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Rotor Spinning of Recycled Denim by Blending with Low-Grade American Pima Cotton

Denim manufacturers in the United States have been sending the majority of an estimated 35,000 tons of cutting-table scraps to landfills each year. If these denim scraps could be utilized to make recycled denim yarns and fabrics of acceptable quality, it could become economically feasible to consume the waste fibers and alleviate a significant disposal problem. Given the quality limitations of garnetted denim fibers, the ITC undertook an investigation of the effectiveness of using low-grade Pima as a carrier fiber.

Procedures:

Both the reclaimed cotton fibers obtained by garnetting denim scraps and the bales of virgin, low-grade Pima cotton were provided by Wright Fibers of Big Spring, Texas. The properties of each

of these fibers, as well as of the blends made with them, were measured with the Spinlab HVI and the Uster AFIS. Results are summarized in Exhibit 1, where the tendency is shown for the measured properties of the blends to behave as a weighted average of the measured properties of each fiber. A major exception, however, occurs for fiber strength, which drops below the HVI value obtained for 100% reclaimed fiber when it is blended with Pima. This is largely due to the fact that HVI measurements on the 100% reclaimed fibers were taken from raw garnetted stock which still contained fragments of yarn that elevated the strength readings. But the measurements on the blended fibers were taken from carded slivers; therefore, all yarn fragments had been removed. Also, the trash from the Pima cotton had been removed by the carding, resulting in a leaf grade of 1 for the blended fibers.

The leaf grade of 5 for the Pima, corroborated by the AFIS trash reading of 1193, reveals that it was discounted cotton that would not be used for the higher valued products typically made with Pima. Otherwise, the fiber test results on the Pima were fairly typical (Exhibit 1). The blended fibers registered leaf grades of 1, due to the Pima trash being removed by carding.

As expected, the reclaimed fibers exhibited a low elongation value, a short staple length, and a very high short fiber content (Exhibit 1). It is noteworthy, however, that these garnetted fibers exhibited no neps and no trash.

The fibers were processed through opening and cleaning via a Hunter Weigh-pan Hopper Feeder, a Rieter B4/1 Mono-cylinder, a Dust Remover, and an

Exhibit 1: Fiber property measurements

	Pima	Recycled Denim Fiber	80% Denim/ 20% Pima	70% Denim/ 30% Pima
Spinlab 900B				
Strength (g./tex)	35.2	30.6	24.8	28.0
Elongation (%)	6.0	4.3	5.0	5.5
Length (in.)	1.27	0.84	1.05	1.13
Length Unif. (%)	86.8	76.7	83.4	84.7
Micronaire	3.1	3.7	3.5	3.4
Leaf	5	1	1	1
Reflectance, Rd	62.6	67.5	66.0	66.1
Yellowness, +b	14.1	10.3	9.3	9.3
Uster AFIS				
Upper Qt. Len. (in.)	1.34	0.75	1.11	1.18
Mean Length (in.)	1.11	0.59	0.84	0.91
Short Fiber (%)	5.4	39.7	20.5	16.9
Diameter (µm)	11.4	14.8	12.9	12.5
Neps (no./g.)	392	---	374	395
Trash (no./g.)	1193	---	78	67

AMH Tuft-O-Matic blender (Exhibit 2). From the blender the fiber went through a Rieter Aerofeed-U Chute to a Rieter C-4 card. More intensive cleaning was bypassed in order to minimize short-fiber loss. Either one or two drawing processes were done, using a Saco Lowell DE-7C and a Rieter RSB851. Rotor spinning at the ITC was done on a Rieter m1/1; this was due to the fact that Wright Fibers was using the m1/1.

In a cooperative effort with the Levi Strauss Company, the American Cotton Growers (ACG) Mill at Littlefield, Texas, took a 70/30 blended sliver provided by the ITC and spun it into denim warp yarn. This was done in the same way that the ACG Mill spins its normal blends of Texas cottons, using a Schlafhorst SE-9 rotor spinning machine. Ultimately, this recycled warp yarn was combined with the ACG Mill's typical filling yarn and woven into denim; again following the same procedures used for making all its denim. Results obtained from these experiments are also reported here.

