ERDC TR-17-14

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U.S. Air Force Rapid Airfield Damage Repair Modernization Program

Refinement of Foam Backfill Technology for Expedient Airfield Damage Repair

Phase II: Development of Prototype Foam Dispensing Equipment and Improved Tactics, Techniques and Procedures

Jared L. Johnson, Mariely Mejías-Santiago, Luke A. Gurtowski,
Christopher S. Griggs, and Craig A. Rutland

December 2017



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Refinement of Foam Backfill Technology for Expedient Airfield Damage Repair

Phase II: Development of Prototype Foam Dispensing Equipment and Improved Tactics, Techniques and Procedures

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Approved for public release; distribution is unlimited.

Prepared for Headquarters, Air Force Civil Engineer Center
Tyndall Air Force Base, FL 32403-5319

Under Project Number P2457442

Abstract

This report describes the development and evaluation of prototype foam dispensing equipment, foam materials, and repair tactics, techniques, and procedures (TTPs) for rapid airfield damage repair (RADR) using foam backfill technology. Three different prototype foam dispensing systems were evaluated, two of which were developed in-house, along with foam products from two vendors and different repair methods and techniques to improve the TTPs for foam backfill technology. Results from full-scale field testing showed that the top performing prototype system was a hose pump system, and the top performing foam material was Foam-iT! 10 Slow. Plastic liners were a successful technique for a moisture barrier to ensure the quality of the repair material. Foam cutting methods, such as scarfer and reciprocating saw, were good options; however, both methods have safety concerns and add time and manpower to the repair process. Overall, the technology proved to be effective in meeting RADR requirements. Repair times were comparable to those of the standard flowable fill backfill method. Repair performance under simulated F-15E aircraft traffic was satisfactory. All repairs met the 2-hr requirement of 100 passes and the expedient repair requirement of 500 passes. Only one repair met the RADR requirement of 3,500 passes.

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Preface

This study was conducted for the U.S. Air Force Civil Engineer Center under the Airfield Damage Repair Research and Development Program. The Technical Monitor was Dr. Craig Rutland, and the Program Manager was Mr. Jeb S. Tingle.

This work was performed by the Airfields and Pavements Branch (APB) of the Engineering Systems and Materials Division (ESMD), U.S. Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL), and the Environmental Engineering Branch (EPE) of the Environmental Processes and Engineering Division (EP), ERDC Environmental Laboratory (ERDC-EL). At the time of publication, Dr. Timothy W. Rushing was Chief, APB; Dr. W. Andrew Martin was Chief, EPE; Dr. Gordon W. McMahon was Chief, ESMD; Mr. Warren P. Lorentz was Chief, EP; and Mr. R. Nicholas Boone was the Technical Director for Force Projection and Maneuver Support. Mr. Charles W. Ertle was Acting Deputy Director of ERDC-GSL, and the Director was Mr. Bartley P. Durst. Dr. Jack E. Davis was Deputy Director of ERDC-EL, and the Director was Dr. Ilker Adiguzel.

COL Bryan S. Green was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
horsepower (550 foot-pounds force per second)	745.6999	watts
inches	0.0254	meters
ounces (U.S. fluid)	2.957353 E-05	cubic meters
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
square feet	0.09290304	square meters
tons (force)	8,896.443	newtons
yards	0.9144	meters

Acronyms

ADR	airfield damage repair
AFCEC	U.S. Air Force Civil Engineer Center
APB	Airfields and Pavements Branch
ASTM	American Society for Testing and Materials
CRADR	Containerized Rapid Airfield Damage Repair
DCP	Dynamic Cone Penetrometer
ERDC	U.S. Army Engineer Research and Development Center
ESMD	Engineering Systems and Materials Division
FOD	foreign object debris
GSL	Geotechnical and Structural Laboratory
GTP	Geotechnical Test Procedure
HMI	Hydraulic Mudpumps Inc.
hr	hour
IED	Improvised explosive device
min	minute
NCFI	NCFI Polyurethanes
NYDOT	New York Department of Transportation
lb/ft^3	pounds per cubic foot
PI	Primal Innovation

psi	pounds per square inch
RADR	rapid airfield damage repair
RS	rapid setting
rpm	revolutions per minute
sec	second
UCS	unconfined compressive strength
USAF	United States Air Force

1 Introduction

1.1 Background

Over ten years of research at the U.S. Army Engineer Research and Development Center (ERDC) under the direction of the Air Force Civil Engineer Center (AFCEC) have produced a wide range of technologies including new materials, lighter and leaner equipment, and improved procedures for rapid airfield damage repair (RADR) (Priddy et al. 2007, Tingle et al. 2009, Priddy et al. 2010, Priddy et al. 2011, Priddy et al. 2013). Non-traditional backfill materials, such as rigid polyurethane foam, were identified as viable crater backfill materials when capped with rapid-setting concrete. Rigid polyurethane foams are capable of meeting compressive strength threshold requirements for backfill materials while reducing logistical burdens. This reduction exists because the foam is placed as a liquid mixture of two components that react and expand to 6-10 times the original liquid volume.

Multiple rigid polyurethane foams identified during earlier investigations were able to meet basic RADR requirements for backfill strength, repair time, and simulated traffic performance when capped with a rapid-setting concrete material (Priddy et al. 2010). This repair method was certified under actual fighter and cargo aircraft traffic in 2009 and was demonstrated to reduce repair times and logistical footprint compared to using either traditional aggregate or flowable fill backfill. However, technology drawbacks, including material clogging within the specialized foam mixing and dispensing equipment and the foam material's sensitivity to moisture, prevented the fielding of polyurethane foam backfill technology for RADR.

Both the individual components and the reactive foam mixture must be handled with care to prevent equipment clogging. This includes clogging that may be caused by foam expansion during crater repair operations and clogging that may occur as a result of material crystallization during storage. Laboratory assessments of foam formulations have been performed to identify commercially available foams to partially address issues related to equipment clogging by identifying foams with slightly longer rise and cure times (Priddy et al. 2010 and Gurtowski et al. 2016). However, additional development efforts were required to fully address

this issue by designing new foam dispensing equipment with components that are invulnerable to material clogging.

The presence of moisture in the craters can have a significant adverse effect on the quality of the foam backfill material (Priddy and Newman 2010). Gurtowski et al. (2016) attempted to address this issue by evaluating several commercially available hydrophobic foams. These materials have the characteristic of repelling water during and after their reaction. However, it was concluded that they do not provide the required strength and react too quickly, potentially causing equipment clogging issues. The lack of a hydro-insensitive foam material brought the need for investigating different methods to prevent moisture intrusion in the crater.

Additional concerns related to the successful fielding of polyurethane foam backfill technology for RADR include the simplicity of operations and maintenance procedures, the ability to recover from adverse events and clogging, and the ability to repair multiple craters in rapid succession.

In 2015, AFCEC tasked ERDC to refine the foam backfill technology to address all these issues and concerns through a research program consisting of three main phases. Phase I consisted of the laboratory testing of new foam materials described in Gurtowski et al. (2016). Phase II consisted of the development of new prototype foam dispensing equipment and improved tactics, techniques, and procedures (TTPs) for crater repair using foam backfill technology. This report presents the main findings of Phase II. Phase III consisted of a technology demonstration and end user evaluation conducted at Silver Flag Exercise Site, Tyndall Air Force Base, FL, in November 2016 and will be presented in a separate report.

1.2 Objectives

The main objectives of the research effort described in this report were to develop and evaluate foam dispensing prototype equipment and improved TTPs for foam backfill technology.

1.3 Scope

Knowledge gained from previous prototype foam dispensing equipment was incorporated into new designs that were tested at different size scales. Two separate prototype systems were designed and built by ERDC

engineers and a third prototype system was designed and constructed by Hydraulic Mudpumps Inc. (HMI) of Manitowoc, WI. The term "Containerized Rapid Airfield Damage Repair" (CRADR) was used to label the two ERDC developed prototype systems (i.e., CRADR 1 and CRADR 2).

Both small-scale and full-scale testing were conducted at ERDC to evaluate prototype foam dispensing equipment and improved TTPs for foam backfill technology. Small-scale testing was conducted for preliminary evaluation of the functionality of three prototype systems and different repair methods to down select top performers. Full-scale testing was conducted to evaluate the efficiency of the selected prototype equipment and methods during full-scale crater repair operations and to evaluate the performance of the repairs under simulated aircraft traffic. Testing consisted of backfilling 8.5-ft x 8.5-ft x 2-ft-deep simulated craters with polyurethane foam materials, capping the repair with rapid-setting concrete material, and initiating traffic with a simulated F-15E single-wheel load within 4 hr of beginning the crater repair. The full-scale field tests evaluated the following:

1. Two commercially available rigid polyurethane foam products
2. Two prototype foam dispensers
3. Moisture barriers
4. Foam cutting equipment

Results from the field testing were utilized to recommend the optimum combination of materials, equipment, and procedures to be used during the technology demonstration and end-user evaluation.

2 Prototype Equipment Design

2.1 System requirements

The U.S. Air Force requires the foam dispensing equipment to effectively:

1. Protect airman health and safety by minimizing contact with foam component materials,
2. Meet or exceed threshold requirements pursuant to a target 4-hr total repair time,
3. Repair multiple craters with no downtime,
4. Maintain function by resisting and/or enabling rapid recovery from nozzle clogging,
5. Demonstrate robust operations with low maintenance burden for repeated uses across long-term time scales, and
6. Minimize capital and operation costs.

More specific objective and threshold performance metrics set by the U.S. Air Force in accordance with capabilities required by deployed forces are provided in Table 2.1. Small craters were defined for this project as total backfill volume of 145 ft^3. The objective fill time for a small crater is 2 min, with an acceptable threshold of 5 min. Using these guidelines and assuming the previously observed foam expansion ratio of 6:1, the design objective should be delivery of each foam component at a flow rate of at least 45 gpm. At a minimum, the foam delivery system should be capable of a single component flow rate of 18 gpm.

Table 2.1. Foam dispenser performance metrics.

Length x Width x Height	**8.5 ft x 8.5 ft x 2 ft**
Total Volume Backfilled	145 ft^3
Required Foam Materials (1/6 of Total)	24 ft^3
Fill Time Objective (Threshold)	2 (5) min
Flow Rate per Component Objective (Threshold)	45 (18) gpm

During field operation, it is likely that multiple crater repairs would be required in a short time frame. The likelihood of multiple craters indicates that there must be a method of rapidly changing out the foam components during operation.

Given the baseline performance objectives defined above, several design concepts were considered for the construction of a full-scale foam dispensing prototype. In addition to meeting the baseline performance objectives, safety objectives and previous design iterations were reviewed to inform the design process.

Polyurethane foams form reactively on mixing an isocyanate cross-linking agent (component A) with a polyol material (component B). The particular chemical forms of the polyol and isocyanate components determine the final chemical-physical properties of the foam. Safety data sheets for foam component materials are included in Appendix A. A summary of the physical properties of each component is provided in Table 2.2.

Table 2.2. Physical properties of polyurethane foam components.

Property	Component A	Component B
Composition	Up to 35% 4,4' methylene bis (phenylisocyanate) (MDI)	Mixed poly-alcohols
Melting Point	37°F	N.A.
Boiling Point	>390°F	N.A.
Flash Point	>300°F	>300°F
Vapor Pressure	<0.00016-mm Hg	None
Vapor Density	>1	>1
Specific Gravity	1.2	1.07
Viscosity	30-100 cPs	20,000-30,000 cPs

Previous ERDC investigations of foam materials at field scale were made using hand-mixed foams (Priddy et al. 2007). These investigations also included determining whether aggregate within the foam material would increase the end strength of the repair. Further investigation was made using a commercial type slab jacking polyurethane system to inject foam into aggregate underlying freshly poured rapid set concrete caps (Priddy et al. 2009). When high-quality concrete debris was used to backfill the crater prior to capping, injecting foam into the system showed no benefit to the strength of the crater repair.

Limited operational utility assessments were made at Tyndall AFB, FL, to determine appropriate procedures for foam backfill materials. A foam dispenser prototype constructed by Edge Sweets Company (ESCO) was demonstrated at the first assessment (Tingle et al. 2009). The ESCO B-100

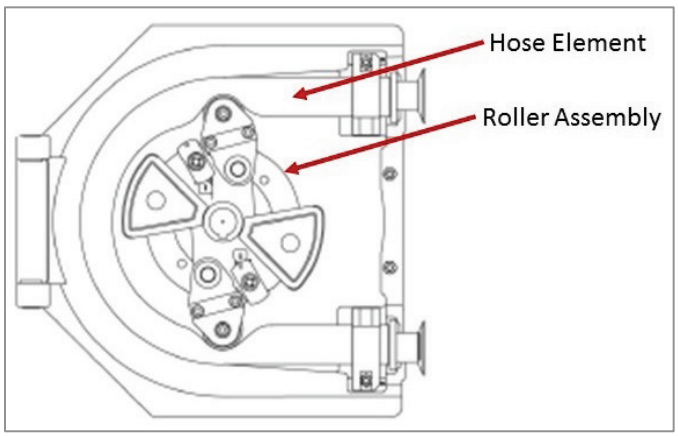
trailer-mounted prototype included an onboard motor-actuated mixing head and solvent flush system. The equipment functioned within the constraints of the test, but a need for much higher flow rates and fewer solvent flushes was identified. The production rate was increased with another prototype constructed with dual rotary lobe pumps (Priddy et al. 2013). This system also had provisions in place for water flushing and included a static mixing element piped directly following the material transfer pumps. This equipment was successfully demonstrated, though a few improvements were suggested. Improvements included better nozzles, improving the quality of the mixed foam material, and eliminating the need for solvent or other flushing materials. Variable performance between craters was observed, indicating that heterogeneous foam mixes may have occurred. With each of these demonstrations completed, Air Force working groups recommended that further improvements to the overall system should be made (Bianchini 2015). These improvements included minimizing operator contact with the foam materials and using available technologies to simplify maintenance and operation of the system. Key to simplifying the system is replacing components that must be cleaned out frequently with disposable and easily changeable components to minimize downtime and maintenance at a work site.

2.2 Pump driven skid system (CRADR1 prototype)

During polyurethane foam formation, a 1:1 ratio (by volume) of component A and component B must be reliably dispensed through a common nozzle with sufficient energy to introduce a well-mixed formulation into the crater. The properties of the two components, especially the orders of magnitude difference in viscosity, can complicate system design, since pump performance is dependent on the physical properties of the fluid. Since the volumetric ratio of the two components is a critical design element, positive displacement type pumps would be indicated as the best design choice for this application. Positive displacement pumps include rotary lobe, piston, diaphragm, and hose pumps that are capable of maintaining a steady flow rate under widely varying suction and discharge pressures. Previous design iterations for polyurethane crater repair used gear pumps (Priddy et al. 2010). One concern that needed to be addressed following previous demonstrations was the tendency of foam materials, especially component A, to harden over time and necessitate extensive pump repairs. This can be mostly mitigated by sufficient cleanout following operations. Another approach is using hose pumps with removable elements. A representative hose pump head is shown in Figure 2.1. An advantage of hose pumps is that

the fluid is completely separate from the moving parts of the pump head. If fluid components begin crystallizing in the transfer hoses and clogging the system, the entire fluid path may be replaced without exposure to the foam components.

Figure 2.1. Representative hose pump head.



Hose pumps were chosen as the basis for an ERDC-designed polyurethane foam dispenser. Hose pumps capable of delivering a threshold value of 22-gpm per component require a 5-hp drive motor. The best way of delivering the required power to the pump head is through independent electrical motors. Three-phase induction motors were chosen so that the component flow rates could be adjusted using a variable frequency drive. The entire system should draw 40-50 A of electrical current at 240 V. A diesel generator set was specified to meet this need.

2.3 Air pressure-driven container system (CRADR 2 prototype)

Gravity is also available as a driving force for fluid flow without the extensive equipment requirements and control systems of a powered, pump-driven dispensing system. An analysis of the performance of a theoretical gravity drain system may be made using Bernoulli's equation for energy balance in a steady-flow piped system.

$$\frac{1}{2\alpha}\left(v_2^2 - v_1^2\right) + g\left(z_2 - z_1\right) + \frac{p_2 - p_1}{\rho} + \sum F + W_S = 0$$

where the variables are defined as

v_i = fluid velocity at point i
α = 0.5 for laminar flow, 1.0 for turbulent flow

g = gravitational acceleration (32.2 ft/s²)
z_i = fluid height at point i
p_i = static pressure at point i
ρ = fluid density
F = frictional forces acting on the fluid
W_s = work performed on the fluid (i.e., pumping power)

For the system as defined by the requirements of a foam dispenser, the conceptual model is a chemical tote with a single outlet ball valve leading to an outlet hose. With no pumping power assumed and friction accounted for by assumed laminar flow with a sudden contraction loss at the tote outlet, as well as a fully open ball valve, the Bernoulli equation for the foam dispensing system becomes

$$\left(\frac{1.55 - 0.55 \, A_3 / A_1 - A_3^2 / A_1^2}{2\alpha} \right) v_3^2 + \left(\frac{32 \mu L}{D^2 \rho} \right) v_3 = g\left(z_1 - z_3\right) + \frac{p_1 - p_3}{\rho}$$

where the additional variables are

A_i = cross sectional area of the outlet hose
μ = fluid viscosity
L = length of the outlet hose

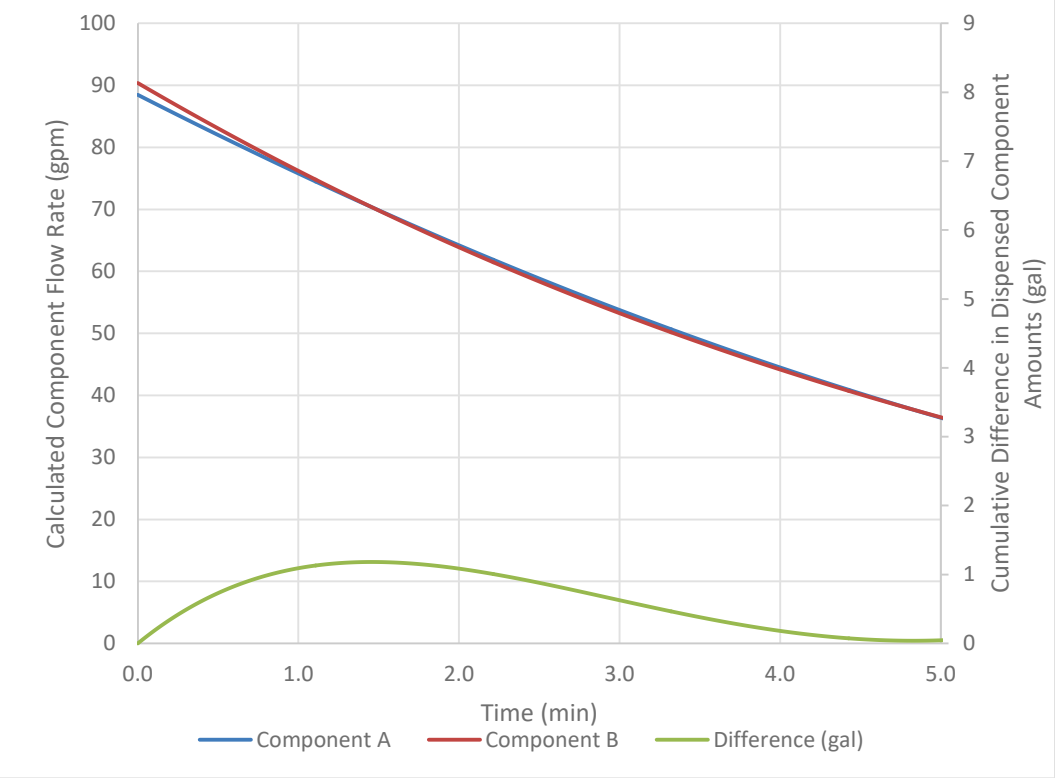
This becomes the design equation that allows for the prediction of the fluid flow rate from each chemical tote assuming laminar flow and a Newtonian fluid, i.e., one in which the apparent fluid viscosity is not a function of velocity.

With a design equation in place to predict each component's flow rate, it only remained to match the component flow rates to one another using entirely passive controls. Strictly gravity draining the totes was not sufficient to maintain high flow rates (threshold 22-gpm) throughout the dispensing cycle, since the height difference between inlet and outlet continually drops during draining. To counteract this, a slight (1 to 5-psig) pressure was applied to the totes. Since ease of operation was considered the main driver for this system design, an equal applied pressure to each tote was assumed. Component A and component B also have differing densities and viscosities leading to large differences in velocity profile as

calculated by the Bernoulli equation. During flow analysis, this was accounted for by assuming a larger outlet pipe diameter for the more viscous fluid (component B).

The predicted flow rates over time and the balance of cumulative dispensed material between the two components in a hypothetical system is shown in Figure 2.2. This system included two component totes with a total initial height of 1.1-m above the final outlet. The component A outlet hose was assumed to be a 2.5-in.-ID polyvinylchloride (PVC) flexible hose, while the component B outlet was assumed to be 3-in.-ID. With an applied headspace pressure of 1 psig, the 300-gal capacity of a chemical tote could be entirely drained within 5 min. The predicted difference in flow rates was also analyzed to look for variations in foam mixture. Over a single tote emptying cycle, a cumulative difference of less than 0.5 gal (0.02%) was observed. Given this analysis, construction and operation of a pressure driven prototype was warranted as a check on the flow characteristic assumptions.

Figure 2.2. Predicted flow from a pressure driven foam dispensing system.



2.4 HMI prototype

A commercial prototype was specially designed and constructed for this project by HMI of Manitowoc, WI. The HMI prototype is a trailer-mounted unit that relies on diaphragm pumps to deliver foam components through a mixing nozzle into the repair crater. Rather than a static mixing element, the design of this system uses higher delivery velocity through an impinging jet head to accomplish mixing of the two components.

The prototype as delivered on 21 July 2016 is shown in Figure 2.3. Two Yamada NDP-50BAS diaphragm pumps (Yamada America Inc., Arlington Heights, IL) were mounted at the rear of the prototype trailer. These pumps were set up with inlet and outlet ball valves, aluminum bodies, and Santoprene™ diaphragms. According to the manufacturer's rating, they are capable of discharging 150 gpm of water at a pressure head of 50 ft when driven by 100-psi compressed air with a flow rate of 180 SCFM. The rated discharge for heavier, more viscous materials, such as the foam components, was not given. Connections from the foam component totes to the suction side of the transfer pumps were made using 2-in. reinforced polyethylene hose and 2-in. polypropylene camlock disconnects. Each connection was sized the same, so care must be taken to ensure that cross-connections of the foam components do not occur. Enclosed space for two 250-gal chemical totes (one for each component) was provided between the generator and pumps. Compressed air was supplied to the pumps by a rotary-vane air compressor. A diesel-engine generator was installed with the compressor to provide power. A supplied-air respirator system was also provided with the prototype as well as spare diaphragms.

The mixing nozzle and prototype dispensing controls are shown in Figure 2.4. The nozzle consists of two steel-pipe component lines directed to a single steel outlet head. This outlet is covered by a flexible coupling and a short section of 1.5-in. PVC pipe. During dispensing, the foam components exit the outlet head at high velocity and impinge within the PVC pipe, creating a well-mixed foam material. The nozzle is connected to two ¾-in. stainless steel ball valves that are connected by a welded steel handle. The fluid lines are opened by pulling this handle towards the operator. Pump operation is begun by opening a ½-in. ball valve at the mixing nozzle to allow air flow from the compressor to the diaphragm pump motors. Since the diaphragm pumps are capable of generating high outlet pressures, it is important to always open the fluid lines at the mixing nozzle before opening the air valve to start the pumps. If this procedure is not followed, it is

possible that high pressure could burst a pump diaphragm or component hose. It is also possible that high pressure in the foam lines could cause operator injury upon opening the fluid lines. Because of these safety concerns, future designs of this type should include mechanical stops that prevent opening the air valve unless the fluid valves are open.

