A COMPARISON OF THE PROPERTIES OF COTTON-COVERED COTTON/ POLYESTER YARNS AND FABRICS REPRESENTING RING, FRICTION, AND TANDEM SPINNING TECHNOLOGIES

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Abstract

Four cotton covered cotton/polyester yarns were produced using both filaments and staple polyester fibers in the core. Three different spinning systems (ring, friction, and tandem spinning processes) were used to produce the cotton covered yarns. For comparison, a 100% cotton yarn and a polyester/cotton random blend yarn were also made on a rotor spinning system. The six different yarns were then incorporated as filling yarns in a medium weight denim fabric which used 100% cotton rotor yarn in the warp direction. The fabrics were stone washed in the presence of a softener. The experimental yarns and the washed fabrics were evaluated for the whole range of quality and performance properties.

Major differences were observed in the stress-strain behavior of the experimental yarns. The breaking elongation of the tandem spun yarn was found to be higher than that of 100% cotton, ring spun filament-core, and friction spun staple-core yarns, while its work of rupture was found to be higher than that of 100% cotton, and friction spun staple-core yarns. Tandem spun yarn also showed the lowest initial tensile modulus among the six yarns. The friction spun staple-core yarn showed the lowest average breaking elongation and an unusually high variation in strength and elongation. Compared to the friction spun filament-core yarn, the ring spun filament-core yarn showed higher tensile strength but lower elongation and lower work of rupture. All the six yarns exhibited a near simultaneous rupture behavior under axial loading. Comparison of yarn evenness properties revealed that the yarns containing staple fibers in the core were in general more even compared to the filament-core yarns. Between the two staple-core yarns (friction and tandem), the tandem spun yarn showed lower CV% values over a wide range of cut lengths. This yarn also gave the minimum imperfection count.

The yarns posed no major weaving problems except that the tandem spun yarn caused excessive lint shedding on the loom. As expected, the two fabrics which used the filament-core yarns in the filling direction showed the highest tensile and tear strengths in the filling direction. However, the fillingwise tensile strength of the tandem spun yarn fabric was very close to that of the two fabrics that used the filament-core filling yarns and the fillingwise tear strength of the tandem spun yarn fabric fell between that of the fabrics representing the filament-core yarns and other all staple yarns.

Comparison of the low-stress mechanical behavior of the stone-washed denim fabrics showed that the fabric containing the tandem spun filling yarn gave not only the maximum compressive softness but also minimum bending and shear rigidities. This fabric, therefore, represented the best tactile quality and mechanical comfort performance among the experimental fabrics. Fabrics made from cotton covered filling yarns received better hand ratings from a panel of young judges compared to the fabrics made from the conventional rotor spun filling yarns.

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Experimental Procedures

Yarn and Fabric Production: Table 1 gives the construction particulars and production rates of the six different yarns used in this work. Of the four cotton covered yarns, two yarns represented filament-core construction and the other two represented staple-core construction. Filament-core yarns were produced on ring and friction spinning systems while staple-core yarns were produced on tandem and friction spinning systems. The possibility of successfully producing core-sheath yarns without the need for any modifications to the existing machines was the main guiding principle used in deciding what type of yarn is produced on which system. The yarn count was chosen to suit the requirements of the filling yarn and the twist levels employed were those considered optimum for each system and each yarn. The polyester fibers used in the rotor spun polyester/cotton yarn were regenerated staple fibers obtained by the melting and re-extrusion of transparent soda bottles. All the core-sheath yarns represented a 30% polyester composition in the yarn while the random blend polyester/cotton yarn represented a 67% by weight of recycled polyester fiber in the yarn. The random blend yarn and the 100% cotton yarn were supplied by a denim manufacturer.

