Scientific Study of Flock Materials and the Flocking Process

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PROJECT OBJECTIVE

1. Develop a fundamental understanding of flock motion in electrostatic, gravitational and pneumatic force field during the flocking process.
2. Establish an understanding of textile based flock materials and processes from the standpoint of test procedures as they pertain to materials processing properties such as electrical conductivity, fiber motion.
3. Develop a fundamental understanding of some of the functional properties of flocked materials such as surface durability, coloration and color measurement.
4. Understand fundamentals of controlling transport phenomena through flocked surfaces and assemblies.

ABSTRACT

Flocking involves the application of fine particles to adhesive coated surfaces. The majority of flocking is done using finely cut natural or synthetic fibers. Flocked finishes impart a decorative and / or functional characteristic to the surface. Flock fibers are usually applied to adhesive coated surfaces mechanically, electrostatically, or by a combination of both techniques. The focal points of this year investigation are modeling of flock fiber motion in an electric field, objective characterization of flock fibers and flocked surface, and correlation between durability and flocking process variables.

INTRODUCTION

Flocking is the application of fine particles to adhesive coated surfaces. The majority of flocking done uses finely cut natural or synthetic fibers. A flocked finish imparts a decorative and / or functional characteristic to the surface; decorative and visual appeal, friction modification, thermal insulation and stability, transitionless power transmission, liquid retention or dispersal, buffing and polishing, and cushioning and protection.

The variety of materials that are applied to numerous surfaces through different flocking methods create a wide range of end products. Flock fibers are usually applied to adhesive coated surfaces mechanically, electrostatically, or by a combination of both techniques. Mechanical flocking can be further divided into windblown and beater-bar methods. Electrostatic flocking sometimes incorporates a pneumatic process to propel fibers toward a surface in an air-stream. The flocking process is used on items ranging from retail consumer goods to products for high-technology and military applications.

This year, the focal points of investigation are modeling of flock fiber motion in an electric field, objective characterization of flock fibers and flocked surface, and correlation between durability and flocking process variables.

MODELLING OF FLOCK MOTION IN ELECTROSTATIC FIELD

Quality of the flock is strongly influenced by the flock density on the finished flock surface. The flock density depends on flock motion in the electric field. The flock motion analyses found in the literature are based on simplified physical constraints in the flocking zone and charges on flock fibers. For example, Bershev derived the velocity profile of flock fibers under the assumption of a constant electrostatic field E and without an air drag force acting on fibers.[Bershev 1977] Other researchers relaxed the electrostatic field restriction by including the disturbance induced by a space charge on flock surfaces.[Kleber and Schmidt 1992].

To derive a more general model of flock motion, the following assumptions are made:

- Flock surface has a uniform finish, and no contamination
- Air medium in the flocking zone is exposed to a constant electric field intensity, which is lower than the dielectric break down and ionization potential of the material.
- Air drag and a pneumatic flow field exist in the flocking zone.
- Flocking is carried out in a steady state condition by a DC flocking unit.
- All fibers carry the same net charge q. Thus, the average charge density r = q C, where C is the number of flock fibers per unit volume

The Equation of Motion

The motion of flock fibers in a composite field consists of electrostatic ($\vec{E}$), pneumatic flow ($\vec{V}$) and gravitational ($\vec{g}$) fields as described by Newton's equation:

$$m\,\vec{a} = q\vec{E} - K\vec{V} - m\vec{g} \qquad (1)$$

where m and q are mass and net surface charge of a flock fiber, and K is a drag coefficient for the short fiber, which was given by Kleber and Schmidt:

$$K = C_0\sqrt{\frac{g_L}{d_F}}\frac{p}{2}r_L l_F d_F \qquad (2)$$

where l_F, d_F are length of fiber and diameter and r_L, g_L are specific weight and kinematic viscosity of air. In order to describe the flock motion trajectory, Eqn. 1 should be solved simultaneously together with electrostatic and pneumatic flow field.

Electrostatic Fields

The charge conservation (Gauss's law) and current continuity in steady state flocking yield:

$$\nabla^2 \Phi = -a\rho \tag{3}$$

$$(\vec{V} - a\nabla\Phi)\bullet\nabla\rho + a\rho^2 = 0 \tag{4}$$

where Φ, ρ, and $\vec{V}$ are the electrostatic potential, space charge density, and airflow velocity, respectively. [Sadiku 1989, Lean 1993] The dimensionless parameter $a = \mu\Phi_0/h/U_0$, where μ is the flock charge mobility, Φ_0 is the reference potential, h is the reference length, and U_0 is the reference velocity. It is a boundary condition for the potential and space charge density on the upper flock dosing screen area. [Klebler and Schmidt 1992] Although the flow field is elucidated from the steady, incompressible Navier-Stoke's equation in the composite field, $\vec{V}$ is considered decoupled from the electrostatic field under the assumptions.

