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GLOBAL CONFORMABILITY TESTING OF FABRICS: A NEW SIMPLIFIED APPROACH

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The conformability of a fabric under loading can be an important usage characteristic. A neat way to evaluate this property is to monitor the force needed to drive a piece of fabric through a circular hole, a practice whose antecedents go back at least a thousand years. A test procedure based on this principle has been developed at TRI which can supply reproducible data for a wide variety of materials, revealing significant quantitative differences. The method is somewhat similar to that used by other investigators, but with certain differences that make the test both simpler and more reliable. The test protocol, originally developed to measure resistance to deformation, can also be used to evaluate deformation memory, that is, wrinkle recovery.

HIGH SPEED MELT SPINNING OF POLY (L-LACTIC ACID) FILAMENTS

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Poly (L-lactic acid) filaments were prepared by high speed melt spinning at take-up velocities up to 5000 m/min. The crystallinity, birefringence, tensile strength, Youngs modulus and yield strength all exhibit maxima at take-up velocities between 2000 and 3000 m/min. The boiling water shrinkage exhibits a minimum in this range. The maximum tensile strength of the as-spun filaments was 385 MPa and the maximum modulus was 6 GPa.

ULTRA-HIGH MODULUS POLYPROPYLENE FIBERS

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Ultra-high modulus polypropylene fibers with exceptional thermal stability are being developed. The route of making these fibers relate to conventional process of melt spinning followed by a unique step of Draw Heat Setting (DHS). Highest modulus and tenacity obtained are around 18 Gpa and 0.72 Gpa. Thermal studies of these fibers exhibited positive thermal expansion coefficient up to temperature of 90 degree centigrade followed by very small thermal shrinkage in the temperature range of 100 degree to 140 degree centigrade. DSC thermograme exhibited a narrow peak for these fibers. SEM studies show existence of highly fibrilated structures. Stress relaxation modulus and creep compliance data indicate quantum gain in time dependent tensile behavior. SAXS data are expected to reveal detail morphological structure. These fibers may find applications in the areas of fiber reinforced composites and geotextiles.

FIBER-FORMING CELLULOSE AND LIGNOCELLULOSE SOLUTIONS

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Lyocell solutions have been prepared by dissolving wood pulp and different lignocellulosic substrates (sugar cane and kenaf) in systems containing N-methyl morpholine oxide at moderate temperatures (80-100 0C). Sudden changes in lyocell solution viscosities were noticed between 75-95 0C (the N-methyl morpholine oxide monohydrate melts at 72 0C) depending on the cellulose or lignocellulose substrate concentration. This behavior was related to the formation of the anisotropic phase, observed also by microscopy in polarized light and differential scanning calorimetry. The rheological properties pertaining particularly to the spinning operations were correlated with different pre-dissolution treatments (alkali partial delignification and/or steam explosion) and nature and concentration of the cellulosic or lignocellulosic substrate in the lyocell system.

STRUCTURE AND PROPERTIES OF HIGH PERFORMANCE FIBERS PRODUCED FROM WHOLLY AROMATIC POLYMERS

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Commercially available high performance fibers produced from wholly aromatic polymers have been shown to be promising in demanding applications. Due to their desirable properties such as high-mechanical and high-thermal stability, these fibers are finding applications in aerospace, military and industry as structural composites with desirable weight to performance ratio. A fundamental understanding of this class of fibers is of paramount importance for the development of high technology fiber based products.

In the present work, the structure and properties of commercially available high performance fibers has been extensively studied by optical birefringence, vibrational spectroscopy and electron microscopy techniques. The main emphasis has been placed on

structural characterization of fibers produces from wholly aromatic polyesters and polyamides.

Refractive indices of fibers immersed in Cargille liquids have been measured using an image splitting interphako microscope in transmission mode. This method of measuring the refractive indices and hence birefringence avoids the fringe jumping problems associated with very highly oriented systems and has been found to be more accurate than other methods. Infra-red and Raman spectroscopy methods have been used in determining the physical and chemical structure of the samples. Both methods have also been used in determining the orientation averages in terms of Legendre polynomials. The second order orientation averages obtained from polarized infra-red spectroscopy data were evaluated using dichroic ratios and transition moment angles of corresponding dipole moments. In the case of Raman spectroscopy, the orientation averages were evaluated using depolarisation ratios and immersion liquids to minimize the effects of polarization scrambling.

