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USE OF INNOVATIVE TECHNOLOGIES IN PROTECTIVE CLOTHING DESIGN

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14. ABSTRACT
The LEHP Garment Team considered innovative technologies to replace sewn seams in CB garments. The Garment Team investigated other innovative methodologies, such as ultrasonic seam sealing, use of various seam tapes for added strength and protection, and the selection of equipment to be used in the process. This investigation also included the review of various seam constructions to ensure that there was compatibility between the fabric seam and the innovative techniques that were investigated. Strong, sew-free waterproof seams were achieved using a combination of ultrasonic sealing with a modified Jentschmann 4796-2-20 V1 B machine and Adhesive Films, Inc., Black EXF-652, one-inch width). Modifications to the Jentschmann machine, seam strength test results, and investigations of other seaming methods are also described in this report.

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JOINING ADHESIVES FABRIC SEAMS PROTECTIVE CLOTHING
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Duraseal is a trademark of Clemson Apparel Research.

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Preface

As part of its ongoing research in the field of protective garments, the Garment Team (GT) at the Philadelphia University Laboratory for Engineered Human Protection (LEHP) investigates innovative technologies and their application to chemical and biological (CB) garments. The GT considered innovative technologies to replace sewn seams in CB garments. Although sewing can produce a product that can be comfortable and protective, the sewing process itself adds to the need for additional protective components. The sewing needle punctures the protective membrane in the fabric, which then must be backed to eliminate the needle punctures.

Therefore, the GT investigated other innovative methodologies, such as ultrasonic seam sealing, use of various seam tapes for added strength and protection, and the selection of equipment to be used in the process. This investigation also included the review of various seam constructions to ensure that there was compatibility between the fabric seam and the innovative techniques that were investigated.

The results of these investigations are described in this report. This report also examines the iterations of technical improvements and changes made to existing technical applications used in the garment industry.

This research was funded by the Department of Defense University Research Initiative. The grant award number was W911QY-04-1-0001. The funding agency was NSRDEC; the program supported was Warrior Systems Technologies.

Introduction

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The Garment Team (GT) at Philadelphia University's Laboratory for Engineered Human Protection (LEHP) considered innovative technologies to replace sewn seams in CB garments. Although sewing can produce a product that can be comfortable and protective, the sewing process itself adds to the need for additional protective components. The sewing needle punctures the protective fabric, which then must be backed to eliminate the needle punctures.

Therefore, the GT investigated other innovative methodologies, such as ultrasonic seaming, use of various seam tapes for added strength and protection, and the selection of equipment to be used in the process. This investigation also included the review of various seam constructions to ensure that there was compatibility between the fabric seam and the innovative techniques that were investigated.

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Ultrasonic seam bonding is a methodology of placing two or more pieces of fabric together permanently. From the outset it has been the preferred method of the LEHP project. Ultrasonic seam bonding introduces no additional needle holes into the fabric and may eliminate the need for seam taping in certain garment areas. Since construction using seam-sealing techniques impacts seam design, location, and shape (acute curves must be considered), possible application of ultrasonically activated polyurethane films and adhesive applications were also being considered during the GT's spiral development process.

The LEHP scope of research is to review the universe of available fabrics that vendors claim are chemically protective. A system of manufacturing (piecing together the fabric and accessory parts) was undertaken using existing garment engineering techniques adopted from standard industry use. Much of the GT's work had two goals:

- Construct garments using minimal sewing (sew-free applications); instead garments would be assembled using advanced ultrasonic, adhesive, and seam-sealing methodologies.
- Instead of designing a garment similar to the traditional two-piece Joint Service Lightweight Integrated Suit Technology (JSLIST), the GT would initially design a one-piece fixed-hood garment.

While pursuing these goals, the GT investigated several fabric bonding systems:

- ultrasonic seam bonding with ultrasonically activated polyurethane films or with adhesives, and seam tape sealing
- the proprietary Duraseal™ system developed at Clemson University
- laser seaming

Following this introduction, this report contains:

- a description of the technologies investigated
- a presentation of the results and a discussion of those results
- a presentation of conclusions drawn from the results
- recommendations for further study
- a list of works cited
- appendices containing product data for UAF-406 adhesive and a report issued by an independent contractor working with the Garment Team to optimize ultrasonic seam development

Methods

Option 1 – Investigation of Ultrasonic Seam Bonding with Adhesives

With the manufacturing and design support of an outside contractor Ricochet Manufacturing, the GT reviewed various methods of construction. Ricochet Manufacturing provided experience in the development and manufacturing of mission-specific barrier protective seam-sealed uniforms for EMS, Emergency Rescue, and First Responders. The staff at Ricochet Manufacturing also have extensive knowledge of the garment manufacturing process.

