NONWOVENS COOPERATIVE RESEARCH CENTER: INDUSTRY UNIVERSITY PARTNERSHIP

Behnam Pourdeyhimi, Professor and Co-Director
College of Textiles
North Carolina State University
Raleigh, NC

The **Nonwovens Cooperative Research Center** (NCRC) was established as a State/Industry-University Cooperative Research Center (State/IUCRC) in 1991 as a result of a grant from the National Science Foundation (NSF). The NSF grant was matched by the State of North Carolina and grants from the nonwovens industry. The grants from the industry were in the form of membership dues. In addition to these sources, the Center has received and continues to receive grants, contracts and gifts from the industry.

The NSF grant was for a maximum of 8 years. NCRC continues to receive funding from the State of North Carolina. NCRC's State budget has become a permanent part of the State allocation. Today, NCRC has a budget of about $1.00 MM per year from the State and the industry.

NCRC serves the nonwovens industry through fundamental and applied research in the technologies of the industry and an active program of technology transfer. The Center has developed **core research**, **non-core research,** and **technology transfer** activities.

Core research programs are developed jointly by the Center faculty/staff and the NCRC member companies. **Core** research programs focus on areas such as

- the development of new materials
- the modification of existing materials
- basic studies that lead to a better understanding of technologies
- applied research directed at process material – property relationships
- the development of instrumentation and test methods for nonwoven fabrics.

Core research programs are supported by funds from the **State of North Carolina** and fees from NCRC **member companies**. The results of the research are proprietary to the NCRC and **to all member companies of the Center**. This information is placed in the public domain, through **presentations and publications, poster presentations, software,** and **patent disclosures**, only **after the approval of the Industrial Advisory Board (IAB)** of NCRC. The policies governing the ownership of intellectual property are discussed under the policy section.

A **non-core** research program focuses on one or more of the above objectives but is carried out for an individual company. The single company sponsored programs can be proprietary and are made public only if the sponsoring company agrees. Non-core projects of special interest can also be developed for a group of NCRC member or affiliate companies. The results of such research are made public only if the sponsoring companies agree.

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The Center carries out an active program of **technology transfer** supported by funds from the **State of North Carolina** and **industrial members**. This program seeks to disseminate technology developed by the Center along with existing knowledge of the management of materials and processes. Such programs are provided in the form of:

- training and assistance in the implementation of Center developed technology
- courses taught at plant sites
- workshops at the Center
- industrial internships
- focused seminars, symposia, and conferences
- one-on-one consulting.

To carry out its research mission, NCRC seeks out talent at North Carolina State University as well as other universities such as Georgia Institute of Technology, Clemson University, University of Georgia, Philadelphia University, University of Tennessee, University of California Davis and others. Such **cooperative research programs** are undertaken by the faculty, staff, and students of these universities with the approval of the IAB.

The Industrial Advisory Board of NCRC has adopted the following vision statement for NCRC:

> "NCRC will be the recognized Center for nonwovens technology, worldwide."

The achievement of this aspiration is indeed a formidable task, for today's nonwovens are highly complex, innovative, "engineered" products requiring a diverse set of expertise.

Today, meaningful performance benefits and superior value are predominantly based on innovations in both the design of products, and on innovative materials these products are made of. This necessitates radically upgrading our research and development capability by bringing together a critical mass of very diverse top R&D talent. This is indeed the path NCRC has pursued since its inception ten years ago. We work with a number of US universities, and some even in Europe, who bring expertise to NCRC over the whole product supply chain. These are matched and complemented by our industrial partners who also cover the same range of expertise. Further, our industrial members are intimately involved in the core research undertaken by NCRC affiliated faculty. However, to truly live up to the expectation that NCRC will be the worldwide resource for nonwoven technologies, we must require that our facilities be expanded to include a high-speed, flexible, pilot scale manufacturing capability covering a broad spectrum of technologies. This goal has been the center of NCRC focus for over a year and reflects the wishes of the industry at large.

We have made announcements regarding the **SpunMelt** facility for NCRC, under construction by two of its recent members (JM Laboratories and Hills, Inc.). In addition, our plans for facility enhancement include a high speed, state-of-the-art **hydroentangling** unit as well as a **high-speed card** line. These three unique capabilities, when complete, will provide a one-of-a-kind pilot facility in North America. It will permit our industrial affiliates and others to engage in product development as well as process design, research and engineering. Coupled with a highly sophisticated set of analytical capabilities, NCRC is fast becoming "the worldwide resource for nonwoven technologies." It is clear that along with evolutions in the industry, our roles in academic institutions also undergo redefinition. The establishment of the facility described above is part of our redefinition. This would not have been possible without the support of the administrative structure of the university system. Our administration has demonstrated complete trust in our vision in this regard and has made it possible for the new facility to be housed in a new high bay building on the Centennial

Campus of the North Carolina State University, across from the College of Textiles.