Figure 2.3. HMI prototype.



Figure 2.4. HMI prototype mixing nozzle with fluid flow and air controls.



3 Prototype Equipment Construction and Initial Evaluations

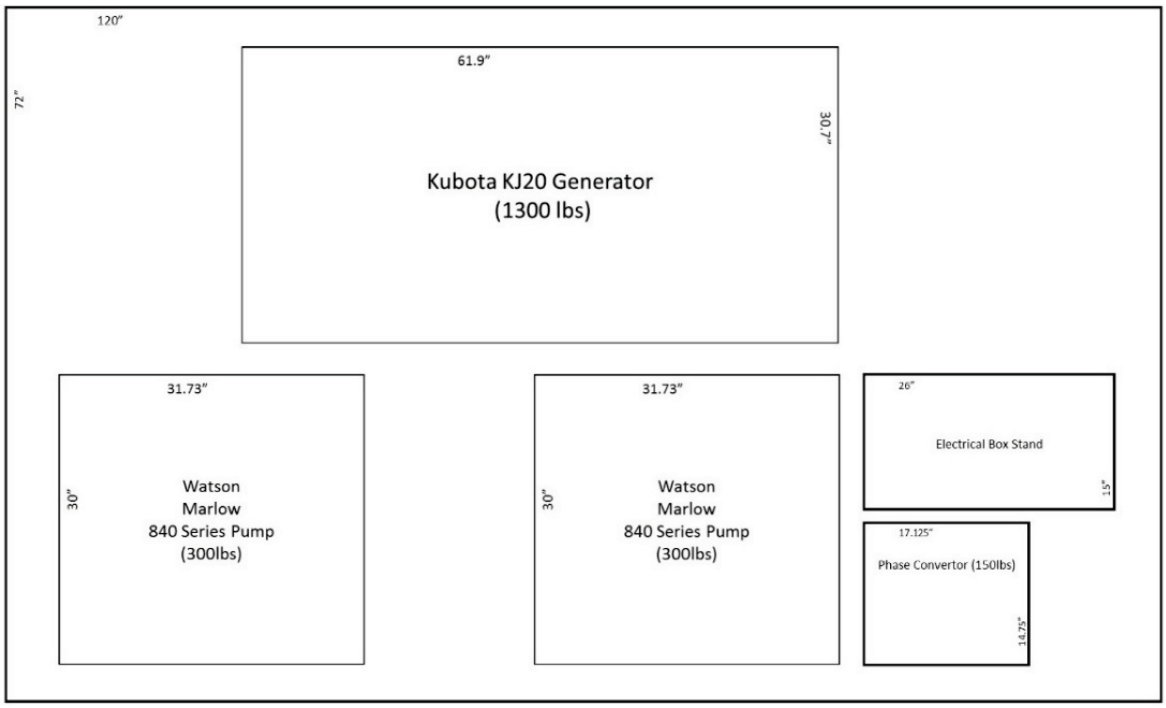
3.1 Pump driven skid system (CRADR1 Prototype)

3.1.1 Assembly

Each of the pump system components was attached to a 6-ft x 10-ft steel skid manufactured locally according to custom design drawings provided by ERDC to facilitate the handling and transport of the system. Layouts are presented in Figure 3.1. Electrical power for the system is provided by a Kubota KJ-20 diesel generator (Gulf Engine, Belle Chase, LA). The generator is capable of delivering 19.6 kVA of power as 240-V single phase, 60-Hz AC. Since three-phase power is required for motor operation, a rotary phase convertor (Phase-A-Matic R15, Phase-A-Matic Inc., Palmdale, CA), was also installed to provide three-phase, 240-V alternating current to the motor drive. Power was supplied to the pump motors through a variable frequency drive (VFD) (DuraPulse GS3-2010, AutomationDirect, Cumming, GA). The VFD was mounted in a weatherproof, powered electrical housing (Weatherflo WF10LP, Pentair Technical Products, Anoka, MN). Two hose pumps are powered by the VFD. They are each a Watson Marlow 840G variable speed pump head directly mounted to a 16.66:1 reducing gear and a 1775-rpm, 5-hp electrical induction motor. Each of the equipment pieces was directly bolted to tapped holes on the mounting skid, and electrical connections were made by a certified electrician. The assembled system is shown in Figure 3.2.

Maximum flexibility was desired for moving material to and from the prototype unit, so 50-ft chemical transfer hoses were installed for the suction and discharge sides of the hose pumps. Since preventing chemical spills is a major point of emphasis for this design, no-spill disconnects (Dixon Bayco, Dixon Valve and Coupling, Chestertown, MD) were installed at the hose ends. These stainless steel couplings were designed to instantly close when disconnected, preventing material spills. The connections were also designed to prevent accidental cross coupling, i.e., the introduction of component A into a transfer hose containing component B and vice versa. This was accomplished by specifying different coupling sizes. Component A transfer lines were 1.5-in. ID with 1.5-in. MNPT connections. Dixon Bayco 2-in. dripless disconnects were fitted to these lines. Component B transfer lines were 2-in. ID lines with 2-in. MNPT ends fitted to 2.5-in. Dixon Bayco disconnects.

Figure 3.1. Skid layouts for CRADR1 prototype.



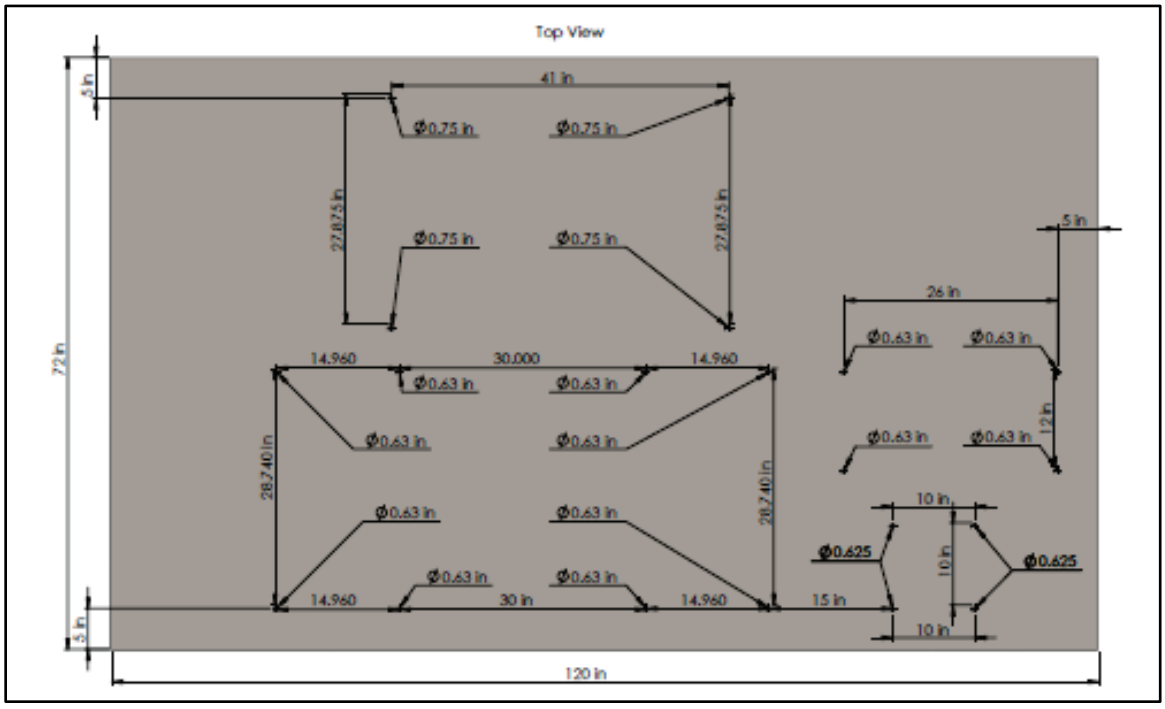
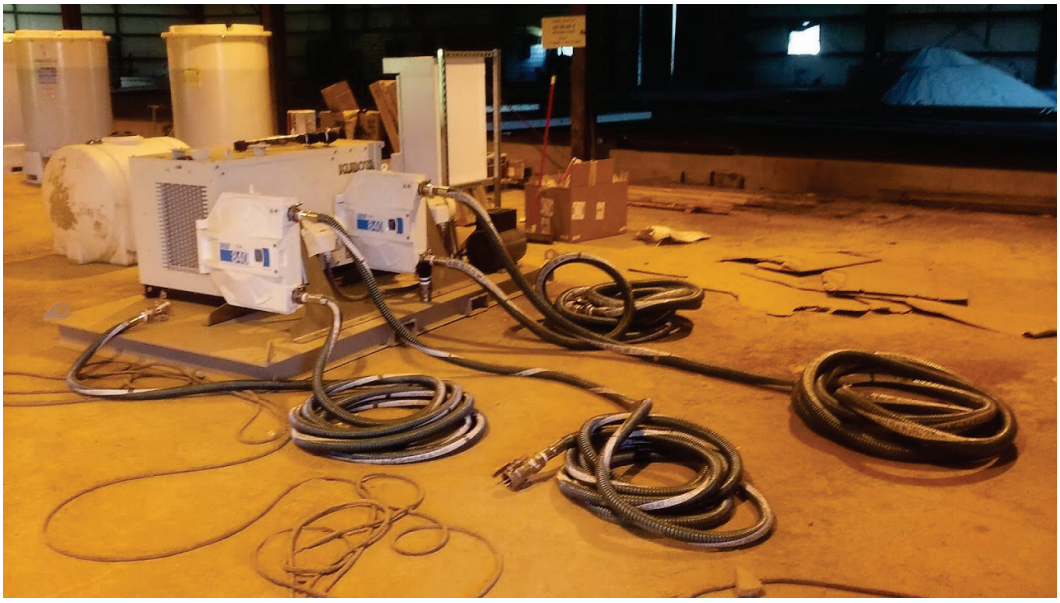


Figure 3.2. Assembled CRADR1 prototype.



A mixing nozzle was assembled so that well-mixed foam product could be introduced to the repair craters. This nozzle consisted simply of a 2-in. polypropylene tee fitted with two Dixon Bayco adaptors as inlets and a 1.5-in. x 36-in. static mixing element as outlet. Given the tendency of foam materials to deposit in dispensing nozzles over repeated use and clog the system, the nozzle was designed to remain inexpensive and easily replaceable. With quick disconnects in place on the dispensing system, it is possible to replace the mixing nozzle in less than 1 min.

3.1.2 Initial evaluation

3.1.2.1 Operation

Following installation of the system components, initial operation was performed on 4 August 2016. Chemical totes containing components A and B, respectively, of polyurethane foam were fitted with Dixon Bayco adaptors and attached to the suction side of the system pumps. Shallow plastic containers with approximately 20-gal capacities were utilized to contain the foam material as it was dispensed. The startup procedure was as follows.

1. Component suction lines were connected to the corresponding material totes. The integrated ball valves at the outlet of each tote were fully opened.
2. Component discharge lines were connected to the mixing nozzle.
3. The suction side and discharge side disconnect valves were opened.

4. The diesel generator was started. The start key was held in the pre-heat position until the engine block indicator light went off, then the key was turned to the start position to start the engine.
5. The main power circuit was turned on. The generator control panel has a main power breaker that energizes 'load center 1'. This load center energizes the phase convertor and the VFD.
6. The individual pump circuit breakers were turned on. Inside the VFD enclosure, individual circuit breakers allowed for the isolation of each pump for test or maintenance purposes. Each of these were engaged for full test operation.
7. The VFD control was set to 45-Hz and engaged.
8. Once the material had been successfully dispensed into multiple plastic containers, the VFD controller was stopped, the disconnect valves were closed, the nozzle was removed to drain out, and the diesel generator was turned off.

As the pumps drew material through the empty lines, component A began dispensing before component B, leading to an initially dense mix with low expansion. This can be attributed to the easier suction draw of component A, given its much lower viscosity. Follow-on tests did not exhibit this same lag in component B dispensing, indicating that it is an issue with pump priming only. For full scale operation, some method of wasting the initial material will be required whenever the system is started with empty lines.

The hose pump system uses larger diameter lines and mixing components than previous demonstration units. One result is that the mixing nozzle drained fully following the initial operation. A photo of the mixing nozzle following the initial operation of the system is shown in Figure 3.3. A small amount of foam material was left in the static mixing element following operation, and this material did react to form small foam blockages not exceeding 10% of the total nozzle diameter. Observations after the demonstration led to the conclusion that mixing nozzles of this type may possibly be reused if drained well between operations, although nozzle replacement will be required for long-term operations.

Figure 3.3. CRADR1 mixing nozzle following initial operation 4 August 2016.



3.1.2.2 Product quality

Fully formed foam as dispensed is shown in Figure 3.4. The foam cured to the point of supporting weight within 15 min. Following 2 hr of cure time, each container was cut in half to determine the quality of the final foam. The final product was tested following 4 hr of total cure time; per the supplier, this material achieves full cure within this time span. The unconfined compressive strength (UCS) of the two samples produced are shown in Table 3.1. Specimens analyzed from these samples did not follow guidelines specified in ASTM D1621-04a and, instead, were cubic in shape, as shown in Figure 3.4. Additionally, samples were not cut evenly. Therefore, error was introduced to the analysis. UCS at 10% strain was analyzed in addition to the maximum UCS and that at 2% strain. Regardless, UCS at 10% strain and maximum UCS exceeded the threshold specified for both samples.

Figure 3.4. Foam samples in 20-gal trays (top left), depth of foam samples (top right), and comparison of resulting UCS sample (bottom right) to lab sample (bottom left).



Table 3.1. UCS of foam samples from Figure 3.4.

Sample	Maximum UCS (psi)	UCS at 10% Strain (psi)	UCS at 2% Strain (psi)
Left Tray	313	289	105
Right Tray	311	287	131
Lab Sample	475	466	321

3.1.3 Single 8-ft crater

3.1.3.1 Operation and visual evaluation

CRADR1 was tested for backfilling an 8-ft x 8-ft x 2-ft-deep crater on 9 August 2016. Dispensing from the prototype is shown in Figure 3.5. The test crater was marked at 3 in. and 18 in. to delineate the initial foam fill depth and final expected depth, respectively. The prototype system was operated with the procedure used for the initial evaluation, and the crater was filled to a depth of 3 in. with FOAM-iT!® 10 SLOW within 5 min. Within 12 min, the foam mixture was tack-free and fully expanded. Within 20 min, the foam backfill was capable of supporting the standing weight of the project team. The 18-in. crater marks indicating a full 6:1 expansion ratio were met on each side of the crater; however, the center of the foam fill was noticeably higher than the sides.

Figure 3.5. Operation of CRADR1 prototype in test crater.



3.1.3.2 Temperature

The surface temperature of the foam was recorded as it expanded. The maximum temperatures recorded are shown in Table 3.2.

Table 3.2. Maximum temperature data for test crater.

Recorded Area	Maximum Temperature (°F)
Center	156
Southwest Corner	139
Northwest Corner	160
Northeast Corner	167
Southeast Corner	150

As the foam expanded and cured, large cracks formed at its surface. These cracks were potentially created to release heat within the foam. The surface of the foam was removed via shovels and an excavator to determine if

internal cavities or anomalies were produced (Figure 3.6). None were observed during this process, but a dark coloration of the foam was visible in certain areas. The temperature of the foam center immediately after surface removal was 255°F. After 2 min of exposure to the atmosphere, this temperature reduced to 230°F. Core samples were collected shortly afterward. The temperature was measured in the remaining cavity of a sample near the center of the crater; this temperature exceeded 310°F.

Figure 3.6. Test crater following foam surface removal.



The foam was excavated completely later in the day. Charring, as shown in Figure 3.7, was observed in small areas of the base of the foam. The temperature of the foam base could not be measured during evaluation. Therefore, the maximum temperature of the foam without performance or visual compromise could not be determined.

Figure 3.7. Charred foam found at test crater base.



3.1.3.3 Unconfined compressive stress

The UCS of the foam material in the test crater was measured by extracting core samples from different areas of the crater before and after foam surface removal. UCS data are shown in Table 3.3. The center of the crater was sampled before and after surface removal to determine if a difference in compressive strength would be observed. The sample collected after surface removal provided a ~100-psi increase in UCS at 2% strain. The cause of this difference is unknown but could be associated with a lack of foam integrity related to heat release at the surface. Additional UCS data are available in Appendix B.

Table 3.3. UCS data of samples from test crater.

Sample	UCS at 2% Strain (psi)	Maximum UCS (psi)	Strain at Max UCS (%)
Northeast (Before Removal)	196.1	312.0	6.4
Northwest (Before Removal)	200.3	317.4	5.6
Center (Before Removal)	162.9	287.0	14.9
Center (After Removal)	263.5	382.9	6.0
Southeast (After Removal)	218.8	335.2	5.7
Average	208.3	326.9	---

The average UCS for the foam in this crater was 208 psi. The target and threshold UCS values for the foam to be deemed successfully were 300 psi and 200 psi, respectively. Samples prepared in the laboratory with FOAM-iT!® 10 SLOW had an average UCS of 321 psi at 2% strain, as shown in Table 3.1. The difference in UCS between the lab- and field-scale samples could be attributed to inadequate mixing within CRADR1's nozzle. In laboratory studies, foam samples were produced at two different mixing rates for 30 sec. Samples produced at the lower mixing rate displayed larger cells and a darker yellow hue relative to those produced at the higher rate (Gurtowski et al. 2016). Figure 3.8 shows that the samples produced by CRADR1 demonstrated cell structure similar to the lab samples produced at the lower rate. As shown in Figure 3.9, the foam is agitated to provide a creamy tan mixture within the nozzle. However, this mixture does not appear homogeneous until immediately before being dispensed. Increased agitation, caused by higher flow rates or narrower or longer nozzles, could provide more homogeneity in the foam mixture and greater UCS. Additionally, the samples analyzed from the crater did not contain a smooth outer layer, known in the polyurethane industry as "skin", which vendors have indicated to provide added strength to the material. Skin, however, was present on the samples prepared in the lab, as depicted in Figure 3.10, and could have further added to the difference in UCS observed between the lab- and field-scale samples. Another discrepancy that could have reduced the strength of the foam was the moisture in the crater's subgrade. Moisture measurements were not collected for this study. Potentially, the soil could have contained enough moisture to impact the results.

3.1.4 Portable unit assembly

Following initial tests, the entire system with chemical totes was placed on a trailer for portability. The final assembled prototype is shown in Figure 3.11. The system unit weights include 1,200 lb for the generator set, <300 lb for each pump and motor, 150 lb for the phase convertor, 100 lb for the enclosure and drive controller, and <1,000 lb for the steel mounting skid. The two component totes weigh 4,900 lb as a set when full; thus, the total weight of the system with chemicals is approximately 8,000 lb.

Figure 3.8. Cell structure of sample from field crater (top) and lab samples prepared at high (left) and low (right) mixing rates.

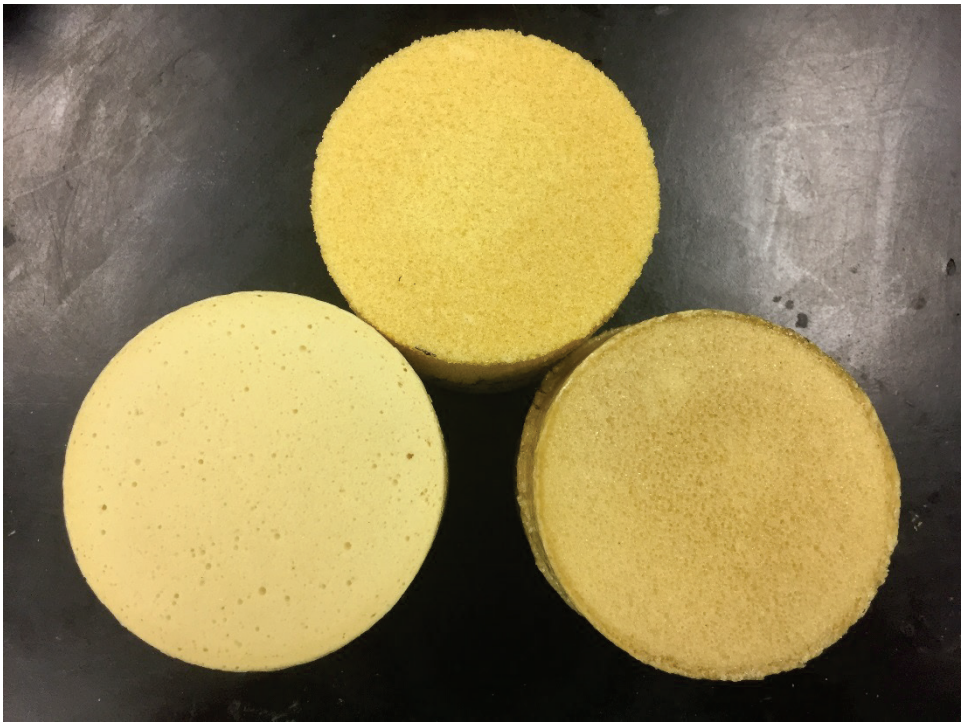


Figure 3.9. Foam mixing within CRADR1 nozzle.



Figure 3.10. Profile view of samples from lab (left) and field (right).



Figure 3.11. Final assembled hose pump foam dispensing prototype.



3.1.5 Prototype costs

A summary of the unit costs for construction of CRADR1 prototype is given in Table 3.4. The actual costs of each component add up to a total system cost of $67,826. When sundry connections and electrical wiring are added to the total, the complete system carries a capital cost of $70,000. Labor, engineering, and overhead costs for the acquisition of chemical processes may be estimated as a fraction of the bare module cost (Turton et al. 1998), and a good first approximation when the individual materials costs are all known is a multiplier of 1. For this case, the total estimated direct costs for acquisition of a hose pump prototype system is $140,000. Cost savings may be realized through specification of cheaper materials, as well as moving to

a 10-kW generator set. The largest single capital cost is the dual hose pumps, and price reductions for those units would need to be the result of further competitive bidding. The greatest cost savings could come from reducing the estimate of overhead and engineering labor, especially since the system has been specified through this development effort.

Table 3.4. CRADR1 prototype costs.

Unit	Number Required	Unit Cost	Total Cost
Watson Marlow 840G Hose Pump w/ 5hp Inverter Duty Motor	2	$21,520	$43,040
Kubota KJ20 Diesel Generator	1	$11,420	$11,420
Phase-A-Matic R15 Phase Converter	1	$2,360	$2,360
Weatherflo Type 3R Enclosure, WF10LP	1	$1,000	$1,000
DuraPulse GS3-2010 Variable Frequency Drive	1	$700	$700
Steel Mounting Skid, Painted	1	$4,000	$4,000
2-in. Chemical Transfer Lines	2	$400	$800
2.5-in. Dixon Bayco Couplers	2	$900	$1,800
2-in. Dixon Bayco Couplers	2	$820	$1,640
2.5-in. Dixon Bayco Adapters	2	$283	$566
2-in. Dixon Bayco Adapters	2	$250	$500
Prototype Equipment Cost			$67,826
Contingency Materials			$2,000
Engineering, Labor, and Overhead (Estimated)			$67,826
Estimated Total Direct Costs for Hose Pump Prototype			$137,652

3.2 Air pressure-driven container system (CRADR 2 prototype)

3.2.1 Assembly

The air pressure-driven prototype foam dispensing system (CRADR 2) consisted of specified viscous material 330-gal chemical totes (Poly Visco, Snyder Industries, Lincoln, NE) with discharge hoses directly connected to a single mixing nozzle and air pressure lines connected to a common source of compressed air. The complete system is shown in Figure 3.12. The component A tote was connected to the mixing nozzle by a 2-in.-ID x 25-ft-long polyethylene hose fitted with camlock quick disconnects. A ball valve at the tote discharge and a ball valve at the mixing nozzle provided start/stop capabilities. Component B was similarly connected to the mixing nozzle with a 3-in.-ID polyethylene hose. The mixing nozzle was a 2-in. polypropylene tee with adapters for the two component hoses and a 2-in.-ID x 36-in. static mixing element.

