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NATICK/TR-15/029**



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FR/HR SEWING THREAD

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**U.S. Army Natick Soldier Research, Development and Engineering Center
Natick, Massachusetts 01760-5000**

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14. ABSTRACT This report contains information regarding the feasibility studies conducted by Nanosyntex during the US Army BAA project to design and develop a Fire Resistant (FR) and Heat Resistant (HR) sewing thread. The main goal of the project is to produce sewing threads made of blends of high performance and commodity fibers to reduce the cost of the thread while meeting the current military specifications of the sewing thread. Additionally, the ability to use up to 30% recycled fibers in the fiber blends of the yarn was successfully demonstrated. First, the yarns of the sewing thread were made using blends of nylon or cotton along with para-aramid and recycled para-aramid fibers. The individual yarns were then twisted into sewing threads using a twisting frame to produce 40 tex and 60 tex sewing threads. These threads were then dyed for tan color 499 as required by the US Army. The sewing threads were tested for physical and mechanical properties. The threads were also tested for fire and heat resistant characteristics. Fabrics sewn using the threads were laundered multiple times to determine any color changes to the thread. Final deliverables included submission of 18 cones of FR/HR sewing threads and sewn fabrics to the sponsor.																															
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FR/HR Sewing Thread

1. Introduction

The following final report outlines the work accomplished by Nanosyntex under Broad Agency Announcement (BAA) contract to the US Army Natick Soldier Research, Development and Engineering Center (NSRDEC) for the topic titled “FR/HR sewing threads”. Work was performed from August 20, 2014 through February 20, 2015. The research discussed herein addresses the design, development and testing of various Fire Resistant (FR)/Heat Resistant (HR) sewing threads for US Army applications. Such a sewing thread offers the ability to maintain the integrity of the FR uniforms and other end use items. This report discusses efforts expended in conducting this research, outlines the results and presents conclusions to be drawn from this effort.

Current FR/HR sewing threads are made using expensive material and are largely ineffective at high temperatures. The main goal of this BAA project was to produce a sewing thread that would be significantly lower in cost when compared to the current FR/HR sewing thread used by the US Army while meeting the current military specifications. To accomplish these goals, the design of the yarns of the sewing threads included commodity fibers such as nylon and cotton as major components in blends, with high performance fibers such as para-aramid (PA) as minor components. To further reduce the cost and promote the “green initiative” at the US Army, recycled para-aramid (R-PA) fibers were used in blends with other fibers.

Raw material fibers were selected and procured domestically in bale form from the suppliers of various fibers. The fibers were then opened or cleaned and blended with other fibers before being made into individual yarns. The yarns produced had various formulations containing predominantly nylon or cotton with PA being the minor component. The yarns that were made had a fineness of 20 tex. The spun yarns were then combined into 2 and 3 plies and twisted on a frame to produce sewing threads that were 40 tex and 60 tex in fineness. The twisted threads were dyed to tan 499 color using a system of reactive dyes in spools. The dyed FR/HR sewing threads were then tested for strength and fire and heat resistance characteristics. Based on the test data, the FR/HR sewing threads produced met the required US Army specifications for breaking strength and fire (non-melt drip) and heat resistance. The sewing threads maintained their original color even after multiple laundering cycles. It was possible to stitch multiple layers of the US Army FR fabric together without any thread breakage using the FR/HR threads produced during this project. These sewn fabrics in conjunction with 18 individual cones of FR/HR sewing threads were submitted to NSRDEC for testing.

2. Key Objectives of the Project

The main goal of this BAA project was to perform research and development to develop a cost-effective FR and HR sewing thread using a blend of virgin and recycled staple fibers.

The specific objectives of the project are listed below:

1. Produce sewing threads using commodity staple fibers such as cotton and nylon in blends with high performance fibers such as PA and R-PA.
2. Utilize raw material fibers that are Berry Amendment compliant.
3. Maximize the amount of recycled fiber to develop a cost-effective sewing thread while maintaining the physical properties.
4. Optimize the level of PA (not to exceed 30% by weight in overall blend) in the sewing thread to achieve a minimum breaking strength value of 1.5 lb for a thread size of 20-49 tex and 3.5 lb for a thread size of 50-70 tex with a breaking elongation of 15-35%.
5. Produce the yarns and threads utilizing the pilot scale equipment with the possibility of scaling up on commercial production machines.
6. Characterize the yarns for breaking strength and FR properties.
7. Produce threads that do not exhibit any melt drip upon exposure to flame and maintain 80% of original thread breaking strength after exposure to 500 °F for 5 min using National Fire Protection Agency (NFPA) method 1977.
8. Produce threads that are dyeable to match tan, coyote and foliage green colors.
9. Produce threads that exhibit color fastness to light and laundering as tested per AATCC TM 16 and AATCC TM 61 methods respectively.
10. Submit the necessary cones (18 in number) containing the successful sewing thread per the BAA solicitation and the technical proposal to the sponsor.

