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DEVELOPMENT OF CLOTH, CAMOUFLAGE, UNIVERSAL PATTERN, FLAME RESISTANT, WOOL/NOMEX^{TM} BLEND

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Approved for public release; distribution is unlimited.

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Natick, Massachusetts 01760-5020

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14. ABSTRACT

A new camouflage printed fabric in a blend of 50% wool and 50% Nomex was developed. The fabric offers inherent flame resistance, machine wash and tumble dry performance. The new Universal camouflage pattern does not require either piece dye or chemical treatment and used traditional wool dyes only. The printed fabric meets color specifications for the standard nylon/cotton combat uniform fabric.

15. SUBJECT TERMS

DYES	FABRIC	CAMOUFLAGE	COMBAT UNIFORM
WOOL	LAUNDRY	LIGHTWEIGHT	FLAME RESISTANT
NOMEX	UNIFORMS	WOVEN FABRICS	THERMAL PROTECTION

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PREFACE AND ACKNOWLEDGEMENTS

This report documents the joint research efforts of the American Sheep Industry Association, Centennial, CO, and the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, (NSRDEC) in creating a new camouflage printed fabric in a blend of 50% 20.5 micron wool and aramid (Nomex IIIA™) which offers inherent flame protection, machine wash and tumble dry performance. The work was carried out under U.S. Army contract number W911QY-04-P-0468 during the period of June 2004 – March 2006. The fabric, prepared for printing with a new Universal camouflage pattern, does not require piece dyeing, enzyme or flame-retardant chemical treatments to achieve optimum performance. The print formulation, based on 1:2 metal complex dyes, which has no affinity for the aramid fiber, met all color specification requirements for the nylon/cotton (NYCO) fabric (MIL-C-44436) including near infra-red reflectance (NIR) and colorfastness. Sufficient yardage of the approved printed fabric was provided to NSRDEC for further laboratory evaluation, and a planned wearer response through a field wear trial. Based on the simplicity of the processes used coupled with a low material cost, the final finished fabric cost is calculated to offer significant savings over the current standard aramid and P140 blend fabric.

The authors are indebted to numerous industry partners for their support and willingness to work with small batch sizes in a production environment. The following industry partners are worthy of special mention in this report. They are: Diego Paullier of Chargeurs for providing open wool top cut two-inch length for carding and blending on a short sample system; Jim Sells of Pharr Yarns for blending and spinning a number of experimental yarns; Merritt Loring of Victor Forstmann, Inc., for weaving, dyeing, finishing and testing of prepared fabrics; Tony Fernandez of Duro Industries for developing print formulations and printing the fabrics. Thanks are also due to numerous specialists at NSRDEC especially Melanie King for evaluating the printed fabrics and approving print production. Finally, we thank the American wool growers for supporting and funding this development effort.

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DEVELOPMENT OF CLOTH, CAMOUFLAGE, UNIVERSAL PATTERN, FLAME RESISTANT, WOOL/NOMEX™, BLEND

1. SUMMARY

This study undertaken to optimize fabric construction and camouflage print technique has shown that a fine two-ply yarn made from a 50/50 blend of domestic 70's grade (20.5 micron) wool and Nomex® Type 462 in a plain weave construction can produce a fabric of less than 6 ounces per square yard. This lightweight fabric met all military performance goals such as mechanical properties, Near Infrared (NIR) and colorfastness of the camouflage print, flammability, machine wash and tumble dry performance, and electrostatic dissipation.

It is further shown that in meeting the above criteria, no chemical treatment to the fabric to impart either flame resistance or machine washability was necessary. Additionally, the fabric does not have to be pre-dyed prior to printing to meet the specified color performance goals. Good NIR and colorfastness was achieved by coloring only the wool component of the blend using standard wool dyes such as pre-metalized dyes.

2. BACKGROUND

This project was a coordinated effort between the American wool industry and the U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC), Natick, MA. A novel, low cost flame resistant fabric was developed from a blend of wool and aramid fibers and camouflage printed to provide maximum survivability, and combat-effectiveness for soldiers and vehicle crews on the battlefield under worldwide environmental extremes.

To achieve such a goal, the developed fabric needed to be lightweight (6.0 ounces per square yard or less), comfortable, cost effective, inherently flame resistant, strong and durable, and with inherent machine wash and machine dry performance. Much of the development work was carried out at various commercial facilities. This method of development offers the added advantage of rapid commercialization of a successful product.