Figure 3.12. Pressure-driven foam dispensing prototype.



3.2.2 Initial evaluation

Initial operation of CRADR2 began 11 August 2016. Each component tote was pressurized to 1 psig in the headspace, and the tote outlet valves were opened. The valves at the mixing nozzle were each then opened enough to fully prime the transfer hoses. Once the hoses were primed, both component valves at the mixing nozzle were fully opened to dispense polyurethane into a plastic container. After opening both valves, component A seemingly flowed more rapidly than component B into the container; the dispensed mixture was a notably dark color similar to that of pure component A. Component B flow was isolated to quickly analyze its flow rate. This evaluation confirmed that component B was flowing at a markedly lower volumetric rate than component A.

A differential pressure test was undertaken to determine the feasibility of the air driven system given the observed rheology of the components. The component B tote was pressurized to 5 psig in the headspace, while the component A tote was left open to atmospheric pressure. Since 5 psig is the maximum allowable pressure in the polyethylene totes, as indicated in Figure 3.13, this test determined the maximum achievable driving force for

component B in the air driven system. With both component valves open, a similar observation to flow under identical pressures was made. Component A was flowing at a much higher volumetric rate than component B, leading to a non-optimal product mix. Once again, the component B flow rate was isolated, and it did not appear to be more than 5 gpm.

Figure 3.13. Warning label (left) and crowning (right) from 5 psig within Poly Visco tote.



Predicted flow rates for component A in an air-driven prototype were consistent, but component B failed to reach the flow rates predicted by the Bernoulli equation. This indicates that either 1) at least one of the required assumptions fails for component B in larger scale testing or 2) an unexpected design failure occurred. Since component B is a polymer solution, the most likely failed assumption would be Newtonian flow. Polymers sometimes exhibit a shear thickening behavior wherein the liquid viscosity of the solutions increases at higher shear rates corresponding to higher flow velocities in pipes. This would increase the energy required to accomplish a given flow rate for component B in any system. Positive displacement pumps can provide the extra power required, but an intentionally low-power system would not be able to compensate. The most likely equipment failure would relate to the viscous material totes. Each of the totes is equipped with a scraper that is meant to sit on top of thick liquids inside the tote and assist in cleaning highly viscous materials from the tote as the liquid level decreases. The possibility of improperly assembled totes was checked by removing the top of the totes to ensure that the side scrapers were present. For the two totes checked, the side scraper assemblies were not on top of the liquid, but rather were found sitting on the bottom of the liquid in the tote. This position would have hindered free draining of the components from the totes, and most likely contributed to the slow flow rates observed during testing. The side scraper assemblies

were removed (Figure 3.14) from the chemical totes. A likely explanation for the position of the side scraper assemblies is that the component vendor did not remove them from the totes before filling. Additional testing was conducted with the scraper assemblies correctly installed; however, the dispensing flow rate was still low and the system was not able to provide a 1:1 ratio.

Figure 3.14. Side scraper assemblies as removed from Poly-Visco totes.



3.2.3 Prototype costs

A summary of the unit costs for construction of CRADR2 prototype is shown in Table 3.5. The actual costs for acquisition of each component add up to a total system cost of $6,900. Labor, engineering, and overhead costs for the acquisition of chemical processes may be estimated as a fraction of the bare module cost (Turton et al. 1998), and an approximation when the individual materials costs are all known is a multiplier of 1. For this case, the total estimated direct costs for acquisition of an air-driven prototype system is $14,300. The greatest cost savings could come from reducing the estimate of overhead and engineering labor, especially since the system has been specified through this development effort.

Table 3.5. CRADR2 prototype costs.

Unit	Number Required	Unit Cost	Total Cost
Poly Visco Drums	2	$2,500	$5,000
3-in. PVC Flexible Hose	1	$200	$200
2-in. PVC Flexible Hose	1	$200	$200
Polypropylene Fittings	1	$150	$150
2-in. Static Mixer	1	$150	$150
Air Hose and Fittings	2	$100	$200
Air Compressor	1	$1,000	$1,000
Prototype Equipment Cost			$6,900
Contingency Materials			$500
Engineering, Labor, and Overhead (Estimated)			$6,900
Estimated Total Direct Costs for Pressure Driven Prototype			$14,300

3.3 HMI prototype

3.3.1 Initial evaluation

Preliminary testing was performed at the HMI facility before shipping. Following successful operation, the foam components were flushed from the prototype with vegetable oil, and the prototype was transported to Vicksburg, MS.

Foam component totes were installed on the HMI prototype, and operation was attempted on 17 August 2016. The generator and air compressor successfully started, and 100-psi air pressure was delivered to the pump air-service regulators. Despite multiple attempts, the diaphragm pumps failed to operate. Some material that appeared to be a mixture of vegetable oil and foam components dripped out of the nozzle, but the air motors on the pumps were not engaging. The mixing nozzle was removed to check for possible blockages (Figure 3.15). Clogging appeared to be present in the mixing nozzle. Operation of the prototype without the nozzle was also unsuccessful, although component A could be dispensed. Even in the absence of the clogged nozzle, the component B pump still failed to operate.

Figure 3.15. HMI prototype mixing nozzle outlet head (upper), Component A connection (lower left), and Component B connection (lower right).



Technicians from HMI traveled to Vicksburg to troubleshoot the system. The steel nozzle was completely clogged with polymerized product and required mechanical foam removal with steel drill bits. Once the nozzle was drilled through, a solvent flush with brake pad cleaning sprays helped to clean the nozzle. The ball valves were also removed from the end of the hoses to check for clogging. A significant amount of material was polymerized in the component B hose. As the technicians began removing this material, pressure from the hose released and sprayed component. Both ball valves were replaced, and a quick function check ensured that both pumps were moving material.

3.3.2 Prototype costs

The actual cost for acquisition of the HMI prototype foam dispensing system was $57,770 (Table 3.6); with overhead the total cost was $94,165. This would be the cost of the first prototype, which may have included manufacturer's overhead for research and development. It would be assumed that, during production, these costs would reduce significantly.

Table 3.6. HMI prototype costs.

Unit	Number Required	Unit Cost	Total Cost
Trailer mounted system, delivered	1	$57,770	$57,770
Prototype Equipment Cost			$57,770
Engineering, Labor, and Overhead			$36,395
Estimated Total Direct Costs for Pressure Driven Prototype			$94,165

4 Evaluation of Additional TTPs

Previously identified issues with using foam backfill for crater repair included the foam material's susceptibility to water and its tendency to create an uneven surface, especially when it is poured in large volumes. Water can change the polymerization reaction during foam formation and lead to less dense foams with lower overall compressive strength (Priddy et al. 2010, Gurtowski et al. 2016). For this reason, different methods for either removing or blocking water within a crater repair were studied to ensure the ability for repairs to proceed under all weather conditions. Another area that required additional research was to explore different methods to cut excess or uneven foam surfaces to ensure adequate concrete cap thickness. Different methods were evaluated to determine the most effective way to level the foam surface without causing additional burden during the repair process. This chapter discusses the research and development efforts to include additional TTPs to address these two issues.

4.1 Moisture barriers

An example of foam application to wet soil is shown in Figure 4.1. For small scale testing of moisture barriers, ~10-lb of dry soil were spread evenly in the bottom of a shallow plastic tray. Water was added to the soil until it was saturated. FOAM-iT!® 10 SLOW was placed on the wet soil using the hose pump foam prototype (CRADR 1), and the material was allowed to fully cure. After 2 hr, the foam was visibly less dense than similar examples of the same foam product applied in dry containers. The foam was also visibly more flexible when pressed by hand.

The simplest solution is pumping to remove standing water in a crater followed by lining the bottom with a waterproof barrier before adding the foam materials. It may also be possible to spray a hydrophobic barrier material into the crater, providing it displaces water evenly and sets up quickly enough to allow the repair to proceed.

Figure 4.1. Polyurethane foam applied to wet soil in a plastic container.



4.1.1 Spray-on barriers

4.1.1.1 Flex Seal

Flex Seal is a proprietary liquid product that is advertised primarily as a paintable rubber sealant for applications such as gutter, roof, or boat repair. A 1-gal container of Flex Seal was tested as a water barrier to compare against the control application (Figure 4.2). Approximately 10 lb of soil was spread evenly on the bottom of a shallow plastic container and soaked to saturation. This wet soil mixture was then covered with 1 gal of Flex Seal poured directly into the container. A paint roller was used to attempt to spread the Flex Seal more evenly, but the material stuck to both soil and roller tending to mix two rather than spread the water barrier across the soil. One possible issue was immediately apparent. The water barrier applied as a liquid tended to push free water from the soil and create small pools of water on the surface of the sealant. This phenomenon may necessitate more stringent drying of the soil before the barrier can be successfully applied.

The sealant was allowed to cure for 2 hr before foam was applied directly on top of the barrier. FOAM-iT!® 10 SLOW was placed using the hose pump foam prototype (CRADR1), and the material was allowed to fully cure. After 2 hr, the foam was visibly less dense than similar examples of the same foam product applied in dry containers. The foam was also visibly more flexible when pressed by hand. There was no apparent improvement in foam performance when compared to the control soil.

Figure 4.2. Flex Seal© applied to wet soil.



Flex Seal as applied did not prevent water from adversely impacting foam performance over wet soil. This may be due to the hydrophobic barrier allowing water to escape upwards and pool on top of the barrier before foam application. It is also possible that a 2-hr cure time is insufficient for this material; a full 24-hr cure time is recommended by the manufacturer. In either case, the material is not capable of meeting threshold requirements for a basic moisture barrier in a crater, and Flex Seal is not recommended for this particular application.

4.1.1.2 Rust-Oleum® NeverWet®

Rust-Oleum® NeverWet® is a highly hydrophobic surface treatment marketed for maintaining ultraclean weather-exposed surfaces. Treated surfaces repel water efficiently enough that the surface is immediately dry upon removal from water. The material is a two-part treatment that may be spray, roll, or dip coated onto materials. A 1-gal kit of NeverWet® was tested as a water barrier against the control application (Figure 4.3). Approximately 10 lb of dry soil was spread evenly in the bottom of a shallow plastic container and soaked to saturation. NeverWet® base coat

was applied liberally to the wet soil using a standard garden sprayer and allowed to cure for 0.5 hr per the manufacturer's instructions. Then NeverWet® topcoat was also applied with a standard garden sprayer until the surface had a white, frosty appearance per the manufacturer's instructions.

Figure 4.3. NeverWet© applied to wet soil.



The sealant was allowed to cure for 2 hr before applying foam directly on top of the barrier. FOAM-iT!® 10 SLOW was placed using the CRADR1 prototype, and the material was allowed to fully cure. After 2 hr, the foam was visibly less dense than similar examples of the same foam product applied in dry containers. The foam was also visibly more flexible when pressed by hand. There was no apparent improvement in foam performance when compared to the control soil.

NeverWet® as applied did not prevent water from adversely impacting foam performance over wet soil, as shown in Figure 4.4. It is possible that spraying the material directly onto wet soil allows hydrophobic interactions to adversely impact the formation of a suitable film. It is also possible that a 2-hr cure time is insufficient for this material. In either case, NeverWet® does not meet threshold requirements and is not recommended for use as a water barrier in crater repair.

Figure 4.4. Cured moisture barrier samples using wet soil. Flex Seal (left), NeverWet® (center), and control group with no barrier (right).



4.1.2 Flexible liners

Flexible liners made of poly(vinyl)chloride (PVC) were purchased from a local hardware store for material compatibility testing. Testing was undertaken in a previously excavated 8-ft x 8-ft crater that was approximately 2-ft deep. Heavy rains from the previous day left visibly wet soil at the bottom of the crater. A 10-ft x 12-ft PVC pond liner was placed in the bottom of the crater before the addition of ~2 in. of foam material (Figure 4.5). After placing the barrier by hand, approximately 2 in. of FOAM-iT!® 10 SLOW was applied to the crater using CRADR1 prototype system.

Figure 4.5. Test crater before (left) and after (right) adding a PVC liner.



Figure 4.6 shows the foam immediately following placement into the crater. In one location on the perimeter of the crater, the PVC liner sagged allowing for foam to contact the wet soil. At this point a small amount of material reacted to form a visibly less dense foam (lower right corner in Figure 4.6), but this reaction zone was limited to a small area of the total crater. Within the rest of the crater, the foam material expanded and cured as normal. Following placement of the foam material, initial curing occurred within 20 min.

Figure 4.6. Test crater with wet soil lined with PVC directly after foam placement.



Since the foam curing reaction generates significant heat, the crater was excavated to look for signs of liner failure underneath the center of the crater. Specifically, the liner was evaluated to ensure that it did not melt or form holes that could lead to water intrusion and weak foam or cavity formation during the repair. Photos of the excavation are included in Figure 4.7. No apparent cavities or holes were observed in the liner during excavation of the repair. The weight of the foam material pressed down on the liner while the temperature of the reaction softened the liner slightly. The result was not a hole in the liner, but rather the liner was pressed into small cavities on the crater subgrade resulting in a better overall contact between the foam backfill and the crater subgrade.

Figure 4.7. Excavating foam out of the test crater to assess PVC liner conditions.



4.1.3 Summary of moisture barriers

The threshold requirement for water barriers during crater repair with foam backfill is prevention of water contact with foam material during the formation reaction with minimal impact on cure times or labor input. Each of the spray-on barrier options required an initially dry, clean surface and 4 to 24 hr of cure time for optimal performance. Neither requirement can be met under anticipated field conditions where the water barriers would be needed. PVC liners may be cut to size and placed in a crater repair quickly by one or two people. These liners have performed well during full-scale testing and are recommended as moisture barriers when polyurethane foam backfill is used for crater repair.

4.2 Foam cutting methods

Previous foam backfill experiments have shown that domes form, resulting in the center of the foam backfill to rise higher than the edges. This requires the removal of some of the cured foam material prior to concrete capping to ensure a minimum cap thickness. Multiple methods were assessed to accomplish this material removal quickly and safely.

4.2.1 Hand tools

As the foam cures, cracks may appear on the surface due to the release of heat generated by large foam volumes. During testing, some attempts were made to use these cracks as points to begin prying up and removing the top inches of the foam backfill with handheld tools such as shovels and axes (Figure 4.8). If the shovel work was begun less than ½ hr after foam curing, a large amount of material could be readily removed in this manner. However, this method did not work well for most craters for two main reasons: First, it was difficult to remove the foam to a set depth; large chunks of material tended to pull up with the shovel and getting a consistent depth of cut proved impossible. Second, this method tended to

create many foam pieces of widely varying size that had to be removed before capping. These pieces would clog the scarfer blade (see paragraph 4.2.3) if follow-on finishing was required or float to the top of the rapid-set cap if they were not removed prior to capping.

Figure 4.8. Removing excess foam with hand tools.



4.2.2 Hot wire

A common method for cutting foam materials, especially Styrofoam components in theater set designs, is to use a hot-wire cutter (Figure 4.9). These cutters use a NiChrome resistance wire that is heated by an electrical power source to make clean cuts in solid foam blocks. A 4-ft hot wire with power supply (https://hotwirefoamfactory.com/4-Foot-Compound-Bow-Cutter.html) was purchased and tested on an 8-ft crater to determine the feasibility of the system for dense polyurethane foams. The hot-wire cutter proved impractical for Airfield Damage Repair (ADR) applications. Rather than burning away a small line of foam, applying the hot wire to the surface of the foam slab caused only a slight melting of the material. Consequently, the cutter could not be pulled through the top of the foam surface to remove any of the foam material.

Figure 4.9. Hot-wire cutter.



4.2.3 Mechanical scarfer

For denser foams associated with insulation materials, a variety of powered cutters (scarfers) are available. Most of these are produced for cutting lightweight interior insulating foams, but one piece of equipment was identified for the planning of dense foam insulation on roofs. This mechanical scarfer is shown in Figure 4.10 with a summary of features in Table 4.1. The mechanical scarfer contains two rows of spinning circular blades. The blades are angled so that, as the drive shafts rotate, the cutting edges of the blades sweep back and forth across the surface of the foam. The cutting depth is set between 0.5 in. and 1.5 in. by the user, and the blade drive is engaged by a hand lever that engages the drive-belt idler pulley. If the operator releases the pull handler, the idler pulley disengages and the blades stop.

Figure 4.10. Mechanical scarfer.



Table 4.1. Summary of mechanical scarfer features.

Equipment weight	115 lb
Engine Fuel	Gasoline
Equipment Cost	$3,500
Operators	2

Operating the mechanical scarfer is relatively simple. Two persons are required to lift the scarfer into the crater. Once the scarfer is in place, the drive engine is started with a pull rope. The operator pushes the scarfer to the edge of the crater, engages the drive belt, and begins cutting the foam surface by pulling the scarfer across the foam. This process is repeated until minimum cap thickness requirements are met. Once the required amount of material is removed, foam dust is left over for removal. Hand removal by shovel into a loader bucket was used during demonstration of the foam backfill technology. The foam dust is also fine enough for removal by vacuum.

The mechanical scarfer produced the most even cut and finish of any of the foam removal techniques. It was capable of cutting foam even after several hours of curing, which was very difficult to accomplish with hand tools. However, its weight requires two people to lift it and its operation creates safety concerns. Great care must also be taken during operation on an uneven foam slab since the scarfer and its rotating blades are pulled

towards the operator during cutting. Operators must take care to stand in a stable position, pull steadily, and release the handle engage lever if anything unexpected occurs.

4.2.4 Reciprocating saw

Reciprocating saws, also known by the trademark Sawzall©, are general-purpose cutting tools widely used in the construction and demolition industries. They are available with a variety of blade types and lengths for different purposes. A general purpose reciprocating saw blade and a specialized foam cutting blade were both tested as foam removal tools in demonstration craters. The procedure for using a reciprocating saw begins with making a linear cut extending into the foam at an angle. The cut line should cross the crater connecting two points that are known to be at the required final depth of the cap. Following the initial cut, an opposing cut may be made to create a V-shaped notch of material that is then removed by hand and discarded. If more material must be removed, additional cut lines may be made moving away from the opposing cut line a few inches at a time. Following the additional cuts, thin slices of material may be broken out and removed by hand until the minimum cap depth requirement is met across the entire crater.

Two types of reciprocating saw were tested for foam material removal. The first was a standard commercially available saw with a construction/demolition blade (Figure 4.11). Standard blades are available in lengths from 4 in. to 10 in. This saw was able to remove foam material quickly, although care had to be taken since the blade can bind or catch on loose material. Operation also requires kneeling over the material, making longer cuts more difficult. A second type of saw with a specialized foam cutting blade attachment was also tested. This modified saw and longer (12 in. to 24 in.) blade are sold for removing excess material from foam insulation applications (Figure 4.12). The foam backfill material is denser than typical foam insulation, being 10 lb/ft^3 rather than <2 lb/ft^3. This impeded the use of reciprocating saw with foam blades, since it did not have sufficient power to cut through the dense foam with a long blade. Reciprocating saws are viable for removing excess backfill material using construction/demolition blades up to 10 in. long, but larger cuts would require a larger saw motor.

Figure 4.11. Standard saw with construction/demolition blade.



Figure 4.12. Modified saw with a specialized foam cutting blade attachment



4.2.5 Summary of foam cutting methods

Excess foam material must be removed to ensure the minimum concrete cap depth. Multiple techniques are available to accomplish this removal subject to safety and performance constraints. The first priority is ensuring the operator's safety. Next is maintaining the integrity of the foam baselayer-concrete cap system. Loose foam material is buoyant in wet rapid-setting concrete, so part of maintaining cap integrity is removing cut material, especially chunks larger than 1 in., before capping.

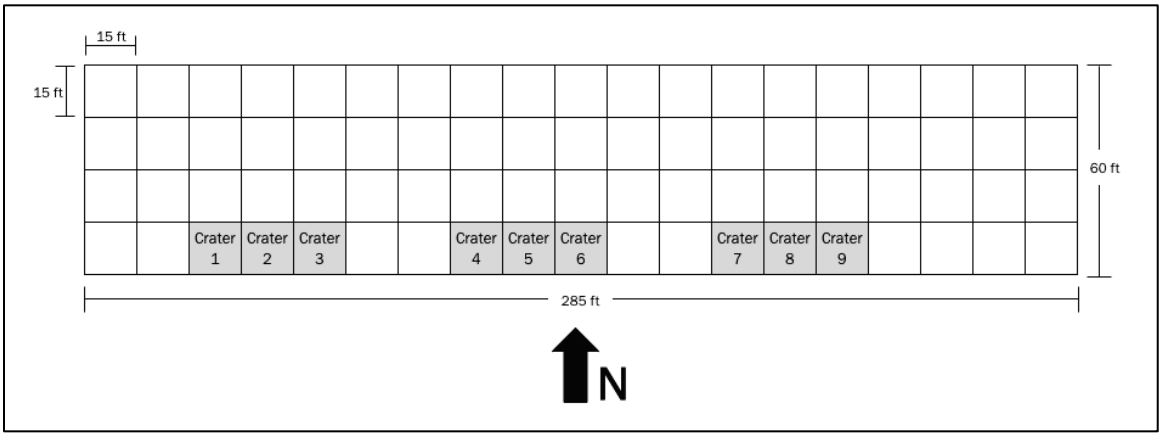
Hand tools, including shovels and axes, as well as multiple-powered cutters, were tested for excess foam removal. Hand tools required more personnel and time than the other methods. They were also ineffective if the material was allowed to set for more than ½ hr before cutting, and they created the largest number of small chunks making cleanup difficult. Hot-wire cutting was ineffective for the 10-lb/ft^3 material used in crater backfill. The mechanical scarfer and reciprocating saw were both effective power tools for excess foam removal. The scarfer was able to create the most even foam surface. However, it is the heaviest option and requires two operators to safely implement. It also creates a large amount of foam dust that must be removed by shovel or vacuum before capping. Reciprocating saws with multi-purpose blades up to 10 in. were also useful for excess material cutting. With further demonstration work, a suitable standard operating procedure for reciprocating saws could be developed.

5 Full-Scale Field Testing

5.1 General test description

Full-scale field testing was conducted at ERDC 12-14 September 2016 to evaluate the new prototype foam dispensing equipment, additional TTPs, and the repair performance. The two polyurethane foam materials recommended during previous laboratory investigations (Gurtowski et al. 2016), Foam-iT! 10 Slow and Primal Innovation Med, were evaluated along with two prototype foam dispensers, i.e. CRADR 1 and HMI. A 13-in.-thick portland cement concrete (PCC) test section that was built for a previous project was used. Nine craters with approximate dimensions of 8.5 ft x 8.5 ft were cut and excavated prior to testing. Figure 5.1 shows the crater locations within the test section. The crater bottoms were squared off and compacted, and 6 in. of crushed limestone was added to provide a consistent subgrade throughout all craters. Testing consisted of repairing three consecutive craters each day using polyurethane foam as the backfill and rapid-set concrete as the capping material. Repair times were recorded to document the duration of each step of the process. Internal and external foam material temperatures were constantly monitored to document the temperature gradient during the foam expansion and setting process. Once each set of three repairs was completed, simulated F-15E single-wheel-load traffic was applied to evaluate the performance of the repairs.

Figure 5.1. Crater layout during full-scale field testing.



5.2 Crater repair procedures

At the beginning of each test day, the subgrade strength of all three craters was assessed using the dynamic cone penetrometer (DCP) test, and soil

density and moisture content were determined using the nuclear density gauge following standard methods ASTM D 6951 and ASTM D 6938. The bottom of each crater was surveyed using rod and level to determine relative depths. Crater dimensions were measured to determine the total crater volume. Then, 10 in. were subtracted from the total crater depth to determine the depth of expanded foam required, and that depth was marked on the crater walls using spray paint. The depth of expanded foam was divided by 6 (foam product's expansion ratio) to determine the depth of liquid foam to be dispensed into the crater. Metal plates like the one shown in Figure 5.2 were placed at the bottom of the craters to mark the depth of liquid foam. Some craters were lined using a PVC liner to protect the foam from being in direct contact with the wet subgrade soil.