All the six yarns were used as filling yarns to produce six different denim fabrics in which the only variable was the filling yarn. A 1.7m wide Nissan air-jet loom running at 700 picks/minute was used to produce the fabrics. The tandem spun yarn showed excessive linting and lint accumulation during weaving. The shedding behavior appears to be the reflection of the low friction drum speeds employed in the fabrication of the experimental yarn. Optimization of drum speed, therefore, can be expected to minimize the shedding problem. The loom-state fabrics representing friction and tandem spinning processes gave a better surface appearance compared to those made from the rotor and ring yarns. Stone washing of the fabrics was performed by a major denim manufacturer, following the standard industry norms. Before stone washing, the fabrics were sewn into tubes that resembled the legs of typical denim pants. The experienced operators who worked on the sewing machines did not notice needle cuts on any of the fabrics. Also, the operators classified all the six fabrics in the "Easy-to-Sew" category.

Evaluation of Yarns and Fabrics: Yarn evenness properties were measured using the Uster-3 evenness tester. The Uster test permitted computation of yarn CV% values at different cut lengths. The single yarn strength test was carried out using the Statimat M tester. In addition to the individual and average stress-strain curves, the strength test provided information on mean strength and elongation, CV% of strength and elongation, initial tensile modulus, nature of yarn failure, work of rupture, etc.

Modulus was measured as the load to elongation ratio obtained between 0 and 0.7% elongation. All the six yarns showed a linear deformation in this range. The parameters used to judge the nature of yarn failure are: 1) post-break elongation (total elongation registered to the post break point which corresponded to 5% of breaking load), 2) load at the first fiber/filament break, and 3) elongation at the first fiber/filament break. Whenever the instrument registered at least 1% drop in strength at any point in the stress strain curve between zero load and ultimate breaking load, the yarn rupture was assumed to be non-simultaneous. Also, the point at which a 1% drop in strength occurred was considered to be the point of first fiber/filament break. Whenever the elongation corresponding to the first fiber/filament break failed to differ by more than 1% from the ultimate breaking load and breaking elongation, it was inferred that the yarn rupture is simultaneous. Similarly if the post break elongation was not at least 1% greater than the ultimate breaking elongation, it was inferred that the yarn rupture is simultaneous.

Fabric tensile and tear strength tests were carried out on the unwashed as well as home washed fabrics (i.e., on fabrics subjected to the standard three home wash test). The home wash procedure also permitted measurement of the shrinkage potential of the finished (pre-shrunk) denim fabrics. The Kawabata Evaluation System (KES-F) was used to measure the hand related low-stress mechanical properties of the six fabrics that were stone washed and tumble dried in the presence of high density polyethylene softener.

Results and Discussion

Table 1 gives a description of yarn construction parameters. Table 2 gives the values for measured yarn properties, while Tables 3, 4, and 5 provide a comparison of measured fabric properties.

Table 1. Yarn construction particulars

Parameter	Rotor Spun 100% Cotton Yarn	Ring Spun Filament-core Yarn	Friction Spun Filament- core Yarn
Count (tex)	98.4	103.5	98.4
Polyester %	0.0	30	30
Nature of Polyester Material	-----------	Medium Tenacity - Multi-Fil	Medium Tenacity Multi-Fil
Position of Polyester in the Yarn	-----------	Core	Core
Production Rate (mets/min)	210	35	280
Maximum Possible Production	250	40	400
Count (tex)	95.2	95.2	64.2
Polyester %	30	67	30
Nature of Polyester Material	Medium Tenacity Staple Fiber	Recycled Staple Fiber	Medium Tenacity Staple Fiber
Position of Polyester in the Yarn	Core	Randomly Distributed	Core
Production Rate (mets/min)	270	180	280
Maximum Possible Production	380-400	230	400