3. INTRODUCTION

Wool is one of the most widely used fibers in the world and when blended with specialty fibers it has many applications for street, recreational, military, and industrial clothing use. Wool offers good shape retention and durability because of its coiled molecular structure; it offers comfort because of its core/sheath structure giving water repellent exterior and vapor loving interior which provides superior moisture management to wearers. It is inherently flame resistant with a Limiting Oxygen Index of 23 because of its high nitrogen and moisture contents, 14 and 16% respectively; it prevents burn injury because it does not melt but instead produces a voluminous char when subjected to flame which is immediately cool to the touch.

It also has certain known negatives. It is not a very strong fiber because of low tensile strength; it is difficult to spin to a very fine yarn count because of its relatively coarse fiber diameter; and it is prone to felting during washing unless specially treated. Much research[1, 2, 3] carried out during the early eighties in blending wool with specialty fibers demonstrated that a minimum of 30% of Flame Resistant (FR) rayon or modacrylic or polyvinyl chloride; a minimum of 40% of FR polyester, or a minimum of 50% meta-aramid, or a minimum of 65% para-aramid is required to produce an inherently FR and machine washable fabric in lightweight fabric constructions.

The current study utilizes Nomex® aramid fibers for blending with wool because it is the only inherently FR fiber produced domestically, - a requirement for U.S. military use. This blend was investigated in depth by the present authors previously in 1995 to overcome some of the known negatives of aramid fabrics currently used by the U.S. armed forces in hazardous environments. High fabric tensile strength (100 pounds or higher) was considered essential for the blended fabric to have a strong future for military protective clothing applications.

Previous development trials using a 50/50 wool/aramid blend using singles yarns in the warp and filling directions had given fabric a tensile strength of 135 pounds in the warp but only 97 pounds in the filling. These values need to be improved to generate sustainable interest by the U.S. armed forces.

Subsequent work indicated that fabrics of comparable weight made from plied yarns were generally stronger than those made from singles yarns. At the time this project was undertaken, there was no commercial knowledge about how fine a yarn could be spun from a blend of 50/50 wool and aramid fibers on a short staple spinning system. Nor was there a fabrication reference to produce a lightweight fabric from such a fiber blend. There were also other unanswered questions such as:

1. What would be the optimum fabric construction to provide a fabric of required strength and durability?
2. Could such a fabric be printed to offer required visual and NIR camouflage properties?
3. Would the blended fabric offer significant advantages in cost or performance for the military to recommend use of such a product as a direct replacement or as an alternate fabric to the aramid blend fabric currently in use?

These issues were addressed and are reported in this study.

4. MATERIALS AND METHODS

Fibers

Wool

The wool used in this study was a domestic 70's grade (20.5 micron) fiber. It was prepared as an open top cut to a two inch staple length for blending on the short staple spinning system. The selection of wool of a mean fiber diameter of 20.5 microns is based on the known coefficient of variation for wool fiber diameter and would ensure that fibers coarser than 30 microns would not be used, which are known to irritate less than 5% of the population. This ensures that skin reddening and prickle associated with wool would not occur and that such wool fabrics are considered suitable for wearing next to the skin[7, 8].

Aramid

The aramid fiber used was produced by DuPont and marketed under the trade name of Nomex® Type 462. This is a specialty blend of three fiber types. It consists of 93% meta-aramid (Nomex®), 5% para-aramid (Kevlar®) and 2% electrostatic dissipative fiber called P-140. In the trade, fabric made from this blend is commonly referred to as Nomex® IIIA, and it is dyeable. A solution dyed (sage green) Nomex® N303 was also used. It is similar to Nomex® Type 462 except that the fiber is producer colored. Both the producer colored and the undyed versions of Nomex® fiber were used to evaluate the color performance of fabric in dyed and printed fabric form.

Yarn

The fibers were blended in a blow room and carded as an intimate blend in a proportion of 50% wool and 50% aramid fibers. This blend was spun to a 28/2 (Ne) cotton count yarns on a modified short staple spinning system. There were no problems encountered in the spinning of such a fine yarn and it was projected that the spin limit of such a blend of fibers could be around 35/1 Ne. Yarn properties are listed in Table 1.

Fabrication

The blended yarns of wool and both the undyed Nomex® and the producer colored Nomex® spun to the same yarn count were dressed as 125 yard warp to yield 112 yards of woven fabric per roll. It is noted that this is a commercial roll length typically used in the worsted wool industry. Two, one hundred yard length pieces were produced from undyed wool/undyed Nomex® and three pieces from undyed wool/producer colored Nomex® fabrics. The fabrics were constructed to provide a 60 inch width fabric in finished form. The expected ends and picks in the finished cloth were calculated at 60 ends and 44 picks. Fabric properties compared to the standard aramid blend fabric are shown in Table 2. The results show that the wool/aramid blended fabric has slightly lower mechanical properties but all the results are more than the suggested minimum performance goals.