Figure 5.2. Marking required expanded foam depth on crater walls (left) and metal marker for liquid foam depth (right).



Once all measurements were completed and the craters were marked, foam dispensing began. Liquid foam was dispensed into the first crater by moving the mix nozzle from side to side to cover the entire crater bottom. Foam dispensing was paused when the depth mark was covered; then, the foam dispenser was moved to the next crater, and so on, until all three craters were filled. When the foam expanded and was tack free, the crater depth was measure to determine if there was enough room for a 10-in.-thick concrete cap. In some cases, especially when PVC liners were not used, the foam surface was uneven and soft, and it required foam leveling.

Once the foam surface was prepared, it was surveyed to determine the thickness of the foam layer, and core samples were extracted from the foam backfill for laboratory determination of UCS. Then, the volumetric concrete mixer was used for placing the rapid-setting concrete caps. On average, three super sacks of Rapid Set® concrete material were used on each crater. A forklift and a hydroseeder were kept on site to constantly feed the mixer

with Rapid Set® material and water, respectively. Since the air temperatures were relatively high all three days (average air temperature was 93°F), citric acid was added to delay set of the Rapid Set® concrete and increase the working time. Once all three caps were completed, the rapid-setting concrete caps were allowed to cure for 2 hr before simulated aircraft traffic was applied following current rapid-setting concrete guidance. The repairs were then trafficked to determine if the repairs could support at least 100 passes within 2 hr of completion.

Generally, each repair was completed in approximately 6 hr, including the time for data collection and foam material core sampling. Actual repair operations were generally completed in a little over 2 hr. Table 5.1 shows a summary of the data collected during the repair of all nine craters. Time and temperature data were collected throughout the entire repair process and are presented later on in this report. The following sections describe specific details of each crater repair.

Table 5.1. Crater repair data.

Crater Number	Foam Dispenser	Foam Product	Average Subgrade Soil CBR (%)	Average Subgrade Soil Moisture (%)	Moisture Barrier	Crater Depth (in.)	Applied Liquid Foam (in.)	Expanded Foam Average Thickness (in.)	Approximate Expansion Ratio[a]	Rapid Set Concrete Cap Average Thickness (in.)
1	CRADR1	FOAM-iT!® 10 SLOW	51.3	2.7%	PVC Liner	25.6	3.0[b]	15.2	5.1	10.4
2	CRADR1	PI Med	28.3	2.5%	PVC Liner	24.1	3.0	11.4	3.8	12.7
3	CRADR1	FOAM-iT!® 10 SLOW	10.4	4.4%	PVC Liner	26.2	3.0	14.4	4.8	11.8
4	CRADR1	PI Med	32.2	4.1%	None	26.2	3.0	13.8	4.6	12.4
5	CRADR1	PI Med	12.7	4.2%	PVC Liner	26.1	3.0	11.6	3.9	14.5
6	HMI	FOAM-iT!® 10 SLOW	—[c]	—[c]	—[c]	—[c]	—[c]	—[c]	—[c]	—[c]
7	CRADR1	FOAM-iT!® 10 SLOW	30.6	2.6%	None	25.2	2.0	14.0	7.0	11.1
8	CRADR1	FOAM-iT!® 10 SLOW	52.6	2.4%	None	25.7	2.0	13.7	6.8	12
9	CRADR1	FOAM-iT!® 10 SLOW	26.0	2.2%	None	25.5	2.0	15.2	7.6	10.3

[a] Determined using the final foam volume, which was measured after foam surface was leveled (cut down).

[b] Foam was placed in two 1.5-in. lifts (100-gal).

[c] Crater not assessed due to equipment failure.

5.2.1 Crater 1

Crater 1 had a total depth of 25.6 in., which required a maximum depth of expanded foam of 15.6 in. to provide a 10-in. concrete cap. This crater was lined with a PVC liner and backfilled by placing two separate applications of approximately 1.5 in. of liquid FOAM-iT!® 10 SLOW with a pause of 8 min between applications. The theory was that, by pouring the foam in layers, the foam temperature would be reduced by the reduction in volume of reacting foam and, thus, the foam surface would not have a dome shape nor would it crack. This would reduce the need for any foam leveling (cutting) method. However, multiple foam material lifts did not create an even surface. The observed repair surface (Figure 5.3, upper right) was less even than that of other craters that were repaired with one foam pour and exceeded the required foam thickness. The repair sequence for Crater 1 is shown in Figure 5.3. An extended stoppage occurred between the pour of foam material and the scarfing process. During this time, the foam had fully cured and could not be easily cut by scarfer or shovel. Instead, an axe and excavator were necessary to reduce the height of the foam to provide a cap thickness of approximately 10 in. Foam in the other craters was cut shortly after becoming tack free.

Figure 5.3. Repair sequence for Crater 1 including the crater prepared for backfilling (upper left), the crater with fully cured foam backfill (upper right), the finished foam surface ready for capping (lower left), and the completed repair (lower right).



5.2.2 Crater 2

Crater 2 had a total depth of 24.1 in. and required a maximum depth of expanded foam of 14 in. to provide a 10-in. concrete cap. This crater was also lined, but, in this case, Primal Innovation Med foam material was applied as backfill in a single pour to a depth of 3 in. This material exhibited a lower expansion than expected and produced a foam layer that was only about 11 in. thick. The surface was relatively level; thus, no cutting was required; however, the resulting concrete cap was thicker than required at about 13 in. The repair sequence for Crater 2 is shown in Figure 5.4.

Figure 5.4. Repair sequence for Crater 2 including the crater prepared for backfilling (upper left), the crater with fully cured foam backfill (upper right), and the completed repair (lower left).



5.2.3 Crater 3

Crater 3 had a total depth of approximately 26 in. and required a maximum depth of expanded foam of 16 in. to provide a 10-in. concrete cap. This crater was also lined with a PVC liner since standing water was observed at the bottom of the crater. In this crater, FOAM-iT!® 10 SLOW was applied as backfill in a single pour to a depth of 3 in.

The liners used during this field test were rectangular and were held in place by using sand bags or duct tape. However, while the foam was expanding in Crater 3, the liner started falling in the crater on the west side, causing the

foam mix to migrate underneath the liner and have direct contact with the wet soil on the crater walls and bottom. In this area, the foam expanded unevenly, resulting in an unleveled surface that required cutting. From this it was recommended to use a larger, square liner and nails to hold it in place. The repair sequence for Crater 3 is shown in Figure 5.5.

Figure 5.5. Repair sequence for Crater 3 including the crater prepared for backfilling (upper left), the crater with fully cured foam backfill (upper right), the finished foam surface ready for capping (lower left), and the completed repair (lower right).



5.2.4 Crater 4

The total depth of Crater 4 was approximately 26 in., which required a maximum depth of expanded foam of 16 in. to provide a 10-in. concrete cap. This crater was not lined to observe the behavior of Primal Innovation Med when it had contact with the moisture in the subgrade and on crater walls. The liquid foam was applied in a single pour to a depth of 3 in. The foam expanded unevenly in excess to what was expected, thus requiring cutting to allow a 10-in. concrete cap. The repair sequence for Crater 4 is shown in Figure 5.6.

Figure 5.6. Repair sequence for Crater 4 including the crater prepared for backfilling (upper left), the crater with fully cured foam backfill (upper right), the finished foam surface ready for capping (lower left), and the completed repair (lower right).



5.2.5 Crater 5

The total depth of Crater 5 was approximately 26 in., which required a maximum depth of expanded foam of 16 in. to provide a 10-in. concrete cap. This crater was lined to compare the Primal Innovation Med foam material behavior to that of Crater 4, which was not lined. The liquid foam was applied in a single pour to a depth of 3 in., and, when it expanded, it was completely leveled. However, expansion was lower than expected, producing a layer thickness of only 11.6 in. and causing the concrete cap to be a lot thicker than required. Foam separation was observed before expansion and solidification. This could have been the cause for the reduced expansion. The repair sequence for Crater 5 is shown in Figure 5.7.

Figure 5.7. Repair sequence for Crater 5 including the crater prepared for backfilling (upper left), the crater with fully cured foam backfill (upper right), foam separation and solidification observed (lower left), and the completed repair (lower right).



5.2.6 Crater 6

The repair sequence for Crater 6 is shown in Figure 5.8. As discussed in more detail in section 6.1.2, the HMI prototype could not adequately supply foam for this crater repair. Therefore, limestone was used as a backfill material. The limestone was then capped with rapid set concrete to provide a suitable surface for trafficking. Because the foam did not meet the objectives, no data were collected from this crater.

Figure 5.8. Repair sequence for Crater 6 including the crater prepared for backfilling (upper left), the crater with poorly mixed foam backfill (upper right), the crater with crushed limestone backfill (lower left), and the completed repair (lower right).



5.2.7 Crater 7

Crater 7 had a total depth of approximately 25 in. and required a maximum depth of expanded foam of 15 in. to provide a 10-in. concrete cap. This crater was not lined, and FOAM-iT!® 10 SLOW was applied as backfill in a single pour to a depth of 2 in. When the foam expanded, the surface was uneven on the east side, which required cutting. Shovels were used to remove large pieces of material before using the mechanical scarfer to accelerate the cutting process. However, as discussed before, it was observed that the large and uneven pieces of foam created by the shovels tended to get caught between the blades of the scarfer, making its operation difficult and slower. Also, during the capping, the remaining foam pieces that were greater than 1 in. floated to the top of the wet concrete. These pieces were removed by shovels as they appeared. The finished foam layer had a thickness of 14 in., which allowed for a concrete cap of 11 in. The repair sequence for Crater 7 is shown in Figure 5.9.

Figure 5.9. Repair sequence for Crater 7 including the crater prepared for backfilling (upper left), the crater with fully cured foam backfill (upper right), the finished foam surface ready for capping (lower left), and the completed repair (lower right).



5.2.8 Crater 8

Crater 8 had a total depth of approximately 26 in. and required a maximum depth of expanded foam of 16 in. to provide a 10-in. concrete cap. This crater was not lined, and FOAM-iT!® 10 SLOW was applied as backfill in a single pour to a depth of 2 in. When the foam expanded, an uneven surface was observed on the east side of the crater; therefore, cutting was required. Only shovels were used in this crater. The final foam layer thicknesses varied from 10-17 in. due to the use of shovels for cutting. However, the minimum concrete cap thickness measured was still 10 in. The repair sequence for Crater 8 is shown in Figure 5.10.

Figure 5.10. Repair sequence for Crater 8 including the crater prepared for backfilling (upper left), the crater with fully cured foam backfill (upper right), the finished foam surface ready for capping (lower left), and the completed repair (lower right).



5.2.9 Crater 9

Crater 9 had a total depth of 25.5 in. and required a maximum depth of expanded foam of 15.5 in. in order to provide a 10-in. concrete cap. This crater was not lined, and FOAM-iT!® 10 SLOW was applied as backfill in a single pour to a depth of 2 in. When the foam expanded, a convex surface, or dome, was observed; thus, the mechanical scarfer was used to cut down the foam surface in order to provide a minimum depth of 10 in. for the concrete cap. The final foam layer thickness was approximately 15 in., which provided a 10 in. of concrete cap. The repair sequence for Crater 9 is shown in Figure 5.11.

Figure 5.11. Repair sequence for Crater 9 including the crater prepared for backfilling (upper left), crater with fully cured foam backfill (upper right), finished foam surface ready for capping (lower left), and completed repair (lower right).



5.3 Repair times

The cumulative repair times beginning with an open crater and finishing with a fully cured cap suitable for traffic are shown for each crater in Table 5.2. The amount of time required to complete the repair ranged from 138.5 min to 181.1 min with an average of 157.5 min. The largest range in individual step times was in the surface preparation of the foam backfill, which ranged from no required time to 41 min. On average, the total time for the foam backfill part of the process was 11 min when foam surface preparation (i.e., cutting) was not required. This is within the requirements established in the Interim ADR TTP (AFCEC 2016). When foam surface cutting was required, the average total backfill time increased to 27 min.

Table 5.2. Repair times.

Crater Number	Time (min)						
	Foam Pour	Foam Rise and Set	Surface Prep	Backfill Total	Capping	Cap Cure	Total
1	13.6	6.5	41.0	61.1	16.0	104.0	181.1
2	3.5	7.0	Not Required	10.5	14.0	114.0	138.5
3	4.0	5.4	25.8	35.2	11.2	124.0	170.4
4	3.7	4.8	5.0	13.5	16.7	120.0	150.2
5	3.6	6.6	1.5	11.7	18.9	129.9	160.5
6	Not evaluated						
7	3.3	8.9	12.0	24.2	11.0	115.0	150.2
8	3.1	10.3	4.0	17.4	12.2	121.0	150.6
9	3.3	9.8	10.3	23.4	11.0	127.0	161.4

5.4 Foam temperature observations

5.4.1 Surface temperatures

Surface temperatures were collected by an infrared sensor for each crater throughout the expansion and curing process of the foam. These temperatures were obtained in the center of the craters and at each of their four corners. Graphs of the recorded surface temperatures for each crater are in Appendix C.

Although the craters exhibit different behaviors in terms of surface temperature, certain trends were observed. For the majority of the craters, the maximum surface temperature was achieved 10 min after pouring the sample. These maximum temperatures varied between 161°F and 193°F. Also, the maximum surface temperature of each crater was observed in one of the four corners; no crater provided the maximum surface temperature in its center. However, no temperature deficit was observed for the center of each crater. Crater 6 displays a different temperature trend because of the inadequate feed of the foam to the crater.

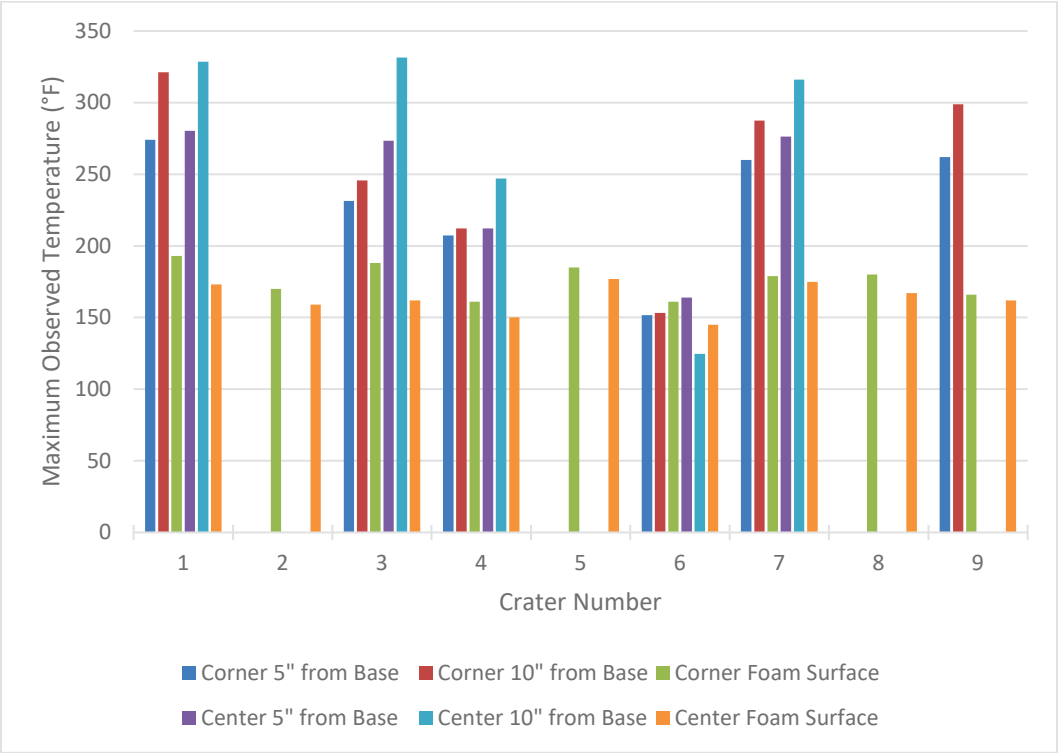
5.4.2 Internal foam temperatures

Foam temperature data were also collected at the center and southeast corner of Craters 1, 3, 4, 6, 7, and 9; corner-temperature data were collected 9 in. from each of the two nearby edges. At each location, temperatures were collected by installing thermocouples 5 in. and 10 in. from the bottom of the crater by attaching them to a piece of rebar that was driven a few inches into

the soil for stability. These temperatures were measured for several days, and the complete data set is shown in Appendix C. Contrary to the surface temperature measurements, the maximum internal temperature for each crater was observed in the center, 10 in. above the base. The minimum internal temperature was observed 5 in. from the base at each crater's southeast corner. The consistent temperature profile shows that the maximum foam temperature is closer to the surface than the base; the target foam height was 15 in. This trend was likely caused by a cooling effect by conduction with the subgrade at the base and sides of the foam sample. This effect was not as significant on the foam surface; however, the surface was cooled via convection with the atmosphere.

The maximum observed temperature at every recorded location for Craters 1-9 is shown in Figure 5.12. For each crater, the maximum temperature was observed within 5 hr of placement. The majority of the locations evaluated showed maximum temperatures within 100 min of the pour. Steady state temperatures of approximately 90°F were achieved 7 days following foam addition.

Figure 5.12. Maximum observed foam temperatures.



5.5 Simulated aircraft traffic

The ultimate repair performance was evaluated under simulated F-15E aircraft traffic to determine the repair response under heavy aircraft loads. Each set of three repairs was trafficked each test day 2 hr after the last concrete cap was placed.

5.5.1 Application of traffic

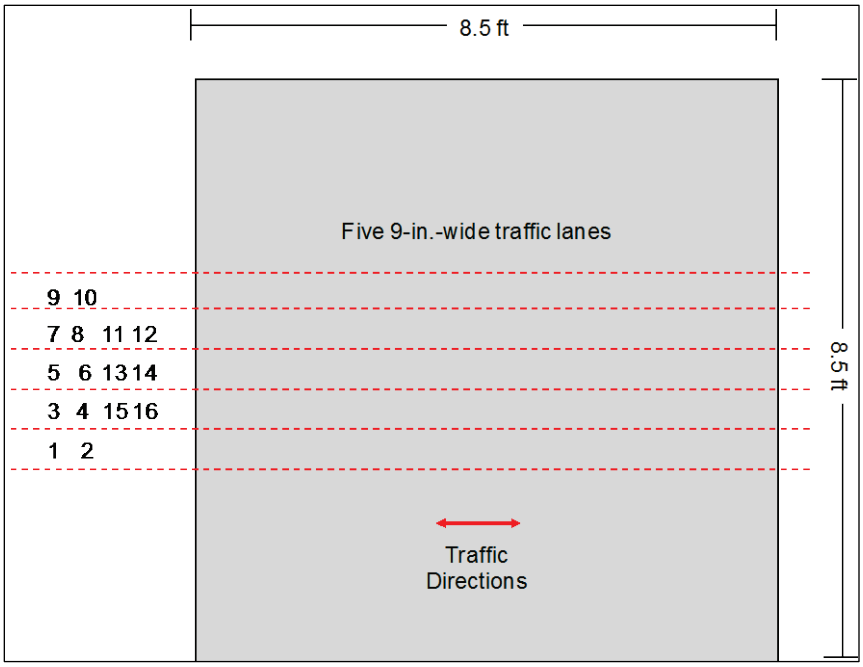
A single-wheel F-15E load cart (Figure 5.13) equipped with a 36-in.-diam, 11-in.-wide, 18-ply tire inflated at 325 psi was used. The gross gear load was approximately 35,235 lb. Normally distributed traffic was applied by driving the load cart forward and then backward in the same wheel path over the length of the repairs and then moving laterally approximately one tire width (9 in.) on each forward pass. This procedure was continued until one pattern of traffic was completed. A total of 16 passes constituted one traffic pattern (Figure 5.14).

Traffic was paused at different pass levels for data collection to assess the deterioration of the repairs as traffic progressed. The first data collection point was after 112 passes. Once all the repairs were completed and received 112 initial passes, the repairs were trafficked simultaneously in groups until failure or until reaching 3,500 passes. Repairs 7 through 9 were trafficked simultaneously first, and then repairs 1 through 5 were trafficked. The RADR threshold performance for expedient repairs under F-15E traffic is 500 passes, and the objective is 3,500 passes.

Figure 5.13. F-15E load cart.



Figure 5.14. Typical F-15E load cart traffic pattern applied to repairs.



5.5.2 Repair failure criteria

Surface deterioration or settling of the backfill was the expected repair failure under heavy traffic. Visual inspections were performed periodically to identify distresses that are associated with potential foreign object damage (FOD) such as cracking, spalling, and shattered slabs. Spalled materials have the potential to be sucked into jet engines or damage propellers and rotors of aircraft. Additionally, spalled concrete and wide cracks present a tire hazard due to the potential of the sharp edges to cut aircraft tires.

Priddy et al. (2016) presents failure criteria used to develop performance curves for conventional USAF cementitious capping materials (rapid-setting concrete). The failure criteria used by Priddy et al. (2016) defined failure as a high-severity shattered slab or spalling greater than 2 ft long, greater than 6 in. wide, and greater than 2 in. deep across 50% of the spall length. In this project, when a spall depth of 2 in. was measured and high FOD potential or tire hazards were identified, the repair was considered failed.

Rod and level surface measurements (Figure 5.15) were collected to document any elevation changes due to settlement or through deterioration of the surface resulting in abrupt elevation changes.

Figure 5.15. Rod and level measurements.



5.5.3 Repair performance under simulated aircraft traffic

Table 5.3 provides a summary of the results from simulated aircraft traffic testing. Eight of nine craters were repaired and trafficked. The thickness of the foam backfill varied from 11.4-15.2 in. between repairs. The thickness of the rapid-set concrete was also variable, ranging from 10.3 to 14.5 in. throughout the repairs. Additionally, other variables between repairs included use of moisture barriers, foam application method, i.e., single pour or layered pour, different foam materials, and the quality of the rapid-setting concrete cap material. These differences did not allow for a direct comparison between repairs, foam products, or prototype foam dispensers based on traffic performance. However, the traffic data show some limited trends that help understand the benefit of some of the features included in the technology. For example, the use of a PVC liner in Crater 3 as a moisture barrier showed a slight improvement in the number of passes to failure as compared to Crater 8, where the repair characteristics were very similar except that a PVC liner was not used. In these craters, the foam material was Foam-iT! 10 Slow, but the same trend was observed between craters that were repaired using the PI Med foam material, i.e., Craters 2 and 4. This shows that preventing the foam material to have direct contact with any moisture in the crater can provide a better quality material and, thus, better support under aircraft traffic.

Table 5.3. Simulated aircraft traffic results.

Crater No.	Foam Product	Moisture Barrier	Avg. Thickness (in.)		Passes to Failure	Failure Mode
			Foam Backfill	Rapid-Set Concrete Cap		
1	Foam-iT! 10 Slow Layered Pour	PVC Liner	15.2	10.4	1504	High-Severity Joint Spall; High FOD Potential
2	PI Med	PVC Liner	11.4	12.7	> 3504	Not failed
3	Foam-iT! 10 Slow	PVC Liner	14.4	11.8	1728	High-Severity Joint Spall; High FOD Potential
4	PI Med	None	13.8	12.4	944	High-Severity Joint Spall; High FOD Potential
5	PI Med	PVC Liner	11.6	14.5	1728	High-Severity Joint Spall; High FOD Potential
6	Not Evaluated					
7	Foam-iT! 10 Slow	None	14.0	11.1	1552	High-Severity Joint Spall; High FOD Potential
8	Foam-iT! 10 Slow	None	13.7	12.0	1440	High-Severity Joint Spall; High FOD Potential
9	Foam-iT! 10 Slow	None	15.2	10.3	1328	High-Severity Joint Spall; High FOD Potential
Meets ADR Threshold of 500 passes				Meets ADR Objective of 3,500 passes		

In general, traffic data showed that overall the foam backfill repair technology meets RADR requirements. All trafficked repairs met the minimum threshold for expedient repair, i.e., 500 passes, and one repair met the objective of 3,500 passes. On average, the repairs were capable of withstanding approximately 1,700 passes of the F-15E load cart without considering all the variables. This agrees with results from previous evaluations using the various repair thicknesses and materials (Priddy et al. 2016).

