Influence of Fiber Type On Fiberweb Properties in High-Speed Carding

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Abstract

The performance of four different fiber types processed at two different carding speeds of 85 and 120 m/min, under fixed operating conditions, was assessed. The totally novel approach of fixing the fiber diameter was used in the experiments. To serve this purpose, we designed four different fibers. In addition, we fixed the number of fibers per unit area of the carded web so as to create constant carding conditions for all experimental fibers. The fixed number of fibers per unit area was achieved by carding the same number of fibers per unit time for a given speed. We took samples from different parts of the card and analyzed them in order to enumerate the effect of fiber type on cardability. Fiberweb uniformity was regarded as a key parameter for assessing the cardability. Several other web and fiber parameters were measured in order to augment the understanding of the role of fiber type in high-speed carding. In general, data revealed that fiberweb uniformity did not significantly differ among fiber types at the two carding speeds 85 m/min and 120 m/min.

Keywords: High-speed Carding, Fiberweb Uniformity, Cardability, Bicomponent Core/Sheath Fiber

Introduction

Among all fiberweb forming systems, carding provides high flexibility by potentially using a wide array of materials to manufacture products with different features. Examples of these are the use of recycled and natural fibers in numerous textile products such as car interiors, wipes, and medical nonwoven products. Other benefits of the carding process are high web uniformity, excellent fiber mixing and blending, control of MD/CD strength ratio, and high flexibility in changing the production rates and products. Although regarded as a conventional fiberweb forming system, the carding process has undergone significant evolution to meet today's high production needs for nonwoven manufacturing lines. Meltblowing and spunbonding can, however, achieve production rates up to 600 m/min [1,4] and therefore, in order to remain competitive, the productivity of nonwoven cards needs to be increased. Recently machine manufacturers were successful in producing high-speed carding machines through the use of better machine design (materials and configuration), feed uniformity control systems, and novel doffing techniques. The fact that some fibers cannot be processed at high speeds as compared to others in carding represents a serious challenge for carding machine producers, fiber finish manufacturers, and nonwoven fabric producers.

In relation to the above mentioned concern, discussions were held with industry members of Nonwovens Cooperative Research Center (NCRC) at NC State University and it was indicated that the general experience was that polypropylene (PP) fibers could be carded at much higher speed than polyester (PET) fibers. Others, however, indicated that their experience revealed that PET fibers could be carded faster than PP fibers. This mixed experiences could be due to the fact that the fiber type was never been studied in a systematic way. The cardability of a fiber depends on numerous interdependent parameters and a change in any one of these parameters could cause a significant difference in cardability. Carding parameters include fiber length, fiber crimp, fiber fineness, feed matt uniformity and openness, card wires types and density, machine configuration, number of fibers processed/unit time, relative speeds of card rollers, fiber finish and finish level, etc. Previous researchers conducted cardability investigations utilizing commercial fibers and attempted to explain their results in terms of differences in fiber diameters, fiber crimp, fiber finish, number of fibers per unit time processed through the card, etc.

The main goal of the research reported in this paper is to determine the effect of fiber type and process speed on fiber cardability. To achieve the goal, we followed new approach to assess the cardability of different fiber types which have the same diameter, fiber length, fiber crimp, and fiber finish. Additionally, process these fibers at constant rate through the card for a given speed. This method could potentially reveal the reasons behind the dissimilar behavior of different fibers in carding.

Experimental Approach

Experiments were designed in a way to allow the elimination of many parameters, which affect the processability of fibers. *Table 1* shows the variables and constant parameters used in the experiments. By this design, the effect of fiber type could be assessed without any doubts since all other parameters (except carding speed) that affect fiber processability were kept unchanged. Thus at a given speed the impact of fiber type on the performance of fibers in carding could be clearly understood. The card used in our experiment had a maximum speed (doffer speed) of 120 m/min. While the design shown in *Table 1* does not allow the determination of the maximum processing speed of each fiber, comparison of fiberweb uniformity at the two selected speeds may be used as a parameter to indicate which fiber could handle faster carding speed.