Scanning electron microscopy has been used for the quantitative determination of surface characteristics such as fiber diameter, cross-sectional area, shape factor and circularity parameters using an image analysis software.

The results show that high performance fibers based on wholly aromatic moieties show high molecular orientation characteristics. It is also shown that there is a direct relationship between the molecular orientation and the mechanical properties.

NEW DEVELOPMENTS FOR SPUNLACING COTTON

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Hydroentangled cotton fabrics are being produced around the world. Cottons unique properties of softness, absorbency, opaqueness and biodegradability are preserved with the hydroentangling process.

The effects of hydroentangling energy, fiber micronaire, fiber condition (raw vs. bleached) and bleaching in fabric form on fabric properties are reported. Results for fabric tensile properties, tear strength, stiffness and absorbency will also be discussed.

EFFECTS OF SOLVENT PRETREATMENT ON COTTON/CELLULOSE ACETATE NONWOVENS

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The success of the utilization of solvent treatment before thermal bonding in the fabrication of environmental friendly nonwovens from cotton and cellulose acetate fiber blends has led to enhanced tensile strengths of the nonwovens at lower calendering

temperatures. The effects of solvent vapor pretreatment times as well as the effects of bonding temperatures and blend ratios on the physical properties of nonwovens were examined by selected statistical methods. In addition, the solvent- assisted thermal calendering process was optimized by using a response surface technique. In this method, distance and desirability functions were used for simultaneous optimization of four physical properties. For better understanding the bonding adhesion between cellulose acetate fibers and cotton fibers, the nonwovens formed by different solvent pretreatment methods were examined by several microstructural analyses. The different solvent application methods, in terms of the softening behavior and the structural changes of cellulose acetate fibers, were compared.

PROBABILISTIC MODELS FOR THE GEOMETRICAL STRUCTURE OF RANDOM FIBER WEBS

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As a key component for characterizing various mechanical and structural properties of nonwoven webs, a set of probability models was developed for the number of fiber intersections to be found within a given area of random fiber web as a function of the number of fibers, aggregate fiber length and the fiber length distribution making up the population. Cases for straight fibers and curved fibers were considered in deriving the expected value and variance of the number of intersections. In addition, an elaborate computer simulation algorithm was developed to verify the theories by eliminating the border effects that are pronounced when the simulation area is relatively small compared to the fiber lengths.

The theories and simulation results have proven, for the first time, that the average number of intersections depends only on the total aggregate fiber length, but neither on the number nor the length distribution of the constituent fibers. The study also has proven that the basis weight variation within a random fiber web can be expressed and measured by the square root of the number of fiber intersections within a given area. The variance of the number of intersections, however, is shown to behave much differently for different number and length distributions of the constituent fibers. Discussions will be given on the application potentials on the work done to date.

EVALUATING NONWOVEN WEB STRUCTURE USING IMAGE ANALYSIS

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The structural variability generally characteristic of nonwoven webs dictates that large web areas must be evaluated to obtain reasonable analysis precision. This restriction limits the choice of analytical techniques are quite useful for evaluating web structure. Image analysis techniques are quite useful for web evaluation because images contain an abundance of web structural information and analytical procedures can be easily automated. We will discuss (i) hardware used in our laboratory for automated sample positioning and automated lens focusing and (ii) software developed on our laboratory for

automated image analysis of large web areas.

THE FUNDAMENTAL DEVELOPMENT OF TOTAL MATERIAL DESIGN SYSTEM FOR WOVEN FABRICS OF APPAREL USE

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In the first part of this paper, the types of designing for textile products are discussed in terms of several view points. An overview of chronological development of textile product design is conducted. In this connection, the concept of total material design is proposed.

In the Second part, the frame of computer-assisted total material design system of woven fabrics for apparel use is presented. One of the most significant features of the system is to carry out differential design by making use of a reference sample.

In the third part, the detailed computer algorithmic flow toward the development of this system is discussed. The executional procedures within the system is tracked through a certain example of rather simple design problem.

In the fourth part, the necessity of prioritization and checking the suitability of design is explained. The technique and structure of prioritization of design parameters for woven fabrics are presented with illustration. The methods for judging the suitability of design and for finding the optimum design are also discussed with illustrations.

