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FLAME-RETARDANT COTTON FABRICS FOR THE MILITARY

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Abstract

Although cotton has many natural advantages, its use for both military and industrial fabrics has declined, largely because high strength requirements cause these fabrics to be excessively heavy. Many cotton fabrics treated with modern flame-resistant and easy-care finishes cannot meet the high performance standards required by the military. However, stronger, more durable fabrics have been produced from predominantly cotton yarns that are reinforced with high-tenacity manufactured fibers through both intimate blending and filament-core yarn techniques. The fibers evaluated included Nomex, Kevlar, nylon, glass and polyethylene. The fabrics produced were treated with flame-resistant and durable-press finishes. Since the yarns contained approximately 70% or more cotton, softness, absorbency, breathability and other desirable properties of cotton were preserved. Fabrics designed for both military uniforms and tentage are discussed.

Introduction

Cotton fabrics have many properties that make them ideally suitable for military uses. The comfort properties of cotton, including softness and absorbency, make it the perfect choice for uniforms and other apparel fabrics. For tentage, cotton fabrics have high wet strength and good breathability. Breathability is especially important in tarpaulin and tentage uses to prevent condensation on the under-side of the fabric. Dry cotton fabrics have the necessary porosity to allow passage of moisture or water vapor. Because of the unique swelling property of the cotton fiber, the cotton fabrics when wet become highly water resistant.

However, despite cotton's many advantages, its use in textile for the military products has declined, largely because the cotton fabrics must be excessively heavy in order to meet the high strength requirements. In addition, flame retardant (FR) finishes for cotton usually require a substantial weight add-on, which can cause fabric stiffening and a subsequent loss in tearing strength.

The Southern Regional Research Center (SRRC) has done considerable research on the development of cotton-rich fabrics with improved strength and durability. Many of these fabrics would possibly be suitable for military uses. Most of the work described here has involved combining cotton with relatively small percentages of high-tenacity manufactured fibers, via either intimate fiber blending or core spinning techniques.

Development of Uniform Fabrics

For many years, 100% cotton chambray was the traditional fabric for U.S. Navy work shirts. In the early 1970's, however, a 50% cotton/50% polyester blend was introduced to improve strength and durability. The blend fabric is still a standard issue for shore duty personnel. For shipboard duty, it was later decided that a flame-resistant finish for work clothing would be beneficial. However, intimate blends of cotton with polyester, particularly if the blend contains 50% or more polyester, are very difficult to treat for flame resistance by application of a traditional cotton finish (1). This is mainly because only the treated cotton component in the blend forms a grid that prevents the flammable synthetic fiber from melting away from the flame. As an alternative, a 100% cotton fabric was evaluated for the FR shirting. However, flame retardant finishes for cotton usually require a substantial weight add-on, which causes some stiffening of the fabric and a corresponding reduction in mobility of the yarns. As a result, the fabric tearing strength was reduced and there was difficulty in meeting the minimum specification requirements with the all-cotton fabric. In addition, there was also some interest in imparting easy care properties to the FR treated shirting fabric. Easy care finishes react with cotton and generally cause substantial decreases in fabric strength and abrasion resistance.

Although decreasing the percentage of polyester in a blend helps to improve the FR performance of the fabric, earlier work had indicated that the lower blend levels of polyester staple fiber with cotton do not provide sufficient strength improvement to meet the required specifications (2). So, in an attempt to overcome these problems, it was decided to explore the use of cotton blends containing Kevlar® or Nomex® aramid fibers. Both of these aramid fibers are substantially stronger than cotton, unaffected by the chemical finishes, and inherently flame resistant.

The cotton used for the blends was a typical mix of rain-grown and irrigated Upland varieties with an average staple length of 1 1/8 inches and an average micronaire value of 4.20. The Kevlar was Type 29 and the Nomex was Type 450. Both aramid fibers were 1.5 denier fine and had a staple length of 1.5 inches to make them compatible for blending with cotton. The Kevlar was extremely strong with a breaking tenacity of almost 22g/den. It was approximately 4 times stronger than the Nomex and over 8 times stronger than the cotton, but it had a breaking extension of only 4%. The Nomex had a breaking extension of about 25%.