Table 1

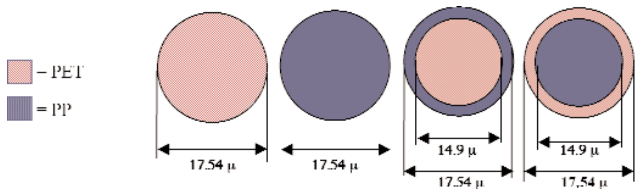
VARIABLE AND CONSTANT PARAMETERS

Parameters	**Constant**	**Variable**
Card Setting	X	
Production Speed		-85 m/min -120 m/min
Relative Speeds	X	
Number of Fibers	X	
Fiber Types		-PET -PP -Bicomponent1 (PET/PP) -Bicomponent2 (PP/PET)
Fiber Diameter	X	
Fiber Finish	X	
Fiber Crimp	X	
Fiber Length	X	
Card Clothing	X	

The design of the experimental fibers was very crucial to this research. The main aspiration when designing the fibers was to create a carding condition which would leave the effect of fiber type isolated when carding under fixed operating conditions. The specifications of the experimental fibers and fiberweb basis weight, which corresponds to a fixed number of fibers processed per unit time for a given speed, are illustrated in *Table 2*.

Table 2

SPECIFICATIONS OF EXPERIMENTAL FIBERS



Fiber Type	**PET**	**PP**	**Bicomponent 1**	**Bicomponent 2**
Fiber Denier	3.00	1.96	2.70	2.25
Outer Diameter, μ	17.54	17.54	17.54	17.54
Inner Diameter, μ	-	-	14.9	14.9
% Weight, PET/PP	100/0	0/100	80/20	37/63
% Volume, PET/PP	100/0	0/100	72/28	28/72
Web basis weight g/m^2	30.0	19.6	27.0	22.5

Fiber Length: 63.5 mm (2.5 inch)

Another essential aspect of the research was the use of bicomponent fibers with a thick core and sheath of minimum thickness. The dimensions of the core and sheath of the bicomponent fibers are identical. This kind of structure allows the observation of how a fiber's behavior in carding is affected by its total physical structure, i.e. surface properties or as a whole. 100% PET fiber has the same surface characteristics of bicomponent fiber 2, which is mostly PP fiber (72% by volume or 63% by weight). Additionally, 100% PP fiber has same surface characteristics as bicomponent fiber 1. Thus, the fiber specifications allow comparison of 100% PET fiber with 100% PP fiber and PP fiber with the same surface characteristics as PET.

Fiber Linear Density Calculation

It was determined that the fiber diameter should be fixed for all fiber types, which not only fixes the interrelation between fiber physics and wire clothing geometry, but could also provide the ability of carding a constant number of fibers per unit area of the fiberweb for each fiber type. In order to specify the above mentioned fibers, PET fiber with linear density of 3 denier was chosen as the base fiber and the diameter of this fiber was calculated as the reference and the linear densities of the other three fibers were subsequently calculated to match the diameter of the PET fiber.

Fiber diameter *df* (cm) can be calculated in terms of fiber denier *N (g/9 km)*, and fiber density ρ_f (g/cm^3). The following equation can be derived by assuming a fiber with uniform circular cross-section:

$$d_f = \sqrt{\frac{4N}{9*10^5\pi\rho_f}} \qquad (1)$$

Substituting in Equation (1) for $\rho_f = 1.38$ and $N = 3$ for polyester fiber, we obtain the value of polyester fiber diameter:

$$d_f = 17.54\,\mu$$

The polypropylene fiber denier can be calculated from Equation (1), by substituting for $d_f = 0.001754$ (cm), and $\rho_f = 0.9$ (g/cm^3). The result is shown in *Table 2*.