COMPUTER AIDED ANALYSIS OF LOOM BEATING-UP MECHANISMS

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Shuttleless looms have superior productivity, high reliability, good versatility, low energy consumption, low maintenance and are highly automated. Although many components of the shuttleless looms are the same as those on shuttle looms, there are some changes in the mechanisms, used for picking, shedding and beating-up. In this study, computer models have been developed for analysis and design of the beating-up mechanism, which is of great importance to the weaving process and the quality of products. For different types of beating-up mechanisms, corresponding models are set up using Working Model, a solid dynamics simulation software. The mechanisms analyzed include the 4-link, the 6-link, and the conjugate-cam beating-up mechanisms, and their characteristics are compared. Results obtained from the models with varying geometric parameters are presented. It is demonstrated that by adjusting certain geometric parameters in the computer model, the system can be easily fine tuned to allow for a relatively longer filling insertion period in a weaving cycle. The conclusions provide useful information for designing looms with smoother operation, lower noise and vibration, and higher speeds.

A SIMPLE MODEL TO PREDICT THE PROPERTIES OF BLENDED FIBROUS STRUCTURES

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A simple theoretical model is proposed for the prediction of properties of blended fibrous structures. The model is verified by using experiment results from blended yarns. A systematic dimensionless analysis is carried out which yields several interesting findings. Depending on the nature of interactions between the fibers of different type in blended yarns, the mechanical behavior of the structures can be classified into three groups, including the ones with positive, negative and zero interactions. For each group, a generalized dimensionless equation is developed for property prediction, and comparisons with experiment data are provided.

DEFORMATION OF A SINGLE HELIX UNDER EXTENSION, COMPRESSION AND BENDING

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The idealized model for a twisted yarn structure assumes that each fiber or filament follows a helical path and that the yarn has a circular cross-section in the undeformed state. The investigation of the behavior of a single helix therefore can be considered as a first step towards the mechanical analysis of yarn deformation under extension, compression and bending which is the type of deformation which occurs in many areas of textiles processes and applications.
This paper presents a theoretical model of the large-scale deformation of a single helix subject to bending, compression and extension using the elasticity theory for one-dimensional formations. A set of first-order differential equations is solved numerically by introducing suitable boundary conditions and employing suitable numerical routine in a FORTRAN program. The effects of varying the ratio of the flexural rigidity to the torsion rigidity of the helix material and varying the helix angle together with the variation of deformation forces are studied. The cross-section of a deformed helix, in relation to the position of the neutral axis and strain energy are discussed.

A NEW HIGH SPEED DYNAMOMETER TO SUBJECT TEXTILE YARNS AT HIGH STRAIN RATES

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The high delivery speeds reached in the present textile processes produce forces that approach, and may even exceed, the breaking strength of textile materials. This phenomenon induces ever more frequently very high rates of strain on linear textiles. Subsequently, unexpected yarn breaks can be observed during the spinning as well as weaving processes. Thus, the control of manufacturing processes inevitably involves knowing the tensile behavior of textile yarns at high strain rates.

We have developed a specialized apparatus to measure linear textiles at strain rates similar to those encountered in manufacturing processes. This new high speed dynamometer (HSD) works at standard conditions. So firstly, the main features, the testing procedure and the equations concerned to the working principle of the HSD are discussed.

Experiments carried out on 57 tex poly (ethylene terephtalate) multifilament yarn have allowed us to investigate the influence of some important parameters, such as inertia effects and transverse vibrations, during the tensile tests. The effects of the strain rate and the gauge length on the mechanical properties of PET are also analyzed.

TENSILE PROPERTIES OF SLACK COTTON FIBER BUNDLES -THEORY AND APPLICATION TO HVI TESTING

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Cotton fiber tensile properties are often measured in a bundle form, Because of the nature of crimps of cotton fibers, the tensile behavior of a cotton fiber bundle differs significantly from that of a straight fiber bundle. A statistical model for the tensile behavior of a slack fiber bundle is developed in terms of its constituent single fiber properties. The results are applied to HVI (High Volume Instrument) tensile tests by simulating the bundle behaviors based on the single fiber properties obtained from Mantis tester. Comparisons are also made with earlier models for straight fiber bundles, and the new model yields the best fit with the HVI tensile test results.