Our expansion represents an investment of over $10 MM. Our five-year strategic plan includes the addition and upgrading of all our existing capabilities in air-lay, wet-lay and needling.

Organization

The organization of the Center is illustrated in Figure 1. The Center has developed **core research**, **non-core research,** and **technology transfer** activities. The Director coordinates the research activities of the Center, carried out by faculty, staff, and students of the participating universities. The **technology transfer** activities are developed and coordinated by an **Associate Director**, supported by a **Laboratory Research Specialist**.

The Director, who reports to the Dean of the College of Textiles and coordinates the activities of the Center with the Department of Textiles Technology and Apparel Management, supervises the overall operation of the Center. The Director is also responsible for:

- recruiting new members and retaining existing ones
- long range planning of Center activities
- maintaining close relationships with the Industrial Advisory Board of the Center
- seeking IAB's assistance and counsel in matters related to membership and research needs.

In addition to the Associate Director for Technology Transfer, the Center Director is assisted by an **Associate Director for Administration** who handles membership recruitment/maintenance functions and other coordination and administrative functions. Additional, support staff needs are met by an **Administrative Assistant**.

A **University Policy Committee,** consisting of senior staff of the University, the College of Textiles, and the Center Director, serves to facilitate smooth operation of the Center. A **Center Analyst** approved by the National Science Foundation (NSF) monitors the operation of the Center to ensure that NSF guidelines are met. Therefore, the Center Analyst plays a critical advisory role.

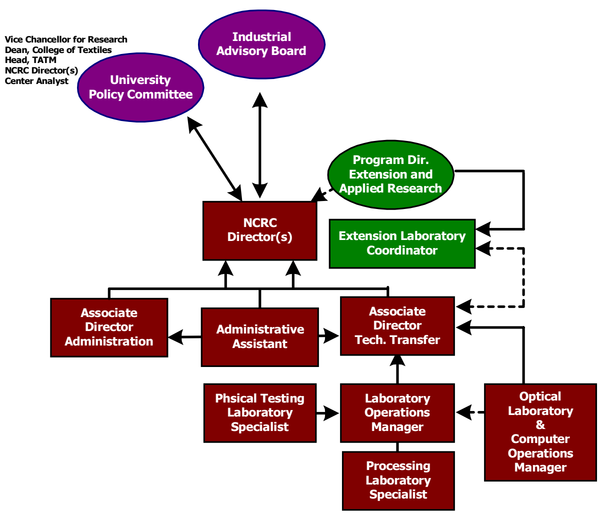

Figure 1. Organizational chart of NCRC.

Membership

Membership in NCRC is governed by the Center Bylaws approved by the IAB. Any company, worldwide, involved in 1) manufacturing nonwoven roll goods, 2) converting roll goods into end use items, or 3) supplying machinery or raw materials to the nonwoven industry is entitled to be a member of the Center. There are different categories of membership available. The fee levels (please see attachment) for the membership are set by the IAB and are reviewed periodically. Present membership of the Center is listed at the end of this document.

Members

The companies with full Membership are represented on the IAB and have voting rights. Therefore, they directly influence the nature of the **core** research undertaken by the Center and monitor its progress. Their representatives are entitled to attend meetings of the Center where results of the **core** research programs are reported. They receive semi-annual progress reports and an annual report from the Center. Their staff members are entitled to attend workshops, training seminars, and research symposia organized by the Center, at reduced fees, mutually agreed upon by the IAB, the Center, and the College of Textiles administration.

Affiliates

Small and medium size companies may join as **Affiliates**. Affiliates pay an annual fee based on their average annual sales (see attachment). Affiliates do not have representation on the IAB, but are invited to attend its meetings. Their representatives are entitled to attend meetings of the Center where results of the **core** research programs are reported. They receive semi-annual progress reports and an annual report from the Center. Their staff members are entitled to attend workshops, training seminars, and research symposia organized by the Center, at reduced fees, mutually agreed upon by the IAB, the Center and the College of Textiles administration.