A plain woven chambray-type fabric weighing approximately 4.25 oz./sq.yd. in the greige state was produced from 100% cotton and 80% cotton/20% aramid fiber blends. The fabrics were first treated for flame retardancy with a 20% aqueous solution of tetrakishydroxymethyl phosphonium chloride-urea precondensate (THPC-urea). The FR-treated fabrics were given a durable-press (DP) finish, which consisted of treatment with a 10% aqueous solution of dimethylodihydroxyethyleneurea (DMDHEU).

Table I gives the properties of cotton and cotton/aramid blend fabrics treated with the flame- retardant finish only and a flame restardant plus a DP finish. The blends contained 20% aramid fiber and 80% cotton. All the fabrics easily passed flammability resistance tests. Overall, the Kevlar blend produced the strongest fabric and, in all cases, exceeded military specifications. The 100% cotton and the cotton/Nomex blend fabrics with just the flame-retardant finish barely met specifications. However, they failed when a durable-press finish was added. The Nomex blends had the best abrasion resistance, indicating improved durability to wear.

Another approach to improving strength properties of cotton fabrics is through the use of core yarns. Core yarns are structures consisting of two component fibers, one of which forms the center axis or core of the yarn, and the other forms the covering or sheath. Generally, the core is a continuous multifilament yarn, while staple fibers are employed for the outer covering or sheath. The yarns can be produced on conventional ring spinning equipment with only minor modifications. A unique system for producing core yarns with improved coverage of the filament core by the cotton wrapping fibers has also been developed at SRRC (3).

Earlier work demonstrated that core yarns could be used to produce fabrics that were significantly stronger than those made from comparable intimate blends (4). The core-yarn fabrics also had better abrasion resistance, and maintained their superior strength and durability even after the various special finishing treatments. Other research results showed that a conventional FR cotton treatment could also be successfully used as a flame-retardant finish for predominantly cotton fabrics containing low levels of flammable man-made fibers (1).

The U.S. Army has used a wind-resistant poplin made from 100% combed cotton for hot-weather battle-dress uniforms. Normal finishing included dyeing and then overprinting with a camouflage design. The fabric in this state, performs reasonably well from the strength and durability standpoint. However, there is some interest in imparting FR and DP properties to this garment. Since these finishes can adversely affect the strength and durability of all-cotton fabrics, research was initiated to develop a stronger, predominantly cotton fabric with satisfactory FR & DP properties.

A cotton/nylon core-yarn fabric with a nylon content of only 30% was designed for this purpose. The fabric was woven with 40/2 plied yarns, and each component of the ply contained a 40-denier, 13 filament, flat, high-tenacity nylon multifilament as the core. The high-tenacity nylon filament selected was about three times stronger than cotton, and had a breaking elongation of about 20%. A plain woven rip-stop design was used, which was similar in construction to the original all-cotton fabric. Flame-retardant finishing included treatment with a 30% aqueous solution of THPC-urea. The fabrics were also treated with a 10% aqueous solution of DMDHEU to impart durable-press properties.

All of the fabrics had excellent flammability resistance, and exceeded the Army's minimum requirements (Table II). The fabrics with the FR-DP combination finish tended to be slightly better than those with only the FR finish. Breaking strength of the cotton/nylon core-yarn fabric was only about 17% greater than that of the 100% cotton fabric after FR finishing. However, the 100% cotton fabric lost much more strength from the DP finish and consequently did not meet minimum strength specifications. On the other hand, the FR & DP finished core-yarn fabric retained much of its initial strength, since most of this strength was derived from the filament core which was not affected by the finish. Thus, while the cotton component of the fabric is weakened by reaction with the DP finish, the overall strength loss of the fabric is minimal. The fabric tearing strength generally followed the same trends as the breaking strength. The treated core-yarn fabrics had adequate tearing strength, whereas neither of the 100% cotton fabrics met minimum specifications. The core-yarn fabrics also had much greater abrasion resistance than the all-cotton fabrics. However, differences due to the treatment cannot be explained, and may have been influenced by the type of softner used on the fabrics.