COTTON COLOR MEASUREMENT AND GRADING

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Since the invention of the High Volume Instrument, known as HVI, the color of raw cotton were measured by HVI colorimeter. The HVI colorimeter measures grayness (RI) and yellowness (+b) using a pair of photo detectors and filters. It gives consistent color measurement but the measurement only agree with human visual inspection to a certain degree. To investigate the relationship among different color measurement and human visual inspection, a research project is undergoing using fiber-optic spectrometer and color image analysis.

The presentation will discuss the following topics:
- Color measurement from spectral and filtering approach.
- Improving cotton color measurement using all three primary colors (R.G.B.) and the influence of a* on color grading.

Advanced color measurement using color image analysis. Using imaging approach, more information can be obtained such as the color distribution of the sample, the content of yellow spots and other stains. The influence of the trash on color measurement will also be eliminated.

COMPARATIVE STUDY OF YARN REGULATORY USING CAPACITIVE AND OPTICAL METHODS

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Mass variation, yarn faults (neps, thin and thick places) and hairiness contribute to a considerable decrease in the quality of the yarn. Besides, these factors generate problems in the weaving and knitting processes, namely stoppages that result in low production rates and poor quality of the final product. The control of these yarn factors is, therefore, important in order to improve the processes and the quality.

In the paper, a review of the theoretical analysis of yarn evenness is carried out. Nowadays, in order to evaluate the yarn evenness, the industry uses regularity test based on a capacitive measurement method. To establish the criteria for the yarn quality, Uster carries out experimental tests all over the world to collect data and create reference graphics with high costs involved.

By using an optical sensor, yarn faults are detected independently of its linear density with a possible advantage of eliminating all the work on data collection.

A comparative study of 100% cotton yarn 24 Ne using Uster Tester III and Zweigle G 580 was made. The two different methods used by the two systems are described and

evaluated and the main results are shown and discussed.

IMPACT OF TECHNOLOGY ON YARN QUALITY

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The paper presents extracts of different pieces of research dealing with factors affecting process and product quality in staple yarn production. It is shown that recently introduced technology for evaluating fibers and yarns can provide useful tools for better understanding the role of fiber and machinery interactions. It also serves as a warning to correctly interpreting data, and examples are used to illustrate the dangers of drawing general conclusions from results which have been obtained from limited experimental data.

BIOLOGICALLY INSPIRED DESIGN: COLOR ON WINGS AND SCALES

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This talk will focus on issues that are important for generation of color in biological systems. Color generation by means other than absorption or emission of light will form the central theme of the talk. Examples of color generation using physical optics (Bragg diffraction, iridescence, thin film interference) will be given based on butterfly wings, humming bird feathers, fish scales (as pigments) and scarab beetles. This will entail discussion of colors produced by selective reflection due the existence of a frozen cholesteric phase (in the case of scarab beetles), interference and how one can produce colors that have close to 100% reflectivities for specific wavelengths. The colors will be characterized in terms of the CIE conventions. The biological relevance of such colors, strategies for using such designs for end-user applications, and in textiles will be discussed.

RECENT ADVANCES IN THE FIELD OF WETTING AND SPREADING OF SPIN FINISHES ON FIBERS

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During the production of polymeric fibers like polyester or polyamide (Nylon 6 or Nylon 66) aqueous emulsions of spin finishes are applied to the fiber bundle in order to allow proper high speed wind-up and to provide the frictional and antistatic properties required for downstream processing.
The wetting and spreading properties of spin finishes on these high-energy polymeric fibers are of paramount importance. Rapid wetting, even distribution and complete coverage of the yarns and their individual capillaries are a prerequisite for minimized

product loss through sling-off as well as for optimal lubrication and protection in processing.

Results of wicking experiments involving a new double capillary set up are presented. They are compared with video-microscopy studies of the wicking behavior in a multifilament bundle.

Additionally, a new laboratory model for the simulation of spin finish sling-off is presented. Model spin finishes have been applied to polyester and polyamide 6 multifilaments and their sling-off behavior was studied as a function of composition (including the effects of the addition of wetting, anti-sling or thickening agents), emulsion viscosity and filament temperature.