3. Material, Methods and Approaches

3.1 Task 1 - Planning, procurement and raw material fiber analysis

The following section contains information on the materials used and the various tasks carried out in this project. This section also outlines the processing methods used to make the FR/HR sewing threads. The principal approach uses novel blends containing commodity and high performance fibers to provide the foundation for achieving the objectives given in Chapter 2.

3.1.1 Raw material fibers utilized in making the individual yarns of sewing threads

The first task of the project involved planning to conduct a series of trials to produce the necessary yarns to make the FR/HR thread. This included procurement of necessary raw material fibers, including the recycled fibers. The following fibers were used for the project:

1. Cotton fibers as shown in Figure 1 were supplied by the United States Department of Agriculture (USDA), New Orleans, LA with fineness that matched that of the synthetic fibers to be used for the project.



Figure 1. Cotton fibers

2. Nylon fibers as shown in Figure 2 were procured from Invista fibers of Greenville, SC. The fiber fineness was at 1.5 denier per filament (dpf) and fiber length was at 1.5 inches.



Figure 2. Nylon fibers

3. PA fibers as shown in Figure 3 were supplied by Teijin Aramid America located in Marietta, GA. Fiber fineness was at 0.9 denier per filament and fiber length was at 2 inches.



Figure 3. PA fibers

4. R-PA fibers as shown in Figure 4 were supplied by Leigh Fibers of Wellford, SC. Fiber fineness was at 1.5 dpf and the fiber length was hugely variable due to the recycling process.



Figure 4. R-PA fibers

5. The required raw material fibers in 25 lb bags as shown in Figure 5 were shipped to the pilot plant facility located at the USDA, New Orleans, LA for processing into yarns.



Figure 5. Fiber bales for processing

3.1.2 Analysis of fiber length and fiber blends

An advanced fiber length analysis was conducted at the USDA test lab and the results are shown in Figure 6.

