CARDING OF MICROFIBERS

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Abstract

Microfibers, used alone or in blends, have created considerable interest in the apparel industry because of their potentially greater comfort and functionality. Additionally, their lower diameter, greater surface area and flexibility offer many applications in areas of nonwovens such as filtration, man-made leather, protective clothing, and wipes. Unfortunately the properties of microfibers that make them attractive for the above applications are also the same properties that lead to difficulties in processing. This paper is an account of systematic experimental investigation into the processing of microfibers on a flat card. The effects of fiber and carding parameters on web quality were determined by assessing the nep content and fiber length after carding. Statistical analyses of the data indicate that all the main parameters studied have an influence on web quality. Furthermore it is shown that there is a strong correlation between the incidents of neps and the increase in short fiber content during carding. An additional observation is that the generation of neps was not uniform across the width of the card and appeared to be influenced by variation in the fiber loading on the doffer across the card.

Introduction

Generally, microfiber is defined as a fiber of less than 1.0 denier. In the early 1930's, man-made fibers of less than 1.0 dpf were produced even though they did not have properties that were then considered suitable for conventional textile applications [6]. More recently, fine man-made fibers were developed with the intent to simulate silk, cotton, and wool. Microfibers less than half size of the finest silk are now available commercially and furthermore microfibers as small as 0.001 dpf are produced by Toray of Japan [5]. U.S. fiber producers have decided not to manufacture microfibers of lower denier than 0.5 due to the difficulties involved in converting finer fibers to yarns and fabrics.

The card is designed to process fibers into slivers for manufacturing yarns, and it is one of the primary processes in the production of webs for nonwoven fabrics. The carded webs are produced using conventional carding machines. A carding machine processes the fibers mechanically through a series of rollers covered with wires. The web is produced by condensing the fibers on a doffer. The purpose of carding can be considered as an effort to produce a non-defected web. The carding stages involve the actions of opening, allowing wastes to fall out, and then carrying the fibers into an open condition so that they can be blended in a random way. If this could be carried out with complete opening, mixing together, and uniform orientation of the fibers, then the carding process would be ideal. Furthermore, perfect web would be produced if nep formation and fiber breakage could be prevented during the actual carding processing.

While there are many publications concerning the advantages of fabric made from microfibers, very few papers dealt with microfiber processibility and the evenness of their fiberwebs. The use of microfiber has just begun to affirm itself in North American nonwoven industry, although it is already well established in Japan and Europe. It is known that the possible areas of application of microfiber are various, and the fiber could find their niches in high technical end uses [1,2,5,8]. For example, filtration is one of the successful applications of microfiber due to the high surface area and hence high electrostaticity of microfibers [1].

Microfiber properties are influenced in many interesting ways, as dpf (denier per filament) is reduced [8]. These changes of properties may affect both processing conditions and potential end uses. A reduction in dpf has an immediate impact on fiber flexibility but this may not always be asset. An increase of flexibility leads to the necessity of reducing the number of steps in processing because there are more chances of nep formation and fiber breakage at each stage where fibers are manipulated. This increase of flexibility due to the reduction of dpf is related to the reduction of bending rigidity. The reduced bending rigidity of microfibers might allow fibers to be easily damaged in carding process. The bending rigidity of fiber dramatically decreases as the fiber denier is reduced.

The number of fibers per unit mass increases dramatically as dpf decreases. From the view of this change, a given card should accommodate the increase in the number of fibers. As the number of fibers increase, the openness of feed stock should be considered. The lack of openness of fibers deteriorates the web quality with an increase of nep count and fiber breakage. In order to control the increase in the number of fibers, wires with high point density, high speed of card elements, or proper settings should be considered.

As dpf decreases, the fiber surface area per unit mass increases dramatically. This in turn causes fiber-to-fiber and fiber-to-wire friction to increase, and it leads to difficulty in fiber transfer from one element to another during carding. To avoid or reduce this problem, it was suggested that certain critical processing parameters be controlled such as the use of low throughput, wires with high point density, and/or high speeds of elements [8].