In terms of failure mode, none of the repairs showed evidence of structural failure, i.e., shattered slab, at the conclusion of trafficking. The mode of failure was typically high-severity spalling at joints perpendicular to the direction of traffic with high FOD potential as shown in Figure 5.16. This mode of failure is typical for this type of crater repair as discussed in Priddy et al. (2016). The reason for this failure mode is the lack of load transfer between the crater repair and the parent slab. The bond strength between the repair material and the parent slab is the limiting factor in determining the durability of the crater repair.

Figure 5.16. Typical failure mode of high-severity joint spall with high FOD potential.



6 Technology Performance Evaluation

The overall performance of the refined foam backfill technology during the full-scale field test conducted at ERDC was evaluated using the following criteria.

1. The prototype foam dispensing equipment should efficiently meet the Air Force's requirements established in Chapter 2.
2. Crater backfill operations using this technology should be completed in less than 30 min per crater.
3. The foam backfill material should be of acceptable quality, i.e., expansion ratio of at least 6 and UCS of 200 psi threshold and 300 psi objective.
4. Repair performance under simulated F-15E aircraft traffic should meet RADR criteria, i.e., 500 passes threshold, 3,500 passes objective.

The final evaluation of this technology will be achieved through a technology demonstration at Silver Flag Exercise Site, Tyndall AFB, FL, where the end user will be conducting multiple crater repairs in a sequence to simulate real-life repair scenarios. Their feedback will be used to further refine this technology.

6.1 Performance of prototype equipment

6.1.1 CRADR1 prototype

A total of eight craters were repaired using the CRADR1 prototype during three test days. In five craters, it dispensed FOAM-iT!® 10 SLOW, and in the remaining three craters, it dispensed Primal Innovation Med foam material.

Overall, the CRADR1 prototype was capable of successfully repairing multiple craters sequentially across multiple operational days with no delays or clogging. Foam component totes were left connected, and materials remained in the delivery hoses from initial operation on 4 August to the end of the technology demonstration on 14 September with no loss of performance. The mixing nozzles were capable of limited reuse if drained immediately following foam dispensing. Generally, the static mixing element could be used 2 to 3 times before foam buildup made the element unusable. The nozzle attachment lasted longer but still would eventually fill up with foam. Given the nature of the foam mixture, any part that comes into contact with both components should be considered disposable after

limited reuse. Additionally, component A crystallizes when left in contact with water or humid air; therefore, any piping or connection pieces that carry component A should be thoroughly flushed or wiped clean with solvent prior to storage. Alternatively, provision could be made to periodically replace the fluid contact pieces. This is possible given the set-up of hose pumps. End-to-end replacement of all the fluid transfer pieces can be accomplished in a few minutes when spare parts are available.

The total foam mixture flow rate for all demonstration craters varied from 20 to 28 gpm. This wide observed range is due to difficulties in measuring exact height of the final fill before the onset of expansion. This demonstrates a foam flow rate meeting the threshold requirement for large crater repairs, although it falls short of the objective flow rate. There was a consistent difference of 2-5% between component flow rates leading to slightly more component A in the foam mix than component B. Large disparities in viscosity between the two components likely causes the flow-rate difference. Applying a slightly differential frequency at the motor controller module will mitigate the flow-rate difference.

Product switch-out, i.e., from Primal Innovation Med to FOAM-iT!® 10 SLOW, was required during the last test day. This event provided a good indication of the time required for switching material totes during repair operations. The process was accomplished at the repair site in about 15 min by using a forklift and prepositioned materials. Primal Innovation Med fluids were removed from the system by feeding foam into trays immediately prior to crater repair. The process is described in Table 6.1.

Table 6.1. Total elapsed time for fluid transfer.

Event	Total Elapsed Time (min:sec)
Truck in position; change start	00:00
Totes Removed	05:00
B tote added to trailer	08:00
B hose connected to tote	08:30
A tote added to trailer	10:48
A hose connected to tote	11:27
Truck moved next to Crater	12:30
Initial feed of foam into trays	13:46
Pour Started	15:02

6.1.2 HMI prototype

The HMI prototype was set up for test filling three sequential craters, i.e., Craters 4, 5, and 6, on 13 September 2016. When the HMI prototype system was started, and polyurethane foam dispensing was begun, both system pumps operated with auditory indications of air motor turnover occurring every few seconds. The polyurethane mixture as dispensed visually appeared to be mostly component A. Dispensing was continued for several minutes to observe whether the component mix would improve with no indications that component B was dispensed at any flow rate. The component A chemical tote was losing volume while the component B tote exhibited no change in volume. The polyurethane mix as dispensed remained dark brown in color when a proper mix would have been creamy tan. Operation of the prototype was ceased before completely filling the crater or moving on to Craters 4 and 5. Craters 4 and 5 were filled using the CRADR1 prototype as described in the previous section.

The dispensing nozzle was not clogged as it had been earlier. It is possible that clogging of the component B hose had reoccurred in the 5-day span of time between unclogging the system and this testing attempt. This could explain the inability to dispense component B. It is also possible that clogging or sticking was occurring in the diaphragm pump for component B. During operations, air pressure feed to the diaphragm pumps was monitored. Regulated feed pressure rose to 100 psi causing the pump air motors to turn over. As the motors began turning, the feed pressure would drop to 60 psi and begin to build again. The air motors would not begin again until line pressure had reached 100 psi.

In summary, two technical issues limited the performance of the HMI prototype. First, clogging at both the nozzle and in the component hoses has not been completely resolved. Material buildup at the nozzle can be mitigated to some extent by flushing with chemical solvent whenever the component flow is shut off. Clogging in the component B hose did not have a definitive cause, so preventing future clogs is uncertain. Second, the pump system appears to be inadequate for the specified foam components. According to the manufacturer's specifications (Yamada 2016), the diaphragm pumps installed on the HMI prototype system are capable of generating a continuous pressure head of 150 ft of water (65 psi) when operating with an air supply of 40 SCFM at 100 psi. Unfortunately, given a component B viscosity of 20,000-30,000 cP, this continuous pressure is only sufficient for a flow rate of approximately 1.4 gpm. Given these two

observations, the HMI prototype system is not capable of meeting the threshold performance requirements set by the Air Force for the foam backfill technology.

6.2 Repair times

Repair times beginning with an open crater and proceeding to a repaired slab suitable for traffic averaged 2 hr 24 min across the nine craters (without considering work stoppages). The largest variance in repair times between craters was observed for the foam surface preparation portion of the repair. This repair step was required for foam backfill that rose higher than specified; thus, excess material was removed to ensure a minimum cap thickness. This repair step represents the largest opportunity for time reduction in the foam crater backfill process.

6.3 Foam material quality

Surveys were conducted of the crater base layer, foam surface after curing and preparation, and concrete cap surface. Average elevations from these surveys were used to calculate an observed expansion ratio for each of the craters (see Table 6.2). Generally, the expansion of the PI Med product was less than that of Foam-IT10. There was an observed inconsistency in the expansion ratios; this is likely due to the removal of some material during surface preparation of the foam backfill layer prior to capping.

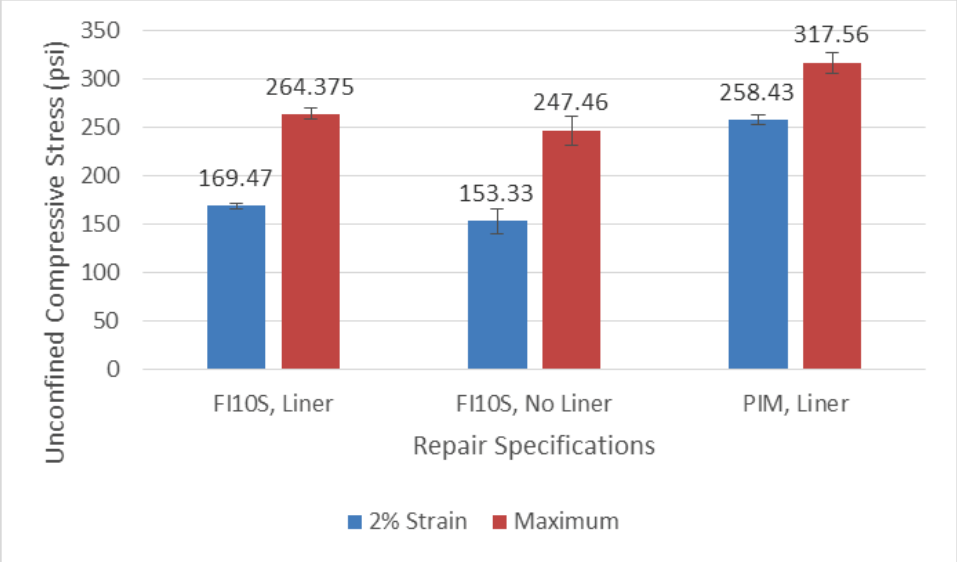
Table 6.2. Foam backfill properties.

Crater	Foam Product	Moisture Barrier	Liquid Foam Applied (in.)	Expanded Foam (in.)	Observed Expansion Ratio
1	Foam-IT! 10 SLOW	PVC Liner	3	15.2	5.1
2	PI Med	PVC Liner	3	11.4	3.8
3	Foam-IT! 10 SLOW	PVC Liner	3	14.4	4.8
4	PI Med	None	3	13.8	4.6
5	PI Med	PVC Liner	3	11.6	3.9
6	Not Evaluated				
7	Foam-IT! 10 SLOW	None	2	11.1	7.0
8	Foam-IT! 10 SLOW	None	2	12.0	6.8
9	Foam-IT! 10 SLOW	None	2	10.3	7.6

Four-in.-diameter core samples were extracted from the expanded foam backfill during the field tests to assess the strength of the dispensed material. From the core samples, 4-in.-tall specimens were cut for unconfined compressive stress (UCS) testing in accordance with ASTM (2004).

The Primal Innovation Med formulation provided significantly higher unconfined compressive stress (UCS) at 2% strain relative to the FOAM-iT!® 10 SLOW, as shown in Figure 6.1. Additionally, use of PVC liners increased the UCS at 2% strain of FOAM-iT!® 10 SLOW foam relative to that poured into a crater with moist soil. These data confirm results observed in previous studies (Priddy et al. 2010 and Gurtowski et al. 2016). These observations are also consistent for maximum UCS. UCS values were lower than those observed in previous laboratory experiments and efforts using CRADR1. Also, foam separation into the separate components was observed for Craters 1-4. The cause of this separation is not known at this time but could have impacted UCS results.

Figure 6.1. UCS of foam formulations with and without PVC liners.



6.4 Repair performance under simulated aircraft traffic

Under simulated F-15E aircraft traffic, all repairs met the 2-hr requirement of 100 passes and the expedient repair requirement of 500 passes. Only one repair met the objective RADR requirement of 3,500 passes. Overall, the repair performance was as expected based on previous research. The average total number of passes of the F-15E load

cart for a 10-in. cap over 16 in. of foam is 1,800 (Priddy et al. 2016). For such a thick concrete layer and without any load transfer mechanism, the durability of the repair is controlled by the bond strength between the repair material and the parent slab. Additional research is recommended to evaluate repairs with thinner concrete caps, i.e., 6 to 8 in., to determine the durability of the foam backfill under traffic.

7 Conclusions and Recommendations

This report focused on the development and evaluation of prototype foam dispensing equipment, foam materials, and repair TTPs for rapid airfield damage repair using foam backfill technology. During this effort, the ERDC evaluated three different prototype foam dispensing systems, foam products from two different vendors, and different repair methods and techniques to improve the TTPs for foam backfill technology.

The main conclusions and recommendations of this research effort are summarized below.

- Of the three prototype foam dispensing systems evaluated, CRADR 1 (pump-driven system) was the only one that successfully delivered foam product during the repair of multiple craters across multiple operational days with no delays or clogging.
- Static mixing elements could be used 2-3 times, if drained immediately following foam dispensing, before foam buildup made the element unusable.
- The hose pump setup allows for quick cleaning or replacement of fluid transfer pieces. This is especially important for component A, which can crystallize when left in contact with water or humid air. It is recommended that any piping or connection pieces that carry component A to be thoroughly flushed or wiped clean with solvent prior to storage.
- Moisture barriers are required when any soil moisture is present. PVC liners performed well during demonstration efforts, although alternative flexible waterproof liners may also function well. Cure-in-place or sprayable moisture barriers were ineffective.
- Mechanical scarfing and cutting with a reciprocating saw were both effective for the removal of excess foam material. Safety and operational preferences will determine future applications of these approaches. This repair step is most likely a source of further time savings for the RADR backfill process.
- The field placed foam expansion ratio and compressive strength were slightly reduced from laboratory observations. The most likely reason for this is the reduction in mixing quality for scaled-up foam delivery compared to laboratory mixers.
- The average repair time was 2 hr and 24 min (without stoppage). With the 2-hr rapid-set cure period, the total repair time is a little over the

objective of 4 hr. These repair times may be reduced when the repair process is conducted in a sequence. More accurate times will be measured during a planned technology demonstration where the repairs will be conducted in a sequence using the full set of repair equipment.

- All repairs met the RADR requirement of 100 passes after 2 hr of repair completion and the expedient repair requirement of 500 passes. Only one repair met the objective RADR requirement of 3,500 passes. Overall repair performance was similar to that recorded during previous traffic tests. Additional experiments are recommended to evaluate foam backfill repairs with thinner concrete caps, i.e., 6 to 8 in., to determine the durability of the foam backfill under traffic. This would help determine the minimum cap thickness required for foam backfill crater repair.

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Appendix A: Safety Data Sheets for Foam Component Materials

SMOOTH-ON

GHS Compliant

Safety Data Sheet

SDS No. 402A

Section 1 - Identification

1.1 Product Identifier: Part A for: EZ-Spray® Plastic; FeatherLite®; FlexFoam-iT® Series; Foam-iT! 3, 4, 5,10, 10 Slow,15 Plasti-Paste® and Plasti-Paste® II; Renew® Flexible Foam 10# and 25#; Renew® Rigid Foam 10#; Shell Shock® Fast and Slow; Simpact® 60A and 85A; Smooth-Cast® 300, 300Q, 305, 310, 320, 321, 322, 385, 45D, 60D, 61D, 65D, 66D, ONYX®; StyroCoat®; Task® 2, 3, 5, 8, 11, 13, 14, 15, 16, 18, 7 FlameOut®; Urethane 444; Urethane 666; and Smooth-Cast® 380 Part B

1.2 General Use: Polyurethane Elastomer

1.3 Manufacturer: Smooth-On, Inc.,
5600 Lower Macungie Rd., Macungie, PA 18062
Phone (610) 252-5800, FAX (610) 252-6200
SDS@Smooth-On.com

1.4 Emergency Contact: Chem-Tel
Domestic: 800-255-3924 International: 813-248-0585

Section 2 - Hazards Identification

2.1 Classification of the substance or mixture

Skin Corrosion/Irritation – Category 2, H315
Eye Damage/Irritation – Category 2B, H320
Acute toxicity, inhalation – Category 4, H332
Respiratory Sensitization – Category 1, H334
Specific target organ toxicity-single exposure – Category 3 (respiratory), H335
Carcinogenicity – Category 2, H351
Specific target organ toxicity-repeat exposure – Category 2 (respiratory), H373

2.2GHS Label elements, including precautionary statements



Pictograms:
Signal Word: Danger

Health Hazards:	H315	Causes skin irritation
	H317	May cause an allergic skin reaction
	H320	Causes eye irritation
	H332	Harmful if inhaled
	H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled
	H335	May cause respiratory irritation
	H351	Suspected of causing cancer.
	H373	May cause damage to organs (olfactory organs) through prolonged or repeated exposure (inhalation).
General Precautions:	P101	If medical advice is needed, have product container or label at hand.
	P102	Keep out of reach of children.
	P103	Read label before use.

Prevention Precautions:	P201	Obtain special instructions before use.
	P202	Do not handle until all safety precautions have been read and understood.
	P260	Do not breathe dust/fume/gas/mist/vapors/spray.
	P264	Wash with soap and water thoroughly after handling.
	P271	Use only outdoors or in a well-ventilated area.
	P272	Contaminated work clothing should not be allowed out of the workplace.
	P280	Wear protective gloves/protective clothing/eye protection/face protection.
	P284	[In case of inadequate ventilation] wear respiratory protection.
Response Precautions:	P303 + P352	IF ON SKIN (or hair): Wash with plenty of soap and water.
	P304 + P340	IF INHALED: Remove person to fresh air and keep comfortable for breathing.
	P305 + P351 + P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
	P308 + P311	IF exposed or concerned: Call a POISON CENTER or doctor/physician.
	P312	Call a POISON CENTER or doctor/physician if you feel unwell.
	P314	Get medical advice/attention if you feel unwell.
	P332 + P313	If skin irritation occurs: Get medical advice/attention.
	P333 + P311	If skin irritation or rash occurs: Call a POISON CENTER or doctor/physician.
	P337 + P311	If eye irritation persists: Call a POISON CENTER or doctor/physician.
	P362 + P364	Take off contaminated clothing and wash it before reuse.
Storage Precautions:	P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
	P405	Store locked up.
Disposal Precautions:	P501	Dispose of contents/container according to local, state and federal laws.

Hazards not otherwise classified (HNOC) or not covered by GHS – none known.

Section 3 - Composition / Information on Ingredients

3.1 Substances

The following ingredients are hazardous according to Regulation 2012 OSHA Hazard Communication Standard: 29 CFR 1910.1200:

CAS	Chemical Name	Concentration
101-68-8	4,4' Methylene bis(phenylisocyanate) (MDI)	15% - 35%
25686-28-6	Benzene, 1,1'-methylenebis[4-isocyanato-], homopolymer	5% - 10%
26447-40-5	Methylenediphenyl diisocyanate	< 1.5%

Section 4 - First Aid Measures

4.1 Description of first aid measures
Inhalation: Remove source(s) of contamination and move victim to fresh air. If breathing has stopped, give artificial respiration, then oxygen if needed. Contact physician immediately.
Eye Contact: Flush eyes with plenty of water. If irritation persists, seek medical attention.
Skin Contact: In case of skin contact, wash thoroughly with soap and water.
Ingestion: Do not induce vomiting unless instructed by a physician. Never give anything by mouth to an unconscious person.
4.2 Most important symptoms and effects, both acute and delayed: None known.
4.3 After first aid, get appropriate in-plant, paramedic, or community medical support.

Section 5 - Fire-Fighting Measures

5.1 Extinguishing Media: Water Fog, Dry Chemical, and Carbon Dioxide Foam
5.2 Special hazards arising from the substance or mixture: None known.
5.3 Advice for firefighters: Use water spray to cool fire-exposed surfaces and to protect personnel. Shut off "fuel" to fire. If a leak or spill has not ignited, use water spray to disperse the vapors. Either allow fire to burn under controlled conditions or extinguish with foam or dry chemical. Try to cover liquid spills with foam. Because fire may produce toxic thermal decomposition products, wear a self-contained breathing apparatus (SCBA) with a full face piece operated in pressure demand or positive-pressure mode.

Section 6 - Accidental Release Measures

6.1 Personal precautions, protective equipment and emergency procedures: Only properly protected personnel should remain in the spill area; dike and contain spill. Stop or reduce discharge if it can be done safely.
6.2 Environmental precautions: No special environmental precautions required.
6.3 Methods and material for containment and cleaning up: absorb or scrape up excess into suitable container for disposal; wash area with dilute ammonia solution
6.4 Reference to other sections: See Section 3 for list of hazardous ingredients; Sections 8 for Exposure Controls; and Section 13 for Disposal.

Section 7 - Handling and Storage

7.1 Precautions for safe handling: Use good general housekeeping procedures. Wash hands after use.
7.2 Conditions for safe storage, including any incompatibilities: Keep container(s) tightly closed and properly labeled. Store in cool, dry, well ventilated place away from heat, direct sunlight, strong oxidizers and any incompatibles. Store in approved containers and protect against physical damage. Keep containers securely sealed when not in use. Indoor storage should meet OSHA standards and appropriate fire codes. Containers that have been opened must be carefully resealed to prevent leakage. Empty containers retain residue and may be dangerous. Avoid water contamination.
7.3 Specific end use(s): These precautions are for room temperature handling. Other uses including elevated temperatures or aerosol/spray applications may require added precautions.

Section 8 - Exposure Controls / Personal Protection

8.1 Control parameters:

4,4' Methylene bis(phenylisocyanate) (MDI)	OSHA PEL	CLV 0.02 ppm 0.2 mg/m3
	ACGIH TLV	TWA value 0.005 ppm

8.2 Exposure controls:

Respiratory Protection: Respiratory protection is not normally required when using this product with adequate ventilation. Should a respirator be needed, follow OSHA respirator regulations 29 CFR 1910.134 and European Standards EN 141, 143 and 371; wear an MSHA/NIOSH or European Standards EN 141, 143 and 371 approved respirators equipped with organic vapor cartridges.

Hand Protection: Wear any liquid-tight gloves such as butyl rubber, neoprene or PVC.

Eye Protection: Safety glasses with side shields per OSHA eye- and face-protection regulations 29 CFR 1910.133 and European Standard EN166. Contact lenses are not eye protective devices. Appropriate eye protection must be worn instead of, or in conjunction with contact lenses.

Other Protective Clothing/Equipment: Additional protective clothing or equipment is not normally required. Provide eye bath and safety shower.

Comments: Never eat, drink, or smoke in work areas. Practice good personal hygiene after using this material, especially before eating, drinking, smoking, using the toilet, or applying cosmetics. Wash thoroughly after handling.

Section 9 - Physical and Chemical Properties

9.1 Information on basic physical and chemical properties:

Appearance : amber liquid
Odor/Threshold: Musty odor
pH: N.A. (non-aqueous)
Melting Point/Freezing Point: 37 °F
Low/High Boiling Point: > 390 °F
Flash Point: >300 °F
Evaporation Rate: Not available
Flammability: f.p. at or above 200 °F
UEL/LEL: Not available

Vapor Pressure: <0.00016 mmHg (68 °F)
Vapor Density (Air=1): >1
Specific Gravity (H_2O=1, at 4 °C): 1.2
Water Solubility: Insoluble
Partition coefficient: Not available
Auto-ignition temperature: Not available
Decomposition temperature: Not available
Viscosity: 30-100 cPs
% Volatile: 0% (v/v), 0% (w/w)

Section 10 - Stability and Reactivity

10.1 Reactivity: No hazardous reactions if stored and handled as prescribed/indicated., No corrosive effect on metal. Not fire propagating.

10.2 Chemical stability: These products are stable at room temperature in closed containers under normal storage and handling conditions.

10.3 Possibility of hazardous reactions: Polymerization may occur. Reacts with water with formation of carbon dioxide. Risk of bursting.

10.4 Conditions to avoid: none known

10.5 Incompatible materials: Water (and moisture), amines, strong acids and bases, alcohols

10.6 Hazardous decomposition products: Thermal oxidative decomposition can produce carbon oxides, nitrogen oxide, hydrogen cyanide, aromatic isocyanates, gases/vapors and traces of incompletely burned carbon compounds.

Section 11- Toxicological Information

11.1 Information on toxicological effects: Information extrapolated based on individual component data. Assessment of irritating effects: irritating to eyes, respiratory system and skin. Skin contact may result in dermatitis, either irritative or allergic.

Skin Corrosion/Irritation: Draize test (rabbit): irritating (based on MDI)

Serious Eye Damage/Irritation: Draize test (rabbit): irritating (based on MDI)

Respiratory/Skin Sensitization:

Buehler test (guinea pig): sensitizing
Mouse Local Lymph Node Assay (LLNA): sensitizing, can cause skin sensitization.

