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EFFECT OF COTTON FIBER QUALITY ON THE STRENGTH PROPERTIES OF A MILITARY UNIFORM FABRIC

G.F. Ruppenicker, A.P. Sawhney, L.B. Kimmel,
J.B. Price, and T.A. Calamari, Jr.
USDA-ARS
Southern Regional Research Center
New Orleans, LA

Abstract

Although cotton has many natural advantages, its use for military uniform fabrics has declined, largely because high strength requirements cause the cotton 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, and are being replaced by fabrics made from synthetic fibers, or blends of cotton with synthetic fibers. The objective of this study was to evaluate the effect of cotton fiber properties on the strength and durability of an Army battledress uniform fabric woven with a unique rip-stop design. Cottons differing by as much as 60% in fiber strength were evaluated. Fabrics produced from these cottons were treated with flame-resistant and easy-care finishes. As would be expected, the stronger cottons produced proportionately stronger yarns and greige-state fabrics. However, differences in fabric strength were still preserved after the fabrics were treated with the special finishes.

Introduction

Cotton fabrics have many properties that make them ideally suitable for military uses. The natural inherent properties of cotton, including softness and absorbency, make it an excellent choice for uniforms and other apparel fabrics. Cotton fabrics also adapt readily to wet processing, dyeing, printing, and various other treatments.

Despite cotton's many advantages, its use in textile products for the military has declined, partly because the cotton fabrics must be excessively heavy in order to meet the high strength requirements. In addition, special finishes that are now required on some military uniform fabrics, including flame-resistant (FR) and durable-press (DP) treatments, often cause substantial losses in fabric strength and durability. As a result, the use of cotton in military uniforms has decreased in favor of cotton/synthetic fiber blends, or in some cases all synthetic fibers.

The objective of this study was to determine the effect of cotton fiber properties on the strength and durability of a specific military uniform fabric. Cottons differing widely in fiber properties were obtained from various regions of the United States and represented both raingrown and irrigated varieties. Efforts were made to obtain cottons differing primarily in fiber strength, since this property has been found to have a greater significant effect on fabric strength than either fiber length or fineness (AATCC 1995; ASTM; Fiori et al., 1956; Fiori et al., 1954). The cottons were processed into a unique rip-stop fabric used for lightweight battledress uniforms.

Materials and Methods

Four cottons were selected for this study, and included two raingrown and two irrigated varieties. One of the irrigated cottons was an extra-long staple variety. Fiber properties of the cottons are given in Table I. Both cottons grown under irrigation were significantly stronger than the raingrown varieties, as determined by Stelometer values. The extra-long staple cotton (I-2) was over 60% stronger than the weakest raingrown variety. The High Volume Instrumentation (HVI) strength data also showed similar results. Classer's staple lengths (not shown in Table I) ranged from 1-1/16-inch for both raingrown cottons (R-1, R-2), 1-1/8-inch for the shorter irrigated cotton (I-1), and 1-1/2-inch for the extra-long staple variety. These differences in fiber length were also confirmed by Fibrograph, Peyer AL101, and HVI measurements. Peyer AL101 data showed that both raingrown cottons had significantly more short fibers than the irrigated varieties, probably because the weaker cottons had more fiber damage from ginning and subsequent lint cleaning. Micronaire readings for the cottons were similar.

All the cottons were processed under standard cotton processing conditions through combing into 1.50 hank rovings. A twist multiplier of 3.9 was used to spin 40/1 and 19/1 (Ne) yarns on a conventional ring spinning frame. The 40/1 yarns were two-plied with a 3.1 TM, and then prepared for weaving. A polyvinyl alcohol (PVA) size was applied to the yarns prior to weaving.

A wind-resistant cotton poplin fabric weighing approximately 6.0-oz./sq. yd. was produced from the 40/2 warp and 19/1 filling yarns. This fabric is designated primarily for hot weather applications. To provide improved tearing strength, the Army specifications call for reinforcing ribs in both the warp and filling directions to form a uniform pattern. Thus, the warp repeat consisted of two ends weaving as one in a plain-weave manner, with 23 ends weaving plain weave. The filling repeat had two picks weaving as one in a plain manner, with 12 picks weaving plain weave. The entire design repeated on 25 ends and 28 picks and is commonly referred to as a rip-stop construction. The reinforcement ribs appeared as one-quarter-inch squares in the fabric.