Associates

Non-profit organizations engaged in activities relevant to the Center may join as **Associates**. Associates pay an annual fee as established by the IAB. Associates do not have representation on the IAB, but are invited to attend its meetings. Their representatives are entitled to attend meetings of the Center where results of the **core** research programs are reported. They receive semi-annual progress reports and an annual report from the Center. Their staff members are entitled to attend workshops, training seminars, and research symposia organized by the Center, at reduced fees, mutually agreed upon by the IAB, the Center and the College of Textiles administration. **Associates** are not entitled to receiving **intellectual property**.

Industrial Advisory Board

An **Industrial Advisory Board** (IAB) has been established. Each Member Company (not Affiliate or Associate) is represented on the IAB. The Board meets at least twice a year and gives advice on the nature of the core research programs carried out in the Center. Research proposals are developed by the faculty in consultation with Member companies based on their perceptions of the needs of the nonwoven industry. The IAB helps prioritize these proposals for the funding decision. Progress reports of the research are presented to the IAB members and their technical representatives twice a year. The Board discusses the importance and quality of the results and recommends the Center's path forward.

The Board also monitors operational aspects of the Center. It plays an important role in the recruitment of new members. It sets policy with regard to membership criteria and operation of the Center by updating and modifying the Bylaws.

Research Programs

Core research programs are developed jointly by the Center faculty/staff and the IAB. Joint faculty/staff/industry Technology Focus Groups are key to this effort. Based on these discussions, projects are formulated by the faculty and presented to the IAB. Each IAB member assesses the usefulness of the proposed project and rates the project's usefulness and relevance to their business.

In addition to the core research programs, the Center also seeks to develop **non-core** research and development projects sponsored by companies on specific problems of **proprietary** or non-proprietary nature. The results of this research are the property of the sponsoring company, within the guidelines of the university. Member companies pay reduced "**indirect cost"** charges on direct costs (less equipment) in case of non-core research. Non-member companies pay the full indirect costs (on the order of 49% of the direct costs, less equipment).

Selected Theses

- Combination of Hydroentanglement and Foam Bonding Technologies for Wood Pulp and Polyester Fibers in Wet Lay Nonwoven Fabrics by Severine Gahide - M.S. thesis- NCSU
- Probabilistic and Statistical Modeling for Geometric Structure of Nonwoven Fabrics by Huiji Chun- Ph. D. thesis - NCSU
- Fundamentals of Fiber Bonding in Thermally Bonded Nonwoven by Aparna Chidambaram- Ph. D. thesis - NCSU
- The Assessment of Cross Machine Uniformity of Carded Web by Ayad Oumera- Ph. D. thesis- NCSU
- The Role of Fiber Finishes in the Conversion of Fibers to Nonwovens by Murali Velmurugan- M. S. thesis - NCSU
- Formation of 3-D Meltblown Structures Using Robotic Control of Fiber Deposition by Raoul Farer- Ph. D. thesis- NCSU
- Biaxial Tensile Testing of Nonwoven Textile Fabrics by Hemen Dattani- M.S. thesis - NCSU
- Constitutive Modeling of Spun-bonded Nonwovens by Smita Bais- Ph. D. Thesis- Clemson University
- Fundamentals of Thermal Bonding in Nonwovens by Rahul Dharmadhikary- Ph. D. thesis- NCSU
- Formation of Fiberweb From Staple Microfibers by Yoon Hwang- M.S. thesis- NCSU
- NWMDB: A Materials Data Management System For Nonwovens by Shachindra Parker- M.S. thesis- NCSU
- Orientation Measurements in Fibrous Assemblies Using Image Analysis by Ravi Ramanathan- Ph. D. thesis- University of Maryland
- Study of Needlepunching Process and Products by Hyungup Kim" Ph. D. thesis- NCSU

