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Technology Demonstration of Thermal Spray Vitrification Process at Fort Drum, NY

Cost/Performance Report

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Executive Summary

In the past, red lead primer has been used on many steel structures to control corrosion. Commonly used structures in the Department of Defense (DoD) include bridges, aircraft hangars, water storage tanks, metal buildings, fire hydrants, and structural steel. When the lead-based paint (LBP) cannot be overcoated because of peeling, it must be removed before repainting. The use of conventional abrasive blasting for removal requires a tight containment structure to keep the lead dust from contaminating air, soil, and water. Increased worker protection is required inside these containment structures because of high dust concentrations. The personal protective equipment (PPE) is time-consuming to put on and cumbersome to use, which reduces worker productivity and drives up costs.

A thermal spray vitrification (TSV) process has been demonstrated in which molten glass is sprayed on the coated structure. The glass encapsulates the LBP and, because of the thermal stresses, falls off upon cooling. The collected waste is vitrified so that it can be disposed of as nonhazardous waste or recycled into value-added products. No containment structure is required, as there are no hazardous effluents produced by this process.

The demonstration and validation of the TSV process was conducted on a fire hydrant at Fort Drum, NY, in 2001. During the Fort Drum demonstration, an innovative hand-held high frequency paint removal device was field tested and proved to be efficacious in assisting in the removal of LBP in conjunction with the TSV process.

These demonstrations met all of the performance objectives, which were to: (1) remove LBP from steel structures in the field, (2) meet all applicable environmental standards, (3) meet all applicable worker health and occupational safety standards, (4) enable recoating of the substrate using a surface-tolerant coating system, and (5) collect data and estimate production rates.

The production rate of the TSV process was estimated at 0.5 to 1 hr per hydrant for the fire hydrant at Fort Drum for paint that was 15 to 25 mils thick. The cost of the TSV per fire hydrant was $196.

A niche market is anticipated for the TSV process. This market would include surface preparation for zone painting on large bridge structures or for small fixed structures such as fire hydrants, where the cost of the containment structure required for conventional technologies would be a large part of the overall cost. The waste glass from the TSV process potentially can be recycled using commercial processes that convert the slag waste into nonhazardous, value-added glass or ceramic products such as abrasives, construction materials, and refractory insulating materials. DoD-wide savings over the next 20 years are estimated at more than $30 million. The TSV procedure has been used to remove LBP from over 300 fire hydrants at Tyndall AFB, FL.

Foreword

This technology demonstration was conducted for Headquarters, Department of the Army under Program Element (PE) 063728A, "Environmental Technology Demonstration"; Project 002, "Environmental Compliance Technology"; Work Unit CF-M B101, "Cost Effective Technologies to Reduce, Characterize, Dispose, or Reuse Sources of Lead Hazards." Bryan Nix, ACS(IM)-FDF, was the Technical Monitor.

The work was performed by the Materials and Structures Branch (CF-M) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. Ashok Kumar. Part of this work was done by Zatorski Coating Co., Inc. under contract DACA42-01-P-0044. The technical editor was Linda L. Wheatley, Information Technology Laboratory – Champaign. Martin J. Savoie is Chief, CEERD-CF-M, and L. Michael Golish is Chief, CF. The Technical Director of the Installation Operations Business Area is Gary W. Schanche (CV-T), and the Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL John Morris III, EN and the Director of ERDC is Dr. James R. Houston.

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1 Introduction

Background

In the past, red lead primer has been used on many steel structures to control corrosion. Commonly used steel structures in the Department of Defense (DoD) include bridges, aircraft hangars, water storage tanks, fire hydrants, catwalks, towers, piping, steel doors, trusses, exterior railings, steel posts, poles, stairways, handrails, cranes, pontoons, and other structural steel. When the lead-based paint (LBP) cannot be overcoated because of peeling, it must be removed before repainting. The use of conventional abrasive blasting for removal requires a tight containment structure to keep the lead dust from contaminating air, soil, and water. Increased worker protection is required inside these containment structures because of high dust concentrations. The personal protective equipment (PPE) is time-consuming to put on and cumbersome to use, which reduces worker productivity and drives up costs.

A thermal spray vitrification (TSV) process has been demonstrated in which molten glass is sprayed on the coated structure. The glass encapsulates the LBP and, because of the thermal stresses, falls off upon cooling. The collected waste is vitrified so that it can be disposed of as nonhazardous waste or recycled into value-added products. No containment structure is required as there are no hazardous effluents produced by this process.

Objectives

The objectives were to:

1. remove LBP from steel structures in the field,
2. meet all applicable environmental standards,
3. meet all applicable worker health and occupational safety standards,
4. enable recoating of the substrate using a surface-tolerant coating system, and
5. collect data and estimate production rates.

Approach

The demonstrations and validations of the TSV process were conducted on a fire hydrant at Fort Drum, NY, in 2001. During the Fort Drum demonstration, an innovative hand-held high frequency paint removal device was field tested and proved to be efficacious in assisting in the removal of LBP in conjunction with the TSV process.

Mode of Technology Transfer

Technology transfer is being accomplished by: (1) Technology Transfer Implementation Plan through the U.S. Army Environmental Center (AEC); (2) PWTB 420-70-2 "Installation Lead Hazard Management;" (3) participation in User Groups and Committees such as the Army Lead and Asbestos Hazard Management Team, Federal Lead-based Paint Committee Meetings at EPA or HUD, and ASTM D01.46 (Industrial and Protective Coatings) Committee; (4) websites maintained by the Army Assistant Chief of Staff for Installation Management (ACSIM) [http://www.hqda.army.mil/acsimweb/fd/policy/facengcur.htm], AEC [http://aec.army.mil/usaec/], and the U.S. Army Engineer Research and Development Center/Construction Engineering Research Laboratory (ERDC/CERL) [http://www.cecer.army.mil], as well as the Hands-on-Skills-Training (HOST) website at http://www.hqda.army.mil/acsimweb/fd/policy/host/index.htm; (5) demonstration/validation of emerging technologies through Army demonstration funding (6.3) starting in Fiscal Year 2000 (FY00) and continuing through FY03, and cost/performance reports resulting from those demonstrations.