Table 1. Properties of wool/aramid blended yarn used in this study.

Count, Ne/ply	28.3/2
Twist singles, tpi	19.8
Twist ply, tpi	14.05
Single end break	1.48 lb
Tenacity, gf/den	1.79
Elongation, %	23.3

Table 2. Comparison between wool/Nomex and 100 % Nomex Fabrics.

Fabric Properties	92% Nomex 5% Kevlar 3% P140	50/50 wool/Nomex, nominal
Yarn Count, Ne/ply	40/2 cc	28/2 cc
Weave	Plain	Plain
Weave Set	69 x 48	60 x 47
Weight, oz/sq yd	4.68	5.8
Tensile Strength, lbs	183 x 127	155 x 121
Tear Strength, lbs	18.6 x 13.4	10.8 x 9.5
Flex Abrasion	4436 x 2886	2582 x 2059
Shrinkage After 5 Washes	1.8 x 1.0	1.2 x 1.8

Dyeing and Finishing

The principal classes of dyes commercially used on wool can be broadly classified as:

- Equalizing acid dyes, for most colors
- Half-milling dyes, for most colors
- Sulfonated 1:2 metal complex dyes, for deep shades (premetalized dyes)
- Selected reactive dyes, for deep bright shades of good fastness.

Any of the above classes of dyes could have been used in this work. However, given the need for deep shades and good color fastness, we used 1:2 metal complex dyes supplied by Ciba under the trade name of Lanaset® Dyes.

Half of the produced pieces were treated with a machine washable finish using a recently developed enzyme process that was patented by the United States Department of Agriculture (U.S.D.A.). A detailed disclosure of the process is not considered appropriate in this report as the use of this process was not found to be necessary for imparting machine washability as seen from results obtained in Table 3. The blended fabrics without any treatment performed just as well in the wash and tumble dry evaluation as the enzyme treated fabrics. This is further discussed later in this report.

Although there were two major positive aspects for the use of the enzyme process, which are a softer hand and a high color yield, the negatives of the process in terms of fiber degradation, reduced colorfastness to washing and added treatment cost outweighed the possible benefit of the application. The process was not applied in the follow-up commercial production trial.

The fabrics were given a traditional wool finishing routine which included scouring in a neutral non-ionic detergent, crabbed to prevent wrinkles, dried two inches wider than wet width, sheared, and fully decated at 110°C steam temperature for 10 minutes using a double vacuum cycle. The fabric was then steam relaxed and semi-decated and rolled on tubes. Sufficient yardage in a variety of the finished fabric types, as described earlier, were given to two commercial printing companies for the development of the most promising color formulation to meet the currently available Universal Print performance goals for visual, NIR and colorfastness of the camouflage printed fabrics.

Test Methods used

Standard American Society of Testing and Materials (ASTM) and American Association of Textile Chemists and Colorists (AATCC) methods were used for general testing of fabric construction and mechanical properties. In addition, greater importance was given to the evaluation of the camouflage colors in terms of NIR and colorfastness to light (AATCC 16), crocking, perspiration and washing. The wash and tumble dry performance was evaluated by the AATCC 135 method. In addition to these, the fabric

Table 3. Properties of various wool/Nomex blended fabrics.

