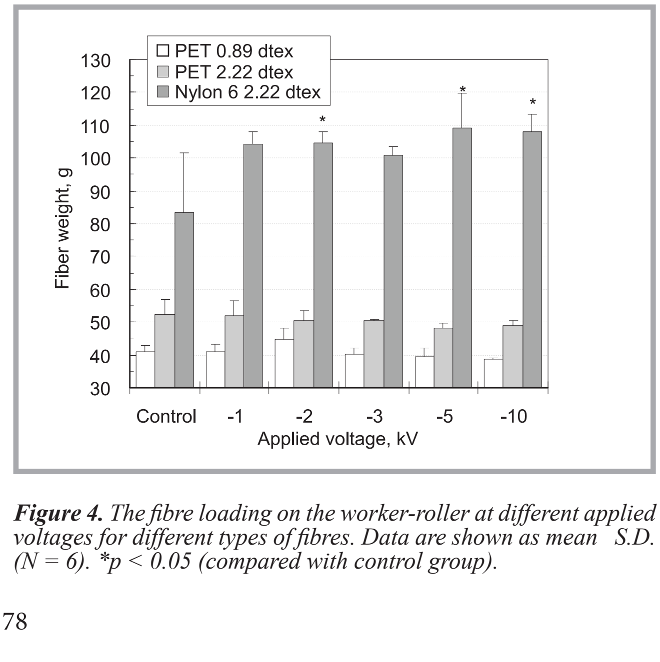

*Figure 4. The fibre loading on the worker-roller at different applied voltages for different types of fibres. Data are shown as mean S.D. (N = 6). *p < 0.05 (compared with control group).*

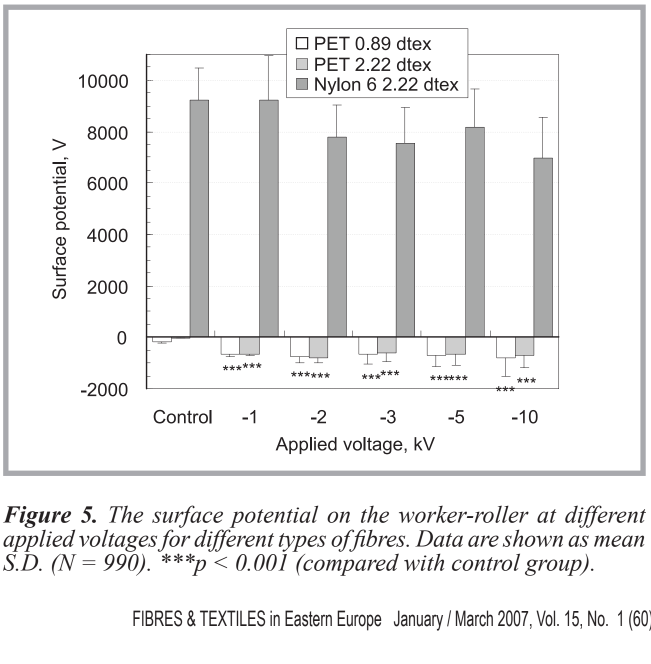

*Figure 5. The surface potential on the worker-roller at different applied voltages for different types of fibres. Data are shown as mean S.D. (N = 990). ***p < 0.001 (compared with control group).*

In the main, the data presents a lifting and zigzag distribution with the increase in the applied voltage (P<0.05 at -2, -5, and -10 kV); that is, the numbers of Nylon 6 fibre on the worker-roller increase after the application of static electricity.