COMPUTER PREDICTION OF COLOUR SENSITIVITY OF DYE RECIPES

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A method has been developed to quantify the colour sensitivity of a dye mixture. In this method, the concept, of the colour sensitivity of matching recipes has been developed so that it covers variations not only in dye concentrations but also in dyeing parameters. Firstly the individual colour sensitivity of a dye mixture to a specific dyeing parameter was quantified by comparing the colour difference between the resulting shade from a normal dyeing condition and that produced by giving a change to the parameter. These resultant data were used to calculate the total colour sensitivity covering the dyeing variables with a model established based on CMC (2:1) equation. A set of disperse dye combinations with different energy levels were applied in dyeing to verify this computer prediction model. It was confirmed that for disperse dye recipes, the temperature error had the same importance as the weighing error had. The results also revealed that a recipe including dyestuffs in different energy levels might more probably cause a failed shade. This research work suggested that the variables of weighing and temperature control should be included in the introduced model for the practical use.

POLYMERIC CARBOXYLIC ACIDS AS NONFORMALDEHYDE DURABLE PRESS FINISHES FOR COTTON FABRICS

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Since the identification of formaldehyde as a probable human carcinogen, extensive efforts have been made to find formaldehyde-free crosslinking agents for cotton cellulose to replace the traditional N-methylol reagents. Among the new crosslinking agents being developed, polycarboxylic acids are the most promising reagents. A polycarboxylic acid forms ester crosslinkages between cellulose molecules, thus providing wrinkle-resistance to cotton fabric. In 1988, Welch reported that 1,2,3,4 - butanetetracarboxlyic acid (BTCA)

was able to provide effective crosslinking for cotton cellulose, thus imparting high levels of wrinkle resistance and laundering durability to cotton fabrics. However, the exceedingly high cost of BTCA has prevented its applications in the textile industry on a commercial scale.

In our previous research, we evaluated the effectiveness of two polymers of maleic acid, i.e., the homopolymer of maleic acid (PMA) and the terpolymer of maleic acid, acrylic acid and vinyl alcohol (TPMA), for crosslinking cotton fabrics. BTCA, PMA, and TPMA have similar molecular structures with carboxyl groups bonded to their molecular backbones, and both are able to form 5-membered cyclic anhydride, which is a reactive intermediate for esterification of cellulose. However, PMA and TPMA are less effective crosslinking agents for cotton cellulose than BTCA, mainly due to low mobility of the anhydride intermediate formed by PMA/TPMA to access cellulosic hydroxyl during a curing process (1,2). Citric acid (CA) was also used for crosslinking cotton. However, CA is a less effective crosslinking agent for cotton cellulose (2). We also found that CA is able to esterify the anhydride intermediate of PMA or TPMA on cotton fabric in a wide range of curing temperatures (2).

In this research, we observed a synergistic effect by combining PMA or TPMA with CA as co-crosslinking agents for cotton fabrics. The combination of TPMA/CA is more effective than the combination of PMA/CA for impacting wrinkle resistance to the finished cotton fabrics. The cotton fabrics finished with the combination of TPMA/CA shows superior durable press performance, good laundering durability, and high fabric strength retention. The superior performance and cost-effectiveness of this new finishing system makes it feasible to replace the formaldehyde-based durable press finishes with this nonfromaldehyde alternative in the textile industry.

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A STUDY OF SMOLDERING IN UPHOLSTERY FABRICS USING THERMAL IMAGING

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A methodology is described for the measurement of dynamic surface temperature gradients on upholstery fabrics using infrared thermography and digital image processing. Thin, porous, textile fabrics, which are predominantly cellulosic in content, are particularly prone to smoldering when exposed to a low energy, localized heat source such as a cigarette fire cone. Using optical access as to the fabric surface, spectral irradiance from the fabric surface was measured using an infrared scanner to infer

transient changes in temperature fields during heating and smoldering of upholstery fabrics. A special radiant heat source was developed that closely replicated cigarette induced heat flux and thus was used to simulate typical exposure conditions. Experiments were conducted using a series of cotton duck and commercial upholstery fabrics, to study the effect of fabric areal density and alkali metal ions (sodium and potassium) on smoldering propensity. Empirical data on the smoldering ignition of various single layer fabrics are presented in terms of peak surface temperature reached and enclosed area at specific isotherms. It was found that when the representative temperature in the smoldering zone is greater than 450oC, the smoldering spread is maintained. Cotton duck fabrics do not show the reported reduction in smoldering propensity with decreasing areal density and washing of alkali metal ions. In contrast, the results for commercial upholstery fabrics do allude to a mitigation of smoldering propensity by a significant lowering of surface temperature and isotherm area measurements. It should be noted, however, that these experiments were conducted on a single fabric layer, not as customarily placed over foam or fiberfill padding.