Machine Selection

A Jentschmann 4796-2-20 V1 B ultrasonic free-standing flatbed welder was reviewed; see Figure 1. This machine was found to provide the most consistent seal (among the machines investigated) and offered two key features not available in other machines investigated. These features are (1) use of a forward rotating sonotrode and (2) use of a belt drive to move materials over the sonotrode; this belt drive ensures an even dispersion of energy.

Figure 1. Jentschmann 4796-2-20 V1 B (www.Jentschmann.com)

This machine is a standalone flatbed ultrasonic bonding machine that provides for continuous gluing of all kinds of fabrics by means of heat-activated adhesive tapes and welding of thermoplastic coated tissues and thermoplastic tissues. (www.Jentschmann.com).

Use of Rotating Sonotrode

Usually, sonotrodes in the form of a stamp are used for welding step-by-step, like high frequency fabric welding machines. For more than 10 years, however, Jentschmann has applied rotating sonotrodes with radial amplitude that allow continuous ultrasonic welding. With this technology, a rotating sonotrode and an anvil roller turn simultaneously, and the fabrics to be welded pass between the two rollers; see Figure 2. The sonotrode, vibrating with 35 kHz, applies the heat (Jentschmann.com).

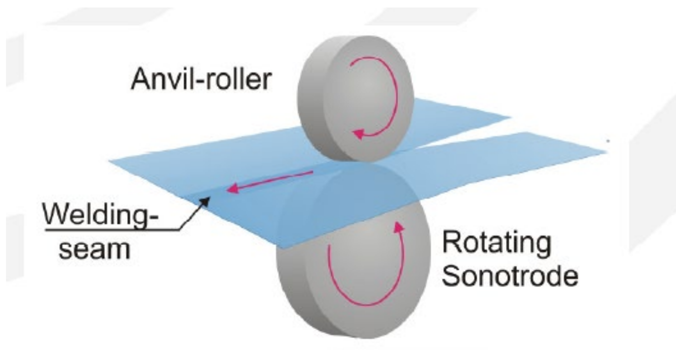

Figure 2. Continuous Ultrasonic Welding with Rotating Sonotrode (www.Jentschmann.com)

This dynamic process requires an exact guiding and holding of the fabrics. The adjustments of the different welding parameters must be very precise and evenly regulated during the welding process (www.Jentschmann.com).

Because the LEHP GT wanted to use this machine for adhesive tape bonding, as well as for ultrasonic seam sealing, the GT worked with the manufacturer's engineering team to replace the anvil-roller with a continuous belt system; see Figure 3. The anvil-roller is not suitable for adhesive tape bonding.

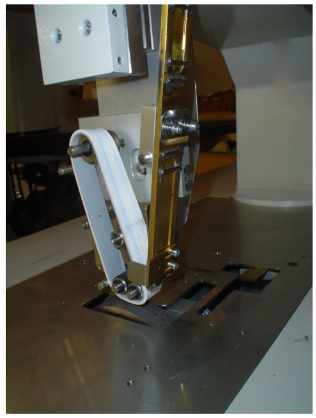

Figure 3. Belt Modification on Jentschmann Ultrasonic Welder (LEHP 2007)

This machine was also determined to be compatible with the manual feeding of material and for integration into automated production plants. Unlike other systems researched, this machine resembles and operates similarly to a traditional sewing machine and has the physical characteristics (machine specifications) to accommodate a production environment.

Machine Features

The machine provides for a working table for placing and positioning the fabric between the sonotrode and the rotating belt. It allows for lowering and lifting the belt by means of a pedal; for starting/stopping of bonding continuously by means of a proportional pedal; and for manually adjusting power output (www.Jentschmann.com).

