**Title:** Fiber Crimp and Crimp Stability in Nonwoven Fabric Processes

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**ABSTRACT**

The purpose of this study is to quantify fiber mechanical behavior during decrimping and recrimping, and relate it to fundamental fiber properties, nonwoven fabric properties, and processability in nonwoven equipment. PET fibers of three different crimp levels have been carded and webs have been produced under various processing settings. Samples from different settings and processing stages are being tested for their single fiber crimp characteristics. An empirical function fitting the stress-strain curves of several single fibers in the crimp region has been found and may deliver parameters that characterize the crimp removal behavior of these fibers and their processing parameters.

**EXECUTIVE SUMMARY**

*(NOT TO EXCEED 1 PAGE)*

Synthetic fibers must be crimped to process on conventional carding equipment. The initial crimp level and crimp retention during processing influence nonwoven fabric performance. Our study’s objectives are 1) to find quantative parameters describing these crimp properties based on their mechanical behavior during loading and unloading, and 2) to determine the possible interaction of fiber crimp and crimp stability on carding and web properties.

Fiber crimp was studied by obtaining the stress strain curve at low stress levels for individual fibers using the Favimat® single filament tensile tester. The major barrier to using such data for crimp analysis is to distinguish the decrimp region from the initial mounting slack, and the onset of crimp removal. We have found that both slack removal regions, and the initial portions of the fiber stress strain curve are linear with strain, while crimp removal is non linear. Crimp can therefore be studied by extracting the non linear region of the stress strain data.

Optical images of fibers during testing were indexed to the stress strain data, and we have discovered that fibers decrimp by bending at the crimp node, not by bending of the straight sections. This has led to formulation of a physical model for decrimping which is currently in the process of being refined.

During this reporting period samples from three bales of PET with very different crimp were produced at Hollingsworth on Wheels, and are currently being characterized.

Activity during the next period will center on characterization of the carded samples, refining the physical model, and selecting parameters which uniquely characterize fiber crimp. The next task will be relating these parameters to carding and fabric performance.

**INTRODUCTION**

In nonwovens, crimp and crimp retention of synthetic fibers during processing are, along with finish, major contributors to processing efficiency, web cohesion, fabric bulk and bulk stability [1]. The meaning of measurable crimp parameters and their influence on processing and fabric characteristics has not been quantified. Experimental stress-strain data from the Textechno FAVIMAT are being analyzed to determine appropriate parameters for the characterization of crimp and crimp stability and for the prediction of processing and fabric characteristics.

### OBJECTIVES

In order to find objective measures to describe fiber crimp, the experimental approach of this project includes the collection of stress-strain data for various fibers, accompanied by the following deliverables:

* A quantitative definition of crimp stability
* A physical model relating filament crimp and crimp retention to fiber and crimp properties such as modulus and geometry
* A determination of the possible interaction of fiber crimp, crimp stability, carding performance and web properties

**EXPERIMENTAL APPROACH**

## Carding Experiments with 3den PET Fibers

The material available for the carding tests were three bales of 3den PET fibers with different crimp levels supplied by Wellman. Table 1 shows the identification of the test material and the crimps per linear extended inch (CPLI).

|  |  |  |
| --- | --- | --- |
| Identification | Crimp Level | Type |
| Bale 1 (**B1**) | 9 CPLI | 218 |
| Bale 2 (**B2**) | 7.5 CPLI | 204 |
| Bale 3 (**B3**) | 9 CPLI | 214 |

Table 1: 3den PET Test Material for Carding Trials

The fibers were processed using a “typical” industrial production line at Hollingsworth according to Figure 1.



Figure 1: Flow Chart with Sample Schedule for 3 den PET

Fiber samples were taken from the bale and after each processing stage (B through G in Figure 1) and webs with two different needling settings were collected after each test (H and J in Figure 1).

The card used in the experiments is the MASTERCARD® from Hollingsworth, which has two cylinders and flat top carding elements, as shown in Figure 2.



Figure 2: MASTERCARD® [2]

Card settings that are most critical to the processing performance of the fibers and the web properties include

* Clearance of Flats to Cylinder
* Feedplate-LickerIn Clearance
* Cylinder Speed.