Results:

Preparation:

Various attempts were made to process 100% reclaimed fiber and alternative blends containing 10%, 20% and 30% Pima. Unusual steps had to be taken to reduce the cleaning allowed on the reclaimed fiber; including sealing off the Hunter Weigh-pan hoppers, by-passing the Rieter ERM opener cleaners, and installing a pan under the ERM beater when it was used.

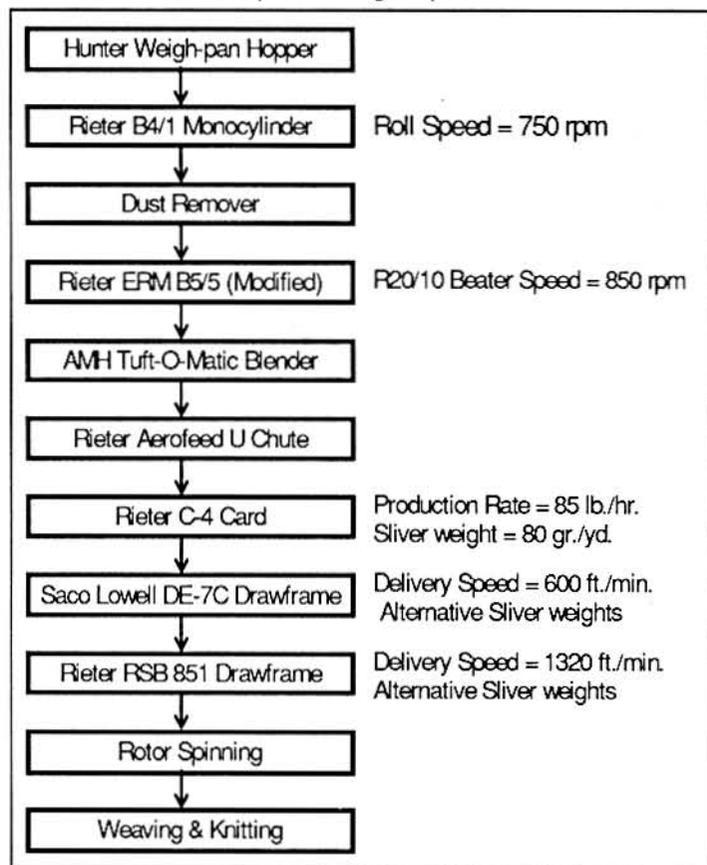
Carding of both the 100% reclaimed fibers and the blends was surprisingly easy; the chute feeder had to be altered to give a thinner batt, due to the high density of the reclaimed fiber. Carding was somewhat sensitive to static; it ran best at 72° F and a minimum of 55% relative humidity. All lots carded well at 85 lbs/hr, producing an 80 gr/yd sliver. Uster evenness tests on card slivers from the blends exhibited coefficients of variation ranging from 3.5% to 3.7%.

Exhibit 3 shows waste quantities through the carding stage. Blowroom waste was 2.8% to 3.0%, while card waste was 12.7% to 14.5%. A lower card waste for the ACG Mill blend made its total preparation waste 1.3 percentage points less than that for the 70/30 blend by the ITC.

Drawing :

Normal drawframes used in the cotton system were not designed to process staple as short as the reclaimed fiber. No method used would successfully draw 100% reclaimed fiber; however, intimate blends with 20% or more Pima would process at drawing. At the 20% Pima level only one drawing

Exhibit 2: Outline of processing steps



was feasible, due to the sliver being too weak for the second pass. Two passes were feasible with 30% Pima in the blend. It should be noted, however, that the drawing slivers exhibited poor uniformity; Uster evenness tests gave no coefficients of variation below 5%.

Spinning :

Both the 80/20 and 70/30 blends spun well on the Schlafhorst and Rieter machines, using typical setup and running conditions for denim yarn production. It is noteworthy that the rotors ran very "clean," with no deposits collecting in rotor groves.