From the data of the assay of the surface s electrical potential (Figure 5), PET 0.89 dtex and 2.22 dtex fibres would generate a few negative charges after the tribo-electrification of the carding, and the surface potential on the worker-roller increases in negative potential when negative voltage is applied to the worker-roller. However, it is not proportional between the measured data and the applied voltage, and it is obvious that the measured average surface potential increases up to a maximum at the applied voltage of -2 kV, and then varies slightly or decreases with a further increase in the applied voltage, due to the occurrence of electrostatic discharge. Moreover, there is a great range of variation for the actual measured data. PET 0.89 dtex fibre should generate more charges than PET 2.22 dtex one after carding under the equal weight of fibres, due to its bigger surface area. In addition, Nylon 6 2.22 dtex fibre would generate a large number of positive charges after the tribo-electrification of carding, and the maximum value of Nylon 6 fibre can reach 14 kV. The original measured surface potential on the worker-roller would be neutralised by the applied negative voltage, and the results present the same distribution (zigzag) with increasing applied voltage compared with the fibre loading test. It implicates that there is a relationship between the measured surface potential and the fibre loading on the worker-roller. We suggest that there is electrostatic repulsion between the negative applied static electricity and the negative charges on the PET fibre, which therefore decreases the fibre loading on the worker-roller. However, the PET fibre merely generates a small amount of charges during the carding process. The fibre load test does not present any significant difference; on the contrary, there is electrostatic attraction between the negative applied static electricity and the positive charges on Nylon 6 fibre, which therefore increases the fibre loading on the worker-roller.

The mean grey value of the image and the basis weight, and the variation of the coefficient of the fibre web before and after electrostatic action for PET 0.89 dtex,

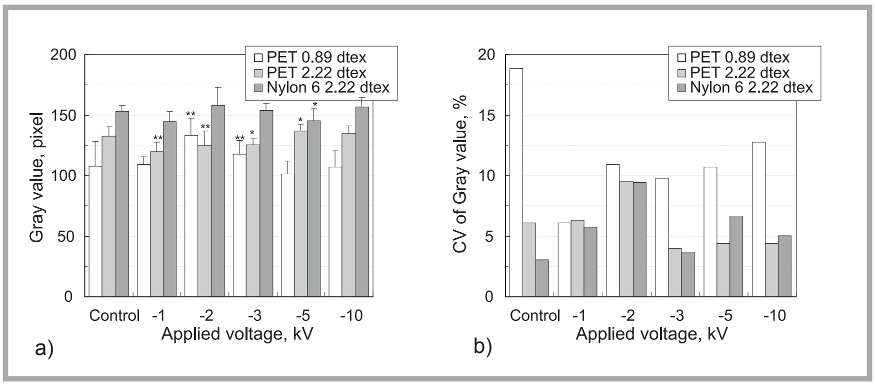

*Figure 6. The grey value (mean S.D., n = 36) (left) and its variation of coefficient (right) of the fibre web image at different applied voltages for different types of fibres. *p < 0.05; **p < 0.01 (compared with control group).*

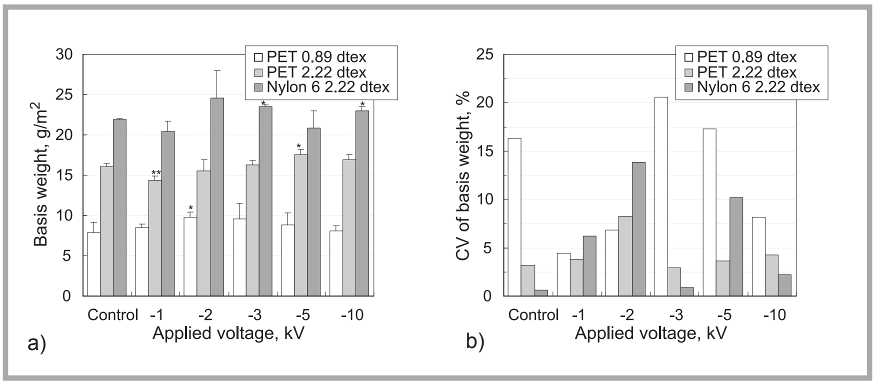

*Figure 7. The basis weight (mean S.D., n = 6) (left) and its variation of coefficient (right) of the fibre web at different applied voltages for different types of fibres. *p < 0.05; **p < 0.01; ***p < 0.001 (compared with control group).*

2.22 dtex, and Nylon 6 2.22 dtex fibres are displayed in Figure 6 and 7 respectively. From the comparison of the basis weight and grey value data, a good linear correlation between the grey value of the image and the basis weight of the fibre web is indicated. It should also be mentioned that the results of the image analysis and the basis weight test seem to show a relationship with the fibre loading data; that is to say, the grey values of the image of the fibre web have a increasing trend when the fibre load on the worker-roller decreases, and the basis weight of the fibre web lifts accordingly. Therefore, both the variation of the coefficient of the basis weight and the grey value decrease, and the web uniformity is improved, such as PET 0.89 dtex fibre at the application of -2 kV, and PET 2.22 dtex fibre at -5 and -10 kV. On the contrary, the web s uniformity may be deteriorated, such as Nylon 6 fibre 2.22 dtex at the application of -2 kV. Thus, the mechanism of the application of static electricity to the carding process could be inferred; namely, the electrostatic repulsion causes a decrease in the amount of fibres on the worker-roller, and the increase in the number of those on the cylinder; the migration of fibres from cylinder to doffer then rises, and so a heavier and more uniform carded web is obtained.