Fabrics	Fabric weight, oz/sq. yd	Tensile Strength, lbs	Tear strength, lbs	Shrinkage after 1 wash, %	Shrinkage after 5 wash, %	Fabric flamm ability	Print evaluation
Undyed /untreated	5.77	137 x 97	11.5 x 10.3	2.2 x 1.3	2.2 x 1.0	Pass	Preferred
Yarn dyed /untreated	5.46	156 x 108	14.6 x 13.2	1.7 x 0.2	2.9 x 0.2	Pass	Not preferred
Undyed /enzyme treated	5.42	120 x 86	6.4 x 4.6	2.5 x 2.7	2.5 x 2.5	Pass	Not preferred
Yarn dyed /enzyme treated	5.02	126 x 86	6.6 x 5.3	3.7 x 2.3	2.2 x 3.0	Pass	Not preferred
Piece dyed wool/ untreated	5.85	151 x 107	12.9 x 9.9	1.7 x 0.4	3.2 x 1.0	Pass	Not preferred
Yarn dyed aramid/piece dyed wool/ untreated	5.46	156 x 108	14.6 x 13.2	1.7 x 0.2	2.9 x 0.2	Pass	Not preferred
Piece dyed wool/ enzyme treated	5.44	123 x 88	7.6 x 7.4	1.4 x 0.8	3.9 x 1.3	Pass	Not preferred
Yarn dyed aramid/ piece dyed wool/enzyme treated	5.14	127 x 90	11.1 x 9.6	1.7 x 0.1	3.2 x 0.4	Pass	Not preferred
Piece dyed wool and aramid/ untreated	5.94	162 x 111	12.3 x 10.3	2.1 x 1.4	2.9 x 1.7	Pass	Not preferred
Piece dyed wool and aramid/ untreated	5.84	137 x 91	8.9 x 7.0	1.8 x 1.1	2.0 x 1.4	Pass	Not preferred

Table 4. Comparison between untreated and enzyme treated wool/Nomex fabrics for IR reflectance values.

Wavelength NM	Desert Sand		Urban Gray		Foliage Green	
	Untreated	Enzyme treated	Untreated	Enzyme treated	Untreated	Enzyme Treated
600	**41.9**	**42.86**	21.17	**11.64**	13.46	**19.06**
620	**42.81**	**43.67**	21.45	**11.56**	13.58	**19.37**
640	43.95	44.24	21.72	**11.75**	13.78	19.62
660	46.86	47.25	22.75	**12.50**	14.49	20.79
680	53.89	54.75	24.07	**15.04**	16.93	20.42
700	62.52	63.99	30.19	**18.64**	20.42	**28.93**
720	68.21	**70.08**	32.98	**21.36**	23.20	**31.84**
740	71.42	**73.27**	35.44	**22.69**	24.67	**33.37**
760	73.35	**75.02**	35.10	**23.34**	25.58	**34.14**
780	74.08	76.00	35.41	**23.82**	25.77	**34.61**
800	75.17	**77.35**	36.76	**25.53**	27.59	**36.44**
820	75.71	**76.39**	35.93	**26.34**	27.70	35.60
840	75.46	76.80	**36.88**	**25.71**	27.76	36.35
860	75.53	77.41	**36.40**	**25.22**	26.73	36.27
Remarks	**Pass**	**Fail**	**Pass**	**Fail**	**Pass**	**Fail**

Results in **Bold** are outside the specified range. More than three outside the range fails the test.

Table 5. Comparison between prepared for print untreated fabrics.

Property	Print on Undyed fabric	Print on Dyed fabric
Weight, oz/sq. yd	6.0	6.0
Tensile Strength, lbs	158 x 114	156 x 114
Tear strength, lbs	14.2 x 11.8	8.0 x 8.1
Flex abrasion, rubs	6794	567
Wash shrinkage, %	3.4 x 2.4	2.8 x 0.5
Flammability Char length, in Burn time, sec	 4.2 x 3.1 0.4 x 0.3	 4.0 x 3.4 0.1 x 0.6
Colorfastness Water Perspiration Crocking Light	 5.0 5.0 4.0 3.5	 5.0 5.0 3.0 3.5

was also subjected to specialized tests covering flame resistance and electrostatic dissipation. These are discussed separately, later. The list of general test methods and performance goals is given in Table 6.

Table 6. Test methods, Minimum requirements and Results on Camouflage Printed wool/Nomex Fabric.

Test method	Description	Requirements	Results
AATCC -8	Colorfastness to crocking – Dry		
	Desert sand	3-4	4
	Urban gray	3-4	4
	Foliage green	3-4	3-4
	Colorfastness to crocking – wet		
	Desert sand	3	4
	Urban gray	3	3.5
	Foliage green	3	3
AATCC - 15	Colorfastness to Alkaline perspiration		
	Desert sand	3-4	5
	Urban gray	3-4	5
	Foliage green	3-4	5
	Colorfastness to Acid perspiration		
	Desert sand	3-4	4-5
	Urban gray	3-4	4
	Foliage green	3-4	5
AATCC - 16	Colorfastness to light		
	Desert sand	3-4	4-5
	Urban gray	3-4	4
	Foliage green	3-4	5
AATCC - 96	Colorfastness to laundering		
	Color change		
	Desert sand	3-4	3-4
	Urban gray	3-4	4
	Foliage green	3-4	4-5
AATCC – 135	Dimensional Changes in laundering	3.0 x 3.0	8.3 x 6.3
ASTM – D 3776	Weight, oz/sq yd	4.7 – 6.0	5.9
ASTM – D 5034	Break strength, lbs		
	Warp	150	159
	Filling	100	118
ASTM – D1424	Teat Strength, lbs		
	Warp	8.0 min	11.2
	Filling	5.0 min	8.4
ASTM – D 737	Air Permeability, CFM max		31.8