The complete simultaneous solutions for equations 1, 3, and 4 describe the flock motion in the flocking zone. The governing equation system derived is numerically solved by finite difference or other methods. The numercal results will be compared with the actual experimental observation of the flocking process.

A closed form of solution of the equation of motion by assuming a spherical charged particle, constant electric field and air drag only was given by Kutsuwada and coworkers: [Kutsuwada 1993, Klebler and Marton 1994]

In x direction:

$$m\frac{d^2x}{dt^2} + 6\pi\eta R\frac{dx}{dt} = qE_x$$

$$x = -\frac{mqE_x}{(6\pi\eta R)^2}\{1-\exp(-\frac{6\pi\eta R}{m}t)\} + \frac{qE_x}{6\pi\eta R}t \tag{5}$$

In y direction:

$$m\frac{d^2y}{dt^2} + 6\pi\eta R\frac{dy}{dt} = qE_y$$

$$y = -\frac{mqE_y}{(6\pi\eta R)^2}\{1-\exp(-\frac{6\pi\eta R}{m}t)\} + \frac{qE_y}{6\pi\eta R}t \tag{6}$$

In z direction (vertical direction):

$$m\frac{d^2z}{dt^2} + 6\pi\eta R\frac{dz}{dt} = qE_z + mg$$

$$z = -\frac{m(mg+qE_z)}{(6\pi\eta R)^2}\{1-\exp(-\frac{6\pi\eta R}{m}t)\} + \frac{qE_z}{6\pi\eta R}t \tag{7}$$

This is a first approximation since the flock fibers are cylindrical shape particles. They have a certain length and diameter with different drag coefficient. The drag coefficient for uniform flock fibers is given by K in equation 2. Spherical particle drag factor $6\pi\eta R$ in equations 5 ,6,and 7 should be modified by K. We hope that the derived governing equation system is numerically solved with boundary conditions by using the results from equations 5 to 7 as an initial guess.

ESTABLISHMENT OF FLOCK MATERIAL PROCESSING PARAMETERS

Materials and Method

Studies were conducted on establishing some basic flock material processing parameters. The instrumentation used and experimental parameters studied were:

1. Flock Motion Tester (MAAG Flockmaschinen GmbH. SPG 1000)- useful for evaluating the motion behavior and the ability of flock fibers to be suspended in, moved by and deposited on to an adhesive coated surface by the force of an electrostatic potential field.

2. Siftability Tester (MAAG Flockmaschinen GmbH RPG 1000)- evaluates the ability of flock fibers to be sifted through a metal wire screen. It simulates the siftability requirements needed in commercial flock processing equipment.

3. Fiber Conductivity (MAHLO Texo-Meter Type DMB-6 with #214 electrode) – determines basic flock fiber electrical conductivity as this property is important to flock motion behavior in an electric field.

These tests were conducted on what was chosen to be a “model” flock fiber material; 3.0 denier 0.05 inch long nylon 66 flock fibers with an AC flocking process surface finish. These fibers were selectively conditioned at 0%, 47%, 60% and 87% relative humidity. This served as the experimental variable in the study.

Results and Discussion

The effect of relative humidity (RH) on flock motion

The flock motion tester measures the rising and dispersion ability of a mass of flock fibers in an electrostatic field. Here a given quantity (2.00 grams) of flock fibers (conditioned at a specified %RH) is placed on a small metal platform that serves as one of the electrodes forming electrostatic field in the test chamber. Upon applying a DC voltage (e. g. 40 kV), a fractional amount of the original 2.00 grams of flock fiber will be dispersed in the electrical field away/off the metal platform. Flock fiber activity is then determined as the grams of fiber disrupted by the electrostatic field per second of exposure to the electrical field. Flock Motion Activity then equals the grams of fiber moved away from the electrode platform per second of time of imposed electrostatic field (e. g. 30 seconds in these experiments). Data on flock activity against %RH are presented in Table 1. As shown, flock fiber activity increases as the moisture contents of fibers (%RH of the conditioning) increases. This may be related to the influence of moisture on the conductivity and induced charge distribution on fiber surfaces. The overall observations of fiber motion in a D.C. electrostatic field indicate that the most uniform fiber activity occurs when the nylon fibers are conditioned at 60% RH. This somewhat coincides with the results of Coldwell and Hersh who conducted some parametric studies on fiber materials in the flocking process using nylon flock fibers conditioned at 70%RH. [Coldwell and Hersh 1978]