The machine also features a welding head option consisting of solid welded steel sheets. This allows for welding with:

- 35 kHz, 600 W ultrasonics with rotating 11 mm sonotrode (optional 20 mm or 7 mm steel)
- a welding speed of 0.3 – 30 m/minute
- 2 differentiable drives for sonotrode and belt

In addition, adjustment of amplitude and/or belt pressure can be proportional to welding speed (www.Jentschmann.com).

The Jentschmann machine allowed the GT to construct a needle-free secure seam in a one-step continuous process combining ultrasonics and adhesive bonding in an unlimited length without stopping and starting. Other processes the GT explored were more labor intensive and required repeated steps due to machine length restrictions and heat application. All seams types bonded with the Jentschmann machine had the least visible adhesive (compared to other methods investigated) because guide motion control was maximized. The bond strength is comparable to or greater than sewn seams in prior MEL testing; see *Results of Seam Strength Tests* on page 12.

Option 2 – Duraseal Seam-Sealing System

In spring 2006 the GT visited Clemson University to review the Duraseal™ system. This system could provide seam-sealing using proprietary methodology developed at Clemson. In this investigation of the Duraseal system the GT and Ricochet Manufacturing, working with Challenger Resources, attempted to develop, within the Duraseal™ system, the machinery required for volume production capabilities. The following findings are based on observations regarding this method in our hands. Although, at the time we investigated it the method was not found appropriate for our needs, it has a number of virtues that could make it suitable for use in others' applications.

In the early stages of the development of the prototype it was determined that the Duraseal system would be a three-step method that involved interrupted intervals, as opposed to a continuous process. Each interval involved repeated air stabilizing, pressing, folding, and sealing with limited length capabilities.

The Clemson three-step seam bonding system uses a single adhesive tape that "wraps" the raw edges of the fabric and creates a bond between the layers. TNO labs in the Netherlands tested this system for resistance to vesicant sulfur mustard (agent HD) penetration, and the system achieved satisfactory results. Strength and peel tests have also been satisfactory with the seam strength being equal to or greater than the base fabric.

Unfortunately, further examination of this seam structure revealed that the single "S" shape proved difficult to construct outside of the laboratory environment and that alternatives must be explored. Also, visual observation revealed that some of the adhesive film remained visible on the external surface of the seam; this visible remainder was unacceptable to NSRDEC because of the risk of shine and or infrared (IR) recognition.

Jarvis et al. examined the Duraseal system and found the "technology has been shown to produce excellent grab strength, good peel strength seams appropriate for use in collective protection products. The polymeric film adhesives used to date are compatible with a wide variety of fabrics with the exception of silicone-coated materials" (n.d., 7).

While this system has been evaluated and found satisfactory for collective protection, the Garment Team has found that this option was not viable for individual protection (specifically garments). Collective protection usually encompasses large fabric structures, such as tents, that employ long, straight seams. In contrast, garments employ a much more complex seam structure, including more articulated curves than collective protection would require. Therefore, the Duraseal system investigation by the GT was terminated because the system, despite its merits, was found to be too complex and potentially costly for garment construction.

Option 3 – Laser Seaming

Laser seaming is another construction option that was explored by the GT and Ricochet Manufacturing. Because of external seam IR ultraviolet recognition concerns, it was decided that this process was not suitable for construction of CB garments, and the method was not pursued further.

Summary of Option Findings

After extensive review of the above options it was decided that the Jentschmann 4796-2-20 V1 B ultrasonic free-standing flatbed machine created the most desirable seam construction. This seam construction enabled the LEHP GT to construct prototype garments with clean sew-free seams. The construction method provided seams that were expected to meet the strength requirements for CG garments.

Experimentation with the Ultrasonic System

After the Jentschmann machine was determined to be the best option among those considered, Ricochet continued the development of this ultrasonic system, which uses sound waves to melt the polyurethane adhesives and, subsequently, to bond the layers of fabric. Experimentation to identify the ideal use of ultrasonically activated urethane films and adhesives with the Jentschmann machine resulted in seams that are observed to be clean and undetectable. These seams were tested at MEL for strength and for abrasion and moisture resistance, and were found to be acceptable.

The LEHP GT at Ricochet Manufacturing examined various potential seam structures that were constructed with ultrasonics and/or hot air taping. Two seam structures shown in Figure 4 showed the most promising results. They are a lapped seam-sealed (bonded with adhesive and seam taped) and flat felled seam-sealed (bonded with adhesive and seam taped).