Preparation of all four fabrics for finishing included desizing and scouring. Since the warp yarns were slashed with polyvinyl alcohol, a simple boil-off with a wetting agent was used for desizing. The scouring was done with a 2.0% caustic solution. The scoured fabrics were then treated for flame resistance with an aqueous solution of tetrakishydroxymethyl phosphonium chloride-urea precondensate (THPC-urea), the complete formula for which was:

25% THPC-urea (Retardol AC)
0.3% Polyethylene softener
0.2% Wetting agent
2.0% Sodium acetate

The formulation represents the solids content of active agents in the pad bath. The pH of the solution was adjusted to about 4.5. The fabrics were first padded to a wet pick-up of about 70%, dried at 180^{0}F for 2 minutes, and then cured in an ammoniator. The cured fabrics were oxidized in a jig with a 0.8% aqueous solution of hydrogen peroxide, washed and dried.

Finally, the FR treated fabrics were given a durable press (DP) finish. The DP finish consisted of padding the fabrics with a 10% aqueous solution of dimethylodihydroxyethyleneurea (DMDHEU) to wet pick-up of about 70%. The complete formula was as follows:

10.0% DMDHEU
3.0% Magnesium chloride
hexahydrate catalyst
0.2% Polyethylene softener

The pH of the solution was adjusted to about 4 with acetic acid. The fabrics were dried at 200^{0}F for 2 minutes, and cured at 325^{0}F for 3 minutes. This finishing treatment was somewhat more severe than that normally used for 100% cotton fabrics, because of the tendency of the FR finish to restrict or limit the reaction with cotton. The DP finish also reacts, to some extent, with the FR finish.

Physical and mechanical properties of the fibers, yarns and fabrics were determined by testing according to ASTM and AATCC procedures (Ramey et al., 1977; Suh et al., 1998). Yarn breaking strength was measured on an Uster single-strand strength tester and by the skein method. Fabric breaking strength was determined by the grab method, and tearing strength by the falling pendulum (Elmendorf) method. Testing for flammability was done by the vertical burn test (USFSS-GSA 1978). This method of testing for FR properties is intended for use in determining the resistance of cloth to flame and glow propagation and the tendency to char. It was designed originally for cellulosic fabrics treated with a flame retardant. Briefly, the test consists of vertically mounting a 12 in. by 2-3/4 in. specimen of fabric in a closed chamber, and igniting it at the lower edge with a gas burner. After an exposure time of 12 seconds the burner is removed, the test specimen is then allowed to self-extinguish, and the length of the char is measured. An average char length of not more than 5 inches is considered satisfactory. The FR and DP treated fabrics were washed once before testing to remove unreacted chemicals.

Results and Discussion

Single-strand and skein yarn strength properties are given in Table II. Of the raingrown varieties, yarns spun from R-2 were, in most cases, significantly stronger than those spun from the R-1 cotton. The extra-long staple cotton (I-2) produced yarns that were about 15% stronger than the other irrigated variety (I-1). Overall, yarns spun from the strongest cotton (I-2) were from 50-65% stronger than those spun from the weakest (R-1).

Generally, greige fabric breaking strengths followed the same trends as yarn strengths, but differences between cottons were smaller (Table III). The major improvement was observed in Elmendorf tearing strength, when the irrigated cotton had two to three times the tearing strength of the raingrown cottons.

Properties of the fabrics treated with a flame-resistant finish are given in Table IV. Generally, the breaking strengths of the FR treated fabrics are slightly greater than those of the greige fabrics. This is probably because the FR treatment does not react with the cotton, but the polymerization process has some tendency to bind the fibers, yarns, and fabrics together. However, there were significant decreases in the tearing strengths. This is because the “binding action” of the FR polymer causes the yarns to resist movement. Consequently, during the tearing action, more yarns tend to break individually rather than in groups. Still the fabrics produced from the stronger cottons overall had greater tearing strengths after FR treatment.