2 Technology Description

Thermal Spray Vitrification Process

The TSV process was developed and patented by the Engineer Research and Development Center/Construction Engineering Research Laboratory (ERDC/CERL) under U.S. Patent No. 5,292,375 (Kumar and Petreanu 1994). In short, molten iron silicate glass is heated in a thermal spray torch and applied to the painted steel substrate. The molten glass strikes the substrate and reacts with the paint. The organic components of the paint are pyrolyzed, while the lead irons are trapped on the glass surface. Due to the quenching stresses, the glass cracks and spalls off the substrate. The glass composition produces a stable and durable waste product that can immobilize up to 25 percent by weight of lead oxide (PbO). This waste product has a leaching rate as measured by the Toxicity Characteristic Leaching Procedure (TCLP) of less than 5 parts per million (ppm) (Title 40, Code of Federal Regulations, Part 261 [40 CFR 261]). In laboratory tests (Marra et al. 1997), the glass also immobilized chromium (Cr), cadmium (Cd), and copper (Cu).

The molten glass is very corrosive and acts like a cleaning agent that restores the surface to the profile it had before it was painted. The appearance of the steel after the removal of the glass is a dull finish with a dusting of loosely adhered powdery residue. This loosely adhered material (mill scale, paint, rust, other detrimental foreign matter) must be removed prior to painting. The surface finish is then acceptable for surface-tolerant coating for atmospheric exposure. The newly coated surface can provide up to 25 years of performance. The surface after the TSV process meets the Society for Protective Coatings (SSPC) specification SSPC 3, “Power Tool Cleaning.”

The principal equipment for the TSV process consists of a commercially available thermal spray torch, powder feeder, gas manifold, flow controllers, as well as compressed air, fuel, and oxygen sources. These are connected with a series of gas and powder feed lines. Figure 1 shows a schematic of the thermal spray system. Manifold and flow controllers manage the pressure of the oxygen and acetylene, which are connected by separate gas feed lines to the thermal spray gun, where they are combined. The glass powder is mixed with compressed air in the powder feeder, and the air is used to transport the powder to the thermal spray gun. The oxygen and acetylene are ignited at the torch, and the powder is introduced into the flame. The flame melts the glass powder and propels the molten droplets onto the surface. The temperature of the flame from the thermal spray torch is about 2000 °C (3600 °F), which is sufficient to melt the glass powder. As the glass is propelled towards the substrate, it cools in the air and sticks to the substrate at a temperature of about 475 °C (800 °F). (Note: Caution must be taken to prevent warping of thin [i.e., less than 3/8 in. (9.6 mm)] sections of steel during the TSV process. A water spray cooling may be used on the opposite side of the section from which the paint is being removed.)

This surface temperature is maintained for approximately 15 seconds, which allows partial vitrification of the LBP. Upon cooling, the difference in the coefficient of thermal expansion causes the glass to crack and spall from the surface. In some cases, a blow from a hammer or similar tool is necessary to remove the vitrified paint. Several applications of glass may be required to remove all the layers of paint.

The glass fragments are collected and remelted in a furnace onsite to fully immobilize the lead and make the glass waste nonhazardous (Covey et al. 1995, 1996). To be classified as nonhazardous, the final product must have a lead leachate concentration of less than 5 ppm, as determined by TCLP. If the glass waste is not remelted, it can be disposed of as hazardous waste. In the application reported here, the glass fragments were remelted in a furnace onsite.

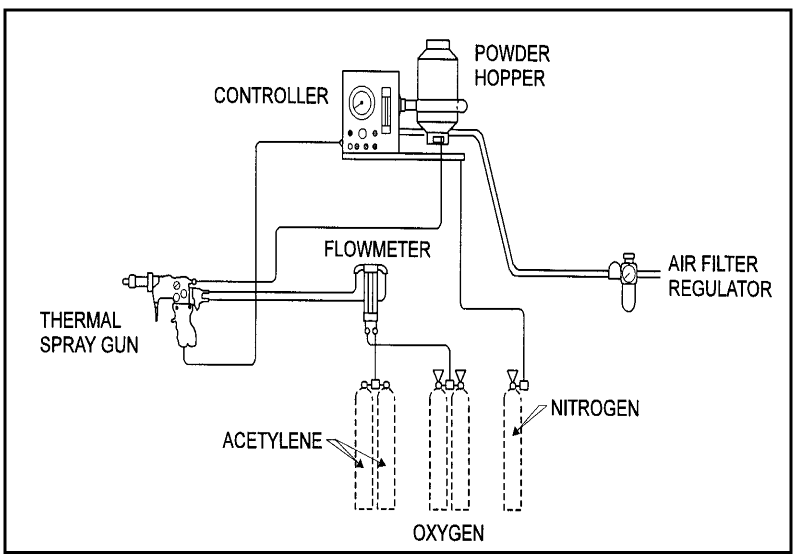

Figure 1. Schematic of the thermal spray process.

The process to complete the vitrification involves a high temperature furnace, stirrers, safety equipment, and a water bath. The optimum procedure developed is based on previous laboratory research and field demonstrations, which included TCLP tests. This procedure is:

- Add the effluent from the TSV process to the furnace until full.
- Heat the furnace to at least 800 °C (1470 °F) and maintain for 3 hr. After melting occurs, stir every 15 minutes.
- Shut off the heat and furnace-cool the effluent to below 260 °C (500 °F).
- After cooling, reheat the furnace to at least 800 °C (1470 °F) and maintain for 2 hr.
- Remove the molten glass from the container by pouring into water or by using utensils to transfer it into water.
- As soon as the danger of scalding is past, remove the glass from the water using separate utensils to prevent contamination.
- Appropriately dispose of the glass as determined by TCLP analysis.

The remelt process may be repeated if the glass effluent does not pass TCLP analysis.

Advantages of the TSV process include reduced cost of environmental compliance and worker health protection associated with LBP abatement, reduced waste effluent, effluent that is nonhazardous, and reduced setup time.

Glass Composition Experiments

TSV technology uses a glass compound designed for high lead solubility and resistance to crystallization. These characteristics provide immediate reaction with the lead and, upon subsequent remelting, ensure containment of the hazardous material. The initial iron borosilicate glass system, Composition A (as shown in Table 1), was selected because of its ability to accommodate a wide variety of hazardous species, its outstanding long-term chemical durability, and its corrosion resistance to a wide range of environmental conditions (Covey et al. 1995).