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Objectives

An extensive literature review showed that microfibers are produced worldwide and nonwoven industries have been interested in microfibers and their usage [3]. It was explained that while the properties of microfibers had many advantages to offer to many textile markets, they also could lead to difficulties of processing and deterioration of fiberweb quality. There was no reported investigation focused on the effects of microfiber properties and carding parameters on carded web quality. While many researchers have investigated the cardability of natural fibers, it is not known whether their findings are applicable to microfibers.

Indeed it is expected that web quality is more sensitive to fiber parameters, carding processing variables, and their interactions than natural fibers. Particular interests are the effects of fiber length on nep formation and fiber breakage using flat-top card at different processing variables.

The objective of the current research is to improve the cardability of microfibers through optimization of fiber parameters, carding processing variables, and their interactions. The cardability is judged by the fiberweb quality in terms of nep count and fiber breakage.

Experimental

Materials

Polyester fibers of 0.9 dpf, which was selected because of its popularity, were used for the entire experimental investigation. The fibers were provided by Wellman, Inc.

Flat-Top Card Specifications

A meter wide flat-top card, was used. The feed roller, cylinder, and doffer are driven independently. The licker-in and flats are connected with the cylinder so that their speeds are dependent on cylinder speed. The possible ranges of carding parameters are shown in Table 1. The waste levels were assumed to be negligible and hence output and input are identical. Throughputs were measured based on this assumption.

Experimental Design

An experimental design was structured to reveal the influence of fiber length, processing variables, and their interactions on the cardability of microfibers. The levels of these independent parameters are shown in Table 2, which represents 2 x 2 x 3 x 4 full factorial design.

Nep Counting

Numerous methods for assessing neps are available. One relatively quick approach to measuring nep count is AFIS, which can also be used to measure fiber length. There is good correlation between manual method using template and AFIS when measuring cotton fibers [11]. However, we found that the nep count of microfiber measured with AFIS is not compatible with template method. It was thus considered more appropriate to utilize visual counting with template. In order to perform accurate assessment of nep count, three samples of fiberweb per run were collected on board while the card was running. Care was practiced in handling the collected fiberweb samples without damaging the fiber orientation, by covering the samples with transparent plate. For each sample, neps were counted equally in three sections across the card. Neps were counted using a template with 20 holes of diameter 2.8 cm each. A linen tester of 25 mm x 25 mm with magnification power of 6 was used to facilitate counting.

For each experimental run, an average of the nep count was calculated from sum of left, middle, and right sections. The average of 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)

Substituting the values of S and N, then

$$Neps\ /\ g = 81.17 \times n \times \frac{1}{W}$$

Fiber Breakage

Preliminary measurements of fiber length distribution were conducted using AFIS and Fibroliner Model FL 100 (both are designed for cotton) to assess which system is capable of handling microfibers without damage. Both systems impose mechanical action to orient the fibers in parallel mode. It was found that the Fibroliner caused more damage (fiber breakage) during sample preparation than AFIS. Considering this finding, AFIS was used to assess fiber breakage due to carding.

To measure fiber length distribution on AFIS, the fiberwebs were gathered manually in sliver form. Experience with microfiber measurements on AFIS showed that reduction in samples (slivers) width was necessary to avoid fiber jamming and reduce fiber breakage by the system.

Measurement of Short Fiber Content (%SFC)

For each experimental run, fiberweb samples were collected, and then fed into feed roller of AFIS which counts 3,000 fibers per sample. SFC (%) and CV (%) of fiber length were calculated directly by the software which is interfaced with AFIS. SFC (%) is the percentage of fibers less than 12.5 mm (0.5 inch) and CV (%) of fiber length is the fiber length coefficient of variation. The degree of fiber breakage caused by card can be assessed by knowing SFC (%) and CV (%) of fiber length before and after carding. SFC (%) and CV (%) were derived from the average of three samples per run.

Measurement of Fiber Loading on Doffer

In order to investigate fiber loading distribution in machine and cross card direction, an IR-based device, designed and developed by Seyam et al [7], was used. Seven sensors equally spaced were located beneath the doffer in cross card direction. For each experimental run, 2,000 data points were obtained from each sensor at a rate of 60 points per second. The fiber load distributions across and along card were estimated using a calibration curve [7].