EFFECT OF ENZYMATIC HYDROLYSIS ON THE LOW-STRESS MECHANICAL BEHAVIOR AND TACTILE QUALITY OF COTTON FABRICS

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The effects of enzyme treatment on the strength and abrasion resistance, surface appearance, subjective hand qualities, and dyeing characteristics of cellulosic textiles have been widely studied and reported in recent years. Literature also gives significant information on how exactly the properties of cellulosic textiles are affected when they are enzyme treated before and after being subjected to other wet treatments such as desizing, scouring, bleaching, mercerization, etc. However, the effects of enzyme treatment on fabric micro-mechanical properties, and the net influence of the property changes on the primary hand qualities such as Koshi (stiffness), Numeri (smoothness), and Fukurami (fullness and softness) have not been widely studies and reported. Thermal comfort performance of the treated fabrics is another aspect that has not been fully investigated. This work reports the measured changes in the mechanical and surface properties of plain weave fabrics subjected to enzyme treatment with and without mechanical agitation. It also describes how the changes in properties translate into hand quality improvements.

Some of the mechanical properties of the treated fabrics differed by as much as 50%, while the hand qualities showed even bigger differences. One way analysis of variance revealed that almost all the measured properties (except initial thickness, percentage thickness compression, and bending rigidity) of the treated fabrics differ from that of the untreated fabric. Results also revealed that there are some unique differences in properties between the fabrics subjected to enzyme treatment with and without mechanical agitation, implying that the level of mechanical agitation employed during treatment can

significantly alter the finishing effects derived.

REAL-TIME X-RAY AND RAMAN STUDIES OF NYLON 6,6 DRAWING
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Todays pictures of the fiber structure and its development are largely inferential; most are based on static measurements after some process of treatment sequence. In-situ measurements provide relief from some of the ambiguities inherent in such tests. High intensity synchrotron X-rays allow real-time collection of WAXS patterns, providing rich information on yarn structure and the mechanism of its formation in the manufacturing process. Recent Raman spectroscopy hardware advances also provide novel opportunities. The new Raman probes are small, somewhat cheaper and more portable than synchrotrons, and can be used for real-time data collection. The two methods are complementary and an application of both to fiber drawing will be described. WAXS is used to train Raman.

Fully formed 66 nylon carpet yarns were drawn over hot pins at the Brookhaven synchrotron. Contemporaneous Raman spectra and 2D WAXS patterns were collected at a wide range of tensions and temperatures. Peaks were decomposed by two dimensional fits to a three phase model; crystal, isotropic and oriented amorphous. Concentration of each phase was indexed by two dimensional integration. Substantial melting of small crystals occurred between 100 and 200oC leading to formation of oriented amorphous material. Above 200oC the oriented amorphous material was converted to isotrophic amorphous. Observed transformations correlate with thermomechanical properties such as modulus and shrinkage force. The most stable crystals are both large and highly oriented; they are probably formed in the draw process. The Brill transition from triclinic to pseudo-hexagonal structure was clearly visible in both X-ray and Raman. Raman band intensities correlated strongly with the transition.

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DEVELOPMENT OF AN INSTRUMENT FOR THE EVALUATION OF BIAXIAL STRESS-STRAIN RESPONSE OF FABRICS
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Todays nonwoven fabrics are engineered or designed to meet specific needs. The applications may vary widely from demanding mechanical behavior (e.g. geotextiles) to precision elastic behavior (e.g. melt-blown elastic waist-bands.) In these applications the material comes under various levels of plane stresses, usually applied simultaneously along both of the principal directions (machine and cross). The fabrics response to these forces is a critical parameter that determines the stability / integrity of the structures and

should be evaluated for design purposes. In addition, fracture, puncture, and tear characteristics of such materials under conditions of biaxial loading are also important. The report describes the design, fabrication, and evaluation of such an instrument. The results of initial evaluation of the instrument is encouraging. Test results show significant influence of load and extension ratios on stress- strain response of some commercially available nonwoven fabrics to biaxial loading. The results can be used for understanding the nature of failure in biaxial tensile loading and thereby design fabrics for particular applications.

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