Development of Tent Fabrics

As already mentioned, cotton is an ideal fabric for tentage. For many years the U.S. Army used a 100% cotton sateen fabric for modular tents, which are tent structures that can be put together in sections for a variety of uses requiring a large continuous space. However, a problem arose when the Army specifications were changed to require that the fabric be fire resistant. The traditional flame-retardant treatment reduced tearing strength of the fabric to such an extent that it could no longer meet the specifications. In order to obtain a suitable fabric with maximum cotton content, a unique glass-reinforced cotton canvas was designed. A duck-type fabric, weighing approximately 9.00 oz/sq. yd., was woven with 17.5/2 plied yarns. Each component of the plied yarn contained a 100-denier (ED 450) glass core. The yarn was approximately two-thirds cotton and one-third glass by weight. The glass core was comprised of approximately 200 individual strands or filaments, each measuring about 6.35 microns (0.00025 inches) in diameter and having a linear density of about 0.5 denier. By contrast, the linear density of cotton fiber averages about 1.5 denier.

Glass has a wide range of properties that make it suitable for military applications. The properties include an exceptionally high tensile strength, excellent resistance to heat, mildew, moisture, and sunlight, and good dimensional stability. However, the glass fiber it is very brittle and has extremely poor flex and abrasion resistance. While the glass filament core in a core yarn structure provides increased strength, the cotton wrapping fibers help in protecting the glass from damage that may be caused by flexing and abrasion of the yarn. The cotton sheath protection is such that a plied cotton/glass core yarn filling can be woven without sizing. Furthermore, a glass-core yarn can be tied with a conventional weaver's knot without shearing the glass component. In contrast, an uncovered glass filament requires an adhesive to splice. The glass-reinforced fabrics also have excellent sewability and produce strong, non-slip seams.

Because glass does not burn, a lower level of FR treatment can be used on the cotton component of a glass-core fabric to obtain acceptable flammability resistance. Accordingly, the glass-core fabric was treated with a 20% acqueous solution of the THPC-urea formulation. Properties of the treated fabric are compared with a similar 100% cotton canvas, as shown in Table III. Both fabrics had very good flammability resistance, but the glass-reinforced fabric had a slightly better level of performance. The glass-reinforced fabric was also stronger than the all-cotton fabric. A significant difference was particularly evident in the tearing strength, in which case the glass-reinforced fabric was almost 60% stronger than the cotton fabric. As would be expected, the all-cotton fabric was superior in the flex-abrasion test. However, a minimum abrasion resistance of 1000 cycles, which is much greater than that normally obtained with 100% glass, is considered adequate for this type of fabric. Another advantage of the glass-reinforced cotton fabric in fire situations is that the glass component will not char or easily breakdown, thereby helping to maintain the integrity of the fabric structure. Such performance could be important in tentage usage.

Another promising area for tent fabrics includes intimate blending of cotton with extra-high tenacity manmade fibers. At present, the strongest fiber available for blending with cotton is Dyneema®. Dyneema is a low density polyethylene fiber produced by a gel-spinning process. Ultradrawing of the gel causes molecular chain alignment which results in an extra-high strength, high modulus fiber. Other advantages of the Dyneema fiber include excellent light resistance, good abrasion and flex resistance, and good chemical resistance. On the negative side, the fiber has a relatively low melting point (about 295°F) and is flammable (5).

The cotton used in the blends was an Acala variety with a 1 1/8 inch staple length. The Dyneema fiber was made available to SRRC on an experimental basis under a research collaboration with DSM High Performance Fibers, The Netherlands (the developer and producer of Dyneema). To be suitable for blending with cotton, Dyneema fiber was produced with a 1.5 denier fineness and a 1.5 inch staple length. It had a tenacity of over 35 g/denier, which is almost 15 times stronger than cotton. Breaking elongation of Dyneema is about 3.0%.