In order to explore the effect of these carding parameters, the carding experiments were performed according to the plan shown in Table 2. Other constant settings of card and needleloom are summarized in Table 3. For all tests, the material output of the card was kept constant at 15 grams/m2, yielding a web weight of 50 grams/m2 after the needleloom.

For each of the 3 bales, fiber samples A, B, C, D and E were taken at random times. Furthermore, fiber samples F#1 through F#11 and G#1 through G#11 and web samples H#1 through H#11 and J#1 through J#11 were collected.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Test# | **Feedplate-LickerIn Clearance [inch]** | | | **Flat Clearances of Finisher Cylinder [inch]** | | | **Cylinder Speed**  **[rpm]** | | |
| 0.017 | 0.029 | 0.034 | l5-0.017 t5-0.017 l6-0.017 t6-0.017  l7-0.017 t7-0.017 l8-0.017  t8-0.012 | l5-0.022 t5-0.022 l6-0.022 t6-0.022  l7-0.022 t7-0.022 l8-0.022  t8-0.012 | l5-0.034 t5-0.034 l6-0.034 t6-0.034  l7-0.034 t7-0.034 l8-0.034  t8-0.012 | 500 | 800 | 1100 |
| 1 |  |  | X |  |  | X |  | X |  |
| 2 |  | X |  |  |  | X |  | X |  |
| 3 | X |  |  |  |  | X |  | X |  |
| 4 | X |  |  | X |  |  |  | X |  |
| 5 |  | X |  | X |  |  |  | X |  |
| 6 |  |  | X | X |  |  |  | X |  |
| 7 |  |  | X |  | X |  |  | X |  |
| 8 | X |  |  |  | X |  |  | X |  |
| 9 |  | X |  |  | X |  |  | X |  |
| 10 |  | X |  |  | X |  | X |  |  |
| 11 |  | X |  |  | X |  |  |  | X |

Table 2: Experimental Plan for Carding of 3den PET fibers

|  |  |  |
| --- | --- | --- |
| **Breaker Cylinder** | Feed Roll Speed | 2.7 rpm |
| Feed Roll-to-Feed Plate Clearance | 0.005 “ |
| LickerIn Speed | 535 rpm / 857 rpm / 1178 rpm |
| LickerIn-to-Cylinder Clearance | 0.010 “ |
| CARDMASTER Flat Clearance | all Plates, Leading & Trailing Edges (l1-l4, t1-t4) 0.022 “ |
| Dofferspeed | 335 rpm |
| Doffer-to-Cylinder Clearance | 0.010 “ |
| Doffer-to-Condenser Clearance | 0.012 “ |
| **Transfer** | Condenser Speed | 24 rpm |
| Condenser-to-Transfer Clearance | 0.022 “ |
| Transfer Speed | 43 rpm |
| Transfer-to-LickerIn Clearance | 0.022 “ |
| **Finisher Cylinder** | LickerIn Speed of Finisher | 278 rpm / 445 rpm / 612 rpm |
| Dofferspeed of Finisher | 21 rpm |
| Doffer-to-Cylinder Clearance | 0.010 “ |
| Crosslapper | | 3.2 Double Layers |
| **Needle Loom** | Input Speed | 5.48 m/min |
| Output Speed | 10.38 m/min |
| Strokes Per Minute | 200 for Slight Needling  760 for Regular Needling |
| PPI | 91 for Slight Needling  348 for Regular Needling |

Table 3: Settings for Carding Experiments with 3den PET

## Single Fiber Crimp Testing

All fiber samples from the carding experiments are being tested for crimp removal behavior, crimp stability and count. The testing setup of the Textechno FAVIMAT is the *Crimp Stability Test with Count Measurement*. The process of one single test is as follows:

1. Fiber is stressed up to a target load at constant rate of extension
2. Target load is applied for a defined time period
3. Fiber is released again at constant rate
4. Minimum load of 0.001 cN/tex is applied for a defined time period
5. Fiber is stressed again at constant rate of extension up to preset tension for count measurement
6. Count measurement is completed