5. RESULTS AND DISCUSSION

Preproduction sample evaluations

Various fabrics were developed and evaluated including those with producer colored aramid fiber and dyeable aramid fiber; with and without the U.S.D.A. enzyme treatment, and fabrics that were piece dyed and overprinted, and a group that was printed only, resulting in a total of ten permutations. The test results on these ten fabrics are listed in Table 3. It was clear from the results shown that the enzyme treatment did not contribute significantly to the wash and tumble dry performance of the blended fabric since the untreated fabrics themselves performed extremely well in the wash test. The enzyme treated fabrics lost weight during the enzyme treatment as expected, and resulted in a small reduction in fabric strength. However the reduction in fabric tear strength due to the enzyme treatment was catastrophic. In addition to the overall reduction in strength, the enzyme treatment, which removed the wool scales, increased the fiber-to-fiber friction. This restricted yarn separation at the point of tear propagation reducing the tear strength. When lubricated with a cationic softener, the tear strength improved significantly and was almost similar to that of the untreated fabric. All of the fabrics demonstrated good flame resistance (FR) as tested by the vertical flame test, which is widely used in the trade for evaluating the flame protection of fabrics. This indicates that no topical treatments were necessary for any of these blended fabrics. Finally, both of our print partners showed preference for working with dyeable aramid fiber as opposed to producer colored aramid for cost and other technical reasons.

The NIR performance and colorfastness of the enzyme treated and untreated fabrics are listed in Table 4. It is seen that the enzyme treated fabrics failed to meet the IR requirements as the deeper shade of the treated fabric also absorbed more of the NIR light. Untreated fabric on the other hand met the NIR performance goals easily and the final selection for fabric production was based on using undyed fibers and without any topical applications for flame resistance or machine washability.

Print formulations

Two alternate print options were investigated. In one, the fabric was first dyed to one of the lighter colors and then overprinted with the darker color screens. In the other the fabric was not dyed and all of the three required colors were printed on undyed substrate. The results are given in Table 5. Dyeing of fabric prior to printing did not increase either the color yield or the colorfastness properties of the printed fabrics. Additionally, the fabric dyed prior to printing also lost some strength. The results clearly demonstrate that the undyed fabric offers significant advantages not only in terms of fabric mechanical properties but also based on savings in manufacturing cost by eliminating an additional process.

Based on the preliminary evaluations the commercial production was undertaken using 28/2 cc wool/Nomex blended yarn and woven to specifications given in Table 2. It was given a pure finish without any topical treatment to impart either machine

Table 7. Flammability tests on various wool/aramid blended fabrics.

		Untreated Fabric	Printed fabric on untreated substrate	Dyed fabric	Printed fabric on dyed substrate
Warp After Flame Time	1.	0.9	0.0	0.0	0.0
(ASTM-D-6413)	2.	0.4	0.6	0.0	0.0
	3.	0.0	0.0	0.0	0.7
	4.	0.5	0.8	0.4	0.0
	5.	0.0	0.5	0.0	0.8
Unit Averages (sec)		0.4	0.4	0.1	0.3
Filling After Flame Time	1.	1.6	0.0	0.0	1.2
(ASTM-D-6413)	2.	0.0	0.0	0.0	0.5
	3.	0.0	0.0	0.8	0.8
	4.	0.0	0.8	1.4	0.0
	5.	0.8	0.7	1.0	0.4
Unit Averages (sec)		0.5	0.3	0.6	0.6
Warp After Glow	1.	0.0	1.5	0.0	5.0
(ASTM-D-6413)	2.	2.6	4.9	0.0	4.1
	3.	0.8	4.1	0.0	2.3
	4.	0.5	5.4	*0.0	4.8
	5.	1.9	4.5	0.0	3.8
Unit Averages (sec)		1.2	4.1	0.0	4.0
Filling After Glow	1.	0.0	9.0	0.0	4.2
(ASTM-D-6413)	2.	3.0	5.9	0.0	3.0
	3.	4.2	8.0	0.0	4.0
	4.	2.2	4.1	0.0	0.0
	5.	5.8	4.8	0.0	0.0
Unit Averages (sec)		3.0	6.4	0.0	2.2
	1.	4.3	1.3	4.3	2.5
Warp Char Length	2.	4.1	3.6	4.4	3.8
(ASTM-D-6413)	3.	1.5	6.4	4.4	4.4
	4.	3.1	4.8	*3.9	4.8
	5.	1.7	5.1	2.8	4.2
Unit Averages (in)		2.9	4.2	4.0	3.9
Filling Char Length	1.	3.0	3.3	1.8	5.1
	2.	2.6	2.1	3.6	4.4
	3.	2.9	2.2	4.3	4.1
	4.	1.5	4.9	5.5	1.3
	5.	4.4	3.0	1.8	3.0
Unit Averages (in)		2.9	3.1	3.4	3.6