A series of crucible melt experiments was conducted in the laboratory with Composition A prepared with between 0 and 40 wt% PbO added to the glass. The lead loading experiment showed that the iron borosilicate glass was able to successfully immobilize up to 25 wt% PbO so that it leached less than the 5 ppm Pb regulatory limit as determined using TCLP testing (shown in Figure 2).

Table 1. Glass compositions.

Species	Initial Composition A Wt %	Modified Composition B Wt %
SiO_2	54.1	54.1
B_2O_3	6.8	10.0
Al_2O_3	4.1	5.1
Na_2O	10.3	16.5
Li_2O	4.7	2.0
MnO_2	2.9	
NiO	0.9	
CaO	1.5	
MgO	0.8	
Fe_2O_3	12.3	12.3
ZrO_2	1.2	

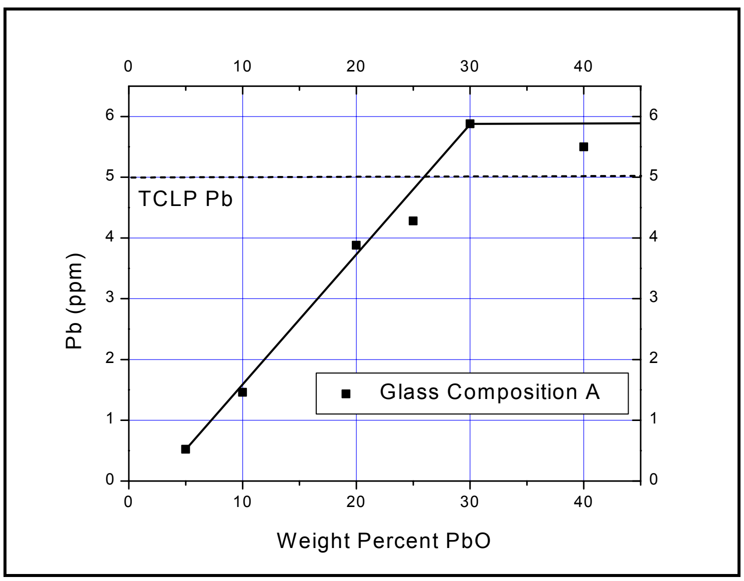

Figure 2. Effect of lead loading on the TCLP concentration of Pb.

To reduce the cost of the glass frit, the chemical formulation was modified by removing the elements considered nonessential. These included calcium (Ca), nickel (Ni), manganese (Mn), magnesium (Mg), and zirconium (Zr). The modified Composition B was scaled to 100 percent and is listed in Table 1. A series of laboratory experiments was conducted to determine the immobilization of lead, cadmium, chromium, and copper. Cadmium can be present on metal fasteners, chromium is a component of lead chromate primers, and copper is used as an antifouling agent in some paints for ship hulls. TCLP analysis was conducted on glass samples of Composition B melted with 25 percent waste loading of the following hazardous permutations: (1) Pb only, (2) 50% Pb and 50% Cu, and (3) 80% Pb, 10% Cd and 10% Cr, as shown in Table 2. The regulatory limits for Cadmium and Chromium release by TCLP testing are 1.0 and 5.0 ppm, respectively. However, there is currently no Federal regulatory standard for release of copper by TCLP testing. The results showed that Composition B successfully immobilized lead, cadmium, chromium, and copper.

Table 2. TCLP results for glass Composition B.

Hazardous Components (25% loading)	Pb (ppm)	Cd (ppm)	Cr (ppm)	Cu (ppm)
Pb	2.8			
50% Pb /50% Cu	2.4			3.9
80% Pb /10% Cd /10% Cr	3.1	0.5	0.1	
Regulatory Limit	5.0	1.0	5.0	—

Processing Parameters Optimization

The thermal spray application process was designed to operate with any industrial type fuel such as acetylene, propylene, or propane, with oxygen as the oxidizer. The powder-carrier gas can be nitrogen (N_2), argon, or dry compressed air. The flame spray gun may be either machine mounted or hand-held by attaching a pistol grip. All of the flame spray tests conducted during this investigation used acetylene as the fuel gas, oxygen as the oxidizer, and ultra-dry industrial-grade nitrogen or dry compressed air as the carrier gas.

The replication of the flame spray process (and its results) is a function of the processing variables such as oxygen and acetylene flow rates, carrier gas flow rate, powder flow rate, particle size and uniformity, duration of flame spray pass, and stand-off distance. Any flame spray process is also influenced by particle molten state and velocity, particle chemical reaction with the environment during flight, heat transfer control to the substrate while spraying, and relative movement of the spray gun to the substrate (Kubel 1987). Although the spray parameters were optimized in this research, minor adjustments must be made in the field depending on the specific characteristics of the compound being flame sprayed. Spray parameters (such as fuel and oxygen pressures and flow rates, standoff distance, powder flow rate and powder carrier gas flow rate) were optimized as shown in Table 3. The use of a reducing atmosphere during the preheating of the substrate was found to improve the removal of the paint.

Table 3. Thermal spray processing parameters.

Parameter	Initial Conditions	Reducing Preheat Condition
Acetylene Pressure (psi)	15.0	15.0
Acetylene Flow Rate (%)	42.0	42.0
Oxygen Pressure (psi)	40.0	40.0
Oxygen Flow Rate (%)	32.0	10.0
Carrier Gas (N_2) Pressure (psi)	42.0	42.0
Carrier Flow Rate (%)	40.0	40.0
Powder Feed Rate (g/min)	88.0	0

Paint-Removal Optimization

The goal of the TSV process is to remove the LBP from the substrate for subsequent recoating with a surface-tolerant system. Following removal of the LBP, a small amount of residual lead may be on the substrate surface. When the surface-tolerant coating eventually needs to be removed for repainting, lead monitoring will have to be conducted to determine the airborne lead concentration and the necessary extent of worker protection. Due to the significantly lower lead concentrations, reduced requirements for worker protection would be expected. Traditional paint removal processes such as abrasive blasting can be used for the subsequent paint removal.