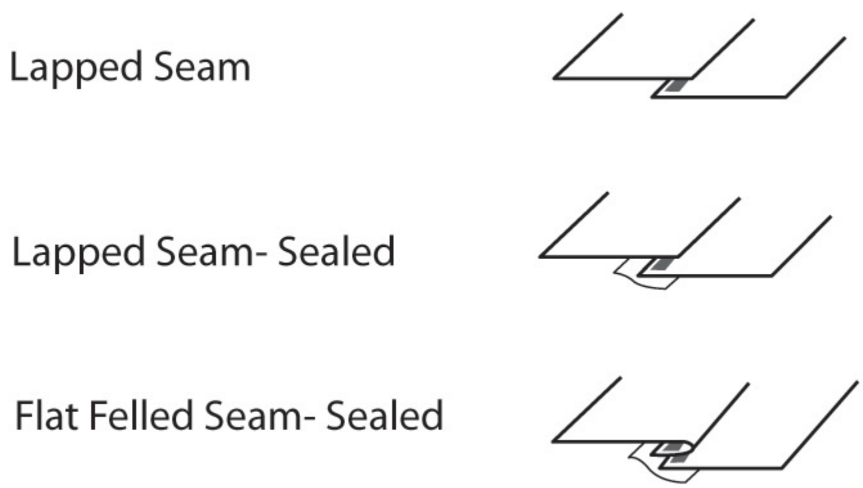

Figure 4. Seam Types (LEHP 2007)

The GT ordered custom detachable folders for the Jentschmann machine. These folders enabled creation of small turn backs and uniform controlled hems. In the lab setting, production time was lessened slightly when these folders were used because changing of folders (different sizes for different applications in the required sequence of operations) caused set up interruption. In a production environment, however, this downtime for changing folders could be eliminated by dedicating an ultrasonic machine to each folder size.

The objective of the continued experimentation was to optimize all seams for strength, comfort, flexibility, protection (based on the concept that a properly constructed seam will contribute to the overall chemical protection of the garment system), and to produce a cost-effective, lightweight prototype garment. Although the bonding created seam shape limitations, it was found that subtle curves could be created by an experienced operator acquainted with the nuances of the machine.

Investigation of Adhesives

Adhesives were investigated through the review of available products. Based on needed thickness and width specifications (.006 X 3/8 inch) the UAF-406 (Adhesive Films, Inc.), a single layer of solvent-free thermoplastic ester-based polyurethane adhesive extruded onto a paper release liner was evaluated in various widths and thicknesses, and selected. The criteria for the selection process were based on manufacturer specification, the compatibility with the fabric, seam construction and adhesive bonding ability.

Addition information used in the selection process was received in the form of a consultant's report (see Appendix B).

> "Initial seam development in April 2006 [Generation 2] focused on developing a strong, waterproof seam. This was complicated by temperature sensitivity of the chemical neutralizing gel between the barrier layers of the chosen fabric. Pressure and temperature levels normally used to bond a three-layer waterproof breathable fabric were found to damage the jell/barrier layer boundary, compromising the waterproof integrity of the fabric. We were thus forced to develop a new seam style that would meet the requirements of the suit without negating the protective properties of the fabric."

The new seam style to which this refers is the lapped seam-sealed.

Seam Strength Tests

Seam swatches were submitted to the LEHP Material Evaluation Laboratory for testing on the SDL/CRE (Constant Rate of Extension) Tester Model M250 using the ASTM D-5034 procedure that measures pounds force. The benchmark used was a sewn pant seam from the JSLIST that tested at 103.9 lbs.

The results of these tests are in the next section.

Results of Seam Strength Tests

The results of the seam strength tests are described below.

May 30, 2006 – Fabric 53H[1] tensile (grab break) and tear strength, and the results were compared to the JSLIST garment (load @ peak):

- JSLIST (sewn) – 103.93 lbs
- Fill/Flat felled seam sealed – Mean 165.65 lbs
- Warp/Flat felled seam sealed – Mean 189.27 lbs

May 7, 2007 – Sealed seam structures 53H garment (Generation 3):

Jentschmann settings-

- Pressure: 1.7/1.8
- Ratio: 92%
- Speed: 1.48/1.50
- Amplitude: 55%

Adhesive tape – EXF-600 (now named UAF-406; see Appendix A) width 8 mm, Lot # 0515-032H-101H.