Selected Center Publications

Books

1. B. Pourdeyhimi (editor), Imaging and Image Analysis for Plastics, (1999).

Journal Articles

2. B. Pourdeyhimi and R. Dent, A note on the Measurement of Fiber Diameter Distribution in Nonwovens, *Textile Research Journal, 69: (4)233-236, (1999).*
3. B. Pourdeyhimi and X. Wang and F. Lee, Making Scratch Resistance Visible. *European Coatings Journal*, (4), (1999).
4. B. Pourdeyhimi and X. Wang and F. Lee, Evaluation of Scratch and Mar Resistance in Automotive Coatings: Surface Reflectivity and Texture. *European Coatings Journal.*
5. B. Pourdeyhimi, H. S. Kim and F. Lee, A New Algorithm for the Measurement of Scribe Corrosion. *European Coatings Journal*.
6. H. S. Kim, M. Latifi and B. Pourdeyhimi, Evaluation of Fuzz in Nonwovens, *International Nonwovens Journal,* Vol. 9, No. 1, 18-22, (2000).
7. M. A. Narter, S. K. Batra, and D. R. Buchanan, Micromechanics of Three-Dimensional Fiberwebs: Constitutive Equations, *Proceedings Royal Society of London*, A 455, pp 3549-3569, 1999
8. H. S. Kim, B. Pourdeyhimi, A. Deshpande, A. Abhiraman, and P. Desai, The Deformation of Nonwovens due to Loading, *Textile Research Journal*, 69, pp 185-92, 1999.
9. M. Latifi, H. S. Kim and B. Pourdeyhimi, A note on Pilling Due to fabric to fabric Abrasion, *Textile Research Journal, In Press.*
10. S. Chand, G. S. Bhat, J. E. Spruiell and S. R. Malkan, "Changes in Structure and Properties of PP Fibers During Thermal Bonding". *Thermochemica Acta* ,in press.
11. Seyam, A. M., Applications of On-line Monitoring of Dynamic Forces Experienced by Needles during Formation of Needled Fabrics, *International Nonwovens Journal* 8, No. 2, 55-60, 1999.
12. Meng, J., Seyam, A. M., and Batra, S. K., Carding Dynamics Part I: Previous Studies of Fiber Distribution and Movement in Carding, *Textile Research Journal* 69, 90-96, 1999.
13. Seyam, A. M., Meng, J., and El-Shiekh, A., Carding Dynamics, Part II: Development of New Device for On-Line Measurement of Two-Dimensional Fiber Loading on Card Elements, *Textile Research Journal* 69, 155-161, 1999.
14. Ghosh, T. Seyam, A. M., and Lee, G., On the Use of Robotics for Melt-Blowing to Form Shaped/Molded Fabric Structures, *Proceedings of the IEEE Robotics and Automation Conference*, San Francisco, April 24-28, 2000.
15. Seyam, A.M., Impact of Needling Parameters on the Location of Maximum Needle Force Due to Fiberweb/Needle interaction, *Proceedings of the Needlepunch International Conference*, Greenville, South Carolina, April 2000.
16. Ghosh, T.K., Farer, R., Grant, E., Seyam, A.M., and Batra, S.K., Formation of Molded Fabric Structures through Integration of Melt-Blowing and Robotics, *Proceedings of the Techtextil Symposium*, Atlanta, Georgia, March 2000.
17. Seyam, A.M., A. Mohamed and H. Kim, Signal Analysis of Dynamic Forces Experienced by Individual Needles at High Speed Needlepunching, *Textile Research Journal* 68 No. 4, 296-301, April 1998.
18. Smita Bais-Singh, Bhuvenesh Goswami, Predicting the Biaxial Tensile Deformation Behavior of Spunbonded Nonwovens, *Textile Research Journal* 68,No. 3, 219-227 1998.
19. Smita Bais-Singh, Sherill B. Biggers Jr., Bhuvenesh Goswami, Finite Element Modeling of the Nonuniform Deformation of Spunbonded Nonwovens, *Textile Research Jour*nal 68, No. 5, 327-341 May 1998.
20. Dharmadhikary, R., H. A. Davis, T. F. Gilmore (deceased), S. K. Batra, Influence of Fiber Structure on properties of Thermally point Bonded Nonwoven, *Textile research Journal* 69 No. 10, 725-749, Oct. 1999.
21. Pourdeyhimi B. and R. Dent, Measurement of Fiber Orientation in Nonwovens, Part 5: Real webs, *Textile Research Journal*, In Press.
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25. K., Gilmore, T. F., "Processing Cotton and Cotton/Pulp Blends for Wet-Laid Nonwovens using Novel Dispersion Technologies," 1998 TAPPI Nonwovens Conference Proceedings, TAPPI PRESS, St. Petersburg, Florida, pp.133-136, 1998.