Exhibit 3: Waste percentages during fiber preparation, for alternative blends

	80/20 Blend for ITC	70/30 Blend for ITC	70/30 Blend for ITC
<u>Blowroom</u>			
Monocylinder	2.8	2.9	3.0
<u>Card</u>			
Lickerin	6.7	5.7	5.8
Flat Strips	<u>7.8</u>	<u>8.4</u>	<u>6.9</u>
Sub-total	14.5	14.1	12.7
TOTAL	17.3	17.0	15.7

Exhibit 4 summarizes the data on spinning and yarn properties from the ITC. The data are organized according to blend levels (80/20 and 70/30) and yarn sizes (6's and 10's). Both yarn sizes processed well, with both processing better when the Pima content was increased from 20% to 30%. The count-strength product (CSP) values increased

about 10% with the higher Pima content, while the elongation increased about 25%.

Spinning and yarn property data from the ACG Mill are summarized in Exhibit 5. For the recycled warp yarn, only the 70/30 blend was used and a typical yarn number of Ne 6.2 was produced. For comparison, yarn data is also shown for the regular warp produced at the ACG Mill. It may be seen that the recycled blend resulted in a yarn that was inferior in all quality measurements. In fact, none of the ACG quality standards were met by the 70/30 yarn.

Exhibit 4: Yarn data from ITC using Rieter m1/1*

Yarn Identification:	80/20 Blend		70/30 Blend	
	6/1	10/1	6/1	10/1
Nominal Yarn No. (Ne):	6/1	10/1	6/1	10/1
Draft	40.1	68.5	40.1	68.1
Twist Multiplier	5.00	5.06	5.00	5.06
Yarn Speed (yd./min.)	124	95	124	95
Yarn Properties				
Skein Test:				
Yarn Number (Ne)	6.00	10.16	6.02	10.01
CSP	2033	1876	2247	2089
Single Yarn Tensile Test:				
Tenacity (g/tex)	12.07	12.19	13.33	12.97
Elongation (%)	6.1	6.0	8.1	7.4
Uster III Evenness Test:				
Non-uniformity CV(%)	17.4	16.7	15.4	15.7
Thin Places/1,000 yd.	44	25	7	9
Thick Places/1,000 yd.	132	94	73	87
Neps/1,000 yd.	127	166	62	150

* rotor type is 4502; rotor speed = 55,000 rpm; opening roller type is T-52; opening roller speed = 7,300 rpm; navel type is smooth; ambient conditions are 72 degrees F and 56% relative humidity.

Fabric Formation :

A variety of knit fabrics (including single- and double-knit jersey, warp knit, and Jacquard knits) were made from the 80/20 yarn. The end products were generally attractive; however, these fabrics were not tested.

Denim-like fabrics were woven with the 70/30 blend. At the ITC, a 14.0 ounce, 3x1 right-hand twill was woven on a Picanol PGW loom using the same yarn for both warp and filling. Weaving performance was poor, with loom stops occurring at about two-and-a-half times an acceptable rate.

Weaving performance in the ACG Mill of the recycled denim versus the regular ACG denim is shown in Exhibit 6. There were almost ten stops per 100,000 picks with the recycled yarn, or nearly four times as many as the ACG Mill experiences with its normal fiber mix. Also, the normal operating efficiency of 98.5% was reduced to 95.4%.

Quality characteristics of the recycled denim fabric woven at the ACG Mill may also be compared directly with the regular ACG denim. This is done in Exhibit 7, where it is seen that the quality measures of the recycled denim were consistently inferior to those for normal ACG denim; nevertheless, they fell within the acceptable range of Levi Strauss' requirements.

Exhibit 5: Warp yarn data from ACG Mill using Schlafhorst Autocoro SE-9*

Yarn Identification:	70/30 Blend	ACG Standard
	6.2/1	6.2/1
Nominal Yarn Number (Ne):	6.2/1	6.2/1
Draft	52.8	52.8
Twist Multiplier	5.00	5.00
Yarn Speed (yd./min.)	156	156
Yarn Properties		
Skein Test:		
Yarn Number (Ne)	6.27	6.20
CSP	2040	2499
Single Yarn Tensile Test:		
Tenacity (g/tex)	11.96	14.55
Elongation (%)	6.8	8.6
Uster III Evenness Test:		
Non-uniformity CV(%)	13.3	11.6
Thin Places/1,000 yd.	69	14
Thick Places/1,000 yd.	17	8
Neps/1,000 yd.	30	5

* rotor type is U240BD; rotor speed = 70,000 rpm; opening roller type is B174DN; opening roller speed = 8,800 rpm; navel type is KN8; ambient conditions are 72 degrees F and 56% relative humidity.