Statistical Analyses

ANOVA were performed to test the main effects and their first order interactions. Whenever there exist insignificant effect of one or more of these factors, the sum of squares of the factors were pooled to the error term. Then ANOVA was repeated considering only those factors with significant influence. Multiple regression analysis were performed to smooth out the data and obtain predicted equations of nep count and fiber breakage in terms of the independent parameters and their interactions. Residual analyses were performed to examine the fitness of the regression model of the data.

Results And Discussion

Nep Formation

The predicted equation of nep count derived from the regression analysis (with $R^2 = 0.94$) is:

$$Y = -2864.0 + 242075S + 137.08L + 404.16F_s - 86.63D + 1.57D^2 + 8987.50SL + 23756.50SF_s - 108.93SD - 0.85LD$$

Where

Y = *nep count, neps/g*

F_s = *feed roller speed, m/min*

S = *Cylinder to doffer setting, mm*

L = *fiber length, mm*

D = *draft*

The ANOVA and residual analyses were the basis for selecting the form (model) of the predicted equations. The equation is presented graphically in Figures 1-5.

The effect of draft can be seen from Figures 1-3. The nep count decreases as draft increases. This trend was consistently true at different fiber lengths, feed roller speeds and card settings. This behavior can be attributed to the fact that the amount of recycled fibers on the cylinder reduced (transfer efficiency of doffer increases) as the doffer speed increases. This reduces over working the delicate microfibers and hence reduces nep count.

Figures 3 and 4 show that nep count increases as throughput increases. The generation of neps due to carding is dependent on the degree of fiber openness at different carding zones. As throughput increases, the number of fibers increases, which thus gives less openness of fibers and hence more chance of nep formation at different carding zones (especially cylinder/flat zone).

Figures 2 and 5 show that longer fibers cause more nep formation than shorter fibers even though the throughput of the shorter fibers was higher at the same feed roller speed. In general, nep formation increases with an increase of throughput. However, a decrease in fiber length might have greater influence on the reduction of nep formation than that of the throughput. Additionally, longer fibers have more tendencies to form neps due to their lower bending rigidity as compared to shorter fibers.

The influence of cylinder-to-doffer setting can be observed from Figures 1, 4 and 5. These figures show that as cylinder-to-doffer setting gets higher, the nep count increases. The increase of cylinder-to-doffer setting increases fiber recycling on cylinder. The delicate microfibers need less work by the wire of the cylinder/flat carding field otherwise fiber breakage takes place and short fibers generated. These short fibers have a great effect on nep formation. Additionally, the increase of cylinder-to-doffer setting allows fibers to “roll up” between two rollers.

Fiber Breakage

The predicted equation (with $R^2 = 0.91$) of fiber breakage represented by % SFC (Short Fiber Content) derived from the regression analysis is:

$$Y = 0.09 + 23.548S + 0.248L + 3.730F_s - 0.80D + 0.01D^2 + 0.850SL + 6.810SF_s - 0.4000SD - 0.005LD$$

Where

Y = *SFC, %*

F_s = *feed roller speed, m/min*

S = *Cylinder to doffer setting, mm*

L = *fiber length, mm*

D = *draft*

Again the ANOVA and residual analyses were the basis for selecting the form (model) of the predicted equations. Figures 6-10 illustrate the above predictive equation graphically.

The effect of draft can be seen from Figures 6-8. The %SFC decreases as draft increases. This trend was consistently true at different fiber lengths, feed roller speeds and card settings. This behavior is related to the fact that the amount of recycled fibers on the cylinder reduced (transfer efficiency of doffer increases) as the doffer speed increases. This reduces the work of wires on the fibers and hence reduces fiber breakage.

Figures 8 and 9 show that %SFC increases as throughput increases. The fiber breakage in carding depends on the degree of fiber openness at different carding zones. As throughput increases, the number of fibers increases. This gives less openness of fibers and hence more fiber breakage at different carding zones (especially cylinder/flat zone).

Figures 7 and 10 show that longer fibers cause more fiber breakage than shorter fibers despite of the throughput of the shorter fibers was higher at the same feed roller speed. In general, fiber breakage increases with an increase of throughput. However, a decrease in fiber length has greater influence on the reduction of fiber breakage than that of the throughput. The main reason of such behavior is that long fibers have more point of contact with fibers and wires than short fibers. This causes more chance for long fibers to entangle and break as compared to short fibers.