26. W. Huang, and K. K. Leonas, Evaluation of a One-Bath Process for Imparting Repellency and Antimicrobial Activity to Nonwoven Surgical Gown Fabrics, *Textile Research Journal*, (In Press)
27. T. K. Ghosh, Development and Evaluation of a Biaxial Tensile Tester for Fabrics, *Journal of Testing and Evaluation (ASTM)*, 27, (4) pp. 282-289, 1999
28. T. Y. Park, and T. K. Ghosh, Modeling and Structural Analysis of the Bending Rigidity of Nonwoven Fabrics, *Journal of the Korean Fiber Society*, 36, (6) pp. 455-462, 1999
29. A. Shahani, D. A. Shiffler, and S. K. Batra, Foamed Latex Bonding of Spunlace Fabrics to Improve Physical Properties, *International Nonwovens Journal*, 8, (2) pp. 41-48, 1999

Selected Center Projects

Recent

- Studies of the Uniformity of Fiberweb Basis Weight and Structure
- Study of Needlepunch Products and Processes
- Processing of Cotton and Cotton/Pulp Blends for Wet Laid Nonwovens
- Mechanism of Microorganism Transmission Through Nonwovens
- Geometrical and Probabilistic Modeling of Nonwoven Fabrics
- Simulation and Image Processing of Nonwoven Fabrics
- Foam Latex Bonding of Hydroentangled Nonwovens
- Carding Dynamics: Assessment and Control of Cross Machine Uniformity
- Processability of Fiberwebs from Staple Microfibers
- Fundamentals of Fiber Bonding in Thermal Bonding of Fibers
- Stress-Strain Response of Fabrics Under Two-Dimensional Loading
- The Role of Finishes in Nonwovens

Current

- Prediction of Performance in Thermally Point Bonded Nonwovens
- Role of Fiber Morphology in Thermal Bonding
- Stress and Structure Distribution in Thermally Point Bonded Nonwovens
- Fiber Crimp and Crimp Stability in Nonwoven Fabric Processes
- Fundamentals of Fiber in Water Dispersion
- The Role of Fiber Finishes in the Conversion of Fibers to Nonwovens: Part II: Fundamental Study of Finish Application
- The Impact of Input Energy, Fiber Properties, and Forming Wire on the Performance and Aesthetics of Hydroentangled Fabrics
- Carding Dynamics – Improving the 3 Dimensional Uniformity of Carded and Cross Lapped Webs
- Modeling In-Plane Liquid Transport in Nonwovens
- Hydroentangled Nonwovens Designed High-Speed, Low-Cost Rigid Fiber Composites.

Proposed

- Surgical Face Masks Barrier Effectiveness: Influence of Construction & Finish
- Morphology Evolution in Bicomponent Fibers in Thermal Point Bonded Nonwoven Fabrics
- Characterization of Transport Properties in Nonwovens
- Evaluation of Structural Variability in Nonwovens Using Image Analysis
- The Influence of Material Variables in Spunbonded Nonwoven Polypropylene Webs
- Analysis and Development of "Articulate" Measurement of Spatial Irregularity in Nonwovens
- Enzyme Treated Flax Fiber as a Basis for Durable or Degradable Nonwovens
- Material-Structure Relations Governing Tissue Ingrowth in Nonwoven

Selected Accomplishments

Three selected examples of significant accomplishment in research are listed below:

Prediction of Performance in Thermally Point-bonded Nonwovens (PIs: A. Abhiraman, Georgia Institute of Technology, Atlanta, GA and Behnam Pourdeyhimi, Nonwovens Cooperative Research Center, NC State University, Raleigh NC) A major effort is being made to develop a rational framework for prediction of relevant mechanical properties of nonwovens, with its initial emphasis on thermally point bonded materials. This work, carried out with an integrated set of experimental measurements and theoretical models, has yielded the following results.

- Among the processing variables, viz., pressure, temperature and area of thermal bonding, temperature and area of bonding have a significant effect on the mechanical properties of the resulting nonwovens.
- At typical processing speeds, the properties of non-bonded domains are essentially unaffected by the bonding process.
- Contrary to common perception, the bonded domains also deform to a significant extent when a nonwoven is deformed.
- The stiffness and its directional dependence in a nonwoven can be controlled by the combination of orientation distribution of the fibers in the web and the shape, distribution and orientation of thermal bonds.
- A model, comprising of a simple combination of the bonded and non-bonded domains' properties, can describe quantitatively the mechanical properties in tension, shear and bending.
- The *directional dependence of stiffness* (in shear, tension and bending), *as well as strength*, can be predicted through simple models that take advantage of the symmetry that exists in most nonwovens.
- The fundamental stiffness constants of a nonwoven are found to have a strong correlation to the bonding process conditions.
- The mechanism of mechanical failure of thermally bonded nonwovens changes from premature disintegration of the bonded domain when under-bonded (e.g., low bonding temperature) to premature fracture at the bonded domains' boundary when over-bonded (e.g., high bonding temperature). The fundamental material constants that govern failure reveal the consequences of such a change in the mechanism of failure.