In laboratory experiments, carbon steel coupons measuring 4 in. x 6 in. x 0.5 in. were painted with PbO-containing primer followed by an aluminized topcoat. These panels were cured in an oven at 60 °C for 7 days for use as test specimens. The remnant lead in the panel was measured using x-ray fluorescence (XRF) lead-detection equipment. The test panels were preheated to about 150 ^{o}C (300 ^{o}F) to drive away the moisture, and the feedstock powder was sprayed and fused using the oxy-acetylene spray gun. Lead removal was tracked by XRF testing of the surface. The initial lead concentration ranged from 6 to 13 mg/cm^2. Following application of the TSV process the surface lead concentration ranged from 0.4 to 1.2 mg/cm^2. The accuracy of the XRF measurements is questionable at or below 1.0 mg/cm^2. Supplementary testing using scrape samples is recommended before making lead hazard control or worker protection decisions. Visual observations and XRF analysis showed that the TSV process successfully removed the LBP from the substrate, as show in Table 4. The resulting surface was suitable for repainting using a surface-tolerant coating.

The glass fragments from the experimental samples were collected. TCLP analysis detected lead leaching from the glass collected. The rapid cooling of the glass on the substrate evidently had provided insufficient time for the lead to completely diffuse into the glass network while on the surface. Instead, lead was trapped on the surface of the glass where it was quickly liberated by the acid used in the TCLP test. Remelting the glass fragments, however, yielded a non-hazardous waste as determined by TCLP testing.

The TSV process is limited to the removal of LBP from steel structures. This technology is not applicable to removing LBP from wood, concrete, or masonry structures because of the relatively high process temperature and the potential to damage the substrate.

Table 4. Results of lead removal experiments.

Sample	Initial Pb XRF Concentration mg/cm^2	Final Pb XRF Concentration mg/cm^2
1	6.9	0.5
2	8.1	0.9
3	6.7	1.2
4	6.7	0.7
5	6.0	0.9
6	10.5	0.6
7	11.5	0.4
8	12.3	1.1

3 Demonstration Design

Physical Set-Up and Operation

The demonstration of the TSV process for LBP removal on a fire hydrant at Fort Drum was conducted by Zatorski Coating Co., Inc., 77 Wopowog Road, East Hampton, CT. Table 5 lists the principle equipment used in the demonstration.

The Metco 6P-II is a reliable, field-rugged thermal spray torch. Spare parts are catalog items available from several vendors. A metal supplier fabricated the sheet-metal collection basin for less than $25. The basin was field-fitted around the hydrant by cutting with metal shears. The basin can be reused after being wiped down or can be disposed of after lead abatement. The remaining items of equipment are catalog items. The Honda EB3000C generator has an integral Ground Fault Circuit Interrupter (GFCI) receptacle and approved spark arrester.

Table 5. Principle equipment used by the contractor.

Equipment	Type or Model	Purpose
Thermal spray torch	Metco 6P-II	Apply glass
Powder feeder	Miller Thermal, mechanical feeder	Feed glass to torch
Hoses and regulators	Fuel, oxygen, and air	Provide utilities for equipment
Campbell-Hausfeld 2-amp compressor	Compressed air powered	Provide carrier gas for the powder feeder
Air cleaners	Metco, lobe type	Remove debris, oil, and moisture from air
Sheet-metal collection basin	22-gage sheet metal 4 ft X 5 ft with 3-in. lip	Contain glass and paint chips in area
Thermal blankets	High-temperature welding blankets	Additional containment for glass and paint chips in area
Hand tools	Paint scraper, wire brush	Remove glass that did not spall
Furnace	Charles A. Hones pot-type furnace, propane	Remelt glass
Safety Equipment	Respirators, gloves, jackets, eye protection	Personal protection for workers
Generator	Honda EB3000C gasoline generator	Power for powder feeder and air compressor

The hydrant from which the LBP was to be removed was in a field location remote from utilities. The nearest buildings were several hundred feet away. This remote demonstration showed that TSV is a self-contained process.

Fort Drum supplied oxygen and acetylene. Zatorski Coating Company supplied all the equipment, propane, and compressed air. The self-contained TSV system was brought to the site in a van.

Monitoring Procedures

Evaluation of the existing paint system included dry film thickness measurement using American Society for Testing and Materials (ASTM) D 1186, *Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Non-magnetic Coatings Applied to a Ferrous Base*. The adhesion of the existing paint system was determined using ASTM D 3359 *Standard Test Method for Measuring Adhesion by Tape Method*.

Following the TSV process, and prior to repainting, the surface profile was compared with visual standards from the SSPB-VIS-1-89, *Visual Standards for Abrasive Blast Cleaned Steel (Standard Reference Photographs)*. The profile was also evaluated using ASTM D 4417, *Standard Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel*.

Analytical Procedures

The personal air samples and area air samples were analyzed for lead according to National Institute for Occupational Safety and Health (NIOSH) Method 7300. The respirable dust level was measured by NIOSH Method 600. The TCLP was performed in accordance with U.S. Environmental Protection Agency (EPA) Method 1311. The lead content of the original coatings and the residual lead on the surface after completion of the TSV process were measured using XRF technology.

Demonstration Site Facility Background and Characteristics

Criteria for selection of the TSV demonstration site were to have: (1) a fire hydrant with LBP, (2) a paint system(s) similar to those used at other DoD installations, (3) a fire hydrant away from utilities to demonstrate the ability of the process to be self-contained, and (4) a site willing to actively participate and assist on the demonstration.

Sampling and analysis found that fire hydrants at Fort Drum, NY were coated with a lead-based primer and various topcoats. This type of paint system is commonly used on fire hydrants and other steel infrastructure within the DoD system and the U.S. Department of Transportation (DOT) for steel structures in atmospheric exposure.

4 Performance Assessment

Fort Drum Fire Hydrant Demonstration

The equipment was located adjacent to the hydrant, as shown in Figures 3 and 4. The soil directly below the hydrant was contaminated with paint chips. The paint chips contained lead. This was determined by using Lead Check® swabs, which are disposable field lead detection chemical ampules with a self-contained brush. The chips and soil were placed in the pot-type furnace shown in Figure 4.

The hydrant was preheated and the glass applied as outlined in Chapter 2, **Technology Description**. Figure 5 shows the use of the TSV LBP removal process for the fire hydrant.