The influence of cylinder-to-doffer setting can be seen from Figures 6, 9 and 10. These figures show that as cylinder-to-doffer setting gets higher, the fiber breakage increases. The increase of cylinder-to-doffer setting increases amount of recycled fibers on cylinder a matter which increase the work on the fibers. The delicate microfibers need less work by the wire of the cylinder/flat carding field otherwise fiber breakage takes place and short fibers generated.

The Correlation between Fiber Breakage and Nep Formation

Comparing the graphs of Figures 1-5 to the graphs of Figures 6-10, one realizes that the trend of SFC is very similar to that of the nep formation. Correlation analyses were performed on our data. Table 3 shows the results of the correlation analyses at different fiber length and draft. The data indicates there is a strong correlation between fiber breakage and nep formation. This is in agreement with previous studies [4,9,10].

Localization of Nep Formation on Web

Figure 11 illustrates that the fiber loading on the doffer is uneven in cross machine direction. It is clear from the figure that the fiber loading on middle part of the doffer is higher than the left and right parts. Figure 12 shows that nep formation is impacted by the location of the sample. The nep count for samples taken from the middle of the carded web is higher than samples collected from the left or right locations. This data suggests that evenly distributed fiber loading across the doffer should lead to less nep formation and fiber breakage.

Conclusions

Nep formation and fiber breakage were influenced by all main independent parameters and their interactions. The increase of draft (increase of doffer speed) led to a reduction of nep and fiber breakage while the increase of throughput led to an increase of nep count and fiber breakage. Increasing doffer speed reduced recycled fibers on cylinder, and it contributed to less nep formation and fiber breakage. However, the increase of throughput resulted in a reduction of openness of fibers and an increase of nep formation and fiber breakage. The increase of cylinder-to-doffer setting resulted in more nep formation and fiber breakage due to the increase of recycled fibers on the cylinder. Longer fibers had higher fiber breakage and neps than shorter fibers. The shorter fibers possessed higher bending rigidity leading to less fiber breakage and neps.

It was found that there is a strong correlation between fiber breakage and nep formation The study of nep localization in terms of fiber load uniformity across card showed that less total neps could be produced if the fiber load uniformity in cross machine direction is high.

Acknowledgement

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Table 1 Parameters of Flat-top Card

Elements	Speed rpm	Diameter mm	Wire points/ in^2
Feed Roller	0-6	100	98
Licker-in	510, 930	254	40
Cylinder	190, 338	1270	684
Doffer	0-20	653	378

Table 2. Levels of Fiber and Carding Parameters of the Experimental Design

Parameters	Levels
Fiber Length, mm(inch)	31.8(1.25), 38.1(1.5)
Feed roller Speed, m/min.	0.63, 0.94, 1.26
Draft	12.7, 19.0, 25.3, 31.7
Cylinder-to-doffer setting, mm(inch)	0.15(0.006), 0.30(0.012)

Cylinder (Licker-in) speed was kept constant at 76 m/min (407 m/min)

Table 3. Correlation Coefficient of Nep Count and %SFC at Setting=0.30 mm

	Draft		
Fiber Length, mm	12.7	19.0	25.3
38.1	0.99	0.67	0.88
31.8	0.92	0.92	0.99

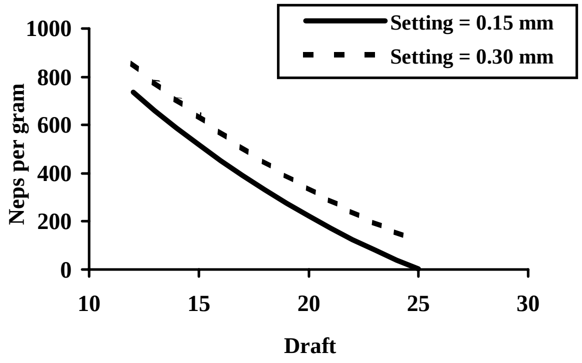

Figure 1. Effect of Draft and Setting on Nep Generation (F. Length = 31.8 mm, F.R. Speed = 0.63 m/min)