Sealed seam structures 53H garment (Generation 3):

- Flat felled single adhesive seam sealed: 87.81 lbs
- Flat felled single adhesive: 37.84 lbs
- Flat felled double adhesive seam sealed: 168 lbs
- Flat felled double adhesive: 141.7 lbs
- Lap seam sealed: 181.9 lbs
- Lap: 99.79 lbs

May 11, 2007 – Abrasion testing on simulated knee patches on 53H (Generation 2 and 3) specimens:

- Wyzenbeek abrasion testing: no loss of bond strength after 15,000 cycles.

[1] The designation 53H was assigned to this fabric when it was added to the LEHP "Universe of Fabrics." For information about these fabrics, see companion technical report *Consolidated Data on Fabric Construction* (Brady 2008).

The testing results were considered when the GT made several modifications to the Jentschmann machine to allow for easier manufacturing of the garments. These modifications included a new belt guide that was installed to reduce the tendency of the energy diffusion belt to move laterally. This lateral movement caused the improper shifting of the fabric and adhesive, thereby creating irregular seams. The modification eliminated this issue.

A “stop energy” knee pedal was installed to eliminate the possibility of fabric burns when dealing with multiple layers. Multiple layers are the result of the intersection of two or more seams. This multiple seam intersection creates bulk that, when forced under the rolling belt, increases the pressure, resulting in burns on the fabric and interruptions to the constant flow of the seam construction. The “stop energy” pedal prevents ultrasonic energy from being delivered to the seam from the roller; therefore, use of this pedal will prevent burns in areas of bulk concentration.

Conclusions

The following conclusions are based on evaluations and observations by the LEHP Garment Team.

- Machine and joining method – When a sew-free seam is desirable, the Jentschmann 4796-2-20 V1 B (as modified by the GT as described previously) and ultrasonic seam bonding are effective methods of seaming garments. This modified Jentschmann machine would be suitable for production environments because of its capacity for producing continuous seams, and its provision of good operator control of fabric and machine.

- Strength – Based on MEL tests, the lap seam was found to be the strongest of the ultrasonic seams in the desired fabric (53H).

- Adhesives – The Adhesive Films, Inc. UAF-406 single-layer solvent-free thermoplastic-ester-based polyurethane adhesive is a good choice when doing ultrasonic seaming.

- Waterproof – In fabric 53H an ultrasonic seam produced with the Jentschmann machine and UAF-406 adhesive is waterproof when backed with Adhesive Films, Inc. sealing tape Black EXF-652 (one inch width), the tape used in the Garment Team's Generation 2 and 3 garments. For information about these garments, see the companion report *Garment System Engineering for Chemically Protective Clothing* (Frumkin et al. 2008).

- Setup time – Considerable time devoted to trial-and-error was needed to adjust speed and pressure calibration to maximize the bond strength on the desired fabric. If the machine would be used in a production environment, the production schedule would require inclusion of this time, especially if different fabric or adhesive would be used.

- Skill level required – After the machine has been set up, the skills needed to operate the machine are comparable to those required for with traditional commercial power sewing methods.

- Adhesive selection – Adhesive Films Inc. experimented with various widths and thicknesses of adhesive tapes to create the ideal bond on the specific chosen fabric (53H). This study would be needed each time a new fabric is used.

Note: This report describes work that is part of a spiral research and development project. Therefore, it is anticipated that the Garment Team's conclusions and recommendations will continue to evolve as this work continues.

Recommendations

The following recommendations are based on evaluations and observations by the LEHP Garment Team.

- A continuous production line environment is necessary to construct multiple garments for a realistic time study process.
- Multiple garments should be constructed for strenuous field performance tests.
- Additional versions of machines with the off-the-arm variation should be acquired for ease of construction and fabric manipulation.
- Generation 4 sewn seam versions should be compared to Generation 3 versions for Human Factors evaluation for strength and comfort of seams.

This document reports research undertaken at the U.S. Army Combat Capabilities Development Command Soldier Center, Natick, MA, and has been assigned No. Natick/TR-22/003L in a series of reports approved for publication

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<www.Jentschmann.com/en/>. "Jentschmann 4796-2-XX." (accessed 4 August 2008).