Figure 8 illustrates the nep formation of PET 0.89 dtex, 2.22 dtex, and Nylon 6 2.22 dtex fibres after carding and electrostatic action. The results show that Nylon 6 fibre causes more nep formation than PET fibre, due to its own dielectric characteristic. Additionally, finer fibres are more likely to form neps due to their lower bending rigidity and higher tribo-electrification, as compared to coarser fibres. The applications of static electricity do not obviously affect the nep formation.

Analysis of various carding speeds

The effect of carding speed was investigated by using three different cylinder speeds, 300, 400, and 500 rpm. The result of fibre loading indicated that the data of these three different speeds show the same trends at various applied voltages for PET 2.22 dtex fibre (Figure 9). On the whole, a high cylinder speed increases the proportion of fibres on the cylinder which contact the worker-roller,

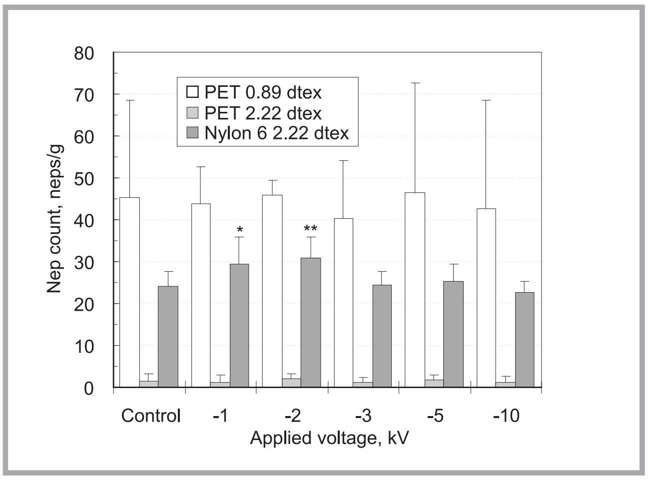

*Figure 8. The nep count of the fibre web at different applied voltages for different types of fibres. Data are shown as mean S.D. (N = 9) *p < 0.05; **p < 0.01 (compared with control group).*

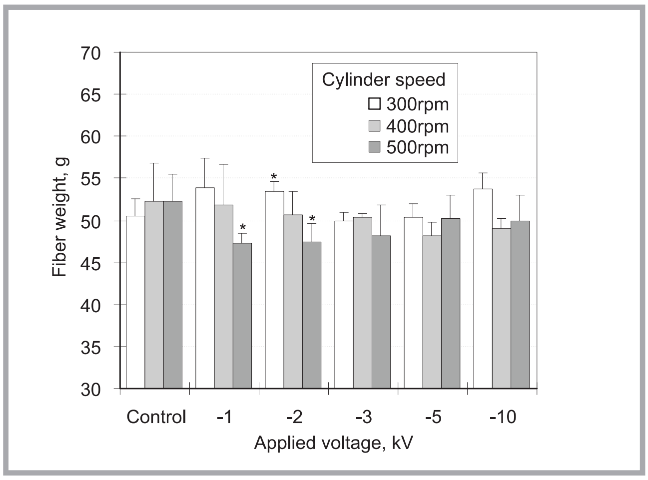

*Figure 9. The fibre loading on the worker-roller at different carding speeds and applied voltages for PET 2.22 dtex fibre. Data are shown as mean S.D. (N = 6). *p < 0.05 (compared with control group).*

and results in an increase in the fibre weight on the worker-roller. This can be explained by the trend of the data of the control group. However, the reason that the fibre load does not continuously increase at the speed of 500 rpm is that not enough fibres transfer to the worker-roller under the constant value of feed quantity. In addition, the fibre load on the worker-roller decreases with the increase in cylinder speed after the application of static electricity, especially at -1 and -2 kV ($P < 0.05$). This can be explained in comparison with the result of the surface electrical potential test, and relates to the effect of feed quantity, cylinder speed, and the voltage applied on the worker-roller.