The crimp stress-strain curve for the entire test is saved in a three-column table form including lower clamp position, measured load and time. Furthermore, the count is recorded. The Favimat software calculates the fiber elongation in percent of initial gage length at the load of 1 cN/tex and a crimp stability value as a ratio of the elongation values at 1 cN/tex of the second and of the first crimp removal cycle. Table 3 shows the testing parameters for the FAVIMAT tests.

|  |  |
| --- | --- |
| Initial Clamp Distance | 20 mm |
| Testing Speed | 50 mm/min |
| Target Load of 1. Crimp Removal Cycle | 2.5 cN/tex |
| Loading Period | 5 sec |
| Recovery Period | 5 sec |
| Load where “Crimp Elongation” and “Crimp Stability” are calculated | 1 cN/tex |
| Load for Count Measurement | 1.5 cN/tex |

Table 4: Parameters of FAVIMAT Crimp Stability and Count Test

Tests on 25 single fibers were performed for every sample. The stress-strain data are being evaluated in terms of differences

1. For different crimp levels (B1, B2, B3)
2. At different processing stages (samples A, B, C, D, E or F)
3. For different carding settings (tests #1 through #11)

The interpretation of the shape of the stress-strain curve involves the fit of a theoretical function with characteristic parameters as described later in this report. This analysis is not finished yet. However, when comparing the stress-strain curves in Figures 3 through 5, it is apparent that fibers of different crimp levels have differently shaped stress-strain curves in the crimp removal region.



Figure 3: Stress-Strain Curves for 25 sample fibers of Bale 1, sample A



Figure 4: Stress-Strain Curves for 25 sample fibers of Bale 2, sample A



Figure 5: Stress-Strain Curves for 25 sample fibers of Bale 3, sample A

As noted in previous reports, Textechno assumes the point of the stress-strain curve at 1 cN/tex to be a characteristic parameter for fiber crimp [3]. However, it was shown before with help of fiber photographs during testing, that this point of the load-elongation curve is not reliably the characteristic crimp removal point for every fiber. Still, for a first qualitative analysis, elongation values at 1 cN/tex were used to compare the different fiber samples and to get an idea about the variability of the measurements. For 25 single tests per sample, the variability of the elongation values within the samples was approximately as high as the variation between samples. Thus, no statistically reliable correlation could be established between fiber crimp level, carding parameters, processing stages on the one side and fiber elongation values at a load of 1 cN/tex on the other side. The variability of the elongation values is only partly due to the variability of fiber crimp characteristics. It also depends on the initial clamping position of the fiber and the variability of the fiber elongation necessary to straighten the overall fiber axis before the actual crimp removal starts. This situation shows that the elongation value at 1 cN/tex is not a suitable parameter to correlate crimp behavior and processing parameters in practice.

Currently, a high number of single fiber crimp tests is being carried out on the three bale samples A, in order to determine the distribution of crimp parameters and how many tests are necessary for a statistical confidence of 95% at a defined precision level. Using the shape of the stress-strain curve in the crimp removal region, rather than single values of the curve at certain load values, will hopefully improve the accuracy to characterize fiber crimp and reduce the variability within samples.

## General Theoretical Function That Fits Experimental Data

In order to model the experimental stress-strain data in the crimp region with a relatively simple theoretical function, the following assumptions were made:

* Each stress-strain curve is generally due to three basic mechanisms:

1. Straightening of the overall-fiber axis, so-called slack removal
2. Crimp removal due to opening of the crimp angle (simplification ignores fiber bending and stretching during crimp removal)
3. Fiber Stretching.

* The initial part of the recorded stress-strain curve is due to the slack removal only, before the actual crimp removal starts. For simplification, this “slack region” is modeled with a straight line.
* Slack removal may still occur during crimp removal. Thus, the theoretical function fitting stress-strain data during crimp removal may be a sum of the actual crimp removal function and the slack removal function.
* Once the crimp is removed, the actual fiber stretching occurs. This behavior can also be modeled with a straight line, where the slope corresponds to the fiber modulus.

Figure 6 demonstrates the modeling of an experimental stress-strain curve.