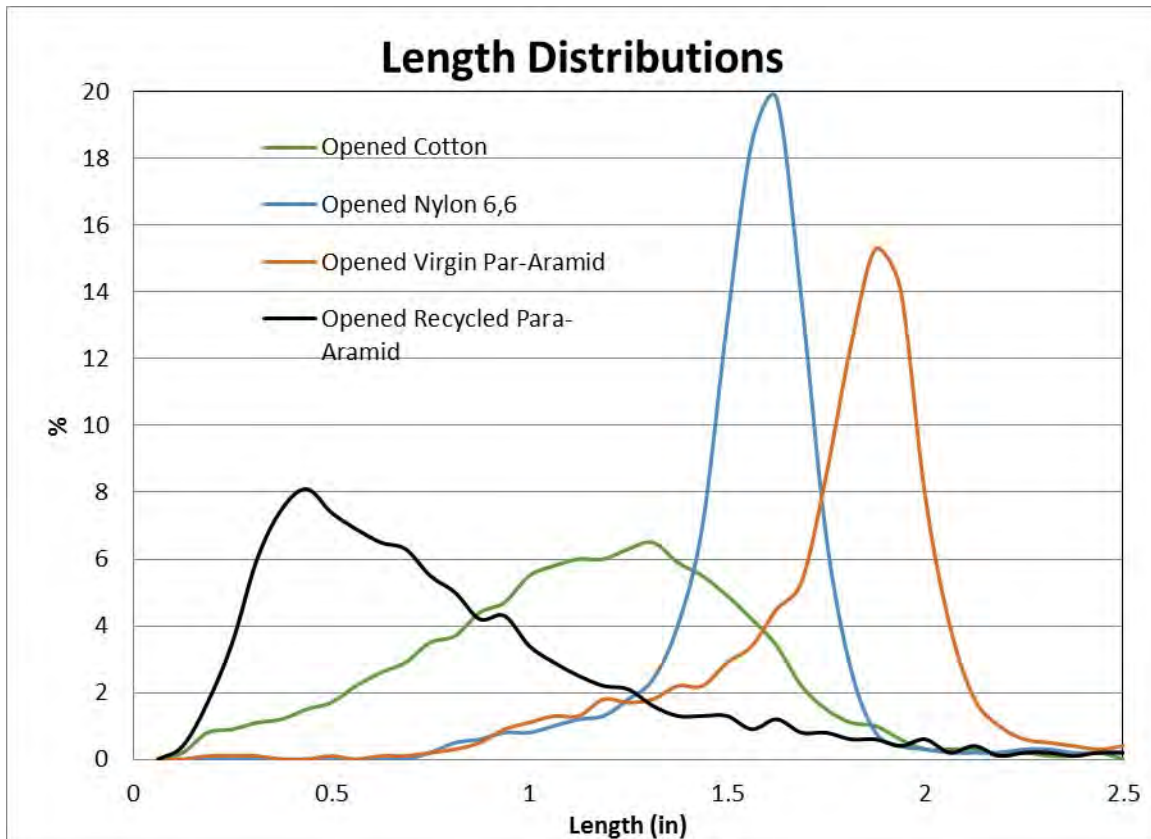


Figure 6. Fiber analysis results

It can be seen that the opened synthetic fibers, nylon and PA, have a much narrower distribution of fiber length as opposed to the opened natural fiber, cotton. Also, the R-PA contains much shorter fibers (less than 0.5 inches in length), as anticipated. Based on the above analysis, the following fiber compositions were opened and blended using the lab scale opening and blending equipment:

Fiber compositions opened and blended:

1. 100% cotton fiber
2. 80% cotton/20% R-PA
3. 80% cotton/10% R-PA/10% virgin PA
4. 80% nylon/10% R-PA/10% virgin PA

The blended compositions were then analyzed for fiber length distribution and the results are shown in Figure 7.

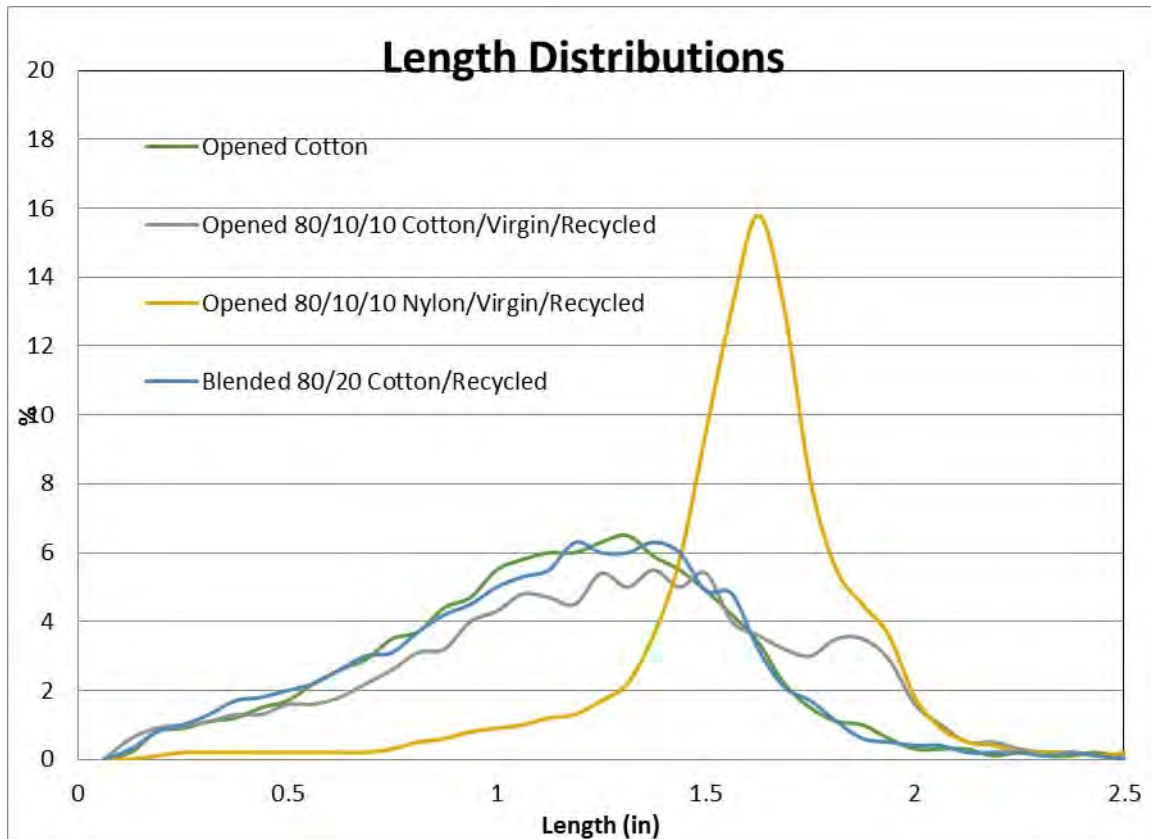


Figure 7. Analysis of fiber blends

It can be seen that the R-PA fiber length was well aligned with that of cotton at a ratio of 20% by weight of the blend. It was assumed that the R-PA was well blended with the cotton fibers to produce yarns with good uniformity.