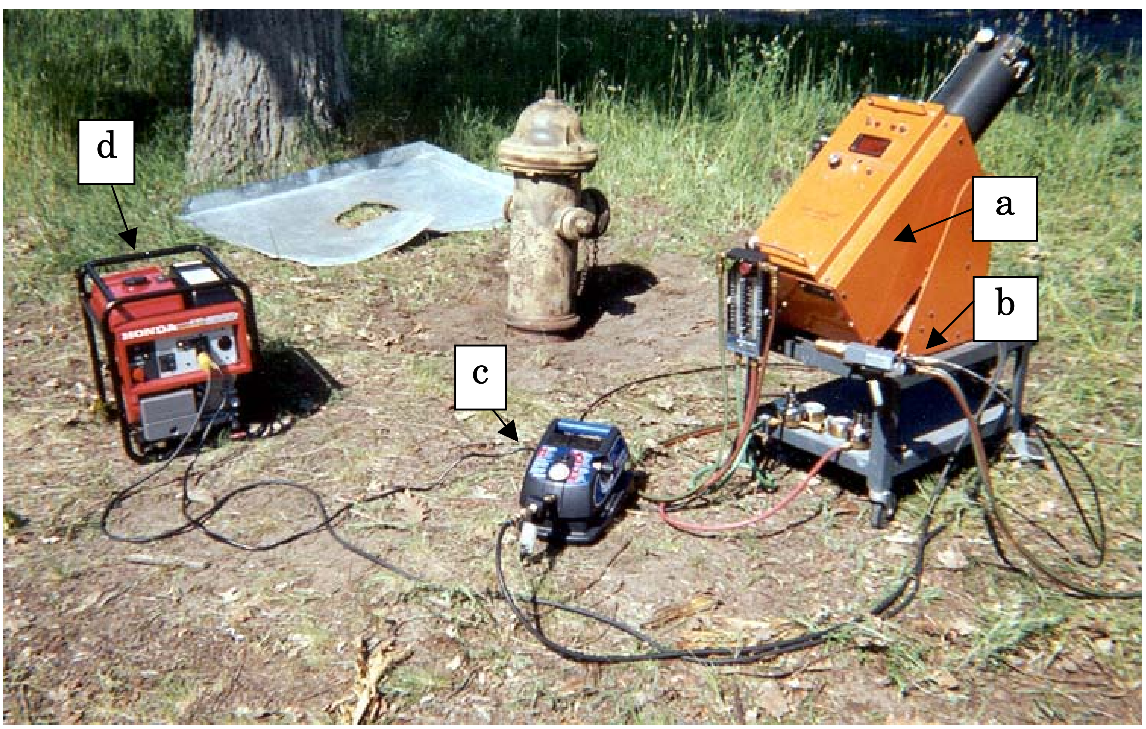

Figure 3. Equipment used for the TSV process staged at the Fort Drum demonstration area: (a) thermal mechanism powder feeder, (b) thermal spray torch, (c) air compressor, (d) portable power generator.

Figure 4. Remelting furnace used at Fort Drum during the thermal spray vitrification process.

Figure 5. The TSV process being demonstrated to remove LBP from fire hydrant surface; sheet-metal collection pan underneath collects vitrified waste.

The vitrified paint waste was collected and placed in the pot-furnace (Figure 6) and remelted according to the standard procedures discussed in the TSV process section of Chapter 2. The remelting to immobilize lead in the glass matrix resulted in approximately 7 lb of effluent. This amount is higher than previously experienced due to the addition of the soil and paint chips found in the area prior to the start of the lead abatement. The resultant effluent passed the regulatory limit of less than 5 ppm of lead as analyzed by the TCLP test (40 CFR Part 261). Figures 7a and 7b show the fire hydrant before and after the TSV removal of LBP.

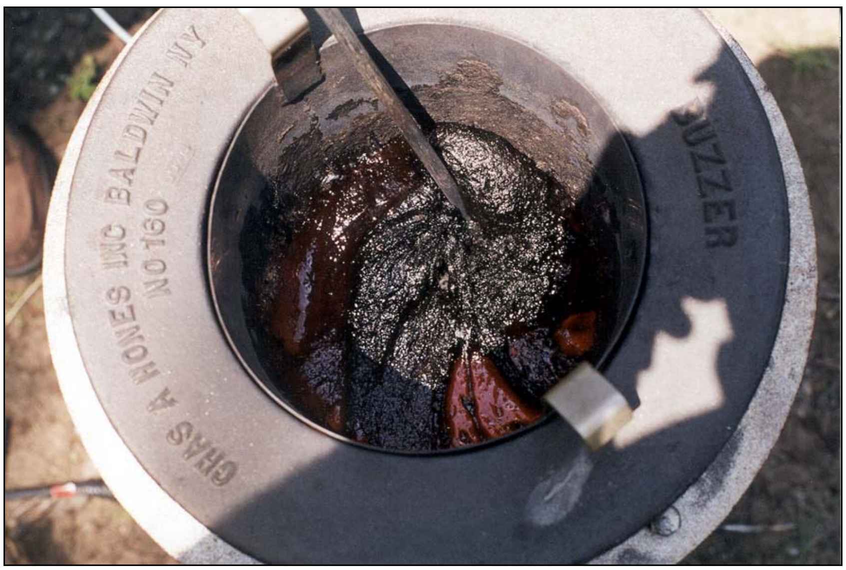

Figure 6. Top view of remelting pot showing removed vitrified waste.

Figure 7a. Fort Drum fire hydrant with LBP prior to TSV process.

Figure 7b. Fort Drum fire hydrant after removal of LBP using TSV process.

Demonstration of High-Frequency Paint Removal Device

The TSV demonstration at Fort Drum also provided the opportunity to test the efficacy of an innovative high-frequency paint-scraping device to remove paint from the substrate. The device is a hand-held tool consisting of an attached scraper powered by a high-frequency generator connected to 120-volt, 60-Hertz alternating current (AC) power. The generator provided enough energy to cause the scraper to vibrate at 20,000 Hz. These vibrations were amplified by ancillary pieces known as “booster” and “horn.” The scraper was attached directly to the horn. Secondary control of the amplitude of the vibrations was accomplished by adjusting the power supply. Several commercial horn designs were evaluated to obtain the optimum amplitude for removal of paint in the thickness range of 15 to 25 mils (0.38 to 0.64 mm). The optimum vibration amplitude was approximately 0.001 in. (0.0254 mm).