Figure 6: Stress-Strain Curve and its Modeling

For several fibers of various materials the function , where P denotes the load, δ denotes the absolute elongation of the fiber and c1 through c4 are constants, showed a good fit to the crimp removal region of experimental stress-strain curves. In this function, the first part could be attributed to the slack removal that is still taking place during crimp removal, whereas the second part could be assumed as characteristic for the crimp removal behavior itself. Thus, the function delivers the two parameters c3 and c4 that could be used to characterize fiber crimp quantitatively. Figure 7 shows experimental stress-strain data of a 3 den PET bicomponent fiber and the fit of the theoretical function in the crimp removal region. The general fit of this function and the magnitude of the fitting parameters c3 and c4 are currently being investigated.

Figure 7: Fit of general function to stress-strain data of 3 den PET bicomponent fiber [4]

## General Function Related to Theoretical Model



Figure 8: Mechanical Model for Crimp Removal

Previously, a mechanical model for the crimp removal mechanism was introduced. This model was based on visual observations and the assumption of spring-like behavior in the tip of the crimp node causing the crimp removal, see Figure 8. With relatively simple equations such as polynomials or exponential functions for the torsional moment of the spring T, no theoretical relationship between load P and elongation δ could be established that would fit the experimental data. However, considering the complexity of polymeric material, a complicated, non-linear spring equation for T, characterizing the crimp node, is justified. Applying the general function shown in Figure 7 and the mechanical model of Figure 8, a function for the torsional spring moment T of the form

 - where *d1* trough *d7* are functions of *c3* and *c4* , see Figure 8 - can be derived.

### SUMMARY & CONCLUSIONS

Carding experiments with 3 den PET fibers have been completed. The influence of

1. Fiber crimp level
2. Carding processing settings
3. Processing stage

on single fiber crimp characteristics is being investigated. Stress-strain data in the crimp removal region are being collected with the Textechno FAVIMAT. Due to very high variability, a statistically reliable correlation between processing parameters and fiber crimp characteristics as determined with the Textechno software could not be established yet. Parameters characterizing the shape of the stress-strain curve in the crimp region rather than single points of the curve seem more suitable to describe fiber crimp characteristics and will hopefully reduce the variability.

A general function that fits the experimental stress-strain data in the crimp region of several different fibers has been found. The general validity of this model function is being investigated and the two shape parameters of the fitting curve are being evaluated quantitatively for various fibers. Based on this function and the previously introduced mechanical model for the crimp removal mechanism, a characteristic function for the torsional spring moment in the crimp node can be derived.

**FUTURE WORK**

The initial subject and time planning for this project was as follows:

1. Literature survey Dec. 1997

2. Choice of testing instrument – machine set-up Jan. – Sep. 1998

3. Fiber testing  
Physical model for stress/strain behavior  
and definition of crimp parameters until March 1999

4. Determine relationship  
carding parameters – crimp retention April 1999 – March 2000

5. Web & fabric analysis April – June 2000

6. Thesis & publications July – Aug. 2000

In compliance with the schedule, carding experiments have been done and stress-strain data of the fiber samples are being collected in order to determine the relationship of carding parameters and crimp characteristics. Due to the high variability, more testing is necessary to be able to see any potential correlation. Focus of the data interpretation will also be the validation of the general theoretical function to fit stress-strain data of any fiber and a quantitative analysis of the characteristic constants of the function.

Once the data interpretation for the 3 den PET fibers is finished, carding trials are planned for other materials such as PP.

In addition to fiber crimp testing, also the webs produced during the carding experiments will be tested and hopefully web properties can be correlated with fiber crimp parameters and carding settings.

**REFERENCES**

[1] William Oxenham, Donald Shiffler: Fiber Crimp and Crimp Stability in Nonwoven Fabric Processes – A Research Proposal Submitted to Nonwovens Cooperative Research Center, March 12, 1997

[2] Hollingsworth: MASTERCARD® Carding Machine – Product Brochure 1999

[3] Textechno FAVIMAT manual, 1998

[4] Software SIGMAPLOT® Version 5.0