3.2 Task 2 - Production of yarns using pilot scale equipment

3.2.1 Production of individual yarns

The second task of the project involved the utilization of processes to produce the individual yarns needed for making the sewing threads. Lab scale equipment located at the USDA pilot facility were utilized to make the yarns. The following materials and processes were used for the study:

1. Raw material fibers – high purity cotton, nylon, PA and R-PA (Figure 8). A 65 g sample was used for processing.



Figure 8. Raw material fibers (Courtesy: USDA, NOLA)

2. Fiber opening and blending – The fibers were opened and intimately blended via two passes using a Spinlab fiber opener/blender. Figure 9 shows the blend of cotton/PA/R-PA fibers that was fed into the carding machine for further opening.



Figure 9. Opened and blended fiber (Courtesy: USDA, NOLA)

3. Carding - A modified card (shown in Figure 10) to handle narrow width (less than 1 m wide) materials was used to make the further opened web as shown in Figure 11.



Figure 10. Carding equipment (Courtesy: USDA, NOLA)



Figure 11. Carded web (Courtesy: USDA, NOLA)

4. Production of sliver – A miniature draw frame as shown in Figure 12 was used to produce the sliver (Figure 13) from the carded web to be used on the spinning machine.

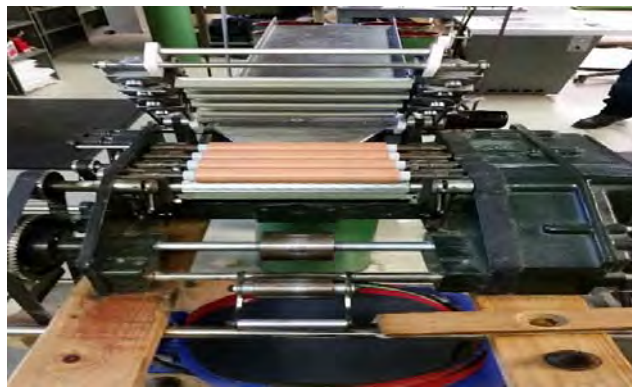


Figure 12. Miniature draw frame (Courtesy: USDA, NOLA)



Figure 13. Drawn sliver (Courtesy: USDA, NOLA)

5. Yarn production – The drawn slivers were combined on a frame to minimize unevenness before being placed on a miniature ring spun frame as shown in Figure 14.

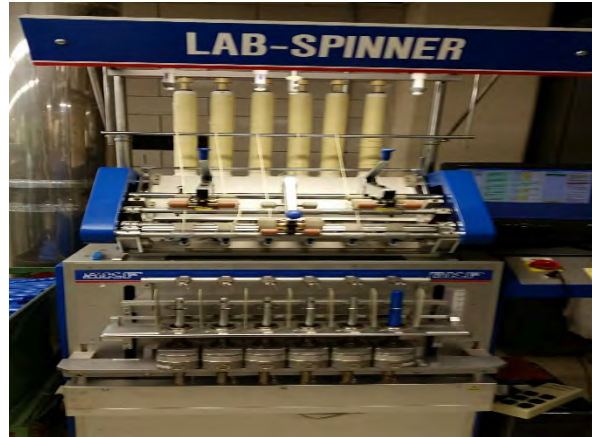


Figure 14. Lab scale ring spinning equipment (Courtesy: USDA, NOLA)

Yarn Samples Formulation:

The following yarn samples were successfully produced and tested for the breaking strength values:

1. Sample 1: 100% Cotton
2. Sample 2: 80% Cotton + 10% Virgin PA + 10% Recycled PA
3. Sample 3: 80% Nylon + 20% Recycled PA
4. Sample 4: 80% Cotton + 20% Recycled PA

3.2.2 Testing of yarns

The breaking strength values of these samples are shown in Figure 15. The turns per inch values were varied for the samples. Since cotton fibers are shorter and weaker than nylon and other synthetic fibers, there was a need to impart more twist during the spinning of 100% cotton yarns and the cotton based blends. The twist multipliers chosen for spinning the yarns were from 3.5 to 5.2 which relates to a turn per inch between 19 and 28 turns per inch. Turns per inch higher than 25 did not result in any appreciable increase in the breaking strength of yarns produced.