The bicomponent fiber denier can be calculated from the following two equations:

$$\frac{w_c}{w_s} = \frac{\pi d_c \rho_c}{\pi (d_f^2 - d_c^2)\rho_s} \tag{2}$$

$$N = \left(\frac{9*10^5\pi}{4}\right)(d_c^2\rho_c + (d_f^2 - d_c^2)\rho_s) \tag{3}$$

Where, w_c/w_s is the weight ratio of core fiber to sheath fiber, d_c is fiber core diameter, ρ_c density of core polymer, and ρ_s density of sheath polymer.

The bicomponent fiber 1 denier was calculated in two steps. The first step is to determine d_c from Equation 2 by substituting for $w_c/w_s = 80/20$, $d_f = 0.001754$ (cm), $\rho_c = 1.38$, and $\rho_s = 0.9$. The second step is to calculate N from Equation 3 since all the parameters on the right hand side of the equation are known.

The denier of bicomponent fiber 2 can be calculated from Equation 3. Then the % polymer component by weight can be determined from Equation 2. The results are shown in *Table 2*. Parameters of *Table 2* were used as processing variables to manufacture the fibers. The fibers were produced by Fiber Innovation Technologies using a finish supplied by Goulston Technologies.

Calculation of Web Weights

Carded web basis weight w (g/m^2) for PET can be calculated from the empirical equation:

$$w = k\sqrt{N} \tag{4}$$

Where, $k = 17$ for double doffer cards [2].

Since it was intended that the number of fibers per unit area of fiberweb would be constant for every fiber type, the total length of fibers per unit area of fiberweb must be constant for all fiber types.

The basis weight of the fiberweb can be expressed in terms of fiber denier N and the total length of fibers in one square meter of fiberweb L as:

$$w = \frac{NL}{9000} \tag{5}$$

Now w can be calculated for PET from Equation 4 and L can be found from Equation 5. Substituting for the value of L (which is constant for all fiber types) and fiber linear density, w for each fiber type can be calculated. The reason for calculating w for each fiber type is to adjust the carding machine parameters to obtain the target basis weight for each fiber and hence ensure that all fiberwebs were obtained by processing same number of fibers per unit time through the card. The result of calculating fiberweb basis weight for each fiber type is shown in *Table 2*. *Tables 3 and 4* show the target linear density and fiberweb basis weight versus the measured values for each fiber type. The results of *Tables 3 and 4* indicate that the target fiber linear density and fiberweb basis weight were closely achieved.

Carding

The experimental fibers were conditioned for at least 24 hours prior to the trial. Because of the limited quantity of experimental fibers, a "cleaning fiber" was run between each trial. This "cleaning fiber" was a 2 denier PP fiber (supplied by Fiber Vision) which had the same finish as the experimental fiber. Before each trial run, a bale of cleaning fibers was run through the card. After the card was ready for the trial, experimental fibers were fed to the card through the fiber opening system and chute feed.

Experiments were conducted at NSC-USA's (Schlumberger-Thibeau Cards) Nonwoven Systems Showroom located at Fort Mill, SC. The card used in the experiments was a Thibeau CA-

Table 3

COMPARISON BETWEEN TARGET AND MEASURED FIBERWEB BASIS WEIGHT

Fiber PET/PP	Process Speed, m/min	Target Weight, g/m^2	Measured Weight, g/m^2
100/0	85	30.0	29.4
100/0	120	30.0	29.5
0/100	85	19.6	20.9
0/100	120	19.6	20.8
80/20	85	27.0	27.6
80/20	120	27.0	28.3
37/63	85	22.5	21.1
37/63	120	22.5	21.3

Table 4

COMPARISON BETWEEN TARGET AND MEASURED FIBER LINEAR DENSITY

Fiber PET/PP	Target dpf	Measured dpf
100/0	3.00	2.99
0/100	1.96	1.95
80/20	2.70	2.70
37/63	2.25	2.40

10 (2255PP) dynamic roller-top card. This had a double doffer configuration and was equipped with latest technology systems such as Servo-X input autoleveler, LDS (Linear Doffing System) and WID (Web Introduction Device). The maximum speed of this card was 120 m/min and the working width was 2.5 meters.