Table 2.. Yarn properties

Property	Yarn 1 Rotor Spun cotton yarn	Yarn 2 Ring Spun Filament- core yarn	Yarn 3 Friction Spun Filament-core yarn
Avg. B.Elong(%)	8.11	10.75	14.75
CV%	6.04	3.4	7.3
Post-Break Elong.,%	8.17	10.84	14.78
Avg. B. Load (cN) &	1050	2276	1863
CV%	5.6	4.2	3.5
Tenacity(cN/tex)	10.67	21.97	18.93
Work of Rupture	2308	5689	7453
(cN.cm)& CV%	11.5(CV)	2.5	10.7
Breaking Time (sec)	12.16	14.07	22.06
%Elon. at Ist Fiber/Fil	8.11	10.74	14.07
Break and CV%	6.0 (CV)	3.5	7.6
Load at Ist Fiber/Fil	1049	2274	1860
Break (cN) & CV%	5.7(CV)	4.2	3.5
Modulus (cN) & CV%	240.6	274.3	352.0
	17.3	8.3	3.8
Yarn Count (tex)	98.4	103.5	98.4
Uster CV%	13.84	13.71	17.63
Imperfections/km			
Thin Places	334.5	134	676
Thick places	15	20.5	117
Neps	12	8.0	29.5

Table 2 (continued)

Property	Yarn 4 Tandem Spun Staple-core yarn	Yarn 5 Rotor Spun P/C Blend yarn	Yarn 6 Friction Spun Staple-core yarn
Avg. B.Elong(%)	12.14	16.66	5.87
CV%	5.5	13.7	24.8
Post-Break Elong.,%	12.15	16.80	5.90
Avg. B. Load (cN) &	1432	834.5	773.4
CV%	5.6	8.3	8.0
Tenacity(cN/tex)	15.03	8.76	12.05
Work of Rupture	4255	4851	1287
(cN.cm)& CV%	10.3	20.5	22.2
Breaking Time (sec)	18.12	24.91	8.7
%Elon. at I[st] Fiber/Fil	12.09	16.66	5.87
Break and CV%	5.5	13.7	24.9
Load at I[st] Fiber/Fil	1429	834	773
Break (cN) & CV%	5.6	8.3	8.0
Modulus (cN) &	193.3	200.6	395.8
CV%	10.5	7.2	22.6
Yarn Count (tex)	95.2	95.2	64.2
Uster CV%	11.45	14.45	13.89
Imperfections/km			
Thin Places	104.5	418	470
Thick places	2.0	15	14
Neps	0.5	8.5	24.5

Table 3. Fabric physical properties

Fabric Property	Fabric 1 Rotor Spun 100% cotton Fil	Fabric 2 Ring Spun Filament- core Fil	Fabric 3 Friction Spun Filament-core Fil
Width (m)	1.6	1.59	1.64
Weight-UW(kg/m^2)	0.5150	0.5425	0.4682
Weight- 3HL	0.4859	0.4988	0.4696
Picks/cm - UW	17.72	17.91	16.14
Picks/cm - 3HL	17.81	17.91	17.72
Warp tear - UW (kg)	4.432	4.967	4.132
Warp tear - 3HL	4.631	4.935	4.30
Weft tear - UW (kg)	3.43	11.70	9.40
Weft tear - 3HL	4.16	13.00	11.83
Warp tens-UW(kg)	92.99	96.62	93.44
Warp tensile - 3HL	88.00	84.37	83.01
Weft tens -UW(kg)	68.94	114.76	103.43
Weft tensile - 3HL	64.86	118.84	104.3
% Elongation	6.00	6.20	2.60
% Shrinkage-3HL W	0.15	0.20	1.40
F	3.40	1.20	1.00
Width (m)	1.61	1.59	1.59
Weight-UW(kg/m^2)	0.5008	0.5110	0.4516
Weight- 3HL	0.4710	0.4754	0.4286
Picks/cm - UW	17.72	17.72	17.91
Picks/cm - 3HL	17.72	17.72	17.91
Warp tear - UW (kg)	4.40	4.736	4.935
Warp tear - 3HL	4.63	4.53	5.067
Weft tear - UW (kg)	5.87	3.96	2.37
Weft tear - 3HL	7.50	4.50	3.03
Warp tens-UW(kg)	96.16	93.44	88.45
Warp tensile - 3HL	85.46	80.74	83.01
Weft tens -UW(kg)	97.52	76.20	48.99
Weft tensile - 3HL	91.63	73.48	43.55
% Elongation	6.00	6.80	6.20
% Shrinkage-3HL W	0.35	0.15	0.20
F	1.20	1.20	2.35

