National Textile Center
FY 2003 (Year 12) Project Proposal

Project No.

F03-MD01

Competency: Fabrication

Electro-Static Web Formation

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Objective:

Currently, four major fiber web formation methods are used: carded, carded cross-lapped, air laid and wet laid. Fiber orientation distribution in such webs is passively controlled and fiber ends are bent and form 'hooks'. We are proposing a new innovative web forming method by electro-static field forces, in which fiber orientation distribution is positively controlled and hook formation is minimized. This novel web formation technique will provide fiber webs with engineered fabric properties such as strength, pore size and bending behavior. The Specific objectives of this proposal are to:

1. Develop models for predicting the movement of long-fibers (1-4 inches) in electro-static fields and for selectively orientating fibers by using electrostatic fields.
2. Expand our understanding how electrostatics can be utilized to generate webs suitable for secondary bonding in various nonwovens processes. The focus will be on developing an understanding of how variables such as polymer type, fiber cross-sectional geometry, fiber length and topical finish affect such a process.
3. Demonstrate the feasibility of using an electrostatic field for creating fiber webs of various fiber lengths and controlled fiber orientations. The created webs will be able to generate enhanced fabrics after bonding.

Relevance to NTC Mission:
It is a significant issue with card and bond fabrics that there is a large difference between the strengths in the CD and MD directions. Currently that difference is a factor of about 4 and if there was some process that could reduce this difference while maintaining high processing speeds, it would be most valuable to the industry. Our research will provide opportunities for developing a new generation of fabrics and fabric forming systems. Our findings shall provide the US fiber, fiber finishes and fabric producers with basic knowledge not only on how to form fabrics using electrostatic principles but also regarding how to engineer the fabric with predetermined geometry and hence predetermined properties.

State of the Art:
Currently, the industry uses four main methods to form fiber webs. These are carded, carded and cross-lapped, air laid, and wet laid fiber webs. The fiber orientation in such webs (which is critical to the final fabric properties such as strength, pore size, bending behavior, etc.) is controlled in a passive manner and the exact fiber orientation distribution (FOD) is determined, by a certain extent, only by the maintenance of a consistent process. In such fiber web formation methods, different trials with different processing parameters are conducted and the fiber orientation distribution is measured for each trial, either directly, or through the analysis of fabric properties. This process is often repeated until somewhat acceptable FOD – fabric properties are developed within the limitations and inherent variability of the process. In addition to limitations in the control of fiber orientation, the traditional technologies have significant limitations relative to their ability to generate low weight fiber webs. We are proposing the use of

electrostatic forces, acting on properly charged fibers in web forming zone, as a method for **positively** controlling fiber orientation and improving the industry's ability of generate low weight webs. The limitation in producing lightweight fiber web is due to the nonuniformity in basis weight produced by these traditional techniques.

In recent work, Hou, Kim and Lewis [Y. Hou's MS Thesis, supported by NTC F97-D01, UMD (Fall 2001)] studied short fiber motion in electrostatic field by high-speed digital photography. They found that short fibers with a conductive finish in an electrostatic field are oriented perpendicular to the equipotential line and move along the field line. Basically there are three ways for charging fibers in electrostatic orientation processes; corona charging, direct (or contact) charging, and tribocharging. Corona charging is not dependent on the surface conductivity of fibers, while tribocharging requires extremely low conductivity in at least one of the frictional pair. [Kleber, W. and K. Marton, *Comparison Of Flocking Methods With Various Current Types*, Proceedings of 13th International Flock Seminar, Darmstadt, Germany, 4-5 October 1994] However, we (Kim, Lewis) found that it is essential to treat fibers with a conductive surface finish to control the fiber orientation and motion in a high-tension electro-static field. Generally, it is desirable to impart a surface resistivity of $10^7 – 10^9\ \Omega$ for corona charging and $10^5 – 10^7\ \Omega$ for contact charging. For positive control over fiber motion in an electrostatic field, contact charging is preferred to corona charging. Controlling the charge species and amount applied to fiber surfaces by corona charging is very difficult, if not impossible. Nagi-Zade and Grosberg studied contact charging and reported that fibers with only field-induced polarization do not have enough force available to straighten such fibers and the orientation of these "uncharged" fibers would take approximately one second. Required time to charge cotton fibers in an electrostatic field are strongly correlated to the field strength. For example, a cotton fiber rested on a positive pole acquires a charge amounting to 2-4 x 10^{-11} C in 23 msec and moves toward the negative pole at an average speed of 7.1 m/sec. [Nagi-Zade, A.T. and P. Grosberg, *The Manipulation of Fibers by Means of a Charged Field,* J. Text. Inst., **64**, 431-436 (1973)]. Thus, we will employ surface finish and direct charging for positive control of fiber motion that allow for the control of fiber web basis weight and its uniformity and FOD.