Table 8. Electrostatic decay of Camouflage printed wool/Nomex Fabric (Method 5931).

Wool/Aramid	Sample #	Initial Sample Charge	Voltage Max.	Decay time @ 10% cut off	Comments
Warp- Face	1	0	4500	0.01	
	2	0	4250	0.01	
	3	0	4500	0.01	
Average		0	4417	0.01	Pass
Warp - Back	1	0	4500	0.01	
	2	0	4500	0.01	
	3	0	4500	0.01	
Average		0	4500	0.01	Pass
Filling - Face	1	0	4500	0.01	
	2	0	4500	0.01	
	3	0	4500	0.01	
Average		0	4500	0.01	Pass
Filling - Back	1	0	4500	0.01	
	2	0	4500	0.01	
	3	125	4500	0.01	
Average		0	4500	0.01	Pass
After Laundering					
Warp -Face	1	0	4125	0.01	
	2	0	4250	0.01	
	3	0	4250	0.01	
Average		0	4208	0.01	Pass
Warp - Back	1	0	4250	0.01	
	2	0	4375	0.01	
	3	0	4250	0.01	
Average		0	4292	0.01	Pass
Filling -Face	1	125	4250	0.01	
	2	0	4000	0.01	
	3	0	4125	0.00	
Average		0	4125	0.01	Pass
Filling - Back	1	250	4500	0.01	
	2	0	4125	0.00	
	3	0	4125	0.01	
Average		0	4125	0.01	Pass

Table 9. Performance of near infrared reflectance values of the final production fabric.

Spectral Reflectance in the Near Infrared

Wavelength (nm)	DS Min	DS Max	DS 500	UG MIN	UG MAX	UG 501	FG Min	FG Max	FG 502
600	28	40	33.10	12	26	19.80	8	18	13.47
620	30	42	33.76	14	26	20.12	8	18	13.65
640	34	48	34.57	14	28	20.54	8	20	13.92
660	38	56	36.83	14	30	21.89	10	26	14.87
680	44	60	43.32	18	34	26.06	10	26	17.81
700	46	66	52.57	24	38	32.41	12	28	22.54
720	48	68	59.61	26	42	37.92	16	30	26.73
740	48	72	63.35	30	46	41.26	16	30	29.29
760	50	74	65.48	32	48	43.08	18	32	30.78
780	54	76	66.19	34	48	43.95	18	34	31.39
800	54	76	66.11	34	50	43.96	20	36	31.61
820	54	76	66.67	36	54	44.23	22	38	32.09
840	55	78	67.06	38	54	45.21	24	40	32.41
860	56	78	67.29	40	56	45.87	26	42	32.86

More than three points out of the range of the requirement, highlighted in yellow, indicate a failure.

Table 10. Properties of final production fabric.

Test performed	Results	Comments
Blend Composition	49.81% wool/50.19% Nomex	Pass
Weight, oz/yd2	5.66	Pass
Weight, oz/running yard	9.6	Pass
Width, inches	61.25	Pass
Warp, threads/inch	60	Pass
Weft, threads/inch	47	Approved
Breaking Strength, lbs	158 x 117	Pass
Shrinkage ,3 wash/TD	3.5 x 1.3	Pass
Fabric pH	6.8	Neutral
Pilling, ASTM D 3512	4.0	v. good
Flammability, Char length, inches Burn time, sec	 Less than 4 inches Less than 2 seconds	 Pass Pass
Antistatic decay	Decay within 0.5 sec	Pass
Color fastness	greater than 3 and mostly 4-5	Pass
IR requirements	Meets universal standard	Pass

washability or fabric flammability as these features were shown to be inherent in the blended fabric. The final finished fabric after printing was evaluated for a variety of properties and these are tabulated in Tables 6 to 10. The results for colorfastness and mechanical properties are listed in Table 6 and show that the final camouflage printed fabric met with all of the performance goals. Additional tests on the printed fabrics were carried out to evaluate a variety of performance features such as flammability, NIR, and electrostatic decay. These are discussed separately in the next section.

