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

Load cells sufficiently sensitive to measure the stress-to-strain reaction of fibers in the crimp region are now available. The purpose of this study is to quantify the mechanical fiber behavior during decrimping and recrimping, and relate it to fundamental fiber properties, nonwoven fabric properties, and processability in nonwoven equipment. In the first period of this project, a literature survey was completed, and several alternate instruments were investigated resulting in the recommendation to purchase the Textechno FAVIMAT.

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].

Recently, load cells of sufficient sensitivity to measure stress-strain data of single fibers in the region of crimp pull-out were embodied in commercial instruments by Lenzing and Textechno. However, an understanding of how to use data obtained from these instruments to characterize crimp stability and predict processing and fabric characteristics is currently lacking [2, 3].

OBJECTIVES

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

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

EXPERIMENTAL APPROACH

What is crimp?

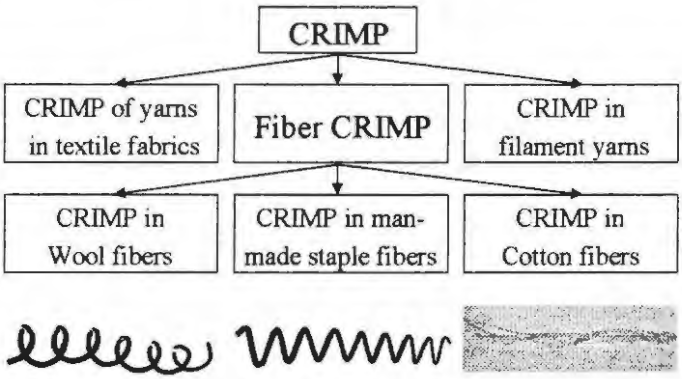


Figure 1: Different kinds of crimp

"Crimp" is used to describe three different things. Yarn crimp in textile fabrics is the waviness or distortion of a yarn due to interlacing in the fabric. Crimp in continuous filament yarns describes their bulk and the formation of the interlocking cross-sections of the mono-filaments. The crimp in staple fibers characterizes the waviness or succession of bends or curls in a fiber [4, 5].

Depending on its shape and constitution, there are three kinds of fiber crimp: The crimp in wool fibers is a three-dimensional, spiral crimp with a shape like a spring, typically called helical crimp. Due to the fiber's chemical constitution, it is very stable, and also produced with all so-called bi-componental man-made fibers. Even though cotton fibers do not have crimp in the sense of bulk, the expression crimp is used to characterize the convolutions of cotton fibers.

The crimp in man-made fibers has a two-dimensional triangular shape and is induced to the fiber by subjecting the filaments to a thermal or mechanical treatment such as stuffer box or edge crimping and then cutting the filaments into staple fibers.

Crimp parameters

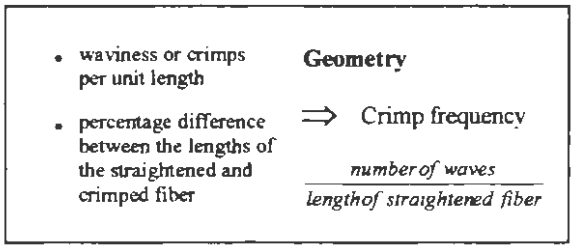


Figure 2: Geometrical crimp definition

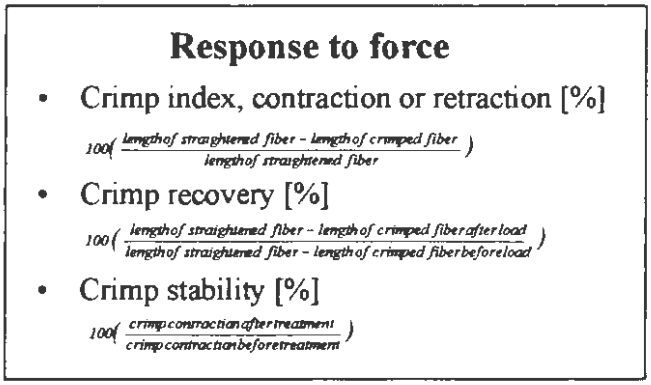


Figure 3: Definition of crimp as response to force

Basically, crimp is defined by the geometry of the fibers as shown in Figure 2. Figure 3 shows parameters that characterize crimp as the fiber's response to an applied tension or force.

How can crimp be measured?

The Standard Test Method for Bulk Properties of Textured Yarns D 4031 [6] covers the measurement of the change in length of a tensioned skein of textured yarn due to change in crimp characteristics brought about by exposure to wet or dry heat. The change in length of crimped, continuous multi-filament yarns, is a measure of skein shrinkage, crimp contraction, bulk shrinkage, or crimp recovery, depending on the strain procedure.