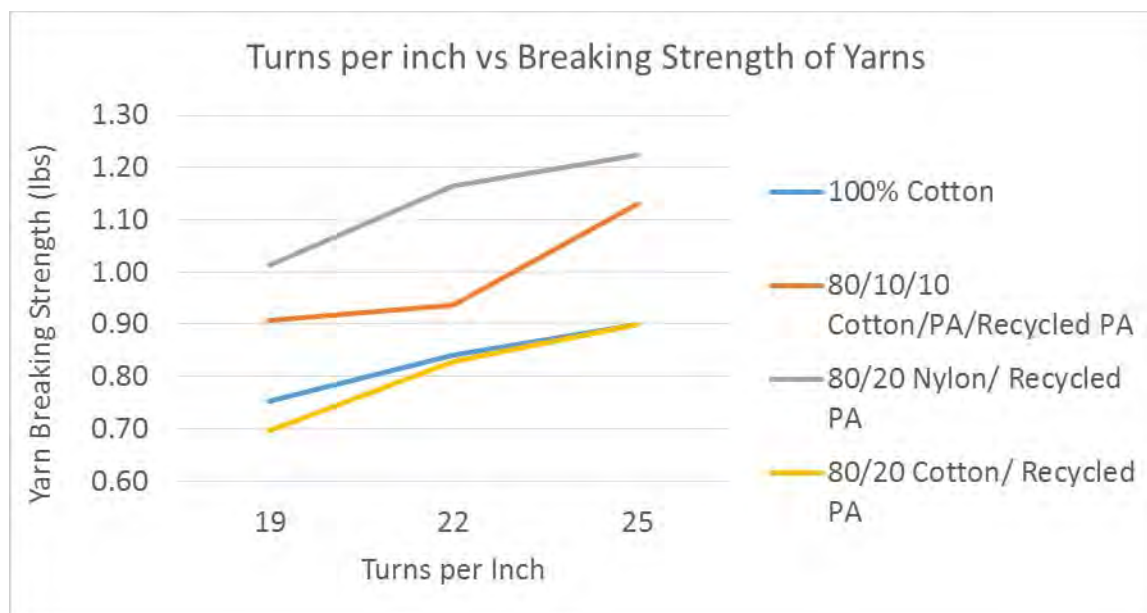


Figure 15. Breaking strength vs turns per inch of yarn

As can be seen from the chart, for a given twist value, the nylon fiber based yarns had the highest breaking strength while the cotton based yarns had lower breaking strength. The breaking strength of cotton was significantly enhanced by adding the high performance PA and the R-PA fibers to the blend. The yarns produced had a linear density of 20 tex. A 2-ply would yield a 40 tex sewing thread and a 3-ply would yield a 60 tex sewing thread. Assuming a linear relationship, the 2-ply thread would have a breaking strength of 2.5 lb and a 3-ply thread would have a breaking strength of 3.6 lb. This is right in line with the minimum breaking strength required for the current BAA solicitation. Since the breaking strength of cotton was not improved by the addition of R-PA fibers in the 80/20 blends, it was decided that the PA content would be increased to 30% for a potential increase in strength while making the final yarns for producing the sewing thread. The new yarn made using blends of cotton and PA had the following formulation: 70% cotton + 15% PA + 15% R-PA. The required yarn packages for making the sewing thread were delivered to the Textile Technology Center of Gaston College, Belmont, NC.

3.3 Task 3 - Production of FR/HR sewing threads using pilot scale equipment

3.3.1 Formulations of sewing threads produced

The third task of the project involved the twisting of yarns made during Task 2 to produce FR/HR sewing threads. A lab scale twisting frame located at Gaston College, Belmont, NC was used to produce a series of threads with the configurations and formulations as shown in Table 1:

Table 1. Formulations used to produce FR/HR sewing threads

Sample ID from the USDA	Sample Description	No. of Plies	Type of Twist Needed for Thread	Twist per inch	Linear Yards per spool (minimum)	Number of Final Spools Needed Containing Sewing Threads
2	80% Cotton + 10% PA + 10% R-PA	3	Z-Z-Z	6.5	500	12
2	Same as above	3	S-S-S	6.5	500	6
3	80% Nylon + 20% R-PA	3	Z-Z-Z	5.0	500	12
3	Same as above	3	S-S-S	5.0	500	6
3	Same as above	2	Z-Z	5.0	500	12
3	Same as above	2	S-S	5.0	500	6
4	70% Cotton + 15% PA + 15% R-PA	2	Z-Z	6.5	500	12
4	Same as above	2	S-S	6.5	500	6

Figure 16 shows the twisting frame that was used to produce the FR/HR sewing threads from individual yarns. Spools containing the threads made of 3 and 2-ply threads were used for dyeing US Army tan and further testing. Based on the breaking strength values obtained, the threads were made using the yarns of the same twist configuration (ZZZ, ZZ, SSS and SS) as opposed to using the combinations and opposite twists. Twists per inch were 6.5 for cotton fiber blends and 5.0 for nylon fiber based blends. The use of yarns containing opposite twist configurations resulted in threads with poor integrity and hairiness. Enough material was made to be used in the dyeing machine and to be supplied as final deliverables for the project.