Flammability resistance of all the FR treated fabrics was excellent. Conditioned wrinkle-recovery values are also given in Table IV, to show that the FR treatment does not contribute to smooth drying properties. Warp plus filling wrinkle recovery values of less than 200 indicate no significant improvement in this property.

Table V shows the properties of the fabrics treated with the FR and DP combination finish. The DP finish, which reacts with and weakens the cotton fiber, resulted in significant decreases in both the breaking and tearing strengths of the fabrics. However, the stronger cottons still produced the stronger fabrics, although the overall differences were less. The DP finish improved flammability resistance slightly. This is probably because of the nitrogen present in the DP finish. The wrinkle-recovery properties of the finished fabrics were significantly improved.

Summary

Four cottons differing widely in fiber strength were evaluated in an Army battledress uniform fabric. The range in fiber strength from the weakest to the strongest cotton was approximately 60%. As expected, the stronger cottons produced proportionately stronger yarns and greige state fabrics. Differences in fabric strength were still apparent after treatments with flame-resistant and durable-press finishes. Finally, it should be noted that the emphasis on fabric strength pertains primarily to military fabrics, which have extremely high strength specifications, and that fabrics made from all the cottons generally meet most civilian standards easily.

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Table 1. Fiber Properties.

Property		Cotton R-1	R-2	I-1	I-2
Individual Instruments					
Stelometer					
Tenacity, 1/8" gauge	(g/tex)	18.81	20.85	25.42	31.43
Elongation	(%)	6.26	7.29	7.73	8.24
Fibrograph					
2.4% Span Length	(in)	1.076	1.044	1.221	1.313
Uniformity Ratio		43.9	44.5	50.2	48.9
Peyer AL1-1					
Upper Quartile Length	(in)	1.045	1.03	1.16	1.325
Mean Length	(in)	0.845	0.83	1.00	1.155
C.V. of Length	(%)	32.3	32.9	23.7	21.9
Short Fibre Content	(%)	14.0	15.4	3.2	1.0
High Volume Instruments					
Spinlab 900 HVT					
Strength	(g/tex)	24.68	27.49	31.96	37.47
Elongation	(%)	6.17	6.56	7.08	7.95
Length	(in)	1.086	1.081	1.199	1.299
Uniformity Index		81.5	80.3	85.8	85.7
Micronaire		4.5	4.6	4.4	4.4

Table 2. Yarn Properties.

Property	Cotton R-1	R-2	I-1	I-2
Tenacity				
Single-Strand (g/tex)				
40/2	14.6	15.3	20.9	24.8
19/1	16.7	15.6	21.1	24.6
Skein (CSP)				
40/2	2549	2748	3592	4205
19/1	2628	2907	3456	3982

Table 3. Greige Fabric Properties.

Property	Cotton R-1	R-2	I-1	I-2
Grab Break (lbs.)				
Warp	86	89	106	117
Filling	59	63	79	84
Elmendorf Tear (lbs.)				
Warp	4.9	6.1	11.7	14.2
Filling	4.1	5.7	9.7	11.8

Table 4. FR Treated Fabric Properties.

Property	Cotton R-1	R-2	I-1	I-2
Grab Break (lbs.)				
Warp	95	93	105	114
Filling	66	70	81	88
Elemendorf Tear (lbs.)				
Warp	3.2	3.7	4.4	5.2
Filling	3.7	4.4	6.3	7.6
Char Length (in.)				
Warp	2.3	2.9	2.1	2.0
Filling	2.2	1.9	2.3	2.1
Conditioned W.R. (degrees)				
Warp + Filling	166	150	149	168

Table 5. FR & DP Treated Fabric Properties.

Property	Cotton R-1	R-2	I-1	I-2
Grab Break (lbs.)				
Warp	63	64	68	75
Filling	47	49	48	55
Elemendorf Tear (lbs.)				
Warp	1.6	1.5	1.9	2.1
Filling	2.0	1.8	2.3	3.0
Char Length (in.)				
Warp	1.9	2.2	1.8	1.6
Filling	1.8	1.9	1.6	1.9
Conditioned W.R. (degrees)				
Warp + Filling	239	231	247	230