Design of Experiment

To study the influence of the fiber type and carding speed the four fibers and two speeds shown in *Tables 1 and 2* were used. As can be seen from the tables, the design requires a total of eight runs (4 fibers X 2 speeds). For each experimental run, a fiber was processed through the card until the card reached a steady state (10-15 minutes) before taking any samples. After that, the card was suddenly stopped using the "emergency brakes" to eliminate any progressive damage or changes to the fiberweb that may have been caused by the slowing of the card. Afterwards, samples from the feed matt and the fiberweb were collected in order to carry out planned tests. The samples were collected from different locations across the card.

Testing and Evaluation

Several tests were executed to measure various characteristics of the collected samples. Fibers, feed matt and web parameters were measured and compared in order to reveal potential effects of the fiber type and carding speed on carding performance and quality. The fibers were evaluated for their linear density, crimp stability, strength, and modulus before and after carding. The carded webs from different fibers and speeds were evaluated for their uniformity, thickness and fiber orientation. The dominant angle was used to represent fiber orientation.

Figure 1

FIBER STRENGTH AT DIFFERENT SPEEDS AND PROCESS STAGES

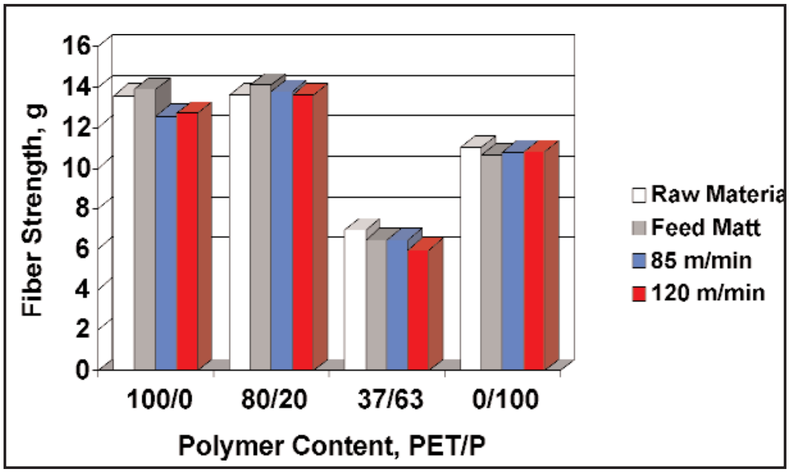
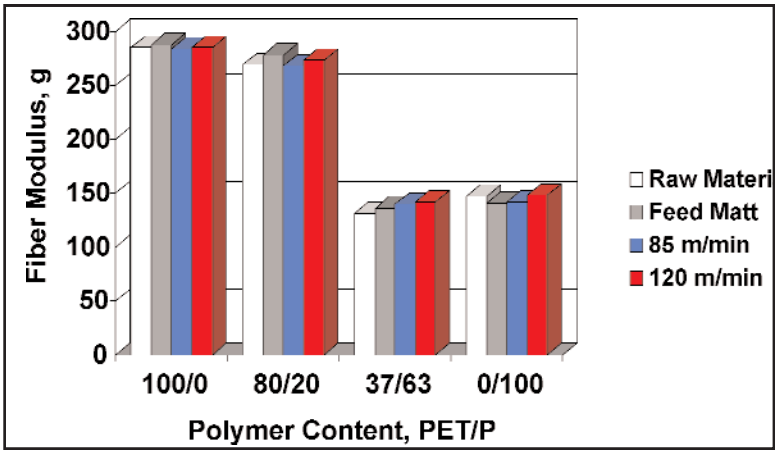


Figure 2

FIBER MODULES AT DIFFERENT SPEEDS AND PROCESS STAGES



Numerous testing techniques and equipment were employed to complete the testing phase of the research. State of the art fiber measurement devices, latest image analysis techniques and a variety of analytical testing instruments were utilized and details of these are reported elsewhere [3].