Specialized tests

Fabric flammability was evaluated by the ASTM D 6413, Standard Test Method for Flame Resistance of Textiles (Vertical Test), using a 12 second ignition time using a butane gas burner. The afterflame time to self extinguish the flame, the after glow time and the char length of the burnt sample were recorded and reported in Table 7. The results show that the after-flame time of less than one second for all fabrics was less than the maximum performance goal of two seconds. The average after glow time was no greater than 6.4 seconds and well below the 25 second maximum performance goal.

In addition to the above evaluation of fabrics for flame resistance, garments made from this fabric were also evaluated using ASTM F-1930, Standard Test Method for Evaluation of Flame Resistant Clothing for Protection Against Flash Fire Simulations Using an Instrumented Manikin. A military protocol[6] was used, where the combat coverall was made from the developmental fabric, except that it was not camouflage printed and was tested over a cotton t-shirt and briefs, which are standard military undergarments. The pass requirements for such a two layer garment configuration are a skin burn of less than 20% when subjected to a flash fire of 2.0 cal/(cm^{2}s) over a period of three seconds. The results of one such test carried out at the North Carolina State University flammability laboratory is presented in Figure 1. The figure shows the computed skin burn value and the location of skin burns. The computed value of percent skin burn was 12.3 and easily meets the minimum pass criteria established by the military.

One other specialty performance goal requested by the military is the evaluation of the electrostatic decay of the fabric. This is measured in terms of the time taken to dissipate an electric charge from the test fabric. The test method used is the Federal Test Method Standard 191A, Method 5931, Determination of Electrostatic Decay of Fabrics where a fabric is charged with 5000 volts and then grounded. The actual initial charge and the time to decay this charge to less than 10% of the original charge is recorded in seconds. The pass requirements for compliance are that the original charge should be at least 4000 volts and the decay time should be less than 0.5 seconds. Such a test was performed at NSRDEC, the results are listed in Table 8, and they show that the fabric fully complied with this requirement both when tested initially and after five launderings.

The final confirmation of compliance was obtained when the production fabric length was commercially printed to a Universal print design with NSRDEC staff approving the color. The subsequent NIR values measured at NSRDEC are listed in