The only standardized procedure for the assessment of crimp in single fibers is the Standard Test Method for Crimp Frequency of Man-Made Staple Fibers D 3937 [6]. The measurement of the crimp frequency is based on a two-dimensional, visual counting and evaluation of the crimp bows with help of optical magnification or projection. This test method for quality control cannot provide minor differences in crimp or a complete crimp characterization, since it is based on the crimp shape to be a sine wave, and any deviation from this ideal shape is undefined.

In order to access mechanical crimp parameters by measuring the length change before and after load, crimp balances were used loading the fiber with a defined tension. However, this method was still lacking sufficient sensitivity to access the small forces applied during crimp removal without actually straightening the fiber.

Testing instruments

There are currently two commercial instruments specifically designed for the measurement of fiber crimp available in the U.S. and Europe: The VIBROTEX by Lenzing, Austria, and the FAVIMAT by Textechno, Germany. The table in Appendix A gives an overview of important features of these instruments.

Initial trials and evaluation of the technical characteristics of the Lenzing VIBROTEX revealed the following draw-backs:

- **No combined fiber fineness measurement available**
  Lenzing claims that crimp properties would be changed by previous denier testing and suggests to measure the fiber titer after the crimp test with a vibroscop and to set the nominal titer provisionally before testing.
- **Fibers are pretentioned by a paper weight**
  The size of the paper weight is chosen according to the nominal fiber titer. Since there are only discrete weight sizes available, a relatively high titer range of fibers will be pretensioned with the same force. This important factor of inaccuracy is even more pronounced by the relatively high variability of the paper weights themselves.
- **Force values are measured and stored in a logarithmic scale**
  There has not been any theoretical interpretation or proof of Lenzing's assumption, that the stress-strain curve in a half logarithmic scale in the crimp section can be approached by two straight lines. This could not either be supported by further testing [7] and initial trials in the course of this project.
- **Testing section is open without any protection against air movement**

The Textechno FAVIMAT is based on the tensile tester FAFEGRAPH equipped with an even 10 times more sensitive load cell than the Lenzing VIBROTEX and additional integrated features like fiber fineness measurement, optical fiber scanning and a robot system for fully automated testing. The measuring section is countersunk in the instrument and can be disclosed by a sliding window.

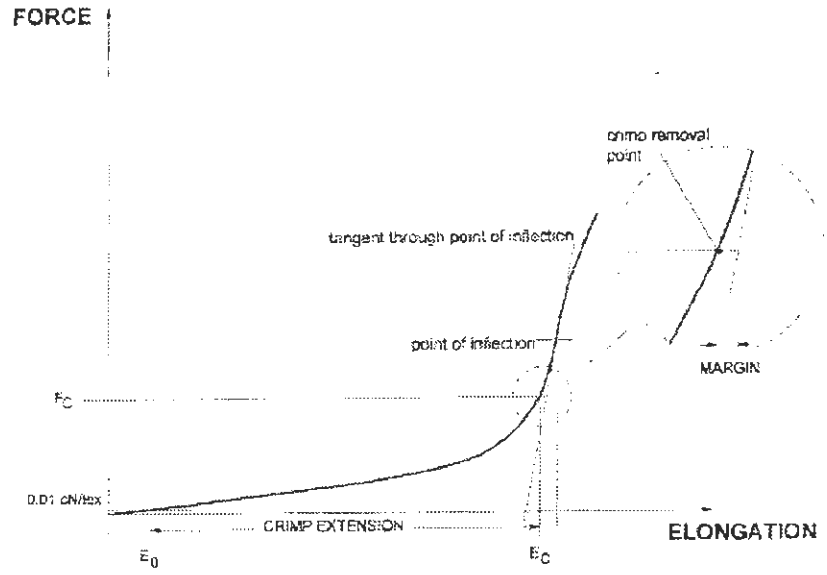


Figure 4: Stress-Strain curve plotted by the FAVIMAT [8]

The load cells of both instruments are based on principally different electrical circuits to capture the signal. The balance type load cell of the FAVIMAT uses two impedances for the voltage measurement that are balanced with each other against outside influences. This principle provides in general very high signal stability with respect to external vibrations. The major

disadvantage of this type of load cell is, that its response time is substantially higher than that one of a load cell working with the principle of a single strain gage transducer. However, the resulting time lagging of the produced signal does not spoil the measurements in the case of slow signal movement if the response time is taken into account and force response to strain is recalculated and reevaluated.

The FAVIMAT also uses paper weights to handle the fibers. However, after clamping, the fiber tension is released to a defined pre-tension measured by the load cell according to the nominal fiber. This principle yields a much more accurate pretension and thus assures that the fiber is not decrimped before the actual testing.

Recently, an opto-electronic sensor has been integrated into the FAVIMAT. This sensor scans the fiber two-dimensionally along its axis and provides number of crimp bows and amplitude in the standard software. The raw data as (x, z) coordinates can be easily accessed under DOS. Figure 4 shows a plot of the FAVIMAT, where (E_C, F_C) is the point of crimp removal.