Since most of the tests carried out did not have established standards, the number of samples was determined by statistical means. Before each test, a preliminary test was carried out and the number of samples needed was calculated using the following formula:

$$n = \left(\frac{z_{\alpha/2} \times \sigma_e}{E} \right)^2 \qquad (6)$$

Where n, $z_{\alpha/2}$, σ_e and E are sample size, constant (1.96 for 95% CI), estimated standard deviation and error (10% was used for all experiments), respectively.

Statistical Analysis System (SAS) was used to reveal any statistically significant similarities or differences in the measured parameters among the fiber types and between the two production speeds.

RESULTS AND DISCUSSION

Fiber Properties

One of the parameters to assess cardability was the change in fiber strength and modulus after carding as compared to the raw materials. *Figure 1* shows the results of the fiber strength at different speeds and processing stages. The results indicate that in general the change in fiber strength is insignificant. Further, statistical analysis using General Linear Model (GLM) procedure revealed that the effects of process speed and process speed/fiber type interaction are not significant. These findings were supported by paired comparison using F-test of fiber strength for each fiber at the two carding speeds.

Figure 2 illustrates the fiber modulus results measured at different processing stages and speeds. The GLM procedure and paired comparison F-test showed that fiber modulus was not influenced significantly by process speed and there was no effect of first order interaction of speed/fiber type on fiber modulus.

The fiber crimp stability, level, and geometry are important parameters for converting fibers into webs. The carding performance is affected by fiber crimp characteristics, especially in high-speed carding. Crimp allows fiber bundles to be more easily held in structure of the fiberweb and fiber separation into individual fibers. This fiberweb cohesion is achieved by the hooks of the crimp. The fiber cohesion has positive contribution to fiberweb uniformity and carding efficiency since incoherent fiberweb breaks and causes frequent stops.

Figure 3 depicts the results of crimp stability (the ability of fiber to maintain its crimp level after it undergoes loading cycles) at different carding speed and process stages. The only fiber with significantly lower crimp stability as compared to the rest of its values at different stages is 37%PET/63%PP fiber processed at carding speed of 120 m/min. This fiber lost 15.8% of its crimp as compared to the raw material stage.

All fibers were evaluated for their linear densities at different process stages to investigate whether change in linear density may take place as a result of processing the fibers since the fibers undergo stretch and heat during processing. Figure 4 shows the results of the fiber linear density. The results of Figure 4 supported by statistical analysis prove that there is no significant change in fiber linear density as a result of processing.

Fiberweb Properties

Carded web thickness, fiber orientation, and uniformity are important structural parameters that influence the final product's properties. *Figures 5-7* show the results of these properties.

Figure 5 depicts the thickness data of eight fiberwebs (4 fibers X 2 carding speeds) processed. The behavior of fiberweb thickness can be explained by the crimp stability behavior shown in *Figure 3*. As it can be seen from *Figure 3*, the PP rich fibers show lower crimp stability than the PET rich fibers. The PP fibers lost significant part of their crimp due to processing while the PET rich fibers maintain their crimp. As a result of crimp loss and lower crimp stability, fiberwebs from PP rich fibers possessed lower thickness than those of fiberwebs from PET rich fibers. The reason behind such behavior is that