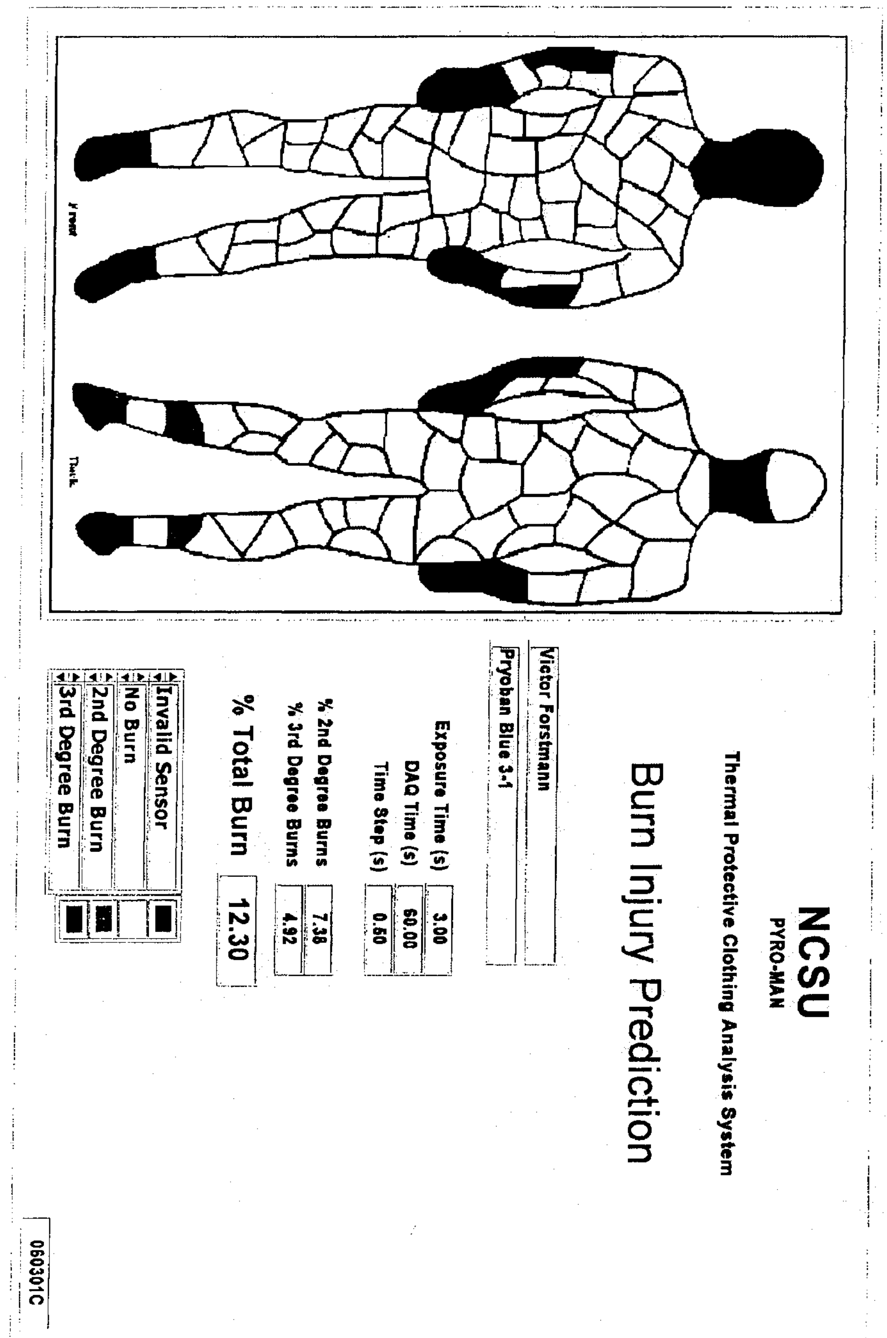

Figure 1. Burn injury prediction using Thermal Protective Clothing Analysis System.

Table 9. The printed fabric met the most stringent requirements for NIR set by the military where only the current NYCO fabric consistently meets these requirements. Four hundred and fifty yards of first quality commercially printed fabric was forwarded to NSRDEC for in-house testing and field trials.

6. CONCLUSIONS

This study undertaken to optimize fabric construction and print technique has shown that a fine two-ply yarn made from a 50/50 blend of domestic 70's grade (20.5 micron) wool and Nomex Type 462 in a plain weave construction can produce a fabric of less than 6 ounces per square yard. This lightweight fabric is shown to meet all of the military requirements in terms of mechanical properties, visual and NIR camouflage, colorfastness, flammability, machine wash and tumble dry performance, and electrostatic dissipation.

It is further shown that in meeting of the above criteria, no chemical treatment to the fabric for either imparting flame resistance or machine washability was necessary. Additionally, the fabric does not have to be pre-dyed prior to printing to meet the specified color standard. A good NIR and colorfastness was achieved by coloring only the wool component in the blend using standard wool compatible dyes.

Based on this study, the final recommendations for fabric manufacturing are given in Table 10. The recommendations are simple and easy to implement in a commercial environment. It specifies intimately blended staple spun yarn in 28/2 Ne; woven as plain weave to a finished set of 60 ends and 47 picks to give a finished fabric weight of 5.8 ounces per square yard. The fabric is best stabilized using a pressure steam setting treatment (110°C for 10 minutes) using a double vacuum cycle in a pressure autoclave. The fabric should be sheared to impart a soft hand and excellent pill resistance and printed using 1:2 metal complex dyes. This development which was carried out in a commercial production environment offers ready transfer of technology in procuring fabrics. The clearly defined parameters coupled with a minimum of production steps ensures that the fabric yield will be high (less waste), and the short production time period ensures a modest manufacturing cost. The fabric so produced provides a challenging alternative to currently used aramid and P140 blend fabric. Sufficient yardage (approximately 450 yards) of first quality printed fabric is submitted to NSRDEC for additional testing and field evaluations.

7. RECOMMENDATIONS

The fabric deliverable requires sponging to remove fabric tensions imparted during the final printing operation prior to making up into garments. This was an unfortunate oversight as this information only surfaced since the production lot was shipped to NSRDEC. It is further recommended that a full manikin test for protection against flame hazards using long underwear be conducted over higher flash exposure times to confirm excellent results seen in the laboratory tests. Finally, a comfort evaluation study is urged to confirm known excellent moisture management properties of this blended fabric.

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 08/019 in a series of reports approved for publication.

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