Appendix A – Product Data for UAF-406 Adhesive

PRODUCT DATA

UAF-406 ADHESIVE

UAF-406 is a single layer of solvent free thermoplastic ester based polyurethane adhesive extruded onto a paper release liner and supplied in various widths and thicknesses.

		Method	Value	
Composition		-	Polyurethane	
Shore Hardness A			ASTM D-2240	77
Specific Gravity			ASTM D-792	1.19 g / cc
Thickness	(produced to date)		.002”, .004”, .006”, .010”	
Melt Point	Kofler Bench		120 °C	
Appearance	Visual		Clear / Slight Amber	

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THE SELLER MAKES NO WARRANTIES, EXPRESS OR IMPLIED, INCLUDING, BUT NOT LIMITED TO THE IMPLIED WARRANTIES AND FITNESS FOR A PARTICULAR PURPOSE.

Appendix B – Consultant's Report on Seam Sealing

The report below was issued by an independent contractor working with the Garment Team and Bill Hord of Ricochet Manufacturing to optimize ultrasonic seam development.

SEAM DESIGN OVERVIEW
by Mark Norder—Contractor to Ricochet Manufacturing

Initial seam development in April 2006 focused on developing a strong, waterproof seam. This was complicated by temperature sensitivity of the chemical neutralizing gel between the barrier layers of the chosen fabric. Pressure and temperature levels normally used to bond a three-layer waterproof breathable fabric were found to damage the jell/barrier layer boundary, compromising the waterproof integrity of the fabric. We were thus forced to develop a new seam style that would meet the requirements of the suit without negating the protective properties of the fabric.

While assisting LEHP and Ricochet staff in May 2007 with assembly of the six suits currently prepared for the upcoming FAST Test, it was decided to again review the various seams available for this project. Seams tested were a mock felled seam, a taped mock felled seam, a folded and taped prayer seam (this is the seam used to date and will be referred to as the Ricochet seam), a taped overlap seam and, as a reference, a sewn and taped seam. All seams were again pressure tested for waterproof integrity and grab break tested for strength. No military specifications for glued seams have been located, so it is felt that an "as good as or better than" standard using sewn seams as a reference would be used for this project. Sewn seams tested on 5/11/07 had a load @ peak of 62.2 and 64.9 kgf. The only glued seams to equal or surpass those results were the taped mock felled seam, the Ricochet seam, and the taped overlap seam. Of the three, the simple taped overlap seam was the strongest at 82.69 kgf. Because it is the simplest, easiest to produce, and most pliable, the question was raised as to what justification the government used for not accepting exposed edges on the exterior of this garment. There has always been speculation that the military was concerned over visual exposure and/or increased abrasion failure from the "unprotected" exposed edge. Janet Brady proposed that the overlap, Ricochet, and sewn seam be subject to a series of abrasion tests to determine which has the greatest resistance to abrasion, and whether or not perceived strength issues regarding the overlap seam's exposed edges are valid. Despite the raw edge, it is believed that the overlap's flat finish and lack of exposed thread will result in the most favorable test results. The obvious benefits of the overlap seam make it imperative that we understand the concerns of the military regarding this type of construction.

Bill Hord had samples of the suit fabric cut on an ultrasonic hand cutter. By cutting the fabric ultrasonically, the shell, barrier layer and liner are bonded together, improving the sealing and reducing the possibility of the edge fraying on an overlap style seam. The strength of this edge weld is directly related to the angle of the cutting edge; the wider the cut, the greater the weld, the stronger the bond. Previous attempts on other projects to use this cut to produce a waterproof overlap seam did not prove completely successful. In discussing this with Bill Hord, I speculated that a broader then normal cut/weld could improve the capability of this seam. An additional concern is cracking of the plasticized weld as the fabric flexes, reducing the waterproof properties of the edge. Having the cut edge on the underside of the top ply when gluing may allow for a smoother, flatter transition, reducing visibility of the seam. Although an overlap seam constructed with the fabric cut in this fashion would still require seam tape for additional strength and added waterproof integrity, these benefits could help improve both the properties of the seam and the ability to get the seam accepted by the military.

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