Earlier efforts in fiber transfer, orientation and separation in electrostatic spinning were reviewed and analyzed by Dogu. [I. Dogu, fundamentals of electrostatic spinning, Tex. Res. J., Part I: **35**,521-532 (1975), Part II: **36,** 676-691 (1976)] Robert Jr. et al reported improved electrostatic spinning system equipped with a new twisting and fiber feeding device. [Robert, Jr., K.Q., A. Baril, R.B. Reif, P.E. McCrady, *New Electrostatic Spinning Concept for Cotton*, J. of Eng. For Ind., **106**, 247-252 (1984)]. In these electro-spinning systems, they employed corona charging methods. These systems experienced difficulties in controlling fiber orientation and speed. This may be due to the fact that corona charging is not reliable and charges imparted on the fibers are varying. Talbot et al invented a method of forming a composite mat of directionally oriented ligunocellulosic fibrous material. [US Patent 4,113,812, Sep. 12, 1978]. This invention is directly related to the current proposal in the positive control of fiber web weight and its uniformity and FOD, even if it is only unidirectional. They employed a particle orientation chamber with vertical electrodes on two sides directly above the horizontal mat supporting surface, which is on top of a moving conveyor belt. The oriented fiber mat in the chamber drops on the mat forming conveyor belt. It was not clear that the particles in the chamber were charged. It seems that it relies on the field-induced polarization for orientation of short fibers. Yao invented an apparatus of electrostatic opening and short fiber separation. This device aligns cotton fibers in a carded web using electrostatic field forces acted upon by a pair of metal belts, which are connected to a high DC tension generator. [US Patent 5,327,617, Jul. 12, 1994]

Based on the review of the state of the art, it is evident that proper arrangement of electrodes, direct charging and a conductive surface finish are needed to provide the positive control of fiber orientation in a web without 'fiber hook' formation. However, the precise control of fiber orientation and motion with electrostatic forces to form a predetermined FOD web has significant challenges. The problems stem from non-uniformity in surface finish applied, fiber geometrical parameters, and deviation of the electrostatic field lines from the theoretically predicted one and other variations.

Approach:
Both experimental and numerical modeling study will be conducted. The experimental study is to provide basic understanding of the physical process for modeling and data validate the numerical model. Numerical modeling of fiber/electro static field interaction will be developed with commercially available multi-physics finite element code.

1. Develop numerical models for predicating the movement of long fibers in the range of 1-4 inches in electro-static fields. Particular emphasis will be given to understanding the impact of fiber length and developing approaches for controlling the orientation of the fibers by the electrode arrangement and high voltage modulation through this process.
2. Confirm the above models through experimentation.
3. Revise the models if the models are significantly different from the experiments.
4. In parallel, to the above work, initiate studies on the relationship between surface charge generation – dissipation and key fiber properties (polymer type, fiber surface, fiber geometry, topical fiber finish, etc.).
5. Based on the above studies, develop techniques that demonstrate the working principles and potential for electro-static control of fibers and their orientation in web preparation.

This Year's Goal:

1. Develop a model describing the staple fiber / electrostatic field interaction after evaluating current relevant models for fiber orientation control by electrostatic means.
2. Establish experimentally the effects of key fiber parameters (polymer type, fiber geometry, surface conductive finish etc.) on surface charge generation /dissipation and fiber motion control in an electrostatic field.
3. Develop a concept of a device to accomplish our objectives in regard to; (a) field and electrode geometry, (b) high voltage application and modulation, if needed, and (c) fiber separation, presentation and web transport system

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Outreach to Industry:

Drs. Seemuth of DuPont and Theyson of Goulston will be significantly contributing in conducting the research as PIs. Through their contact with numerous US fabric producers, the knowledge created by our research team will be quickly transferred. Additionally, the team will publish the findings in well-known journals and well-attended industry conferences.

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New Resources Required:

High-tension generators, chargeability tester of fibers with surface finish and fiber motion analyzer based on high-speed digital camera are available at UMD Flock Materials Laboratory. Goulston Technologies and DuPont Nylon have pledged to provide technical assistance in special measurements, fibers and fibers' finishes. However, we need required components and mechanisms for fibers and fiber web transportation and electric field modulation.