Figure 3

FIBER CRIMP STABILITY AT DIFFERENT SPEEDS AND PROCESS STAGES

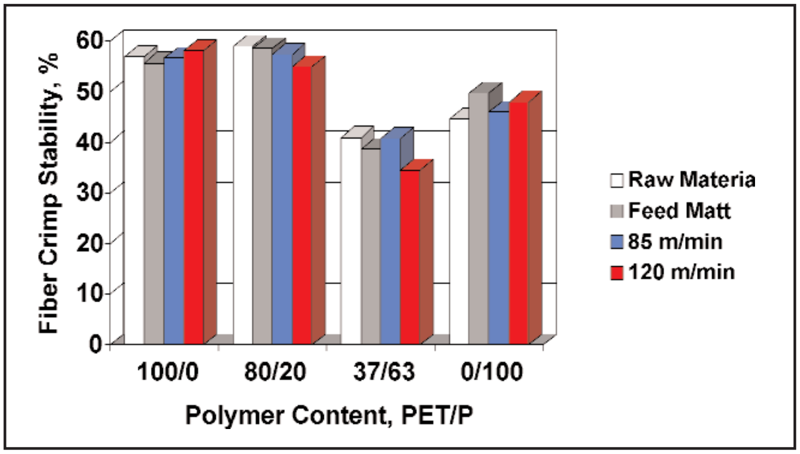


Figure 4

FIBER LINEAR DENSITY (DENIER/FILAMENT OR DPF) AT DIFFERENT SPEEDS AND PROCESS STAGES

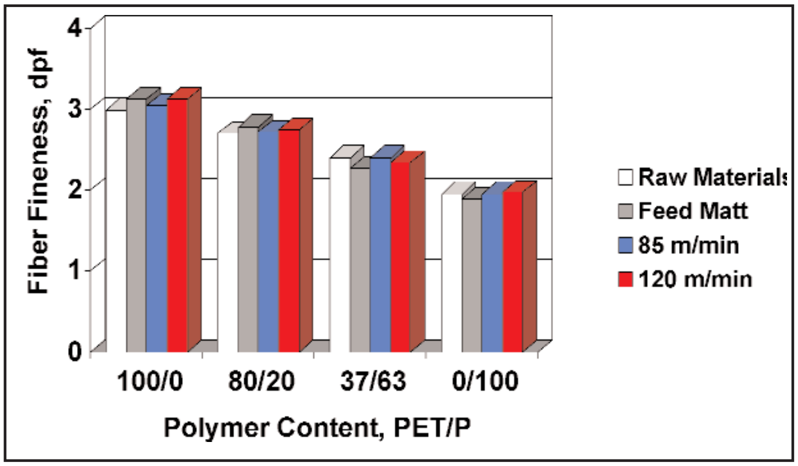
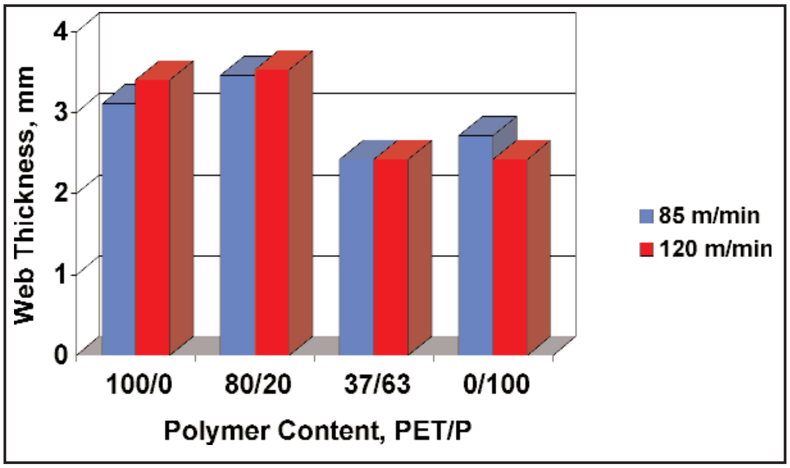


Figure 5

EFFECT OF FIBER TYPE AND CARDING SPEED ON FIBERWEB THICKNESS



with high fiber crimp the air trapped inside the structure is high a matter that leads to bulkier (or thicker) fiberwebs than those processed using low fiber crimp.

Figure 6 shows the effect of fiber type and carding speed on the web fiber orientation represented by the dominant angle. Here the angle 90° represents the machine direction (MD). The results of the eight fiberwebs indicate that: (1) Most of the fibers are oriented approximately in MD, (2) The process speed did not cause significant change in fiber orientation except in the case of PP which showed the highest difference between the two speeds (5.6°). While the 5.6° fiber orientation difference is statistically significant per paired F-test, its practical implication for most nonwovens applications is not significant.