Table 1: Effect of Electrostatic Action in a DC Electric Field of Flock Fibers Conditioned at Various % Relative Humidity (a)

Relative Humidity (%)	Flock Activity (mg/s)
0	0 (b)
47	5
60	9
87	23

(a) Fractional weight of a 2.00 gram mass of flock fibers that are moved away from the base electrode per second when a DC field of 40 kV is applied for 30 seconds.
(b) Very little electrostatic activity observed with 0 % RH(dry) flock fibers.

Effects of Moisture on Mechanical Siftabilty

The RPG 1000 Siftability Tester was used to determine the mechanical siftability of flock fibers as a function of %RH conditioning. In this test, 20 gram samples of flock fibers are rotated in a metal screen walled cylindrical chamber. Siftablity is determined as the weight of fibers that are sifted through the wire mesh of the screen after 60 revolutions of the siftability chamber. Table 2 presents results of the siftability of nylon flock (3.0 denier, 0.05” long) as a function of % RH. The data show that siftablity of the flock fibers decreases as the % RH conditioning increases. This result reflects the observation that at the higher % RH, the flock fibers are found to agglomerate (ball-up) more in the siftability chamber as it is rotating. Agglomerated flock fibers do not sift very well. This observed agglomeration is most likely caused by the added moisture in the fiber system. This will increase the contact adhesion between the fibers and promote clumping of the flock fibers into bundles.

Table 2: Siftability of Nylon Flock Fibers (3.0 denier, 050” long) Conditioned at Various Relative Humidity

Relative Humidity(%)	% of Flock Sifted(a)
0	20
47	16
60	15
87	10

(a) percent of the 20.0 gram sample of flock sifted through the cylindrical metal wire screen after 60 revolutions

Effect of Moisture on Conductivity of Flock Material

The testing apparatus used for this test was the MAHLO Texo-Meter, type DMB -6- F conductivity apparatus. The electrode used was of a ring type electrode (type 214) and an insulating polymer cylinder. The synthetic coated, metallic baseplate normally used for volume conductivity was replaced with a flat sheet of aluminum for the determination of surface conductivity. The sample size for this experiment was 20.0 grams in weight. Three samples conditioned in each dessicator maintained 0, 47, 60, and 87% RH were weighed out. These samples were then placed on the aluminum baseplate and between the ring electrode one at a time. The Texto-meter was then calibrated as specified by the manufacturer of the device. The ring electrode was then firmly placed on the flock sample and the measurement was taken off of the display after a minute had passed. The effect of moisture content of flock fibers on electrical surface resistance and conductivity is shown in Figure 1. It is observed that fibers conditioned at low RH (up to 20 %) show the conductivity of non-conductors. In this range of conductivity (smaller than 10^{-9} Ω^{-1} cm^{-1}), contact charging of flock fibers is not possible. Flock fibers conditioned in the range of between 40% to 70 % RH show the most effective contact charging resistivity. [Klebler and Marton 1994]