Table 4. Tensile, shear and bending properties of stone-washed denim fabrics

		Tensile				Shear			Bending	
S.No	Type of Filling Yarn	LT	WT	RT%	EMT%	G	2HG	2HG5	B	2HB
1	100% Cotton - Rotor	0.67	26.96	42.60	11.38	2.54	3.84	7.02	314	30.79
2	Filament-core - Ring	0.63	25.35	49.57	11.63	2.54	4.16	7.38	402	33.34
3	Filament-core - Friction	0.65	25.35	49.45	10.00	2.29	3.63	7.14	484	40.54
4	Staple-core - Tandem	0.65	25.99	41.46	12.69	1.45	2.62	4.47	167	16.67
5	P/C Blend - Rotor	0.67	25.25	48.31	10.19	2.22	3.79	6.69	295	26.77
6	Staple-core - Friction	0.67	27.95	47.44	10.13	2.27	3.67	6.83	385	33.44

LT: Linearity of the stress-strain curve (lower the value, less stiff is the fabric)
WT: Energy in extending fabric to a load of 5N per cm width - J/m^2
RT%: Percentage tensile resilience (higher the value, more springy is the fabric)
EMT%: Percentage elongation at a load of 5N per cm width

G: Shear rigidity (higher the value, stiffer is the fabric - N/m)
2HG: Shear hysteresis at 8.7 mrad (higher the value, less is the recovery from shear - N/m)
2HG5: Shear hysteresis at 87 mrad (higher the value, less is the recovery - N/m)

B: Bending rigidity (higher the value, less flexible is the fabric - uNm)
2HB: Bending hysteresis (higher the value, less recoverable is the fabric - mN)

Table 5. Compression properties of stone-washed denim fabrics

S.No	Type of Filling	LC	WC	RC%	EMC%	TO	Rating Hand
1	100% cotton - Rotor	0.54	0.48	39.09	25.39	1.43	5.8
2	Filament-core - Ring	0.54	0.46	41.00	23.64	1.45	6.6
3	Filament-core - Friction	0.50	0.53	39.97	28.09	1.51	6.3
4	Staple-core - Tandem	0.40	0.45	31.56	31.39	1.47	7.4
5	P/C Blend - Rotor	0.46	0.48	37.89	27.99	1.49	5.2
6	Staple-core - Friction	0.42	0.38	30.12	25.75	1.41	6.5

LC: Linearity of the load versus thickness curve (lower value implies better softness)
WC: Energy in compressing to a pressure of 5 kPa - J/m^2
RC%: Compressive resilience (%)
EMC%: % Thickness compression at 5 kPa press (higher values imply better softness)
TO: Fabric thickness at a pressure of 5 Pa - mm

Yarn Evenness and Imperfections: Previous work [2,3] has shown that the Uster evenness of cotton covered yarns containing a staple fiber core is comparable to that of the corresponding random blend yarns. Literature however fails to give a similar comparison of evenness values for two types of covered yarns containing staple fibers and continuous filaments in the yarn core. From the CV% values listed in Table 2, it can be seen that the two yarns containing staple polyester in the core are more even compared to the filament-cored yarns. This result may come as a surprise at the first look because one would expect a more uniform composite yarn when the core is composed of continuous filaments as opposed to staple fibers. However, the inferior uniformity results shown by the filament-cored yarns can be explained on the basis of the differences in the core yarn tensions and also on the basis of the of the relative positioning of the staple fibers and filaments within the yarn.