Figure 7 depicts the effect of fiber type and carding speed on fiberweb uniformity index. In general, as the carding speed increases the fiberweb uniformity gets lower. The paired comparison using F-test showed that there is no significant effect of carding speed on fiberweb uniformity except in the case of 80%PET/20%PP fiber. This is unexpected since the results of *Figures 1-4* prove that 80%PET/20%PP fiber did not undergo significant changes in properties due to carding.

Figure 6

EFFECT OF FIBER TYPE AND CARDING SPEED ON FIBER ORIENTATION

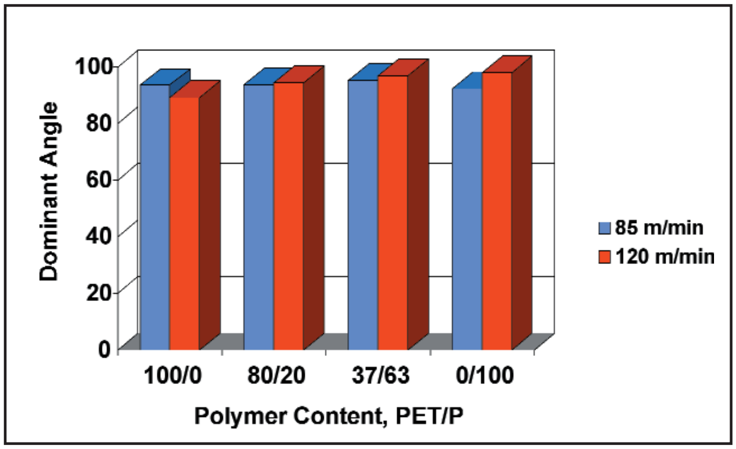
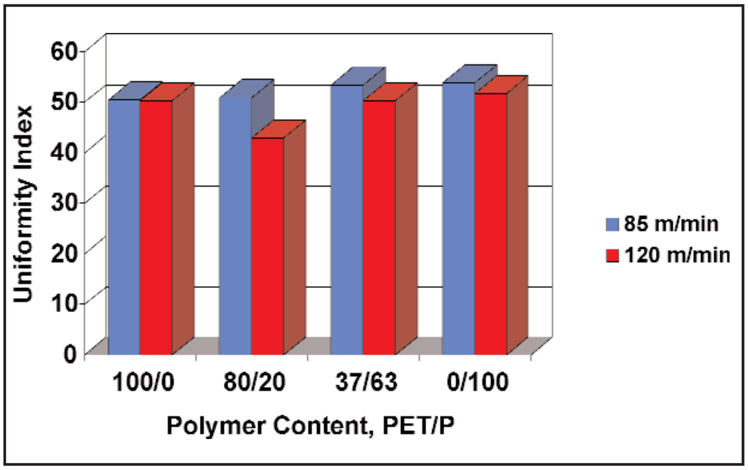


Figure 7

EFFECT OF FIBER TYPE AND CARDING SPEED ON FIBERWEB UNIFORMITY



Conclusions

We have employed a novel approach to investigate the impact of carding speed and fiber type on fiberweb properties. Four fibers were designed and extruded with same fiber diameter, length, crimp, and finish. The fibers were processed using state-of-the-art high-speed card. The processing parameters were kept constant including the number of fibers per tooth of a card element. With this setting, the effects of all the parameters (except carding speed and fiber type) were nullified. The fiber properties (strength, modulus, crimp stability, and linear density) were measured and reported to investigate whether fiber properties would change as a result of processing. For all four fibers, fiber strength, modulus, and linear density did not significantly change by carding as compared to the raw fiber. Additionally, PET rich fibers did not significantly change their crimp and crimp stability by processing while PP rich fibers showed significant loss in crimp and lower crimp stability due to carding. Despite the crimp loss and lower crimp stability of PP rich fibers as compared to PET rich fibers, the fiberweb uniformity and fiber orientation were not affected by fiber type and carding speed. The crimp loss and the lower crimp stability of PP rich fibers caused reduction in fiberweb thickness as compared to those fiberwebs made from PET rich fibers.

Our investigation showed that PP and PET fibers cardability are almost identical within the experimental range studied.

Acknowledgement

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