Studies in animals suggest that dermal exposure may lead to pulmonary sensitization. However, the relevance of this result for humans is unclear.
Germ Cell Mutagenicity: no data
Carcinogenicity: A carcinogenic potential cannot be excluded after prolonged exposure to severely irritating concentrations. These effects are not relevant to humans at occupational levels of exposure. OECD Guideline 453 rat inhalation 0, 0.2, 1, 6 mg/m3 result: lung tumors.
Reproductive Toxicity: Repeated inhalation uptake of the substance did not cause damage to the reproductive organs. Assessment of teratogenicity showed that the substance did not cause malformations in animal studies, however toxicity to development was observed at high doses that were toxic to the parental animals.

Development:
OECD Guideline 414 rat inhalation 0, 1, 4, 12 mg/m3
NOAEL Mat: 4 mg/m3
NOAEL Teratogenic: 4 mg/m3

Specific Target Organ Toxicity – Single Exposure: causes temporary irritation of the respiratory tract
Specific Target Organ Toxicity – Repeated Exposure: no data
Aspiration Hazard: no data
Acute Toxicity: calculated based on MDI
LD50 oral (rat): > 6,250 mg/kg
LC50 inhalation (rat): >6.25 mg/l (OECD Guideline 403)
LD50 dermal (rabbit): > 29,400 mg/kg
Chronic Exposure: NOAEL: 0.6 mg/m3; LOAEL: 3.1 mg/m3 (based on MDI)
Potential Health Effects – Miscellaneous: no data

Section 12 - Ecological Information

12.1 Toxicity:
LC0 (96 h): > 1,000 mg/l, *Brachydanio rerio* (OECD Guideline 203, static)
EC50 (24 h): > 1,000 mg/l, *Daphnia magna* (OECD Guideline 202, part 1, static)
EC0 (72 h): 1,640 mg/l (growth rate), *Scenedesmus subspicatus*, (OECD Guideline 201, static
12.2 Persistence and Degradability: Poorly biodegradable (0% BOD OECD Guideline 302 C). This product is unstable in water. The elimination data also refer to products of hydrolysis.
12.3 Bioaccumulative Potential: Significant accumulation in organisms is not to be expected. Bioconcentration factor 200 (28 d) *Cyprinus carpio* (OECD Guideline 305 E)
12.4 Mobility in Soil: Adsorption to solid soil phase is not expected.
12.5 Results of PBT and vPvB assessment: no data
12.6 Other Adverse Effects: The substance will not evaporate into the atmosphere from the water surface.

Section 13 - Disposal Considerations

13.1 Waste treatment methods: Under RCRA it is the responsibility of the user of the product to determine at the time of disposal whether the product meets RCRA criteria for hazardous waste. Waste management should be in full compliance with federal, state and local laws.
Empty containers retain product residue which may exhibit hazards of material, therefore to not pressurize, cut, glaze, weld or use for any other purposes. Return drums to reclamation centers for proper cleaning and reuse.

Section 14 - Transport Information

Not classified by DOT, IATA or IMDG
14.1 UN number: none
14.2 UN proper shipping name: none
14.3 Transport hazard class(es): not applicable
14.4 Packing group: not applicable
14.5 Environmental hazards: none known
14.6 Special precautions for user: none known
14.7 Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code: not applicable

Section 15 - Regulatory Information

15.1 Safety health and environmental regulations/legislation specific for the substance or mixture:
In the United States (EPA Regulations):

TSCA Inventory Status (40 CFR710): All components of this formulation are listed in the TSCA Inventory.

SARA 302 Components: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.
SARA 311/312 Hazard(s): Acute, Chronic
SARA 313 Components:

CAS	Chemical Name	Concentration
101-68-8	4,4' Methylene bis(phenylisocyanate) (MDI)	15% - 35%

California Proposition 65**:** This product does not contain any chemicals known to the state of California to cause cancer, birth defects, or other reproductive harm.

15.2 Chemical safety assessment: No chemical safety assessment has been carried out for this substance/mixture by the supplier.

16 - Other Information

HMIS	
H	2
F	1
R	1



NFPA

SDS Version: 6
Date Prepared: November 24, 2015

Glossary: ACGIH-American Conference of Governmental Industrial Hygienists; ANSI-American National Standards Institute; Canadian TDG-Canadian Transportation of Dangerous Goods; CAS-Chemical Abstract Service; Chemtrec-Chemical Transportation Emergency Center (US); CHIP-Chemical Hazard Information and Packaging; CLV-Ceiling Limit Value; DSL-Domestic Substances List; EC-Equivalent Concentration; EH40 (UK)-HSE Guidance Note EH40 Occupational Exposure Limits; EPCRA-Emergency Planning and Community Right-To-Know Act; ESL-Effects screening levels; GHS-Globally Harmonized System of Classification and Labelling of Chemicals; HMIS-Hazardous Material Information Service; IATA-International Air Transport Association; IMDG-International Maritime Dangerous Goods Code; LC-Lethal Concentration; LD-Lethal Dose; LEL-Lower Explosion Level; NFPA-National Fire Protection Association; OEL-Occupational Exposure Limit; OSHA-Occupational Safety and Health Administration, US Dept. of Labor; PEL-Permissible Exposure Limit; SARA (Title III)-Superfund Amendments and Reauthorization Act; SARA 313-Superfund Amendments and Reauthorization Act, Section 313; SCBA-Self-Contained Breathing Apparatus; STEL-Short Term Exposure Limit; TCEQ-Texas Commission on Environmental Quality; TLV-Threshold Limit Value; TSCA-Toxic Substances Control Act Public Law 94-469; TWA-Time Weighted Value; UEL-Upper Explosion Level; US DOT-US Department of Transportation; WHMIS-Workplace Hazardous Materials Information System.

Disclaimer: The information contained in this Safety Data Sheet (SDS) is considered accurate as of the version date. However, no warranty is expressed or implied regarding the accuracy of the data. Since the use of this product is not within the control of Smooth-On Inc., it is the user's obligation to determine the suitability of the product for its intended application and assumes all risk and liability for its safe use.

This SDS is prepared to comply with the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) as prescribed by the United States (US) Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200), the Canadian Workplace Hazardous Materials Information System (WHMIS), and European Union Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 (REACH).

Classifications of the chemical in accordance with 29 CFR 1910.1200, signal word, hazard and precautionary statement(s), symbol(s) and other information are based on listed concentration of each hazardous ingredient. Unlisted ingredients are not "hazardous" per the OSHA Hazard Communication Standard (29 CFR 1910.1200), WHMIS and EC No 1907/2006 and are considered trade secrets under US Federal Law (29 CFR and 40 CFR), Canadian Law (Health Canada Legislation), and European Union Directives.

GHS Compliant

Safety Data Sheet

SDS No. 402B

Section 1 - Identification

1.1 Product Identity: Part B for: Clear Flex® 30; FeatherLite®; FlexFoam-iT® Series; Foam-iT! 3, 10 and 10 Slow, 15, 26; Renew® Flexible Foam 10# and 25#; Renew® Rigid Foam 10#; Simpact® 60A and 85A; StyroCoat®; SMASH! Plastic®; Smooth-Cast® 300, 300Q, 320, 325, 45D, 60D, 61D, 65D, 66D, ONYX® Fast and Slow; Task® 2, 3, 7 FlameOut®, 8, 11, 15, 21; URE-BOND® II; Urethane 444; Urethane 666; and Part A for Smooth-Cast® 380

1.2 General Use: Polyurethane Elastomer

1.3 Manufacturer: Smooth-On, Inc.,
5600 Lower Macungie Rd., Macungie, PA 18062
Phone (610) 252-5800, FAX (610) 252-6200
SDS@Smooth-On.com

1.4 Emergency Contact: Chem-Tel
Domestic: 800-255-3924 International: 813-248-0585

Section 2 - Hazards Identification

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture according to United States Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200), the Canadian Workplace Hazardous Materials Information System (WHMIS) and Council Directive 1999/45/EC and its subsequent amendments.

2.2 GHS Label elements, including precautionary statements

Hazard Pictogram(s): none

Signal word: none

General Precautions

P101: If medical advice is needed, have product container or label at hand.
P102: Keep out of reach of children.
P103: Read label before use.

Hazards not otherwise classified (HNOC) or not covered by GHS - none

Section 3 - Composition / Information on Ingredients

3.1 Substances

No ingredients are hazardous according to 2012 OSHA Regulation 29 CFR 1910.1200 criteria.

Section 4 - First Aid Measures

4.1 Description of first aid measures

Inhalation: Remove source(s) of contamination and move victim to fresh air. If breathing has stopped, give artificial respiration, then oxygen if needed. Contact physician immediately.

Eye Contact: Flush eyes with plenty of water. If irritation persists, seek medical attention.

Skin Contact: In case of skin contact, wash thoroughly with soap and water.

Ingestion: Do not induce vomiting unless instructed by a physician. Never give anything by mouth to an unconscious person.

4.2 Most important symptoms and effects, both acute and delayed: none known.

4.3 After first aid, get appropriate in-plant, paramedic, or community medical support.

Section 5 - Fire-Fighting Measures

5.1 Extinguishing Media: Water Fog, Dry Chemical, and Carbon Dioxide Foam
5.2 Special hazards arising from the substance or mixture: None known.
5.3 Advice for firefighters: Use water spray to cool fire-exposed surfaces and to protect personnel. Shut off "fuel" to fire. If a leak or spill has not ignited, use water spray to disperse the vapors. Either allow fire to burn under controlled conditions or extinguish with foam or dry chemical. Try to cover liquid spills with foam. Because fire may produce toxic thermal decomposition products, wear a self-contained breathing apparatus (SCBA) with a full face piece operated in pressure demand or positive-pressure mode.

Section 6 - Accidental Release Measures

6.1 Personal precautions, protective equipment and emergency procedures: Only properly protected personnel should remain in the spill area; dike and contain spill. Stop or reduce discharge if it can be done safely.
6.2 Environmental precautions: No special environmental precautions required.
6.3 Methods and material for containment and cleaning up: absorb or scrape up excess into suitable container for disposal; wash area with dilute ammonia solution
6.4 Reference to other sections: See Section 3 for Hazardous Ingredients; Section 8 for Exposure Controls; and Section 13 for Disposal.

Section 7 - Handling and Storage

7.1 Precautions for safe handling: Use good general housekeeping procedures. Wash hands after use.
7.2 Conditions for safe storage, including any incompatibilities: Keep container(s) tightly closed and properly labeled. Store in cool, dry, well ventilated place away from heat, direct sunlight, strong oxidizers and any incompatibles. Store in approved containers and protect against physical damage. Keep containers securely sealed when not in use. Indoor storage should meet OSHA standards and appropriate fire codes. Containers that have been opened must be carefully resealed to prevent leakage. Empty containers retain residue and may be dangerous. Avoid water contamination.
7.3 Specific end use(s): These precautions are for room temperature handling. Other uses including elevated temperatures or aerosol/spray applications may require added precautions.

Section 8 - Exposure Controls / Personal Protection

8.1 Control parameters: none defined
8.2 Exposure controls:
Respiratory Protection: Use of this product does not require the use of a respirator. Should other occupational exposure factors warrant a respirator, follow OSHA respirator regulations 29 CFR 1910.134 and European Standards EN 141, 143 and 371; wear an MSHA/NIOSH or European Standards EN 141, 143 and 371 approved respirators equipped with appropriate cartridges.
Hand Protection: Wear any liquid-tight gloves such as butyl rubber, neoprene or PVC.
Eye Protection: Safety glasses with side shields per OSHA eye- and face-protection regulations 29 CFR 1910.133 and European Standard EN166. Contact lenses are not eye protective devices. Appropriate eye protection must be worn instead of, or in conjunction with contact lenses.
Other Protective Clothing/Equipment: Additional protective clothing or equipment is not normally required. Provide eye bath and safety shower.
Comments: Never eat, drink, or smoke in work areas. Practice good personal hygiene after using this material, especially before eating, drinking, smoking, using the toilet, or applying cosmetics. Wash thoroughly after handling.

Section 9 - Physical and Chemical Properties

9.1 Information on basic physical and chemical properties:

Appearance : translucent viscous liquid
Odor/Threshold: Mild to sweet odor
pH: N.A. (non-aqueous)
Melting Point/Freezing Point: N.A.
Low/High Boiling Point: N.A.
Flash Point: >300 °F
Evaporation Rate: Not available
Flammability: f.p. at or above 200 °F
UEL/LEL: Not available

Vapor Pressure: None (Polymeric Resin)
Vapor Density (Air=1): >1
Specific Gravity (H_2O=1, at 4 °C): 1.07
Water Solubility: Insoluble
Partition coefficient: Not available
Auto-ignition temperature: Not available
Decomposition temperature: Not available
Viscosity: 20,000 – 30,000 centipoise
% Volatile: Nil

Section 10 - Stability and Reactivity

10.1 Reactivity: No hazardous reactions if stored and handled as prescribed/indicated., No corrosive effect on metal. Not fire propagating.
10.2 Chemical stability: These products are stable at room temperature in closed containers under normal storage and handling conditions.
10.3 Possibility of hazardous reactions: Hazardous polymerization cannot occur.
10.4 Conditions to avoid: none known
10.5 Incompatible materials: strong bases and acids
10.6 Hazardous decomposition products: Thermal oxidative decomposition can produce carbon oxides, gasses/vapors, and traces of incompletely burned carbon compounds.

Section 11- Toxicological Information

11.1 Information on toxicological effects:
Skin Corrosion/Irritation: no data
Serious Eye Damage/Irritation: no data
Respiratory/Skin Sensitization: no data
Germ Cell Mutagenicity: no data
Carcinogenicity: No component of this product at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by IARC, NTP, or OSHA.
Reproductive Toxicity: no data
Specific Target Organ Toxicity – Single Exposure: no data
Specific Target Organ Toxicity – Repeated Exposure: no data
Aspiration Hazard: no data
Acute Toxicity: (calculated)
Chronic Exposure: no data
Potential Health Effects – Miscellaneous: no data

Section 12 - Ecological Information

12.1 Toxicity: no data
12.2 Persistence and Degradability: no data
12.3 Bioaccumulative Potential: no data
12.4 Mobility in Soil: no data
12.5 Results of PBT and vPvB assessment: no data
12.6 Other Adverse Effects: no data

Section 13 - Disposal Considerations

13.1 Waste treatment methods: Under RCRA it is the responsibility of the user of the product to determine at the time of disposal whether the product meets RCRA criteria for hazardous waste. Waste management should be in full compliance with federal, state and local laws.
Empty containers retain product residue which may exhibit hazards of material, therefore to not pressurize, cut, glaze, weld or use for any other purposes. Return drums to reclamation centers for proper cleaning and reuse.

Section 14 - Transport Information

Not regulated by DOT, IATA or IMDG
14.1 UN number: none
14.2 UN proper shipping name: none
14.3 Transport hazard class(es): not applicable
14.4 Packing group: not applicable
14.5 Environmental hazards: none known
14.6 Special precautions for user: none known
14.7 Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code: not applicable

Section 15 - Regulatory Information

15.1 Safety health and environmental regulations/legislation specific for the substance or mixture:
In the United States (EPA Regulations):
TSCA Inventory Status (40 CFR710): All components of this formulation are listed in the TSCA Inventory.

SARA 302 Components: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.
SARA 313 Components: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 313.
SARA 311/312 Hazards: none

California Proposition 65**:** This product does not intentionally contain any chemicals known to the state of California to cause cancer, birth defects or other reproductive harm.

15.2 Chemical safety assessment: No chemical safety assessment has been carried out for this substance/mixture by the supplier.

16 - Other Information

HMIS	
H	1
F	0
R	0



NFPA

SDS Version: 4
Date Prepared: November 24, 2015

Glossary: ACGIH-American Conference of Governmental Industrial Hygienists; ANSI-American National Standards Institute; Canadian TDG-Canadian Transportation of Dangerous Goods; CAS-Chemical Abstract Service; Chemtrec-Chemical Transportation Emergency Center (US); CHIP-Chemical Hazard Information and Packaging; DSL-Domestic Substances List; EC-Equivalent Concentration; EH40 (UK)-HSE Guidance Note EH40 Occupational Exposure Limits; EPCRA-Emergency Planning and Community Right-To-Know Act; ESL-Effects screening levels; GHS-Globally Harmonized System of Classification and Labelling of Chemicals; HMIS-Hazardous Material Information Service; IATA-International Air Transport Association; IMDG-International Maritime Dangerous Goods Code; LC-Lethal Concentration; LD-Lethal Dose; LEL-Lower Explosion Level; NFPA-National Fire Protection Association; OEL-Occupational Exposure Limit; OSHA-Occupational Safety and Health Administration, US Dept. of Labor; PEL-Permissible Exposure Limit; SARA (Title III)-Superfund Amendments and Reauthorization Act; SARA 313-Superfund Amendments and Reauthorization Act, Section 313; SCBA-Self-Contained Breathing Apparatus; STEL-Short Term Exposure Limit; TCEQ-Texas Commission on Environmental Quality; TLV-Threshold Limit Value; TSCA-Toxic Substances Control Act Public Law 94-469; TWA-Time Weighted Value; UEL-Upper Explosion Level; US DOT-US Department of Transportation; WHMIS-Workplace Hazardous Materials Information System.

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Classifications of the chemical in accordance with 29 CFR 1910.1200, signal word, hazard and precautionary statement(s), symbol(s) and other information are based on listed concentration of each hazardous ingredient. Unlisted ingredients are not "hazardous" per the OSHA Hazard Communication Standard (29 CFR 1910.1200), WHMIS and EC No 1907/2006 and are considered trade secrets under US Federal Law (29 CFR and 40 CFR), Canadian Law (Health Canada Legislation), and European Union Directives.

Primal Innovation

Revised July 2011

SAFETY DATA SHEET

1 – IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

Identification of the substance:
Name: FILLER - Iso A-side

Company/undertaking identification:
Registered company name: Orange Box Power
Address: 101 Gordon Steet, Sanford, FL 32771
Telephone: 1-407-323-9500

Emergency telephone: +1 (800) 424-9300
Association/Organization: CHEMTREC

Use of substance/preparation:
Rigid Urethane Pour Foam.

2 – HAZARDS IDENTIFICATION

EFFECTS OF ACUTE EXPOSURE: Harmful by inhalation. In eyes it will cause irritation and may result in mild cornea opacity. May cause skin irritation. Ingestion may cause adverse health effects.

EFFECTS OF CHRONIC EXPOSURE: The isocyanate component is a respiratory sensitizer. It may cause allergic respiratory reaction. Medical supervision of all employees who handle or come in contact with isocyanates is recommended. This should include pre employment and periodic medical examinations with respiratory function tests. Persons with asthmatic conditions or other chronic respiratory diseases or recurrent eczema or sensitization should be excluded from working with isocyanates. Once a person has been diagnosed as having been sensitized to an isocyanate, no further exposure should be permitted.

R-phrases: R20: Harmful by inhalation. R36/37/38: Irritating to eyes, respiratory system and skin.
R42/43: May cause sensitization by inhalation and skin contact.

3 – COMPOSITION/INFORMATION OF INGREDIENTS

Name	EC No.	CAS-No.	Content	Classification
4,4'-Diphenylmethane-Diisocyanate	202-966-0	101-68-8	40-50 %	Xn, R20-36/37/38-42/43
MDI, isomers and homologues		9016-87-9	40-50%	Xn, R20-36/37/38-42/43

The Full Text for all R-phrases are Displayed in Section 16

4 – FIRST-AID MEASURES

General rules, in case of doubt or if symptoms persist, always call a doctor.

Inhalation: Remove victim immediately from source of exposure. Move the exposed person to fresh air at once. If systems persist, obtain medical advice.

Ingestion: Do NOT induce vomiting. Rinse out mouth and give plenty of water to drink. Summon a doctor immediately.

Skin contact: Wash with soap and water. Get medical attention if symptoms such as skin irritation or dermatitis persist.

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Eye contact: Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes and seek medical advice.

Advice to doctor: Treat symptomatically.

5 – FIRE-FIGHTING MEASURES

Extinguishing Media: Dry chemical, carbon dioxide, foam or water spray jet. Do not use full water jet.

Products of Combustion: Oxides of nitrogen and carbon (CO, CO_2, NO, NO_2). Hydrocarbons and HCN.

Special Protective Equipment for Firefighters: Do not inhale explosion and/or combustion gases. Use self-contained breathing apparatus.

6 – ACCIDENTAL RELEASE MEASURES

Personal Precautions: Avoid skin and eye contact. Wear personal protective equipment. Avoid breathing vapor and keep upwind where necessary. Ensure adequate ventilation. Remove contaminated clothes as soon as possible. Clean-up should only be performed by trained personnel. People dealing with major spillages should wear full protective clothing including respiratory protection. Use suitable protective equipment (section 8).

Environmental: Prevent spills from entering and spreading to drains, sewers, water courses, and soil.

Spill Clean Up Methods: Extinguish all ignition sources. Absorb leaking product with sand, earth or other suitable inert material and collect. Disposal according to section 13.

7 – HANDLING AND STORAGE

Usage Precautions: Avoid spilling, skin and eye contact. Provide good ventilation. Persons susceptible for allergic reactions should not handle this product. Use appropriate personal protective equipment (section 8). Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed.

Storage Precautions: Store in tightly closed original container in a dry, cool/ambient temperature and well-ventilated place. Keep away from moisture. Due to reaction with water producing CO2-gas, a hazardous build-up of pressure could result if contaminated containers are re-sealed. Do not reseal contaminated containers.

8 – EXPOSURE CONTROLS/PERSONAL PROTECTION

Control Parameters: Ensure adequate ventilation on workstation. Medical supervision of all employees who handle or come in contact with respiratory sensitizers is recommended. Persons with respiratory problems including asthmatic-type conditions, chronic bronchitis, other chronic respiratory diseases or recurrent skin eczema or skin allergies should be evaluated for their suitability of working with this product. Once a person is diagnosed as sensitized, no further exposure to the material that caused the sensitization should be permitted.

Chemical Name: 4,4'-Diphenylmethane-Diisocyanate (CAS # 101-68-8/EC # 202-966-0)

Exposure Values: ACGIH TLV: 0.005 ppm (8 hours)-TWA (2008).
PEL: CEIL: 0.02 mg/m^3 LTEL (Long-term exposure limit) (2006).

Engineering Measures: Use local and general exhaust ventilation to maintain airborne concentrations below TLV. Suitable respiratory equipment should be used in cases of insufficient ventilation or where

operational procedures demand it.

Personal Protective Equipment:

Respiratory Equipment: If the product is heated or sprayed under manual handling, use suitable mask with filter A1P2 or A2P2 or an approved air purifying respirator equipped with organic vapor cartridges and a HEPA (P100) particulate filter may be used under conditions when a cartridge change-out schedule has been developed.

Skin and Hands Protection: Wear suitable gloves: neoprene, nitrile or acrylonitrilebutadiene rubber or PVC. Wear full chemical suit when manually spraying this material. Change suit or clean gloves if contaminated.

Eye Protection: Wear chemical safety goggles / full face shield if there is a potential for splashing.

Hygiene Measures: DO NOT SMOKE IN WORK AREA! Wash hands and any other area that may have been exposed at the end of each work shift and before eating, smoking and using the toilet. Wash promptly if skin becomes wet or contaminated. Promptly remove any clothing that becomes contaminated. When using do not eat, drink or smoke.

9 – PHYSICAL AND CHEMICAL PROPERTIES

Appearance: Liquid

Odour: Slightly Musty

Colour: Amber

Flash Point: >200 deg C.

Solubility in Water: Immiscible. Reacts with water, sometimes violently if uncontrolled.

Relative Density: 1.23

VOC Content: 0%

10 – STABILITY AND REACTIVITY

Stability and Reactivity: Stable under normal temperature conditions. Reaction with water (moisture) produces CO2 gas. Exothermic reaction with materials containing active hydrogen groups. The reaction becomes progressively more vigorous and can be violent at higher temperatures if the miscibility of the reaction partners is good or is supported by stirring or by the presence of solvents. MDI is insoluble with,and heavier than water and sinks to the bottom but reacts slowly at the interface. A solid water-insoluble layer of polyurea is formed at the interface by liberating CO2 gas.