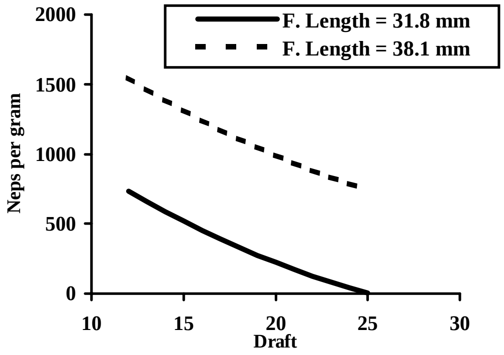

Figure 2. Effect of Draft and Fiber Length on Nep Generation (Setting = 0.15mm, F. R. Speed = 0.63 m/min)

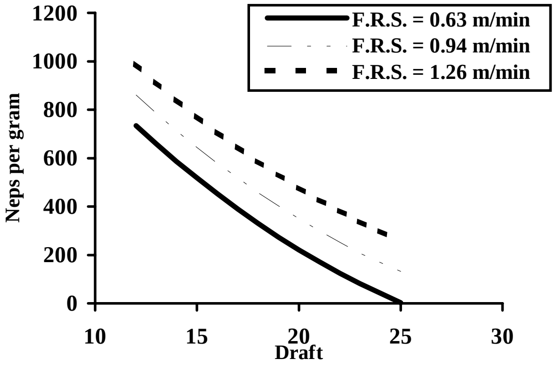

Figure 3. Effect of Draft and Feed Roller Speed on Nep Generation (Setting = 0.15 mm, F. Length = 31.8 mm)

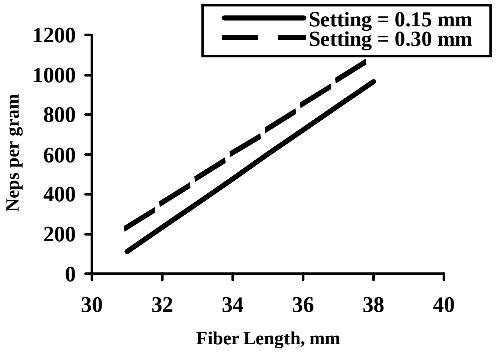

Figure 4. Effect of Fiber Length and Setting on Nep Generation (F. R. Speed = 0.6 m/min, Draft = 20)

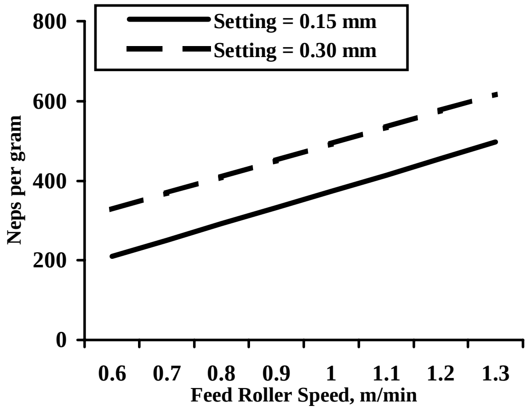

Figure 5. Effect of Feed Roller Speed and Setting on Nep Generation (F. Length = 31.8 mm, Draft = 20)

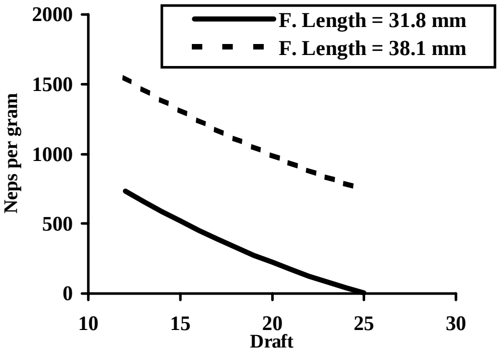

Figure 6. Effect of Draft and Setting on %SFC (F. Length = 31.8 mm, F. R. Speed = 0.63 m/min)