The work on mechanical properties of thermally point-bonded nonwovens has potentially significant practical implications. The quantitative correlation between (i) fundamental stiffness constants of nonwovens and the bonding conditions (bond area, bonding temperature, etc.), (ii) the fiber orientation and non-bonded domain's stiffness constants, and (iii) the parameters that govern failure and the bonding conditions, can be used to design optimum combinations of material and process parameters for desired mechanical properties. Also, when the current experimental work on bond patterns and the modeling work on bridging the continuum and micro-mechanical approaches to predict mechanical properties is completed, it should facilitate the design of nonwovens to enhance or suppress directional dependence of mechanical properties as desired for specific applications.

Surgical Gown Fabrics as Barriers to Small Particle Transmission: Evaluation Using Confocal Microscopy (PI: Karen Leonas, Nonwovens Cooperative Research Center, NCSU, Raleigh NC and University of Georgia, Athens, GA.) In recent years, the potential for occupational exposure to blood borne pathogens, such as human immuno-deficiency virus (HIV) and hepatitis B, has received much attention. Protective surgical apparel can play an important role in minimizing disease transmission in the operating theater. Bacterial and viral diseases are spread through both airborne and blood borne pathways. Surgical apparel can reduce the transfer of microorganisms by creating a physical barrier between the infection source and a healthy individual (Goldman, 1991). To develop fabrics that effectively prevent the transmission of liquids and microorganism, it is important to understand the transmission mechanism. However, there is little research reported evaluating this aspect.

Attempts to identify this mechanism have failed due to large size differences between the particle and fabric components. Also, fabrics are three-dimensional structures composed of void and non-void areas. Traditional Scanning Electron Microscopy (SEM) and light microscopy techniques provide detailed surface and near surface structural information, but it is not possible to achieve adequate depth characteristics with these techniques. With a relatively new microscopy technique, laser Scanning Confocal Microscopy (LSCM),it may be possible learns additional information concerning the transmission mechanism.

Using the LSCM technique, nonwoven fabrics used in surgical gowns and drapes were evaluated. Solutions containing fluoresbrite microspheres were applied to the fabric's surface under conditions that would enhance transmission. The microspheres ranged in size from 0.5 to 1.0 microns, consistent with the size of S. auerus, and were prepared in liquid solutions. Using LSCM, three dimensional image micrographs were constructed and the location of the microspheres within the fabric structure determined.

LSCM was used to evaluate the transmission pattern of fluoresbrite microspheres in solution through fabrics used in surgical gowns and drapes. The surface tension of the liquid did not impact the distribution pattern of the spheres. The fabric construction and fiber content of the fibers influenced the particle distribution. The nonwoven composite fabric showed strike-through at the edges of the point bond sites. Strike-through of the spunlaced fabric was a result of fabric failure and specific characteristics associated with this could not be identified in this study. In the fabrics that contained a hydrophilic/hydrophobic fiber blend the particles were more heavily concentrated at the hydrophilic fiber locations. This may be the result of aqueous solutions being absorbed by hydrophilic fibers.

Geometric and Probabilistic Modeling of Nonwoven Fabrics (PIs: Moon W. Suh, Jae L. Woo, Nonwovens Cooperative Research Center, NCSU, Raleigh NC and NC State University, Raleigh NC) Using probability theory, the research models the formation of a fabric and seeks to define and determine its structure while trying to get closer to reality. For the first time, it has been possible to not only develop the basic theory but also develop in parallel an accurate computer simulation method. In both cases, the number of fiber intersections (overlaps) per unit area and its statistical variation for a known number of fibers comprising a known total length of fiber (in the unit area) become critical measures of the structural geometry.

On the practical end, the results obtained thus far have the potential for optimizing physical properties of nonwoven fabrics such as tensile strength, elongation and their variations as a function of basis weight. The results obtained on intersection geometry are now being extended to the so-called "pore size and distribution" that is critical to properties such as porosity, water/air permeability, filtration efficiency and acoustical characteristics. While this study is theoretic in nature, its implications in practice are far reaching. It attempts to model the formation of a nonwoven fabric under idealized conditions.

On the theoretical/fundamental end, the nature of this research has opened an entirely new domain of geometrical probability theory with potential for application to many other fields of scientific endeavor.