Compared to a staple fiber core, a multi-filament-core can be expected to sustain a greater amount of tension and tension variation during spinning and this is true for the core yarns corresponding to both ring and friction spinning technologies. Thus while staple polyester fibers can be expected to exist as a relatively unmixed bundle in the yarn core, the bundle of core filaments may not represent a similar unadulterated integrity. In other words, cotton fibers can be expected to get trapped between the filaments because of the variation of filament tension. A random trapping of short fibers can be expected to result in a random radial displacement of some of the filaments in the core filament yarn. This random radial displacement of filaments brought about by the trapped short fibers can be expected to cause additional short-term variation in the yarn. In fact, careful observation of a partially peeled filament-core friction yarn under a stereo microscope revealed small bunches of short fibers lying trapped between the filaments. It appears that the trapped fibers are mainly responsible for the high short-term variation shown by the filament-core friction yarn.

Of the two staple-core yarns, tandem spun yarn gave the minimum CV% over the entire range of cut lengths. This yarn also gave minimum values for imperfection count. The superior uniformity of the tandem spun yarn is perhaps linked to the principle of yarn formation itself. Tandem spinning uses both air-jet and friction spinning processes in tandem [5]. The air-jet spinning unit first forms an integrated 100% polyester yarn, using polyester fibers. The friction spinning process then wraps cotton fibers around the core polyester yarn. Since the cotton fibers are wrapped on the surface of an already twisted polyester yarn, we have in effect, a doubling action in the spinning process, which makes the composite yarn more uniform compared to either of the yarn components. The mass regulation arising as a result of the doubling of strands appears to be responsible for the better uniformity of the tandem spun yarn.

Yarn Tensile Properties: The yarn tensile properties (Table 2) suggest that the filament-cored yarns are stronger than the all staple yarns. It can also be seen that the work of rupture of the tandem spun yarn is greater than that of 100% cotton , and friction spun staple-core yarns. The breaking elongation of this yarn is found to be higher than that of 100% cotton, ring spun filament-core, and friction spun staple-core yarns. The tandem spun yarn is also the strongest yarn among the four all staple yarns. The cotton/polyester yarn gave the highest breaking elongation while the friction spun staple-core yarn gave the lowest breaking elongation. The post- break elongation values as well as the load and elongation values corresponding to the first fiber/filament break suggest that all the six yarns exhibit more or less simultaneous rupture under axial loading. The initial tensile modulus of both the friction yarns is rather high which perhaps is a reflection of the high levels of twist present in these yarns. Tandem spun yarn gave the lowest value for tensile modulus. Lower initial modulus values of yarns and fabrics is generally desirable from the point of view of mechanical comfort. A fabric that is easy to stretch under low load conditions can be expected to impose less load on the body, thus providing for better mechanical comfort.

Comparing the tensile behavior of the two filament-core yarns (filament-core friction and filament-core ring yarns), it can be seen that the friction yarn has a higher breaking elongation and higher work of rupture compared to the ring yarn. The difference in work of rupture appears to arise not only from the difference in breaking elongations but also due to the difference in the shape of the stress-strain curves. The higher breaking elongation of the friction yarn may be partly due to the higher yarn twist, and partly due to the radial displacement of filaments referred to in the section on yarn evenness properties. Short fibers trapped between the filaments may not only cause higher breaking elongation but also greater variation in elongation. From Table 2, it can be seen that the elongation of the friction yarn is in fact more variable than that of the ring yarn while the variation in breaking loads appears to be more or less similar.

Fabric Strength: From Table 3 which gives the strength values for unwashed (UW) and washed (3HL) fabrics, it can be seen that the two fabrics containing the filament-core yarns in the filling direction gave the highest weft-way tensile and tear strengths. The weft way tensile strength of the tandem spun yarn fabric was very close to that of the two fabrics that used the filament-core weft yarns while the weft way tear strength of the tandem spun yarn fabric fell between that of the fabrics representing the filament-core yarns and other all staple yarns. The fabric made from tandem spun yarn, therefore, gave the highest tensile and tear strength values among the four fabrics that used the all staple filling yarns.