The scraper blade was a wear item, designed as a consumable, and was constructed from 16-gage mild steel (1.58-mm thick), 0.75-in. wide (1.9 mm) with a sharpened edge. Initial laboratory tests on pliable paint showed no need for a shield to catch paint chips, as they were allowed to fall from the work surface via gravity into a catch pan placed beneath the work. A “windshield” was later designed, however, to capture paint chips in cases where the paint removal was conducted where blowing winds could scatter the chips.

The fire hydrant at Fort Drum on which this device was demonstrated had several brittle LBP layers. During the demonstration, several of the paint chips broke off and were propelled several inches. The windshield was used and successfully caught the paint chips. The scraper was modified in the field to dig through the pooled paint around the threaded studs and nuts holding the cap to the body of the fire hydrant. This was accomplished by reducing the width of the scraper to approximately 3/8 in. (9.5 mm) and by cupping it to resemble a curved wood chisel. This proved to be the better configuration for removing paint from the decorative identifying markings cast into the body of the hydrant.

The procedure to remove paint from the hydrant in the field was as follows. With a capture pan placed around the base, the hydrant was charged with glass from the TSV process. The glass provided a capture and sweeping compound for the paint chips, in addition to providing some of the glass for subsequent vitrification. The operator let the vibrating scraping blade do all the paint removal work rather than try to use it as a manual scraper. The operator ensured that all the paint chips fell into the catch pan and that the vibrating unit was operating in accordance with established parameters. The chips and glass from the capture pan were then placed into the pot furnace and processed in the same manner as for TSV.

The innovative hand-held high-frequency paint removal device assisted the operator in removing LBP from the hydrant. Based on the results of this field demonstration, this generation of the high-frequency paint removal unit works best in conjunction with TSV, rather than being used alone. The scraper design needs to be improved, however, to access the small clearances between the studs/nuts and the cap for some hydrant designs, as well as other cast features in the body (e.g., decorative or identifying markings). Another obvious improvement for the field is to outfit the unit with a suction device to suck paint chips from the areas being processed in order to reduce the possibility of contaminating the area and to reduce the handling of paint chips. This would be especially useful for friable LBP, which would be removed as a combination of hazardous chips and dust. Zatorski Coating Co. is continuing to improve this system for use on metal and nonmetal (e.g., wooden) substrates.

5 Cost Assessment for Fort Drum Fire Hydrant Demonstration

Table 6 shows the cost projections of using TSV on a large number of fire hydrants, based on the demonstration at Fort Drum.

Table 6. Costs for lead abatement for fire hydrants using TSV.

Startup		**Operation and Maintenance (Surface Preparation and Repainting)**		**Demobilization**	
Activity	$	Activity	$	Activity	$
Rate (Foreman)	$25/hr	Rate (Foreman)	$25/hr	Rate (Foreman)	$25/hr
Hours	0.3	Hours	0.5	Hours	0.3
Rate (Laborer)	$21/hr	Rate (Laborer)	$21/hr	Rate (Laborer)	$21/hr
Hours	1.0	Hours	1.0	Hours	1.0
		Rate for remelt of glass assuming three hydrants	$25/hr		
		Hours	3/3 hydrants		
Labor Subtotal	$28.50		$58.50		$28.50
Consumable parts for equipment	$15	Glass Powder	$20		
		Utilities (compressed gases, fuel)	$14.5		
Materials Subtotal	$15		$34.50		
		Waste transportation and disposal (nonhazardous)	$5		
Overhead	$6		$17		$3
Category total	$49.50		$115		$31.50
Total					$196
Cost/Fire Hydrant					$196
Approx. Cost ($/sq ft)					$28

The cost estimates in Table 6 are valid for lead removal from fire hydrants, pipe stands, and related equipment by the TSV process. The data are from this demonstration, as well as a previous demonstration (see **Other Significant Observations**, p 29). The assumed labor rates are $25/hr for a painter/foreman and $21/hr for a laborer. The production rates range from 1/2 to 1 hr per hydrant depending on the number of layers of paint. The labor to remelt the glass is estimated at 4 hr using a production-type furnace. The effluent for a minimum of three hydrants can be processed at one time.

Less than 5 lb of glass was used to remove the paint from the hydrant. Additional glass was used during the remelt portion of the process due to the presence of additional paint chips and soil found prior to the start of the process. For quantity purchases, the glass can cost as little as $0.50/lb. This estimate is based on using a combination of virgin glass and recycled glass. Zatorski Coating Co., Inc., demonstrated the ability to reduce the recycled glass to usable size for the process and the ability of the recycled glass to perform in the TSV process.

The cost analysis shown in Table 6 for three applications of the TSV process shows a cost per hydrant of $196. This cost estimate uses conservative assumptions for glass consumption and amount of labor. With experience, the operators will reduce the labor content of the TSV process. Glass costs are assumed at $4/lb for small quantities of glass. The TSV process is portable and can be performed on one hydrant at a time without removing the hydrant. This allows lead abatement of hydrants and related structures to be performed as a scheduled activity or as “fill-in” jobs when time permits.

The alternative to the TSV process for hydrants is removal of the hydrants to a central facility, grit blasting, recoating and replacement. The removal and replacement of the hydrants alone needs a minimum of 2 persons at 4 hr each. At $21/hr this cost is $168. The blasting is estimated at 1.5 hr for a cost of $31.50, and the disposal of the hazardous waste is estimated at $20. This cost is $219.50 per hydrant not counting consumables such as grit, grit blast nozzles, etc. In addition, the central grit blasting facility will be contaminated with lead. Cost of painting is assumed equal for both processes. This result is a net savings of $23.50 per hydrant or 11 percent over the cost of blasting at a central facility.

6 Implementation Issues

Cost Observations

Several factors influence the cost and performance of the TSV process. The condition and thickness of the paint determines the amount of preheating and the number of glass layers that must be applied to remove all the paint to prepare the surface for recoating with a surface-tolerant paint. The complexity of the structure also negatively influences the productivity of the process. Structures with excessive bends, corners, crevices, and recessed areas are more difficult to access and may require additional time for depainting and for final cleanup before repainting. For fire hydrants, the typical time is 1/2 to 1 hr per hydrant depending on the number of layers of paint.