Exhibit 6: Weaving performance in ACG Mill

Yarn Identification:	70/30 Blend	ACG Standard
Stops/100,000 Picks:		
Warp	5.32	1.78
Filling	3.19	0.46
Mechanical	<u>1.06</u>	<u>0.27</u>
TOTAL STOPS	9.57	2.51
EFFICIENCY RATING	95.4%	98.5%

Conclusions:

The use of Pima as a carrier fiber to enable rotor spinning of garnetted, recycled cotton is technically feasible; its efficiency as a carrier is likely to make it an economically feasible alternative to Upland type cottons. Use of better grades of Pima might significantly improve spinning performance and yarn quality; the recycled denim fiber produced by Wright Fibers is remarkably free of trash. However, more work is needed to improve drawing, which would translate into better evenness of the spun yarns.

The opening-through-spinning processes that use recycled fibers would almost certainly need to be isolated from areas used to process virgin cotton fibers. The contamination of machinery would be too difficult to handle in a commercial context.

Special thanks are due to Herb Wright of Wright Fibers, Big Spring, TX; Emerson Tucker, Plains Cotton Cooperative Association, Lubbock, TX; American Cotton Growers' Mill, Littlefield, TX; and the Texas Food and Fibers Commission. At the ITC, the project was managed by Edwin R. Foster, Textile Engineer, and by William D. Cole, Manager of the Short Staple Spinning Laboratory.

Exhibit 7: Fabric performance in ACG Mill

	70/30 Blend	ACG Denim	Acceptable Range
Original Fabric Wt. (oz.)	14.3	14.5	14.0 - 15.5
Washed Fabric Wt. (oz.)	14.1	14.3	13.5 - 15.0
Warp Shrinkage (%)	1.4	1.3	0.0 - 4.0
Filling Shrinkage (%)	2.3	2.6	2.0 - 4.0
Stiffness (cm.)	15.0	10.5	7.5 - 16.5
Elongation (%)	8.4	10.0	7.5 - 11.5
Warp Tensile (lb.)	181	213	180 min.
Filling Tensile (lb.)	165	172	130 min.
Warp Tear (lb.)	12.6	14.5	11.5 min.
Filling Tear (lb.)	12.9	13.3	10.0 min.

HIGH-TECH WINDER INSTALLED

We are pleased to announce the installation of a 10-position Schlafhorst Autoconer System 238, in the short-staple spinning laboratory at ITC. It was donated by Schlafhorst Inc. of Charlotte, NC. In addition to other uses, it will serve the winding needs generated by our recently acquired Zinser Ringspinner 330 HS.

The Autoconer System 238 is equipped with the following:

- circular magazines and an automatic package doffer;
- Autospeed yarn tension control;
- electronic monitoring of the winding path and the splicing operation; and
- the Informator RM system which registers, controls and monitors the entire winding sequence.

We sincerely appreciate the generosity of Schlafhorst Inc. This new equipment will greatly enhance our efficiency in the research and service work done by the ITC.

RESEARCH POSITION FILLED

We proudly announce that Dr. Reiyao Zhu arrived at The International Textile Center this February to assume her position as Head of Fibers Research. Along with her husband, Cheng, and three-year-old son, Carson, she has begun to adjust to life in Lubbock, Texas. She is already contributing to the research work of the ITC.

Dr. Zhu came to the ITC from the Department of Industrial Technology, University of Bradford, Bradford, UK, where she had been employed since receiving her Ph.D. at The University of Leeds, Leeds, England, in 1992. Her Bachelor of Engineering degree and Master of Science degree are from China Textile University, Shanghai, Peoples Republic of China.