The warp way tensile strength of all six fabrics shows a drop after washing but the drop in weft way strength is confined to the four fabrics that represent the all staple filling yarns. In other words, the two fabrics made from the filament-core filling yarns show an increase in weft way tensile strength after washing, suggesting that the integrity of the filament-core yarns may be improving after washing. In general, the washed fabrics show an increase in tear strength in both directions but the increase in the weft direction is greater than the increase in the warp direction. The increased slackness of the fabric and the greater thread mobility achieved after washing appear to be responsible for the higher tear strength shown by the washed fabrics. Among the six fabrics, the fabric made from the poly/cotton filling yarn showed the least change in tear strength. This appears to be a reflection of the high polyester composition of the filling yarn (67% as opposed to 30%).

Hand Related Low-Stress Mechanical Properties: Tables 4 and 5 suggest that the fabric made from the tandem spun yarn is different from the rest of the fabrics in terms of bending, shear, and compression properties. This fabric thus showed the lowest values for bending and shear rigidities (B and G), bending hysteresis (2HB), shear hysteresis (2HG and 2HG5), compression linearity(LC), and tensile resilience (RT%.). The same fabric also showed the highest values for tensile elongation(EMT%) and percentage thickness compression (EMC%). These differences clearly suggest that the stone washed fabric made from the tandem spun yarn gives not only maximum compressive softness but also minimum resistance to bending and shear deformations. This fabric therefore showed the best combination of low-stress mechanical properties from the point of view of hand quality and mechanical comfort performance.

Subjective Rating of Fabrics for Hand Quality: A group of twenty-two undergraduate textile majors were asked to assign hand values to the stone washed fabrics in the range of 0-10, 0 representing extremely poor hand quality which will make the fabric unsuitable for use in denim garments, and 10 representing the best hand quality. The average ratings assigned by the group are listed in Table 5. It can be seen that in terms of subjective hand preference also, the tandem yarn fabric came on the top.

Conclusions

We looked at some new ways of producing engineered yarns for denim fabrics. Our work focused on three aspects: i) design and production of cotton covered cotton/polyester yarns on modern spinning systems, ii) incorporating these yarns as filling yarns in a denim fabric, and iii) evaluation of the relevant fabric properties in washed and unwashed states. Results showed that cotton covered yarns offer significant advantages in terms of fabric strength and durability, tactile quality, dimensional stability, surface appearance and rate of production. Subjective and objective evaluation of hand qualities revealed that the tactile quality of the fabric made from the tandem spun filling yarn is superior to that of fabrics made from the conventional 100% cotton and polyester/cotton filling yarns.

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Literature Cited

1. Marsh, J. T., in An Introduction to Textile Finishing, Chapter IX: Anti-Shrink Cotton, Chapman & Hall Ltd., London, 240-258 (1950).

2. Sawhney, A. P. S., Robert, K.Q., Ruppenicker, G.F., and Kimmel, L. B., Improved Method of Producing a Cotton Covered/Polyester Staple-Core Yarn on a Ring Spinning Frame, Text. Res. J.**62**, 21-25(1992).

3. Sawhney, A. P. S., Ruppenicker, G.F., Kimmel, L. B., Salaun, H. L., and Robert, K.Q., New Technique to Produce a Cotton/Polyester Blend Yarn with Improved Strength, Text. Res. J.**58**, 601-604(1988).

4. Radhakrishnaiah, P., Sukasem Tejatanalert, and Sawhney, A.P.S., Handle and Comfort Properties of Woven Fabrics Made From Random Blend and Cotton covered Cotton/Polyester Yarns, Text. Res.J.**63**, 573-579(1993).

5. Sawhney, A. P. S., Kimmel, L. B., Ruppenicker, G.F., and Thibodeaux., D. P., A Unique Polyester Staple-Core/Cotton-wrap Yarn Made on a Tandem Spinning System, Text. Res. J.**63**, 764-768(1993).