Performance Observations

The thermal spray demonstration was conducted on a complex cylindrical surface with decorative markings and a hemispherical cap. For LBP abatement, the TSV process reduces the amount of hazardous lead dust to levels that permit the process to be performed without special containment. Because the exposure levels for the TSV process are less than for other processes (such as abrasive blasting), the protection required for workers also may be reduced.

The waste from the process is substantially less than with other processes, and this waste is nonhazardous. The TSV process produces approximately one-half to three-quarters of a pound of nonhazardous waste for each square foot of LBP removed.

The TSV process produces a surface that needs little additional preparation for painting. These demonstrations used a needle gun to remove any loosely adhered glass materials from the surface.

The nonhazardous waste can be disposed of in a landfill or recycled for several uses, including abrasive blast media, grit for nonskid surfaces, grit for roofing shingles, or as sprayable glass for the TSV process.

The TSV technology can be used for small LBP abatement jobs with quick set-up times and low set-up costs. Examples of this type of application include highway expansion joints, bridge-bearing areas, and small freestanding infrastructure items such as fire hydrants.

Other Significant Observations

These results can be compared to a previous demonstration/validation of the TSV process for removing LBP. A technology demonstration/validation of the TSV process was conducted in 1998 at the Marine Corps Base Hawaii (MCBH) on the island of Oahu to remove LBP from interior and exterior sections (totaling 171 sq ft) of an aircraft hangar door, as shown in Figure 8 (Kumar et al. 1999; Weber et al. 1999).

The paint was about 20 mils thick on the exterior door, and 7 mils thick on the interior door. The door surfaces were relatively flat and thin compared to the fire hydrant at Fort Drum, which was cylindrical with thicker steel. Also, as previously noted, the fire hydrant presented a more complex surface with decorative markings and a hemispherical cap. Thus, the fire hydrant required preheating prior to application of the glass, whereas the hangar door did not. However, because of the thinner steel of the hangar door, 0.143 inches (3.63 mm), a water-misting system was required to prevent the door from warping. The water-misting system was not necessary for the demonstration of TSV on the fire hydrant. Paint with a thickness of 10 to 25 mils (0.25 to 0.64 mm) was removed from the MCBH hangar door in two applications of glass at a rate of 35 sq ft/hr, for an average production rate of 700 mils-sq ft/hr. LBP was removed from the fire hydrant at Fort Drum in about 0.5 hr with the assistance of an innovative high-frequency paint scraping device. The surface area of the fire hydrant from which paint was removed measured approximately 7 sq ft. Thus, the paint removal rate from the fire hydrant was estimated at 280 mils-sq ft/hr, considerably lower than the paint removal rate for the hangar door. This difference in production rate can be attributed to the fact that it is considerably more difficult to remove paint from the cylindrical surfaces of the fire hydrant. The high-frequency paint scraping device proved to be efficacious in removal of the LBP from the fire hydrant when used in conjunction with TSV; however, this device was not available for the TSV demonstration on the hangar door. Its use probably would have increased production rates for such typical flat surfaces.

Figure 8. Application of the TSV process to remove LBP from a hangar door at Kaneohe Marine Corps Base, HI.

Table 7 shows the costs of removal of LBP for a 1,000-sq-ft application, based on the demonstration of TSV on the hangar door at MCBH. In this case, the estimated cost of using the TSV process ranged from $3.52 to $3.89/sq ft.

The cost of TSV processing for fire hydrants was estimated at $196 per hydrant, or about $28/sq ft. The increased complexity of the convoluted surface of the fire hydrant, and tight clearance constraints increases the cost per unit area about seven-fold, compared to the relatively flat surface of a hangar door. As previously noted, however, the use of the TSV process to remove paint from the fire hydrant is projected to result in an 11 percent savings over the cost of removing the hydrant to a central facility to perform abrasive blasting, and then reinstalling the hydrant.

Regulatory and Other Issues

The principle regulatory issues involve the protection of the environment and the worker during LBP abatement. The principle regulatory drivers are: (1) Clean Air Act (CAA) and the 1990 CAA Amendments, including the National Emission Standards for Hazardous Air Pollutant (NESHAPS), (2) Clean Water Act (CWA) of 1977 as amended with the National Pollution Discharge Elimination System (NPDES) Permit Requirements, and (3) Resource Conservation and Recovery Act (RCRA). The principle regulatory drivers to protect workers during LBP abatement are: (1) Title 29, Code of Federal Regulations (CFR) Part 1910, Occupational Safety and Health Administration, "Safety and Health Regulations for Construction."

Table 7. Costs for lead TSV process for a 1,000-sq-ft flat surface application (based on demonstration on MCBH hangar door).

Startup		Operation and Maintenance (Surface Preparation and Repainting)		Demobilization	
Activity	**$**	**Activity**	**$**	**Activity**	**$**
Rate (Foreman)	$25/hr	Rate (Foreman)	$25/hr	Rate (Foreman)	$25/hr
Hours	8	Hours	19 – 31	Hours	8
Rate (Laborer)	$21/hr	Rate (Laborer)	$21/hr	Rate (Laborer)	$21/hr
Hours	0.5	Hours	6-8	Hours	8
	8	Rate (Foreman) for remelt	$25/hr		
		Hours	8		
Labor Subtotal	**$368**		**$801-$1,143**		**$368**
Materials for Containment of glass	$100	Glass Powder	$500		
		Utilities (compressed gases, fuel)	$200		
Misc. Materials			$100		
Materials Subtotal	**$100**		**$800**		
		Consumables	$175		
		Equipment Depreciation (10 yr, 60%)	$10		
		Worker Protection, environmental and health monitoring	$250		
		Waste Transportation and disposal (nonhazardous)	$125		
		Waste disposal (hazardous)	$200		
Overhead	$47		$236 – 270		$37
Category total	**$515**		**$2,597-$2,973**		**$405**
Total					$3,517 - $3,893
Cost ($/sq ft)					**$3.52 - $3.89**

Based on data and regulatory permission obtained on previous demonstrations, this activity is classified as a repair/construction activity and does not need EPA air permits.