Impacts of Micronaire on Water Retention Part II: Results with Graft Polymerization

In the last issue of *Textile Topics* (Fall 1994) we reported the effect of micronaire on the water retention of cotton fiber. A tendency was shown for decreasing water retention with increasing micronaire values, using the centrifuge method to measure water retention. Given that the water retention capacity for cotton fibers is enhanced by graft polymerization of vinyl monomers to the cellulose, an examination of differential effects of such chemical alteration on cotton with different micronaire values is of both scientific and practical interest. This is the subject of the second part of our report.

In graft polymerization of vinyl monomers, the monomer is attached chemically to the cellulose and forms polymer chains. The location and extent of polymer formation would depend upon the morphology of the cotton fiber. Graft polymer would be formed within the growth layers of the fibers and within the lumen [1]. Therefore, it is expected that more polymer would be formed within low micronaire cotton fiber (which has more empty space) than within high micronaire cotton.

In order to provide indirect evidence on the above conjecture, acrylamide was graft polymerized in the cotton fiber in the presence of ceric ammonium nitrate (CAN) as a free radical initiator (see Exhibit 1). Acrylamide was used because of its water solubility, high volatility, and ease of handling.

The method of Kamogawa, et. al. [2] was employed wherein the cotton fibers were treated

with aqueous solutions of 7% and 15% acrylamide (wt./vol.), adjusted to pH 1.8 with nitric acid. The treatment was carried out for one hour at room temperature under nitrogen atmosphere. The fibers were washed with hot water at 80°–90° C, using frequent changes of water to remove water-soluble materials, cerium compounds and ungrafted polymer. Then they were air dried. The apparent amounts of grafting were determined by using the Kjeldahl procedure for nitrogen determination.

Nitrogen contents of the polyacrylamide grafted cotton fibers are shown in Exhibit 2. The 2.7 micronaire cotton had substantially higher nitrogen content than either the 3.8 or the 7.1 micronaire fibers, under identical experimental conditions. We attribute this to the fact that the low-micronaire cotton has less cellulose deposition and therefore more available empty space for the polymer to grow within each fiber. However, the nitrogen content of the high (7.1) micronaire cotton was slightly higher than that of the medium (3.8) micronaire cotton. The reason is likely to be related to the fact that the 2.8 and 3.8 micronaire values came from American Upland cottons, while the 7.1 micronaire value came from an Asiatic cotton variety. This very coarse Asiatic cotton may have more space available between cellulose deposits than does the finer American Upland cotton. In short, the comparability of micronaire values is quite dependent on the comparability of cotton varieties.

If the amido groups of the polyacrylamide grafted cotton are converted into carboxyl groups, the water-holding capacity of the fibers will be increased. With a view of enhancing hydrophilic properties of the polyacrylamide grafted cotton fibers, the pendant amido groups of polyacrylamide grafted cottons were hydrolyzed to sodium salt of

Exhibit 1: Graft polymerization of acrylamide on cotton fiber

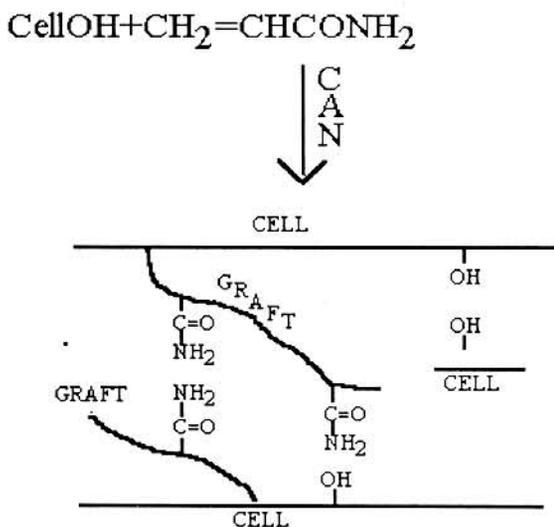


Exhibit 2: Nitrogen content of polyacrylamide grafted cotton

Micronaire	Treatment	% Nitrogen
2.7	7% Acrylamide + 0.2% CAN	2.35
2.7	15% Acrylamide + 0.2% CAN	3.20
3.8	7% Acrylamide + 0.2% CAN	1.06
3.8	15% Acrylamide + 0.2% CAN	2.34
7.1	7% Acrylamide + 0.2% CAN	1.31
7.1	15% Acrylamide + 0.2% CAN	2.39

carboxyl groups on treatment with sodium hydroxide [3]. The chemical reaction is shown in the following:



Polyacrylamide grafted fibers were treated with 1.0% sodium hydroxide (wt./vol.) at 80°–90° C for 30 minutes. The material-to-liquor ratio was 1:40. Afterward, fibers were washed repeatedly with cold and hot water to attain a neutral pH, were air dried, and were then subjected to water retention tests by the centrifuge method (re. Part I of this report).

Exhibit 3 shows the water retention measurements, both before and after alkaline hydrolysis, on the three cotton fibers used in this part of the study. As expected, the water retention of the PAM grafted cotton fibers decreased as micronaire values of the cotton fibers increased.

For cotton treated with 7% acrylamide:

- That with a 2.7 micronaire reading had 95% water retention before alkaline hydrolysis and 228% after alkaline hydrolysis.
- That with a 3.8 micronaire reading had 60% water retention before alkaline hydrolysis and 107% afterward.
- That with a 7.1 micronaire had “before” and “after” readings of 52% and 91%, respectively.

For cotton treated with 15% acrylamide:

- All water retention levels were substantially above those exhibited by the same cottons treated with 7% acrylamide. The increases amounted to about 140% for the 2.7 micronaire and about 80% for both the 3.8 and 7.1

micronaires.

- The relative increases in water retention levels resulting from alkaline hydrolysis were generally small. They appear insignificant for both the 2.7 and 7.1 micronaires. The impact does look significant for the 3.8 micronaire cotton; the reason is not clear.

Summary and Conclusions:

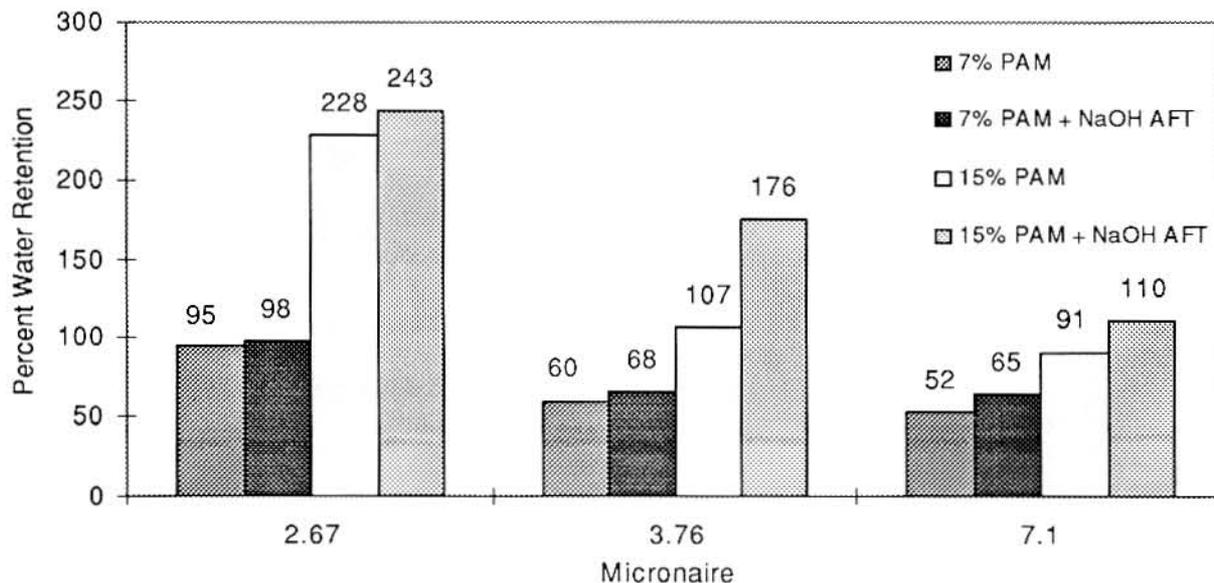
Part I of this report demonstrated a strong inverse relationship between water retention (as measured by the centrifuge method) and micronaire values of cotton fibers. Part II now shows:

- 1) that the water retention of all cottons is greatly enhanced by graft polymerization of acrylamide;
- (2) that there is a clear tendency for more polymer deposition within the low micronaire cotton fibers;
- (3) that converting amido groups of the polyacrylamide grafted cotton into sodium salt of carboxyl groups greatly enhances the water retention of cotton fibers; and
- (4) that the low micronaire cotton again maximizes water retention (by the centrifuge method).

The empirical conclusions about the relationships among water retention, micronaire, and chemical alteration of cotton fibers could be strengthened and expanded with a more complete experimental design and more sophisticated selection of fiber samples.

This research was funded by the Texas Food and Fibers Commission and conducted by Dr. R. D. Mehta, Head of Finishes/Chemical Research at the ITC. A paper on these results was presented at the 1994 American Association of Textile Chemists and

Exhibit 3: Effect of micronaire on water retention of PAM grafted cotton before and after alkaline hydrolysis



Colorists (AATCC) International Conference and Exhibition. It is reprinted with permission from AATCC.

References:

1. Arthur, J. et.al., "Thermal stress behavior of radiation-induced graft polymers of cotton," Textile Research Journal, **33** (1963), pp. 896-899.
2. Kamogawa, H. and Sekiya T., "Graft polymerization of acrylamide onto cotton fabric for further treatments," Textile Research Journal, **31** (1961), pp. 585-591.
3. Chemistry of Acrylamide, Bulletin PRC 109, Process Chemicals Department, American Cyanamid Co., Wayne, N.J., 1969.

VISITORS

Visitors to the International Textile Center during the past three months include:

- Antonio Alberto Cabeco Silva, Universidade do Minho, Guimaraes, Portugal;
- Rosie Rogers, Wellman, Inc. Charlotte, NC;
- James Pope, Zellweger Uster, Knoxville, TN;
- Mike Rodriguez, Rieter Corporation, Spartanburg, SC;
- Morris Bryan and Mark Terrin, Picanol, Greenville, SC;
- George Yarborough, Earl Wallace and Hermann Dörfinger, Schlafhorst Inc., Charlotte, NC;
- Al Martinez, Graico International, Dallas, TX;
- Ben White, Graico International, Lubbock, TX;
- Harvey Campbell, BC Cotton, Inc., Bakersfield, CA;
- Roger Bolick, Allied Fibers, Hopewell, VA;
- Danny Gilmore, G. A. Goulston Chemical Co., Monroe, NC;
- Kathy O'Connell, Terra Nova Tex-styles, Austin, TX;
- James Sweeten, Ol' Sonora Trading Co., Sonora, TX;
- Nichole Steiner, Wayman Johnson and Al Lynch, Levelland Knitting Mills, Levelland, TX;
- Videj Limpayaraya, Tech Textile Co., Ltd., Bangkok, Thailand;
- Robin Hurrell, KSR Instruments Ltd., Leigh, England;
- Ken Benton, Allied Signal, Chester, VA;
- Jia Zhongjiang, Jiang Tianshu, Liu Jianbo, Wang Shoudong and Qin Jiuyi, China Association for Science & Technology (CAST), Beijing, People's Republic of China;
- Grady Barr, Terry Crosswhite, Stephanie Dugan, Lisa Reeves, Ken Burgess, J. V. Martin, Eric Geisler and John Breier, Abilene, TX;
- Mark Ellison, Norma Ritz and Bobby Champion, Texas Department of Agriculture, Austin, TX;
- Twenty-five Texas Tech University Agricultural Economics students, accompanied by their instructor, Dr. James Graves;
- Thirty-one members of the Floyd County (Texas) Farm Bureau;
- Seven graduate students from Texas Tech University's College of Human Sciences; and
- Six students from O'Donnell High School, O'Donnell, TX, accompanied by their instructor, Brenda Connor.