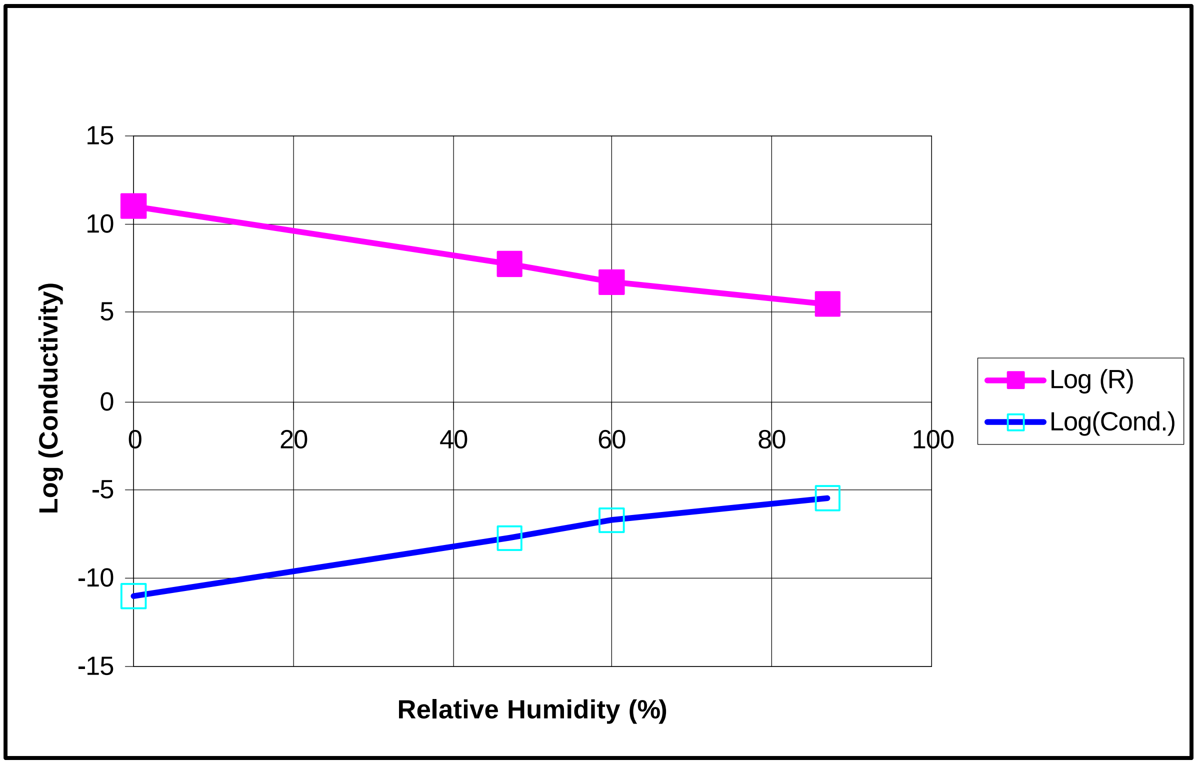

Figure 1. The effect of moisture content of flock fibers on electrical surface conductivity.

CONCLUSIONS

A mathematical model for flock motion in composite fields was derived. This model will be used to simulate the flocking process. Flock processing parameters will be experimentally measured and used in the numerical solution of model equations. Taguchi experimental design and analysis will be carried out to establish optimum processing conditions for creating quality flock products.

A summary analysis of the data obtained in this study on the effect of RH conditioning of nylon 6/6 flock fibers on (1) motion in an electrostatic field, (2) siftability through a metal screen and (3) fiber electrical conductivity is presented in Table 4. Overall, the optimum conditions for flock processing of nylon 6/6 flock fibers appears to be in the 60% RH range. In our experiments, the poorest %RH conditions for these flock fibers are at the extremes of 0% and 87%. This seems logical since at low 0% RH, the dielectric, insulation properties of nylon 6/6 fibers will predominate. Under these dry conditions, if a fiber attains an electrical charge, the fiber will retain it. These charged fibers can therefore become individually polarized. Polarized particles in an electrical field will tend to agglomerate and result in a non-uniform disturbance by an electrical field.

Table 4: Summary of Processing Property Behavior of Nylon 6/6 Flock Fibers Conditioned at Various Relative Humidities (RH).

MOISTURE CONDITION	FLOCK MOTION	SIFTABILITY	ELECTRICAL CONDUCTIVITY ($\Omega^{-1}\ cm^{-1}$)
0%RH	Non uniform deposition, little fiber movement	Static electricity build-up, clumping	very low 10^{-11}
47%RH	Non uniform deposition, some fiber movement	Same as 0% RH	low 10^{-8}
60%RH	Uniform, even fiber deposition on test surface	good siftability, fiber separation	moderate 10^{-7}
87%RH	Very uneven, heavy deposits on test surface	agglomeration, clumping	higher 10^{-6}

Alternatively, with nylon fibers conditioned at 87% RH, it is certain that a layer of water is absorbed on their surface. While this will lead to a rapid dissipation of any disrupting electrical charges that may accumulate on the surface, this moisture layer will increase the propensity for fiber-to-fiber adhesion by occlusion and capillarity effects. It is concluded that conditioning the nylon 6/6 fibers at an intermediate relative humidity, say 50% to 70% RH, is a compromise. At this %RH range, the surface charges induced onto the flock fiber by the electrical field are not retained on the fiber long enough to cause serious agglomeration of the fiber particles. Also, moisture induced inter-particle adhesion is low enough so that clumping or "treeing"of the flock fibers in an electrical field does not occur.

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