From the control group data, the measured surface potential on the worker-roller (data not shown) slightly increases in negative voltage with the increase in the cylinder speed; the fibre load on the worker-roller would therefore be reduced with the increase in cylinder speed due to electrostatic repulsion when applying the static electricity to it. Because of the decrease in the fibre load on the worker-roller, i.e. the reduction in the amount of fibres that transfer to the worker-roller from the cylinder, the measured surface electrical potential on the worker-roller also falls with the increase in cylinder speed ($P < 0.001$).

Equally, this image analysis data (Figure 10) presents a good linear correlation between the grey value of image and the basis weight (data not shown) of the fibre web. Furthermore, the results of the image analysis and basis weight tests also show a relationship with fibre loading and surface potential data on the worker-roller as well as those in the above section. It is found that the grey value of the image of the fibre web increases with the increase in the cylinder speed. This is because the amounts of fibre transferred to the worker-roller from the cylinder decrease with the increase in the cylinder speed. In other words, the residual fibres on the cylinder increase, and finally the amounts of fibre migrating to the doffer would increase (i.e., the actual weight of the fibre web increases). In addition, from the data of their coefficient variation, they do not show any obvious trends at different cylinder speeds.

Analysis of various settings of carding elements

The analyses of the settings of the carding elements were investigated by using three different gauges of 5, 7, and 12 in./1000 between the cylinder and the 4th worker-roller. The fibre loading and surface electrical potential data on the worker-roller at various settings of the carding elements and applied voltages for PET 2.22 dtex fibres are shown in Figures 11 and 12 respectively. It shows that the data of the fibre load on the worker-roller decreases with the increase in the gauge between the cylinder and worker-roller, as was expected. Additionally, the wider setting between the cylinder and worker-roller would leave more electrostatic voltage on the worker-roller, due to the increase in the initial voltage of the electrostatic discharge.

Additionally, the result of image analysis (data not shown) shows that the grey values of the fibre web images do not show any obvious difference at the various settings of the carding elements. Furthermore, from the data of their coefficient variation, they present a higher CV at wider settings, and it should be mentioned that the CV can be lower at a wider setting after the application of static electricity (at -3, -5, and 10 kV).

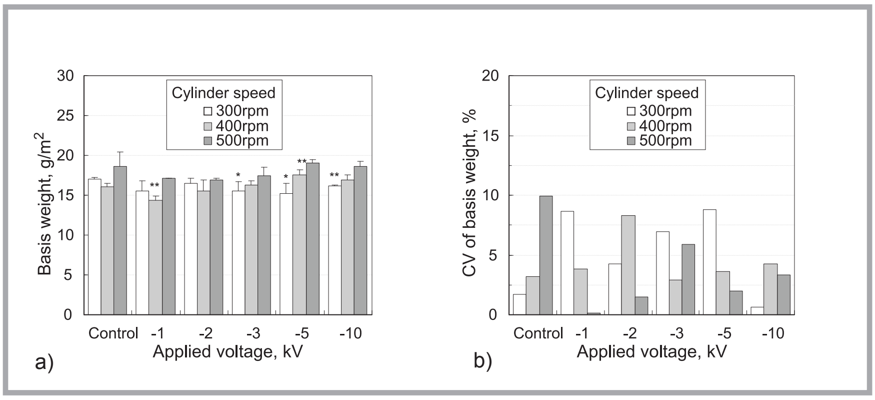

*Figure 10. The grey value (mean S.D., n = 36) (left) and its variation of coefficient (right) of fibre web image at different carding speeds and applied voltages for PET 2.22 dtex fibre. *p < 0.05; **p < 0.01 (compared with control group).*