**Figure 16. Lab scale yarn twisting equipment (Courtesy: Gaston College, NC)**

3.3.2 Breaking strength of FR/HR sewing threads

The FR/HR threads were then tested for the breaking strength characteristics and the test results are shown in Table 2:

Table 2. Breaking strength of FR/HR sewing threads before dyeing

Sample ID from the USDA	Sample Description	No. of Plies	Type of Twist Needed for Thread	Final Tex	Breaking Strength (lbf)	Breaking Elongation (%)
2	80% Cotton + 10% PA + 10% R-PA	3	Z-Z-Z	60	3.7	4.0
3	80% Nylon + 20% R-PA	3	Z-Z-Z	60	4.2	20.0
3	Same as above	2	Z-Z	40	3.0	20.4
4	70% Cotton + 15% PA + 15% R-PA	2	Z-Z	40	2.6	3.3

It can be seen from the above table that the threads tested had very good breaking strength characteristics. The nylon/PA fiber blend based threads showed better performance than the cotton/PA fiber blend based threads. Based on these preliminary tests, it appeared that it was possible to meet or exceed the breaking strength targets for the BAA project. The cotton fiber based threads have shown brittle characteristics as evidenced by their very low breaking elongation values.

3.4 Task 4 - Dyeing of FR/HR sewing threads

The fourth task of the project involved dyeing FR/HR sewing threads made during Task 3 to produce threads that were matched to the US Army tan color 499. A color standard for US Army tan 499 in the fabric form was provided by the sponsor. The sewing threads produced in the previous task were dyed and color matched at the dyeing lab located at the Textile Department of Gaston College, Belmont, NC. The preliminary color match was conducted at the labs of dye chemical supplier Dystar, Inc., located in Charlotte, NC. Based on this color match, a color formulation was selected to be applied to all the samples with various compositions shown in Table 2.

Dyeability:

The cotton fiber and their blends based sewing threads were dyed using a reactive dye system to produce threads with good color and light fastness attributes. This was successfully accomplished on 80/10/20 and 70/15/15 blends of cotton/PA/R-PA fiber blends. The dyed threads were assembled into a sock form using a lab scale knitting machine for color evaluation as shown in Figure 17. The blend with less cotton (70%) was closer to the tan 499 color standard than the blend with more cotton fibers (80%). The nylon fiber based sewing threads did not dye

in a uniform manner as shown in the following picture. Further work is needed to develop a dye system to produce uniform color.

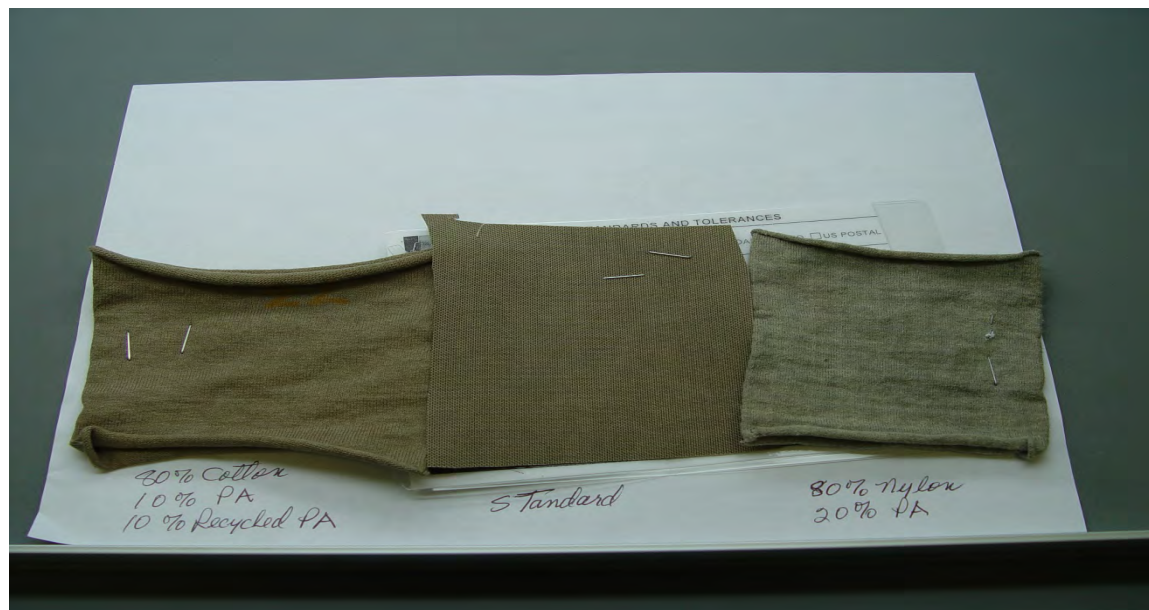


Figure 17. Dyed samples of FR/HR thread in fabric form vs the supplied color standard fabric (in the middle)