Regulatory acceptance for this demonstration was based on the successful demonstration and data from the demonstration of the TSV process at Rock Island, IL (Boy et al. 1998) and the data from the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) reports (Carol 1997a, 1997b).

The TSV process involves both removal and subsequent onsite remelting of the glass. The EPA views this as a single operation and not a waste treatment operation based on the Illinois EPA Division of Air Pollution Control classifying the TSV process as a repair/construction activity and regulating the process as an LBP cleaning operation. The contract required onsite melting of the glass to complete the TSV process and render the waste as nonhazardous. This step was completed and the waste was ground into powder for reuse. A sample of the processed glass was retained for reference.

Lessons Learned

- This project demonstrated and validated the TSV process for safely and effectively removing LBP from a cylindrical fire hydrant at Fort Drum. The main environmental and technology issues documented were: (1) the number of passes required to remove the lead from the surfaces, (2) the production rate under field conditions, (3) verification that the glass can be classified as a nonhazardous waste after being remelted, and (4) the projected costs for implementation.
- From previous work, when the TSV process is used in a well-ventilated outdoor area, the workers should wear a NIOSH-certified half-face air-purifying respirator equipped with high-efficiency particulate air (HEPA) filters, a face shield, and protective gloves.
- During remelting of glass, workers do not need to use respirators; however, face shields and protective gloves should be worn.
- Onsite homogenization requires a minimum of 5 hr at 1470 °F (800 °C) to ensure homogenization of the melt and full immobilization of the hazardous species in order to render the waste nonhazardous.
- Production rates for the TSV process are about 35 sq ft/hr on flat areas. For fire hydrants, the typical time is 1/2 to 1 hr per hydrant depending on the number of layers of paint.
- The cost of LBP removal by TSV for a fire hydrant is about $196 per hydrant. The low cost of disposal is the result of the small amount of effluent produced and the effluent being nonhazardous. The cost does not appear to vary with hydrant type or complexity.
- An innovative high-frequency paint-scraping device proved to be efficacious in assisting in the removal of the LBP when used in conjunction with TSV. Some modifications were suggested to reshape the tool end of the unit and to provide a suction device to reduce the possibility of lead-dust contamination.
- The glass waste from the TSV process can potentially be recycled using commercial processes that convert the waste into nonhazardous value-added glass or ceramic products such as abrasives, construction materials, refractory insulating materials, or new glass powder for the TSV process.

The TSV process is especially effective where the cost of full-containment structures cannot be spread over a large area. This includes zone lead abatement for large structures and small fixed structures such as fire hydrants, posts, highway overpass rails, fence posts, light stands, fire call boxes, etc.

Process Scale-Up

The estimated surface area of steel structures at Army facilities such as water tanks, bridges, aircraft hangars, antennas, ladders, poles, railings, catwalks, metal buildings, etc. is about 118 million sq ft. The total surface area of steel structures in the DoD is estimated at 200 million sq ft. The U.S. Army Corps of Engineers (USACE) also has 275 navigation locks and dams and 383 other dams with service bridges on lakes and reservoirs, which have an estimated 100 million additional square feet of steel. Most of this steel was coated with red lead oxide primer to protect it from corrosion. Over the next 20 years, this steel will have to be repainted. The cost analysis, based on data collected during the demonstration, estimated the cost of the TSV process to range from $3.50 to $9.50/sq ft with an average cost of about $5.00/sq ft. This is $3.00/sq ft less than the currently used abrasive blasting, which has an average cost of $8.00/sq ft.

To fully commercialize the TSV process, scale-up of the glass remelting process will be required. Scale-up would include the use of a larger size glass melter so that all the vitrified glass from one day's paint removal could be remelted in one operation. The larger melter would also permit measurement and control of the melt temperature and could provide stirring of the molten glass. Such a melter may require mounting on a truck or a trailer to be deployable in the field.

Alternately, the vitrified glass could be recycled and used as feedstock to produce new glass powder or other glass or ceramic products. According to the recycling exemption of the RCRA, the vitrified product would not be classified as solid waste if it is used or reused as an ingredient in an industrial process to make a product (Seiler 1997). Recycled products can be other glass or ceramic products. Potential uses currently under investigation by Seiler Pollution Control Systems, Inc., Dublin, OH, include abrasive grit blasting media for blasting, buffing, and polishing applications as well as roofing tile granules and architectural materials. Seiler has received approval from the California EPA's Department of Toxic Substance Control (DTSC) to produce recyclable materials from three different waste feed stocks: abrasive blast media, steel mill dust, and industrial wastewater treatment sludge.

Tyndall Air Force Base (AFB), FL, used this procedure to remove LBP from over 300 fire hydrants during 1998 and 1999. Personnel at Tyndall AFB had considered alternative paint removal options, and deemed this technology the most suitable for LBP removal from fire hydrants. After they purchased the necessary equipment (similar to that described for the technology demonstrations at MCBH and at Fort Drum, NY), Tyndall provided training on operation of the TSV process to their in-house personnel. As a result, in-house resources are available to remove LBP from other small structures should the need arise. Use of this process is estimated to have saved Tyndall AFB approximately $7,000 versus blasting at a central facility.

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14. ABSTRACT

The thermal spray vitrification (TSV) process was developed and patented by the U. S. Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL) to remove lead-based paint from steel structures. TSV consists of spraying a molten glass from a thermal spray torch onto a painted steel surface. When the glass strikes the paint, it pyrolyzes the organic components, and lead is trapped within the glass, which cracks and spalls off the substrate. Remelting the vitrified paint residue immobilizes the lead in the glassy iron silicate matrix, and renders the waste nonhazardous.

This report documents the results of a demonstration of TSV on a fire hydrant at Fort Drum, NY, along with an innovative hand-held high-frequency paint removal device that was used in conjunction with the TSV process.

TSV results in significant cost savings, as no containment structures or worker health and environmental monitoring are required. The formation of a nonhazardous waste also decreases disposal costs. At this time, the TSV process is best suited to niche markets where the cost of full containment structures cannot be spread over a large area.

15. SUBJECT TERMS
lead-based paint (LBP), thermal spray vitrification (TSV), Fort Drum NY, cost analysis, environmental compliance, steel structures

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