Conditions to Avoid: Avoid high temperatures.

Incompatibility: water, alcohols, amines, bases and acids.

Hazardous Polymerization: Polymerization may occur at elevated temperatures in the presence of alkalies, tertiary amines and metal compounds.

Hazardous Decomposition Products: Oxides of nitrogen and carbon (CO, CO_2, NO, NO_2). Hydrocarbons and HCN.

11 – TOXICOLOGICAL INFORMATION

FILLER– SIDE A ISO

Acute Toxicity data for 4,4'-Diphenylmethane-Diisocyanate (CAS # 101-68-8/EC # 202-966-0)

Test	Species	Result	Exposure
LD 50 Dermal	Rabbit	>5000 mg/kg	-
LC 50 Oral	Rat	>5000 mg/kg	-
LC 50 Inhalation	Rat	0.49 mg/L	4 hours

Potential Acute Health Effects:
Inhalation: Toxic by inhalation. May cause sensitization by inhalation.

Skin Contact: Irritating to skin. May cause sensitization by skin contact.

Ingestion: Low oral toxicity. Ingestion may cause irritation of the gastrointestinal tract.

Eye Contact: Irritating to eyes.

Potential Chronic Health Effects
Target Organs: Contains material which may cause damage to lungs, skin and upper respiratory tract.

Carcinogenicity: Rats have been exposed for two years to a respirable aerosol of polymeric MDI which resulted in chronic pulmonary irritation at high concentrations. Only at the top level (6 mg/m3), there was a significant incidence of a benign tumor of the lung (adenoma) and one malignant tumor (adenocarcinoma). There were no lung tumors at 1 mg/m3 and no effects at 0.2 mg/m3. Overall, the tumor incidence, both benign and malignant, and the number of animals with the tumors were not different from controls. The increased incidence of lung tumors is associated with prolonged respiratory irritation and the concurrent accumulation of yellow material in the lung, which occurred throughout the study. In the absence of prolonged exposure to high concentrations leading to chronic irritation and lung damage, it is highly unlikely that tumor formation will occur.

Mutagenicity and Teratogenicity: There is no substantial evidence of mutagenic potential and no birth defects were seen in two independent animal (rat) studies. Fetotoxicity was not observed at doses that were not maternally toxic. The doses used in these studies were maximal , respirable concentrations, which are well in excess of defined occupational exposure limits.

Fertility and Developmental Effects: No known significant effects or critical hazards.

12 – ECOLOGICAL INFORMATION

Aquatic Ecotoxicity:

Ingredient	Species	Result	Exposure
4,4'-Diphenylmethane-Diisocyanate	Daphnia	Acute EC50 >1000 mg/L	48 hours
4,4'-Diphenylmethane-Diisocyanate	Fish	Acute LC50 >1000 mg/L	96 hours

Mobility: Considering the use of the substance, it is unlikely that significant environmental exposure in the air or water will arise. Immiscible with water, but will react with water to produce inert and non-biodegradable solids. In air, the predominant degradation process is predicted to be a relatively rapid OH radical attack, by calculation and by analogy with related diisocyanates.

Environmental Effects: The measured ecotoxicity is that of the hydrolyzed product, generally under conditions maximizing production of soluble species. Even so, the observed ecotoxicity is low/very low. A pond study shoed gross contamination caused no significant toxic effects on a wide variety of flora in all trophic levels (including fish), no detectable diaminodiphenylmethane (MDA), and no evidence of bioaccumulation of MDI or MDA.

FILLER– SIDE A ISO

13 – DISPOSAL CONSIDERATIONS

Dispose of waste material at an approved waste treatment facility in accordance with applicable local and provincial regulations and requirements. Do not dispose of waste with normal garbage, or to sewer systems. Empty containers should be decontaminated and either passed to an approved drum recycler or destroyed. Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

14 – TRANSPORT INFORMATION

General: The product is not classified as hazardous goods for land, sea and air transport according to the respective regulations (ADR, IMDG, IATA-DGR).

DOT Classification: UN #: NA3082, Proper Shipping Name: OTHER REGULATED SUBSTANCES, LIQUID, N.O.S. (Methyl Diphenyl Diisocyanate), Class: 9, Packing Group: III, Reportable Quantity: 5000 lbs (2270 kg)...single containers less than 5000 lbs are not regulated.

15 – REGULATORY INFORMATION

Listed in TSCA (Toxic Substances Control Act) and EINECS.

United States
HCS Classification: Toxic material
Irritant
Sensitizer

CERCLA: Hazardous Substances:

Components	Concentration	Section 304 CERCLA Hazardous Substances	CERCLA Reportable Qty	Product Reportable Qty
4, 4'-MDI	15	Listed	5000 lbs	33,333 lbs
Chlorobenzene	0.00109	Listed	100 lbs	9,101,253 lbs

Release of more than any reportable quantity to the environment in a 24 hour period requires notification to the National Response Center (800) 424-8802 or (202) 426-2675.

SARA 313: Form R-Reporting Requirements: Diisocyanate compound (category code N120), Concentration: 78%.

California Prop 65: This product contains no listed substances known to the State of California to cause cancer, birth defects or other reproductive harm, at levels which would require a warning under the statute.

FILLER– SIDE A ISO

16 – OTHER INFORMATION

General Information: This product should be used as directed by Sanco, Inc. For further information consult the product data sheet or contact Technical Services.

Information Sources: This safety data sheet was compiled using current safety information supplied by distributor of raw materials.

Revision Comments: This SDS supersedes all previous issues and users are cautioned to ensure that it's current. Destroy all previous data sheets and if in doubt contact Sanco, Inc.

Issued By: MS

Revision Date: July 2011

Risk Phrases in Full REACH (EU):	**R20**	Harmful by inhalation.
	R42/43	May cause sensitization by inhalation and skin contact.
	R36/37/38	Irritating to the eyes, respiratory system and skin.

Hazardous Material Information System (USA):

Health	2
Flammability	1
Reactivity	1

Rimal Innovation

Revised July 2011

SAFETY DATA SHEET

1 – IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

Identification of the substance:
Name: FILLER - Poly B-side

Company/undertaking identification:
Registered company name: Orange Box Power
Address: 101 Gordon Street, Sanford, FL 32771
Telephone: 1-407-323-9500

Emergency telephone: +1 (800) 424-9300
Association/Organization: CHEMTREC

Use of substance/preparation:
Rigid Urethane Pour Foam.

2 – HAZARDS IDENTIFICATION

The ingredients in this material are classified as Non-hazardous under OSHA Hazard Communication Standard (29 CFR 1910.1200).

Potential Acute Health Effects
Eyes: Slight hazard in case of eye contact (May cause irritation).
Skin: Slight hazard in case of skim contact (May cause irritation).
Inhalation: Slightly hazardous in case of inhalation.
Ingestion: Slightly hazardous in case of ingestion.

General Information: Read the entire MSDS for a more thorough evaluation of the hazards.

3 – COMPOSITION/INFORMATION OF INGREDIENTS

Name	CAS-No.	Content
Polyether Polyol	Proprietary	>50 %

4 – FIRST-AID MEASURES

General rules, in case of doubt or if symptoms persist, always call a doctor.

Inhalation: If inhaled, remove to fresh air. If breathing is irregular or stopped, administer artificial respiration. If breathing is difficult, give oxygen. If systems persist, obtain medical advice.

Ingestion: Do NOT induce vomiting without medical advice. Clean mouth with water and drink afterwards plenty of water. Never give anything by mouth to an unconscious person. Get medical attention is symptoms appear.

Skin contact: Wash with soap and water. Get medical attention if symptoms occur.

Eye contact: Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention if symptoms occur.

Notes to physician: No specific treatment. Treat symptomatically.

5 – FIRE-FIGHTING MEASURES

FILLER– POLY B SIDE

Extinguishing Media: Extinguish preferably with dry chemical, carbon dioxide or foam. Waterspray/mist may be used. Do not use water jet.

Special Protective Equipment for Fire-fighters: Wear self-contained breathing apparatus.

Products of Combustion: Thermal decomposition products are toxic and may include oxides of carbon and nitrogen and other irritating or toxic gases.

6 – ACCIDENTAL RELEASE MEASURES

Personal Precautions: Wear personal protective equipment. Avoid breathing vapor. Ensure adequate ventilation. Remove contaminated clothes as soon as possible.

Environmental: Prevent spills to enter and spread to drains, sewers, water courses, and soil.

Spill Clean Up Methods: Extinguish all ignition sources. Absorb leaking product with sand, earth or other suitable inert material and collect. Dispose of material in accordance with local and provincial standards.

7 – HANDLING AND STORAGE

Usage Precautions: Avoid spilling, skin and eye contact. Provide good ventilation. Persons susceptible for allergic reactions should not handle this product. Keep from contact with oxidizing materials.

Storage Precautions: Store in tightly closed original container in a dry, cool and well-ventilated place.

Storage: Store at ambient temperature. Keep in original container.

8 – EXPOSURE CONTROLS/PERSONAL PROTECTION

Control Parameters: Exposure via the air and normal handling.

Engineering Measures: Use local and general exhaust ventilation to maintain airborne concentrations below TLV. Suitable respiratory equipment should be used in cases of insufficient ventilation or where operational procedures demand it.

Personal Protective Equipment:

Respiratory Equipment: If the product is heated or sprayed under manual handling, use NIOSH approved, air-purifying respirator with organic vapor cartridges and N-95 filters. Full face-piece is recommended. None required under normal conditions of use.

Body and Hands Protection: Wear suitable gloves: neoprene, nitrile or acrylonitrilebutadiene rubber or PVC. Wear full chemical suit when manually spraying this material. Change suit or clean gloves if contaminated.

Eye Protection: Wear chemical safety goggles / full face shield if there is a potential for splashing.

Hygiene Measures: DO NOT SMOKE IN WORK AREA! Wash hands and any other area that may have been exposed at the end of each work shift and before eating, smoking and using the toilet. Wash promptly if skin becomes wet or contaminated. Promptly remove any clothing that becomes contaminated. When using do not eat, drink or smoke.

FILLER– POLY B SIDE

9 – PHYSICAL AND CHEMICAL PROPERTIES

Appearance: Liquid

Odour: Odourless/slightly sweet

Colour: Transparent Light Amber

Flash Point: >130 deg C.

Solubility in Water: Non soluble.

Relative Density: 1.07

VOC: None

10 – STABILITY AND REACTIVITY

Stability: Stable under normal temperature conditions.

Conditions to Avoid: Oxidizing agents

Hazardous Decomposition Products: Thermal decomposition products by fire are toxic and may include hydrocarbons, oxides of carbon.

11 – TOXICOLOGICAL INFORMATION

No Toxic Substances

Potential Acute Health Effects:

Skin Contact: Slight irritation.

Eye Contact: Very slight irritation.

Inhalation: Very slight irritation to the respiratory system.

Ingestion: No known significant effects or critical hazards.

Potential Chronic Health Effects:

Target Organs: None known.

Mutagenicity: No known significant effects or critical hazards.

Carcinogenicity: No known significant effects or critical hazards.

Teratogenicity: No known significant effects or critical hazards.

Fertility Effects: No known significant effects or critical hazards.

Developmental Effects: No known significant effects or critical hazards.

FILLER– POLY B SIDE

12 – ECOLOGICAL INFORMATION

No Data Reported

13 – DISPOSAL CONSIDERATIONS

Dispose of waste material at an approved waste treatment facility in accordance with applicable local, state and national laws. Do not dispose of waste with normal garbage, or to sewer systems. Empty containers should be decontaminated and passed to an approved recycler.

14 – TRANSPORT INFORMATION

Not regulated by the DOT, TDG, IATA-DGR or IMDG.

15 – REGULATORY INFORMATION

S36/37/39	Wear suitable protective clothing, gloves and eye/face protection.
S28	After contact with skin, wash immediately with plenty of water.
S42	During spraying wear suitable respiratory equipment.
S45	In case of accident or if you feel unwell seek medical advice immediately.
S61	Avoid release to the environment. Refer to special instructions/safety data sheets.

Approved Code of Practice: Safety Data Sheets for Substances and Preparations. Classification and Labelling of Substances and Preparations Dangerous for Supply.

16 – OTHER INFORMATION

General Information: This product should be used as directed by Sanco, Inc. For further information consult the product data sheet or contact Technical Services.

Information Sources: This safety data sheet was compiled using current safety information supplied by distributor of raw materials.

Revision Comments: This SDS supersedes all previous issues and users are cautioned to ensure that it's current. Destroy all previous data sheets and if in doubt contact Sanco, Inc.

Issued By: MS

Revision Date: July 2011

Risk Phrases in Full:

R22	Harmful if swallowed.
R36	Irritating to eyes.
R48/22	Harmful: danger of serious damage to health by prolonged exposure if swallowed.

Hazardous Material Information System (USA):

Health	1
Flammability	1
Reactivity	0

Appendix B: CRADR1 UCS Data

This section includes UCS data collected throughout the development and demonstration of the CRADR1 prototype. Included are stress-strain curves for the samples analyzed throughout the process.

Figure B1. Average stress-strain curves for two foam samples in 20-gal trays shown in Figure 3.4.

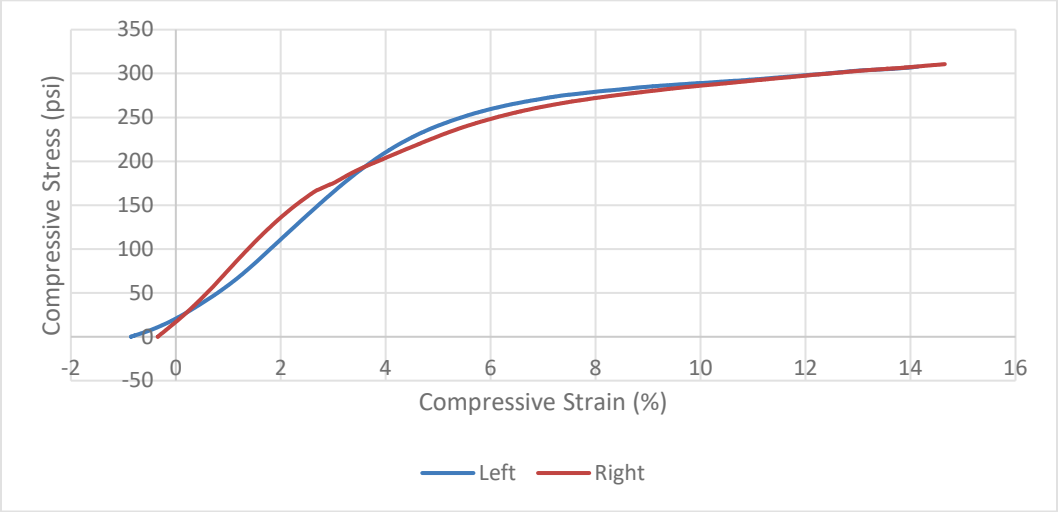


Figure B2. Stress-strain curves for 8-ft x 8-ft crater.

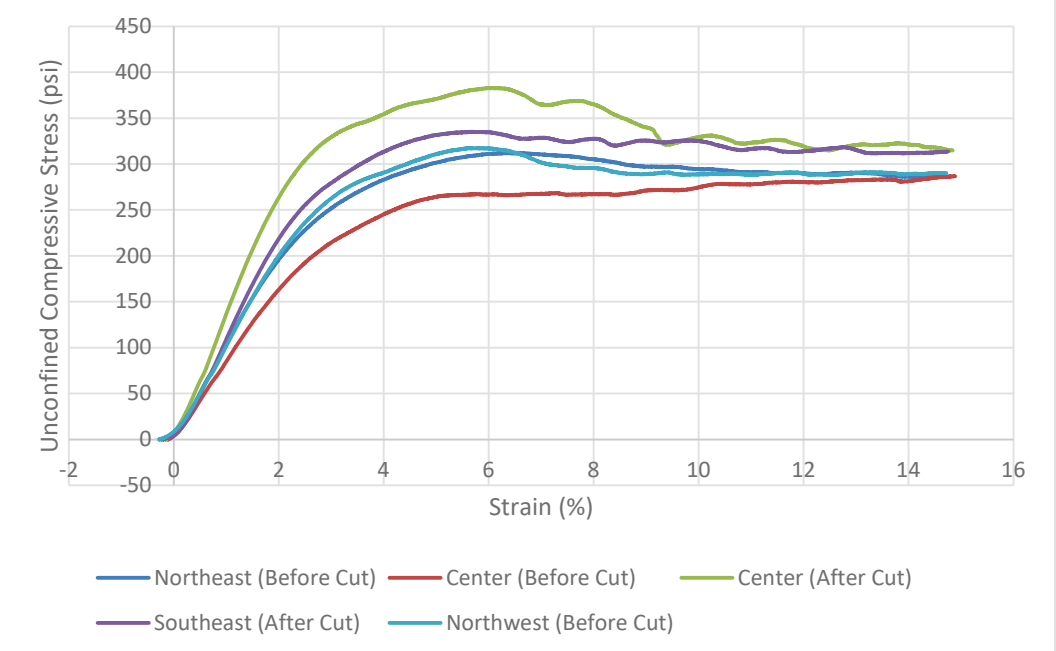
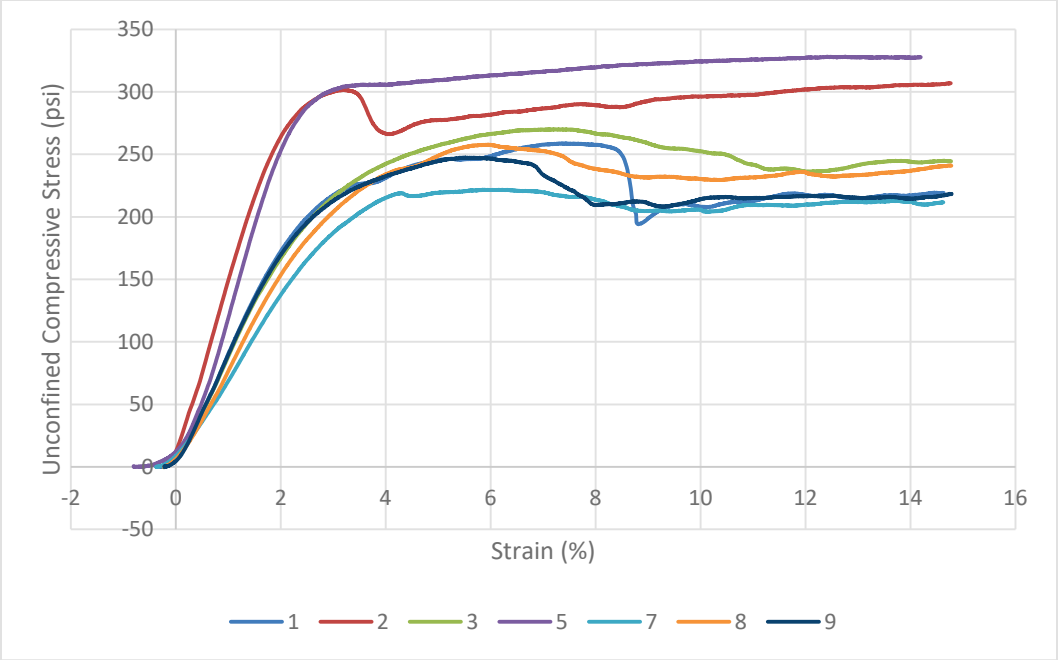


Figure B3. Stress-strain curves for full-scale demonstration.



Appendix C: Foam Temperature Data

This appendix provides higher resolution figures of the internal foam temperature data collected during the technology demonstration. The maximum temperatures observed are also included.

Figure C1. Crater 1 surface temperature data.

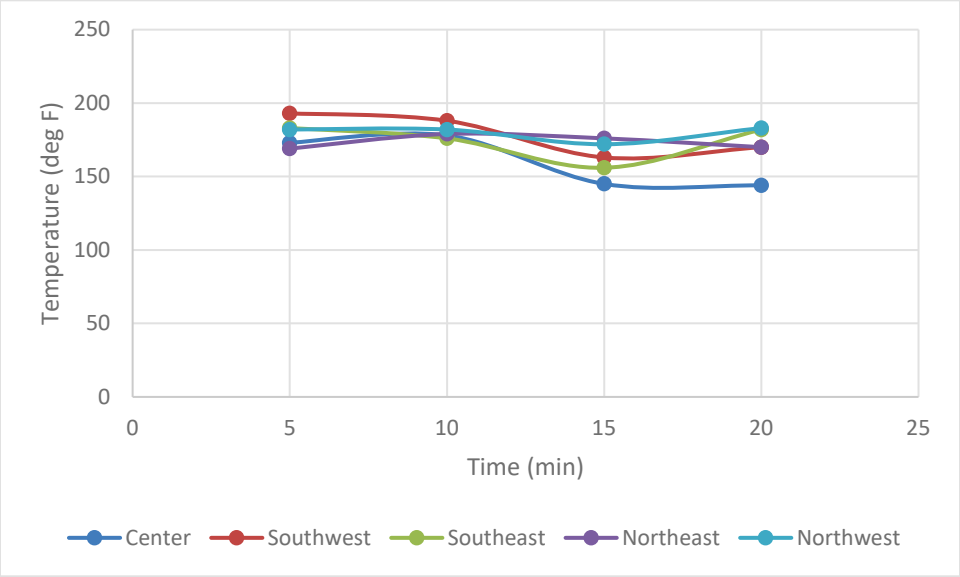


Figure C2. Crater 2 surface temperature data.

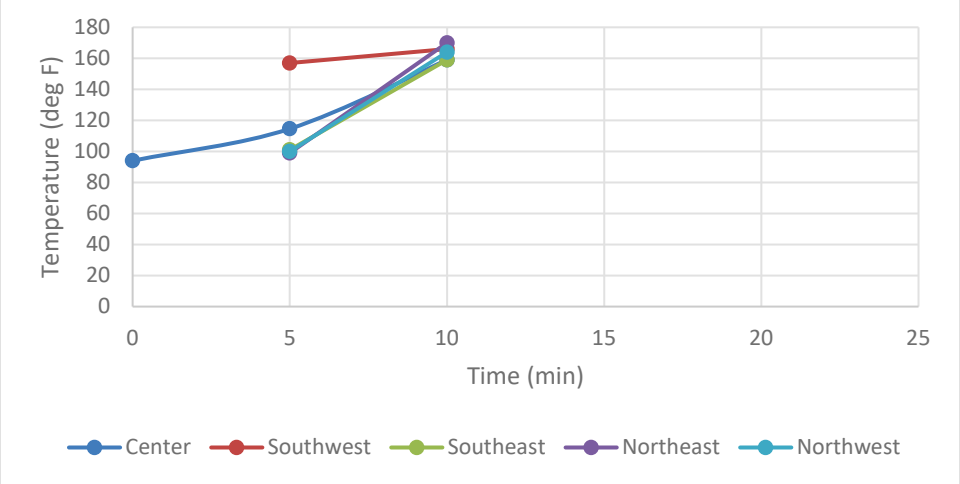


Figure C3. Crater 3 surface temperature data.

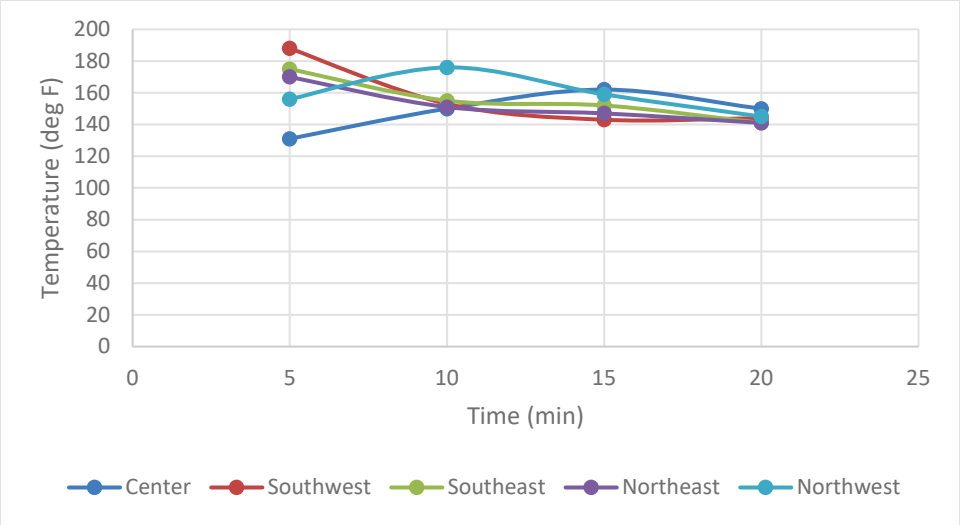


Figure C4. Crater 4 surface temperature data.