3.5 Task 5 – Testing and evaluation of dyed FR/HR sewing threads

3.5.1 Breaking strength and elongation

The fifth task of the project involved the testing and evaluation of the dyed sewing threads for physical and mechanical properties. The dyed FR/HR sewing threads were tested for breaking strength and breaking elongation using the Uster Tensorapid® tensile tester for staple and filament yarns located at the Textile Department of Gaston College, Belmont, NC using the following conditions:

Sample length: 500 mm

Test Speed: 5000 mm/min

The breaking strength values are reported in pounds and the elongation in percentage. The breaking strength and elongation test speeds used were those normally used in industry and did not conform to the ASTM D 204 test method with a sample length of 10 inches and a rate of 12 inches per minute.

3.5.2 Flame and heat resistance

The sewing threads of 80/10/10 cotton/PA and R-PA fiber blend were exposed to 500 °F in a free state inside an oven for 5 min per test method NFPA 1977. The exposed threads were then

cooled to room temperature and tested for breaking strength and elongation using the Uster Tensorapid® tester.

3.5.3 Colorfastness

The sewing threads were tested for colorfastness per standard test method AATCC TM 61 Test 2A laundering by the skein of threads three times in a washing and drying machine. The sewing threads tested were made of all cotton and para-aramid fiber blends. The nylon fiber based sewing threads were not tested due to the non-uniformity in color of the yarns.

3.5.4 Launderability

Three 20 inch by 20 inch FR fabric pieces were used to study the colorfastness of sewn FR/HR threads after multiple laundering cycles (wash and dry cycles) per AATCC test method 135. The first sample was used as a control with sewn FR/HR threads. The second sample was laundered 13 times and the third sample containing sewn FR/HR threads was laundered 25 times. The sewing threads tested were made of all cotton and para-aramid fiber blends. The nylon fiber based sewing threads were not tested due to the non-uniformity in color of the yarns.

3.5.5 Sewability

The FR/HR sewing threads made from yarns of 80/10/10 blend of cotton/PA and R-PA fibers were used to stitch four layers of FR fabric together per ASTM D 1683 using 301 lock stitch type using a Singer sewing machine model # 4423 with a 90 gauge needle. The following parameters were used for sewing the fabrics:

Sewing speed: 1.86 inches per second

Number of stitches per inch: 6.6

Number of stitches per second: 12.26

Type of thread used in the looper bobbin: polyester

4. Results and Discussion

4.1. Breaking strength and elongation of FR/HR sewing threads

The breaking strength values of various FR/HR sewing threads tested using the Uster Tensorapid® tester before and after the dyeing process are shown in Table 3. It can be seen from the results that all the sewing threads produced exceeded the target values of breaking strength (3.5 lb for 60 tex and 1.5 lb for 40 tex threads). This effect was achieved even with the addition of short staple R-PA fibers within the individual yarns of the threads.

Table 3. Breaking strength of FR/HR sewing threads before and after dyeing

Sample ID from the USDA	Sample Description	Tex Size (nominal)	Type of Twist used for Thread	Breaking Strength (lbf) before dyeing	Breaking Strength (lbf) after dyeing	Breaking Elongation (%) before dyeing	Breaking Elongation (%) after dyeing
2	80% Cotton + 10% PA + 10% R-PA	60	Z-Z-Z	3.7	3.1	4	4.2
3	80% Nylon + 20% R-PA	60	Z-Z-Z	4.2	3.9	20	21
3	Same as above	40	Z-Z	3.0	2.5	20.4	20.4
4	70% Cotton + 15% PA + 15% R-PA	40	Z-Z	2.6	2.3	3.4	3.4

It can also be seen from Table 3 that there is a slight reduction in tensile strength after dyeing and finishing of the sewing threads due to the untwisting of the fibers that takes place during the dyeing and finishing processes. However, the threads still maintained the target breaking strength values after the dyeing process. The nylon based threads had slightly higher breaking strength than the cotton based threads as anticipated. However, the nylon threads did not dye as well as the cotton threads. The higher tex size threads had higher breaking strength.

The breaking elongation values are virtually unchanged after the dyeing and finishing process. The nylon based threads had much higher elongation than that of the cotton based threads. Based on these test results and the fact that there were dye pick-up issues with nylon based sewing threads, it was decided that additional tests be performed using the cotton fiber based sewing threads.

4.2. Breaking strength of threads after exposure to heat

The breaking strength of the sewing threads was tested after exposure to 500 °F in an oven for 5 min and the test results are shown in Table 4.