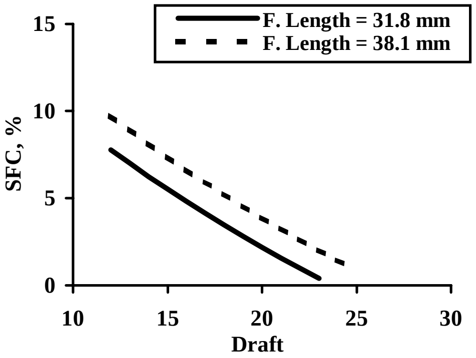

Figure 7. Effect of Draft and Fiber Length on %SFC (Setting = 0.15mm, F. R. Speed = 0.63 m/min)

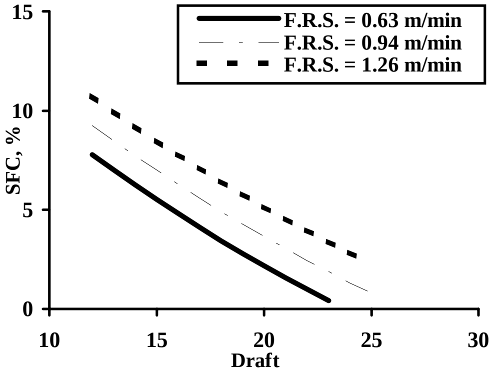

Figure 8. Effect of Draft and Feed Roller Speed on %SFC (Setting = 0.15 mm, F. Length = 31.8 mm)

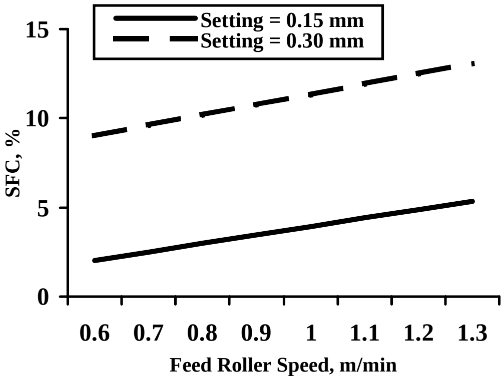

Figure 9. Effect of Feed Roller Speed and Setting on % SFC (F. Length = 31.8 mm, Draft = 20)

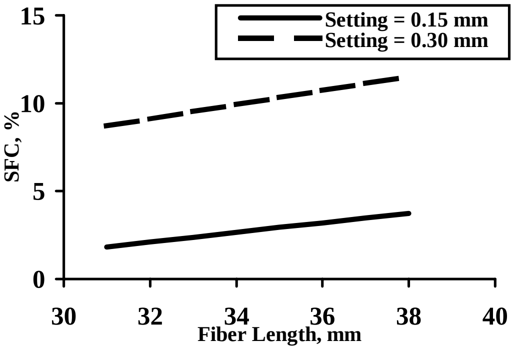

Figure 10. Effect of Fiber Length and Setting on %SFC (F. R. Speed = 0.6 m/min, Draft = 20)

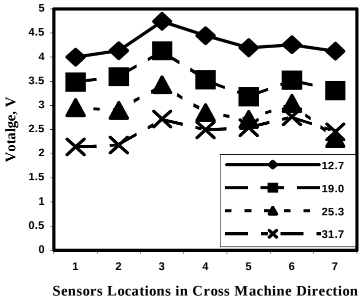

Figure 11. Doffer Fiber Loading in Cross Machine Direction (Fiber Length = 38. 1 mm, Throughput = 5.03 kg/hr/m, Cylinder (Licker-in) Speed=760 (407) m/min., Cylinder-to-Doffer Setting = 0.30 mm)

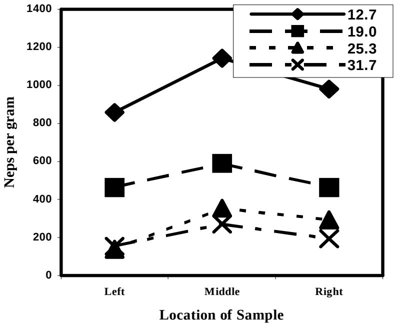

Figure 12. Nep Count vs. Location of Sample (Fiber Length = 38.1 mm, Throughput=5.03 kg/hr/m, Cylinder (Licker-in) speed=760(407) m/min., Setting = 0.30 mm)