Visual evaluation of crimp behavior



Time [min:sec]	0	0:36	1:06	1:16	1:23	1:31	1:56	2:21	2:31	3:36	4:53	4:55
Extention [mm]	0	3	5.5	6.33	6.92	7.58	9.67	11.75	12.58	18	24.42	24.58

←Testing starts ←Crimp removed, Extension starts

←Slack removed, Crimp pull-out starts Break

Figure 5: Videotaped movement of upper clamp and tested fiber with the MTS® Sintech

Polyester fibers were tested with the most sensitive load cell of the MTS® Sintech at a speed of 5 mm/min, with 20 mm gage length. The stress-strain curve clearly showed that the sensitivity of the instrument is not sufficient in the area of crimp removal. However, the curve can be correlated to the visual observations made with a highly sensitive video camera, plotted in Figure 5.

The point where slack was removed and the crimp pull-out would start, was defined as that point where the angle of the crimp bows changed The starting extension for crimp removal was thus detected to be approximately 6.33 mm. This can be correlated to a shifting of the noise level in

the stress-strain curve. A further correlation could be observed at the point of perfect crimp removal. The extension where the fiber was visually estimated to be first totally straightened, here approximately 12.6 mm, is fairly exact the extension where a linear section of the stress-strain curve starts.

CONCLUSIONS

Highest available sensitivity, implemented fineness and optical crimp measurement and other advantages of the Textechno FAVIMAT make this instrument the most suitable for measuring fiber crimp. The Lenzing VIBROTEX could only be used with major software changes, an additional fineness measuring unit and a construction to protect the measuring unit.

Optical monitoring of mechanical crimp testing is helpful to correlate the change in crimping angle to stress-strain data. The optical sensor provided by Textechno will have to be improved. One draw-back is the measurement only in two dimensions. The major disadvantage is, that the sensor is only set up to scan the fiber once before starting the actual mechanical test, instead of monitoring the fiber coordinates continuously as functions of time. It will be necessary to implement a software change in order to scan the fiber at several discrete stages of the mechanical crimp measurement.

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

The literature review has been completed as presented in this report. Having chosen the Textechno FAVIMAT, we hope to get access to this instrument by April 1998 to start with systematic crimp testing. First tests with various fibers will focus on exploring the influence of testing parameters such as

- Gage length
- Testing speed
- Paper weights
- Fiber fineness measurement during/before testing
- Response time of the load cell
- Sample preparation.

For the interpretation of the testing results, not only characteristic values such as crimp contraction, recovery and stability will be evaluated but rather the continuous stress-strain curve.

For example the parameter crimp recovery does not describe a fiber accurately, since two basically different kinds of fiber possess 100% crimp recovery, those with crimp like a perfect spring and no hysteresis, and those with no crimp at all. This creates obvious interpretation and correlation problems.

For at least polyester fibers, it was found experimentally that the complete crimp / decrimp curve can be correlated quite simply by plotting $(\text{stress})^{-1/2}$ versus the strain [11]. Such a simple correlation indicates strongly an underlying physical relationship. We started to develop a theoretical model correlating stress and strain imposed to the fiber during crimp removal, based on the effect of the moments introduced at the triangle of one crimp bow when both ends of the fiber are subjected to a certain force. Hopefully, theoretically derived results will support the former experimental findings.

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APPENDIX A

	Lenzing VIBROTEX	**Textechno FAVIMAT**
SPECIFICATIONS	• Electronical testing of mechanical crimp properties of single fibers • Computational data analysis • New VIBROTEX 400 is planned to be released at the end of march 1998	• Static tensile testing of single fibers and filaments according to DIN 53 816, ASTM D 76 and D 21101, ISO 5079 • Fineness measurement • Testing of mechanical crimp properties • Optical crimp geometry measurement (fiber scanning) • Robot for fully automated testing available • Computational data analysis
GAGE LENGTH	20 mm; variable from 5 to 50 mm on the new VIBROTEX 400	Continuously variable between approx. 5 mm and 80mm
FORCE MEASURING EQUIPMENT	• Strain gage transducer with response time 0.00025 sec • Automatic calibration to 0 at the testing start	• Self-compensating measuring system • Balance type load cell • Automatic calibration • Response time approx. 0.15 sec
FORCE RANGE	0.01 cN to 20 cN	200cN
FORCE RESOLUTION	±0.001 cN	±0.0001cN
DISTANCE RESOLUTION	±0.01 mm	±0.1 µm
TESTING SPEED	0.1 to 100 mm/min separately adjustable for removal and recovery of crimp.	0.1 to 100mm/min return speed 300mm/min
DATA OUTPUT	• Analog, logarithmic output for the force • Display and print of the stress-strain curve in a logarithmic scale for the force • Data can be accessed easily under DOS with the new VIBROTEX 400 • Printer	• Linear output for stress and strain • Sophisticated, very flexible software • Easy access of the raw data under DOS • Printer