Table 4. Effect of heat exposure on the breaking strength of sewing threads

Sample ID	Breaking Strength Before Heat Exposure (lbf)	Breaking Strength After Heat Exposure (lbf)
80/10/10 Cotton/PA/R-PA	3.14	3.09

As can be seen from the above table, the breaking strength of the sewing threads was not significantly reduced by heat exposure. The reduction in tensile strength is only 1.6% and the FR/HR threads met the fire and heat resistance specifications of the BAA project.

When tested for the melt drip of the sewing threads using the NFPA 701 standard, it was evident that there were no melt drips when the FR/HR threads were exposed to flame and the threads completely charred.

The sewing threads from the cotton/ PA blends as shown in Table 4 were selected as the prime candidate for further testing as opposed to the sewing threads based on nylon/PA fiber blends. This is because the nylon fiber based threads did not dye well and were also of similar strength as that of the blend shown in the table.

4.3. Colorfastness of threads after laundering

The sewing threads were tested for colorfastness by laundering the skein of threads three times in a washing and drying machine. The threads maintained the original color with a rating of 4. This is due to the exceptional dyeability of cotton fibers in the blend even though the PA fibers in the blend do not pick up any dye molecules and are only stained.

4.4. Performance of threads after multiple laundering cycles

Three 20 inch by 20 inch multi-cam fabric samples were sewn with the FR/HR threads. One of the samples was used as control or unwashed and the other two samples were laundered (wash and dry cycles) for 13 and 25 cycles. The objective of this wash test was to see if the color of the FR/HR sewing threads were affected during the laundering cycles. The control fabric is shown in Figure 18, the fabric that was laundered 13 times is shown in Figure 19 and the one that was laundered 25 times is shown in Figure 20.



Figure 18. Control fabric sewn with FR/HR threads (unwashed)



Figure 19. Laundered fabric (13 cycles)



Figure 20. Laundered fabric (25 cycles)

It is evident from these pictures that the FR/HR sewing thread retained the original color after multiple laundering cycles. This is due to the fact that the dye molecules have greater affinity to the cotton portion of the thread (80% of the blend) although the PA fibers are only stained during the dyeing process. Visual observation indicated that the threads did not have much of a fuzzy surface even after multiple laundering cycles. Also, the threads were intact and no breakage or pull out was seen in the laundered samples.

4.5 Sewability of FR/HR threads

It was demonstrated that multiple layers (four layers) can be sewn using the FR/HR sewing threads using a Singer sewing machine without any issues with the breakage of threads as shown in Figure 21.



Figure 21. US Army multi-cam FR fabrics (four layers) sewn together using FR/HR thread

4.6. Recommendations for Future Work

1. Further optimization studies could be conducted using commercial production equipment where the yarns and the sewing threads could be more efficiently twisted to avoid any potential breakage of sewing threads.
2. Alternate dyeing formulations and systems could be utilized to avoid any issues with the dyeing of nylon fibers in blends with PA fibers.

5. Conclusions

1. The feasibility of producing low cost FR/HR threads from yarns containing blends of commodity and high performance fibers was clearly demonstrated in this project using pilot scale equipment.
2. The yarns were successfully produced from blends of cotton, nylon, PA and R-PA staple fibers.
3. The utilization of commoditized and recycled fibers results in lower cost FR/HR threads while supporting the “green” initiatives of the US Army.
4. The raw material fibers were procured and the threads were made using domestic resources to comply with the Berry Amendment.
5. Product and process variables were optimized to produce FR/HR sewing threads that exceeded the target values for the breaking strength values of 1.5 lb for the 40 tex and 3.5 lb for the 60 tex sewing threads while not exceeding a breaking elongation value of 15-35%.
6. Threads produced from both the nylon and cotton fiber based blends did not exhibit any melt drip upon exposure to flame and maintained a minimum of 80% of the original thread breaking strength after exposure to 500 °F for 5 min using NFPA method 1977. This is due to the presence of para-aramid fibers in both the blends used to make the threads.
7. Threads were dyed to match tan color standard 499.
8. Launderability tests carried out on the FR/HR threads made of cotton fiber based blends showed that the threads maintained their original color without any large amount of fuzz formation or thread damage. The nylon fiber based blends were not tested due to the poor dye pick up.
9. Sewability tests showed that it was possible to stitch multiple layers of fabrics without any damage to the needle or thread.
10. The necessary cones (18 in number) containing the successful sewing thread along with the sewn fabric samples were submitted to the sponsor at the end of the project.
11. Both cotton blended sewing threads failed to meet the percent elongation requirement of 15-35% elongation.
12. Two dye package spools of 80/20 Nylon/PA sewing thread were provided to Natick for testing. One was Tex 40 and the other Tex 60.