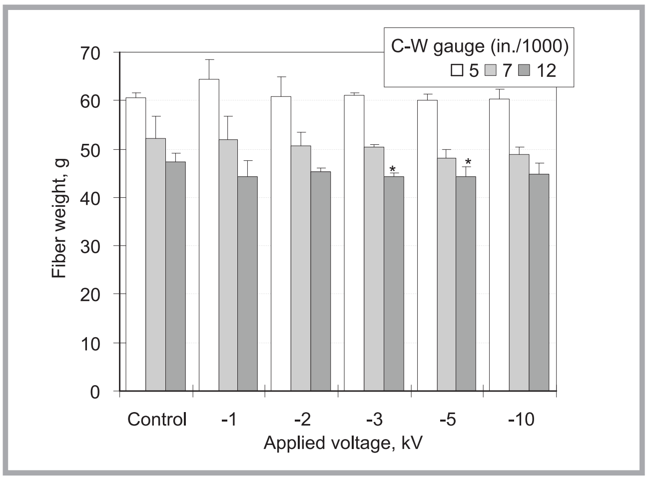

Figure 11. *The fibre loading on the worker-roller at different cylinder-worker gauges and applied voltages for PET 2.22 dtex fibre. Data are shown as mean S.D. (N = 6). *p < 0.05 (compared with control group).*

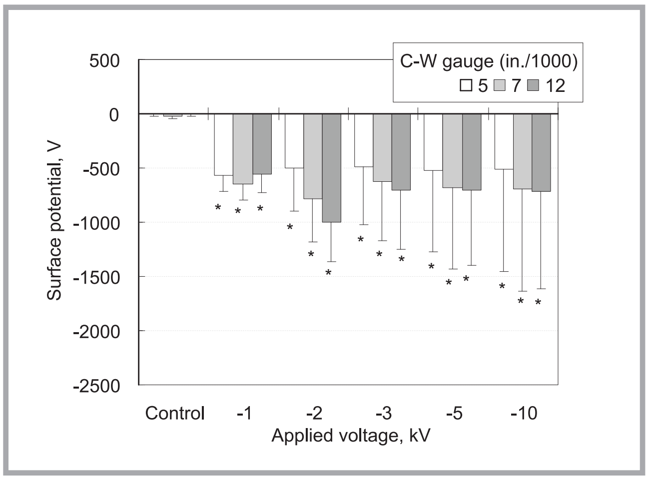

Figure 12. *The surface potential on the worker-roller at different cylinder-worker gauges and applied voltages for PET 2.22 dtex fibre. Data are shown as mean S.D. (N = 990). ***p < 0.001 (compared with control group).*

Conclusions

In this paper, the feasibility of applying static electricity to the carding process, to improve the uniformity of the fibre web of carded nonwovens, was evaluated for three different fibre types at various speeds and settings of the carding elements. Based on the discussions above, the following conclusions were obtained.

- The results show that there is a relationship between the measured fibre loading and the surface potential of the worker-roller and the uniformity of the fibre web. Furthermore, there is a good linear correlation between the grey value of image and the basis weight of the fibre web.
- PET fibre generates some negative charges, and Nylon 6 fibre generates a large number of positive charges after the tribo-electrification of carding.
- Nylon 6 fibre causes more nep formation than PET fibre. Finer fibres have more tendencies to form neps as compared to coarser fibres. The applications of static electricity do not affect the nep formation.
- The measured surface potential on the worker-roller increases in negative voltage with the increase in the cylinder speed for the control group, and then the fibre load is reduced when applying the static electricity to it. Thus, the measured surface electrical potential on the worker-roller will also lower with the increase in cylinder speed. The grey value of the image of the fibre web increases with the increase in the cylinder speed.
- The values of the fibre loads on the worker-roller decrease when the gauge between cylinder and worker-roller is increased. The wider setting between cylinder and worker-roller would leave more electrostatic voltage on the worker-roller. The CVs of the grey value of the fibre s web image increase at wider settings, and it should be mentioned that the CV can be lower at wider settings after the application of static electricity.
- The change of fibre loading on the worker-roller depended on the electrostatic repulsion or attraction between polarities in the tribo-electrification process and those when static electricity was applied. Thus, the fibre load decreased for PET fibres, and increased for Nylon 6 fibre after the application of static electricity. Then, PET fibre received a heavier carded web, and the Nylon 6 fibre received a lighter one than the control group. The heavier fibre web has a relatively lower coefficient variation.

Generally, the electrostatic technique indeed can improve the roller fibre load and the web uniformity by using suitable fibre types and polarity of the applied static electricity.

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