A duck-type fabric, weighing approximately 9.00 oz./sq. yd., was produced from the cotton/Dyneema blend yarn. The fabric was treated for flame retardancy with a 50% solution of Apex Flameproof #344-HC. Apex #344-HC is produced by the Apex Chemical Corporation and is an aqueous dispersion of a 2:1 ratio of decabromodiphenyl oxide and antimony trioxide. This treatment provides an excellent FR finish for tent fabrics.

Table IV shows a comparison of the properties of the FR treated cotton/Dyneema blend fabric with those of the 100% cotton fabric. Breaking and tearing strengths of the blend fabric were much greater than those of 100% cotton fabric. Breaking strength was increased about 85% with the addition of 20% Dyneema. Tearing strength also showed a much larger increase. Warp tearing strength of the fabric containing 20% Dyneema was almost three times greater than that of the 100% cotton fabric. The Dyneema/cotton blend also had much better abrasion resistance. This probably was because of the excellent inherent abrasion resistance of the Dyneema fiber. Both fabrics easily passed vertical flammability resistance tests.

Conclusions

Fabrics of predominantly cotton content with exceptional strength and durability can be produced by combining cotton with small percentages of high-tenacity manufactured fibers, either by intimate blending or through core yarn techniques. The fabrics can be treated with flame-resistant and durable-press finishes and still meet most military specifications.

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Table 1. Properties of Treated Cotton and Cotton/Aramid Intimate Blend Fabrics.

Property[1]	Military Specifications	100% Cotton		20% Kevlar		20% Nomex	
		FR[2]	**FR+DP[3]**	**FR**	**FR+DP**	**FR**	**FR+DP**
Char Length (in)	5.0	2.5	2.3	2.2	1.8	1.8	1.7
Breaking St. (lbs.)	80	81	53	104	81	81	58
Tearing St. (lbs.)	4.0	3.9	2.6	6.8	4.9	4.2	2.7
Flex Abrasion (cycles)	N.A.[4]	1311	445	1150	776	1446	1122

[1] Warpwise.
[2] Flame-retardant finish.
[3] Flame-retardant plus durable-press finish.
[4] No specifications available.

Table 2. Properties of Rip-Stop Uniform Fabrics Treated With Flame-Resistant and Durable-Press Finishes.

Fabric Property[1]	Military Specification	100% Cotton		Cotton/ Nylon Core	
		FR	**FR+DP**	**FR**	**FR+DP**
Char Length (in)	5.0	1.5	1.4	2.4	1.6
Breaking Strength (lbs)	100	103	77	120	107
Tearing Strength (lbs)	4.0	3.7	2.1	6.2	5.4
Flex Abrasion (cycles)	N.A.[2]	652	1058	1510	5240

[1] Warpwise
[2] No specifications available

Table 3. Properties of Cotton/Glass and 100% Cotton Fabric Treated with a Flame Resistant Finish.

Fabric Property[1]	**Military Specifications**	**100% Cotton**	**Cotton/ Glass Core**
Char Length	5	l.8	1.6
Breaking Strength (lbs)	175	156	169
Tearing Strength (lbs)	6.0	5.5	8.7
Flex Abrasion (cycles)	N.A.[2]	6082	1134

[1] Warpwise
[2] No specifications available

Table 4. Properties of FR Treated Cotton/ Dyneema® Intimate Blend Fabrics Compared with100% Cotton Fabric.

Fabric Property[1]	**Military Specifications**	**100% Cotton**	**80% Cotton 20% Dyneema®**
Char Length	5	3.5	3.8
Breaking Strength (lbs)	175	175	323
Tearing Strength (lbs)	6.0	6.1	17.3
Flex Abrasion (cycles)	N.A.[2]	944	3752

[1] Warpwise
[2] No specifications available