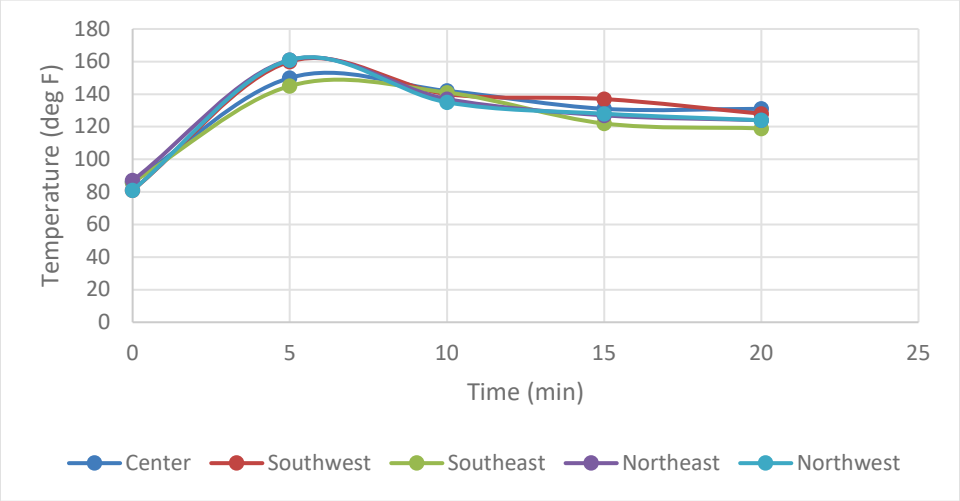


Figure C5. Crater 5 surface temperature data.

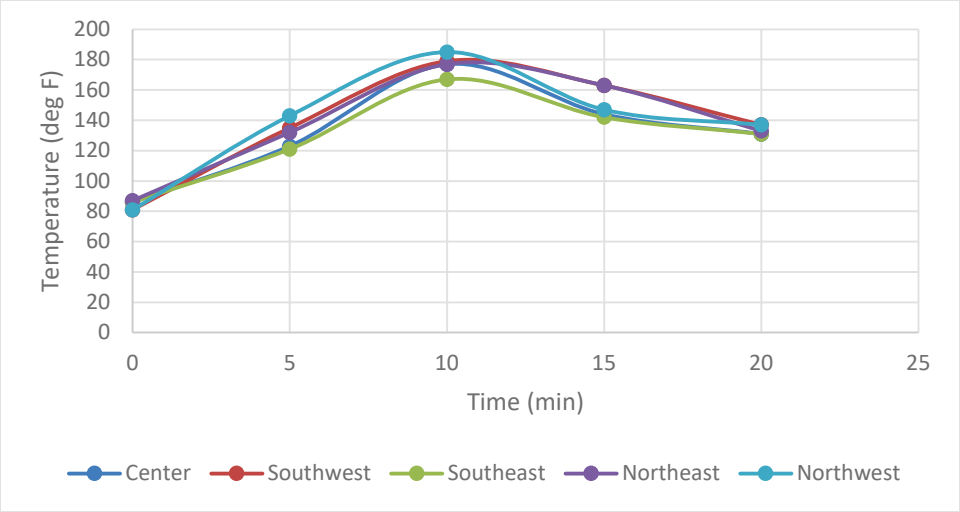


Figure C6. Crater 6 surface temperature data.

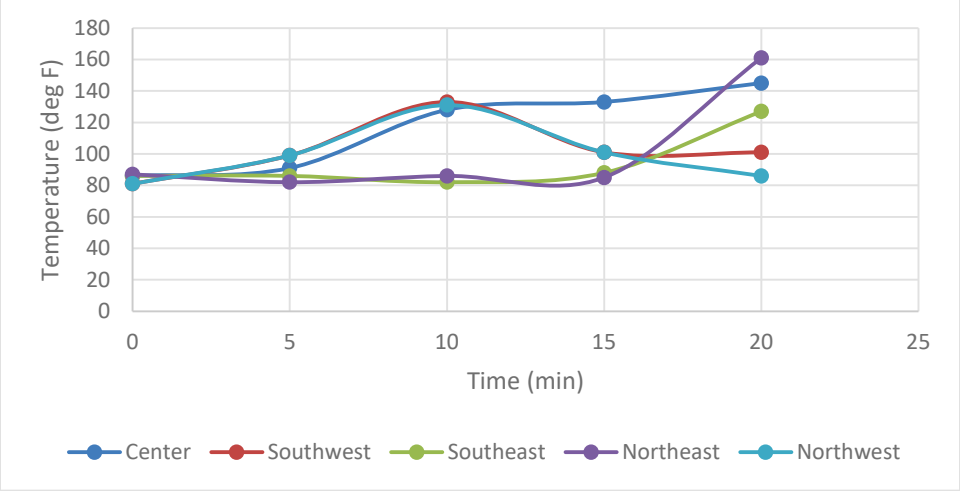


Figure C7. Crater 7 surface temperature data.

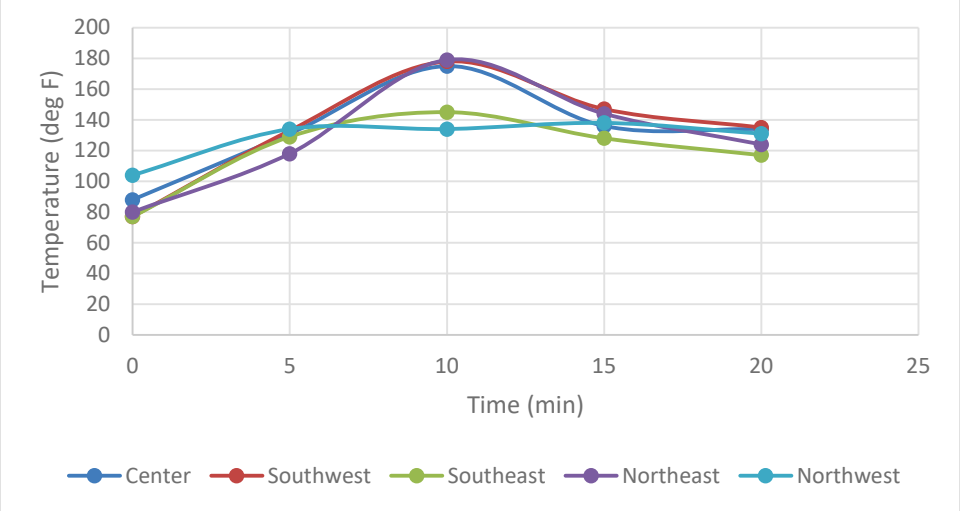


Figure C8. Crater 8 surface temperature data.

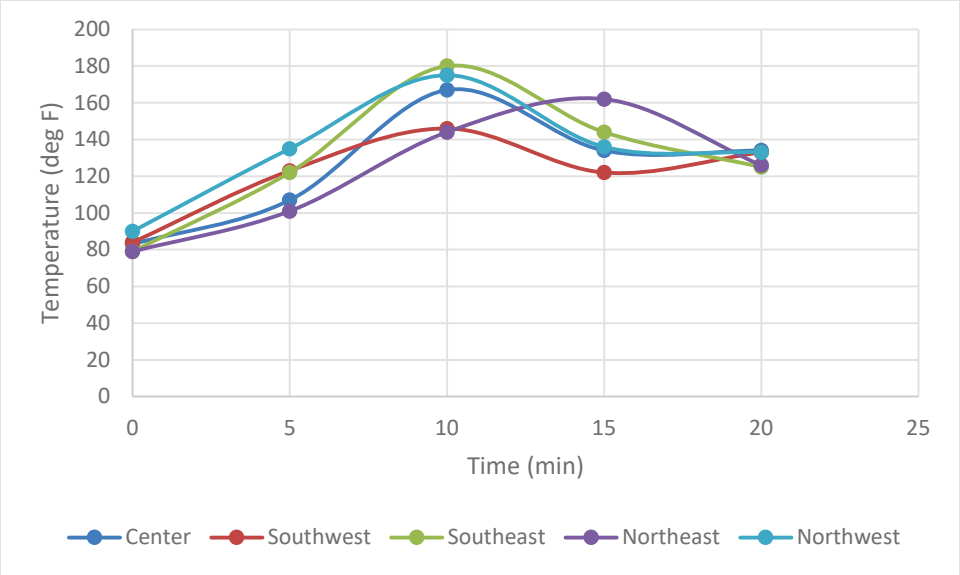


Figure C9. Crater 9 surface temperature data.

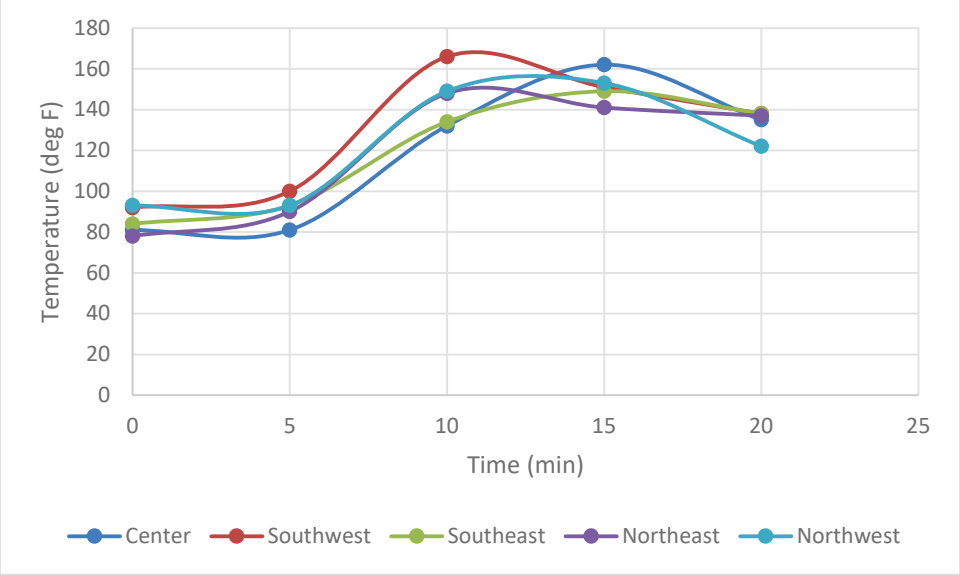


Figure C10. Craters 1 and 3 – internal foam temperature data.

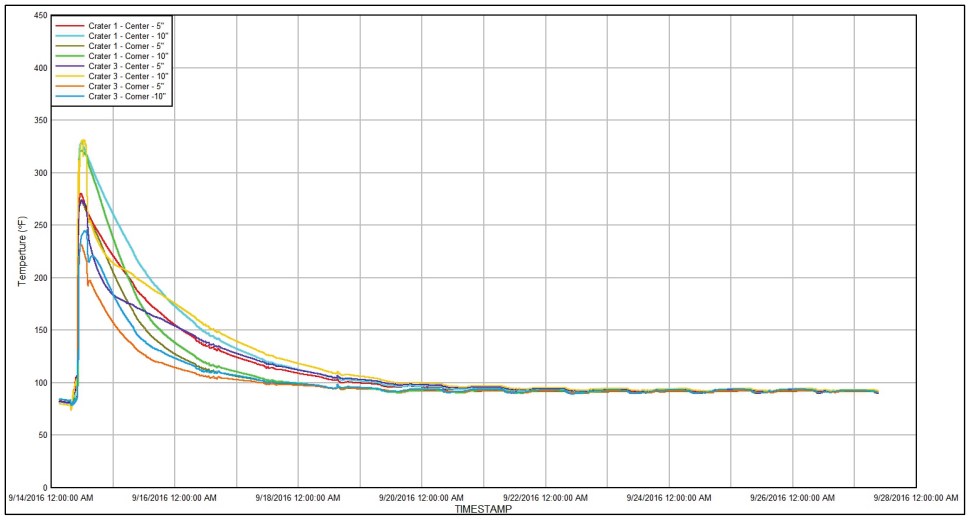


Figure C11. Craters 4 and 6 – internal foam temperature data.

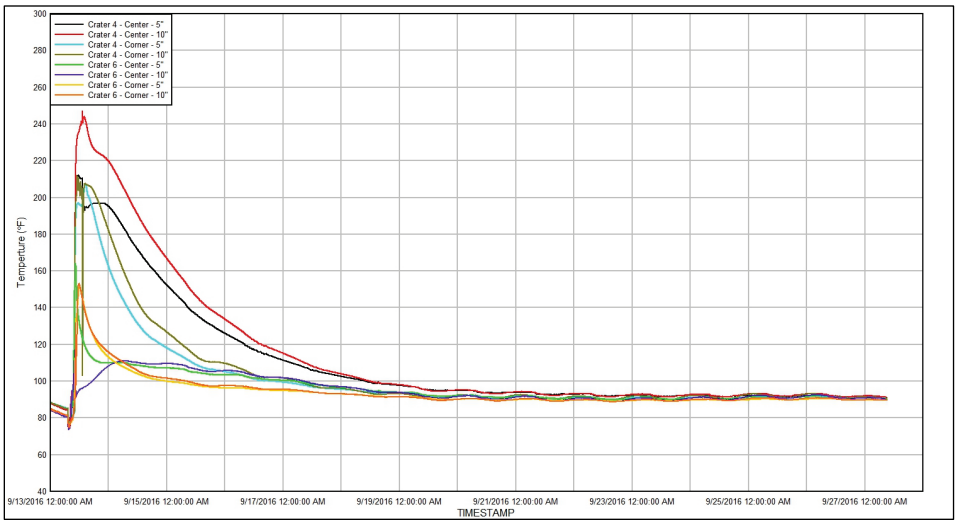


Figure C12. Craters 7 and 9 – internal foam temperature data.

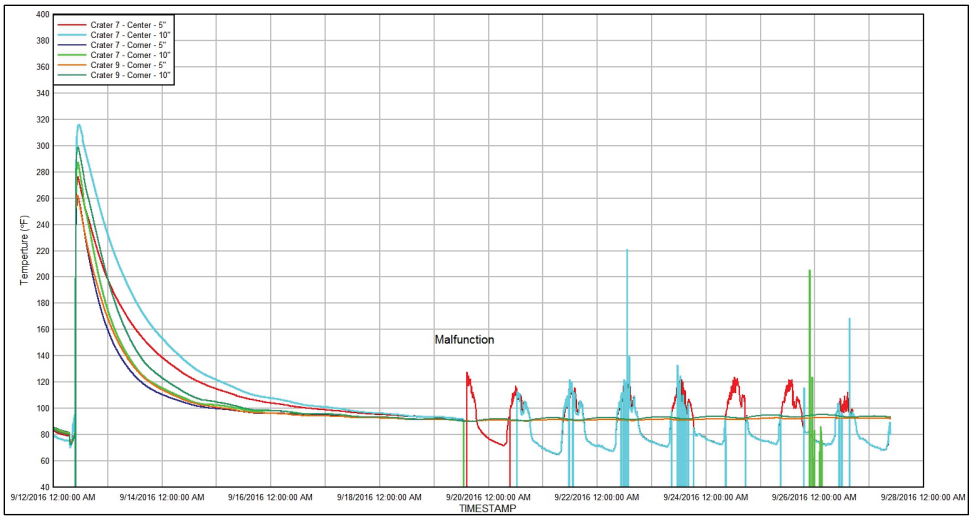


Figure C13. Craters 1 and 3 – internal foam temperature trend and maximum.

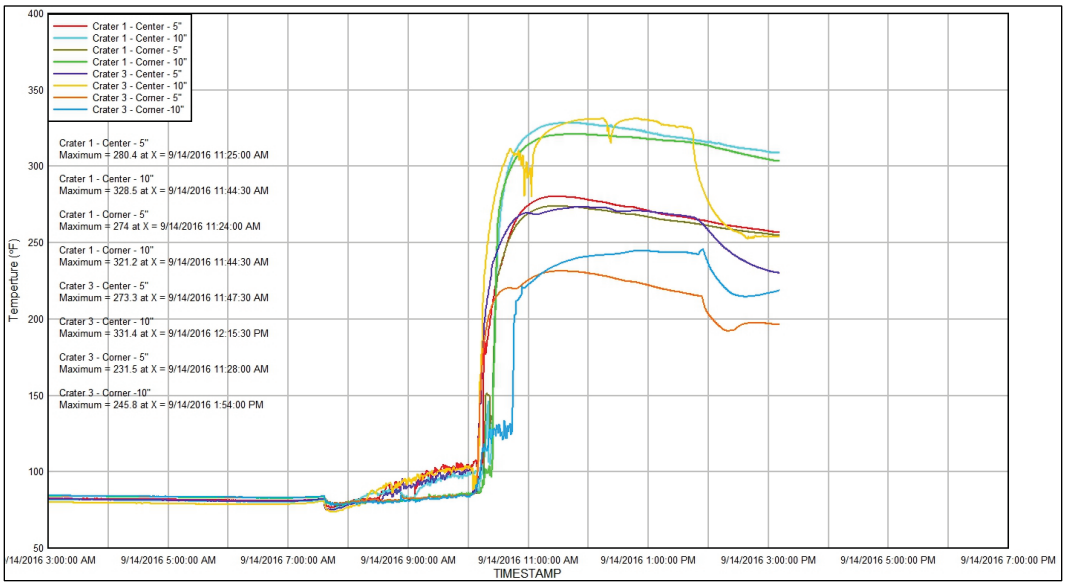


Figure C14. Craters 4 and 6 – internal foam temperature trend and maximum.

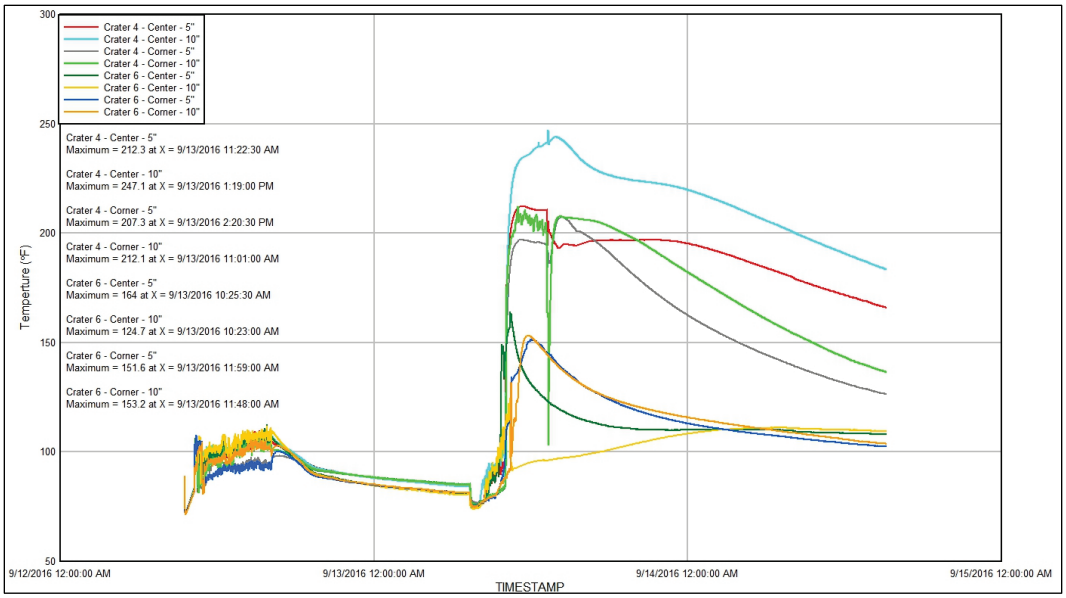
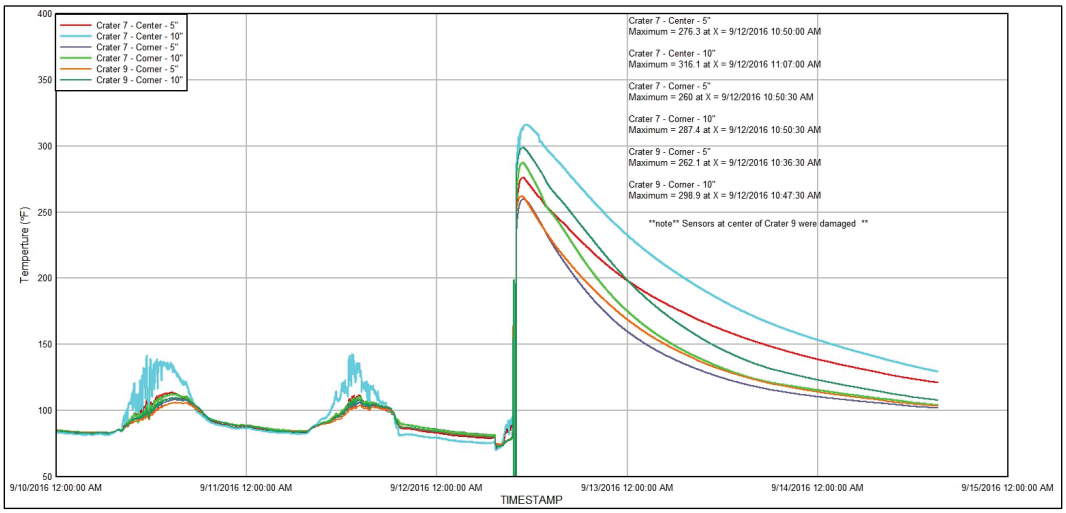


Figure C15. Craters 7 and 9 – internal foam temperature trend and maximum.



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
December 2017	Final	

4. TITLE AND SUBTITLE

Refinement of Foam Backfill Technology for Expedient Airfield Damage Repair; Phase II: Development of Prototype Foam Dispensing Equipment and Improved Tactics, Techniques and Procedures

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER
P2457442

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Geotechnical and Structures Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC TR-17-14

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Headquarters, Air Force Civil Engineer Center
Tyndall Air Force Base, FL 32403-5319

10. SPONSOR/MONITOR'S ACRONYM(S)

AFCEC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report describes the development and evaluation of prototype foam dispensing equipment, foam materials, and repair tactics, techniques, and procedures (TTPs) for rapid airfield damage repair (RADR) using foam backfill technology. Three different prototype foam dispensing systems were evaluated, two of which were developed in-house, along with foam products from two vendors and different repair methods and techniques to improve the TTPs for foam backfill technology. Results from full-scale field testing showed that the top performing prototype system was a hose pump system, and the top performing foam material was Foam-iT! 10 Slow. Plastic liners were a successful technique for a moisture barrier to ensure the quality of the repair material. Foam cutting methods, such as scarfer and reciprocating saw, were good options; how-ever, both methods have safety concerns and add time and manpower to the repair process. Overall, the technology proved to be effective in meeting RADR requirements. Repair times were comparable to those of the standard flowable fill backfill method. Repair performance under simulated F-15E aircraft traffic was satisfactory. All repairs met the 2-hr requirement of 100 passes and the expedient repair requirement of 500 passes. Only one repair met the RADR requirement of 3,500 passes.

15. SUBJECT TERMS

Runways (Aeronautics) – Maintenance and repair
Foamed materials – Testing
Cratering
Foam Backfill
Rapid Airfield Damage Repair
Urethane foam
Moisture barriers
Foam dispenser
Airfield Pavement
Fills (Earthwork)

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified		115	