FINAL REPORT

FIELD TEST OF A NEW PROCEDURE FOR REMOVING LEAD-BASED PAINT FROM BRIDGES

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INTRODUCTION

According to the National Bridge Inventory, of the more than 200,000 steel bridges listed, between 80 and 90 percent of them were painted with lead-based paint (Appelman, 1998). Of the approximately 7,000 bridges in Virginia with steel superstructures, well over half were painted with paint systems that contain lead-based formulations (Virginia Department of Transportation, 1998). Making repairs to such superstructures is complicated by the necessity of having to deal with the presence of lead, from the standpoints of both the environment and worker health.

Lead is the fifth most widely used metal in the industrial world. Although its use has enabled technological and cultural development for thousands of years, its use has also created problems in public health that have fomented pain, suffering, and economic loss to generations around the world. The lead compounds used in gasoline and traffic paints have contributed to high levels of lead in the soil immediately adjacent to many of the nation's highways, especially in urbanized areas (Society for Protective Coverings, 1997).

Mitigating the ill effects of lead is a physical and economic burden that has plagued many public works agencies at all levels of government, as well as the owners of private facilities. The predominant method for removing paint in preparation for repainting involves abrasives blasting, i.e., using specific media particles in a compressed air stream directed against the painted surface. The blast particles are composed of, typically, natural and synthetic aggregates and metals such as iron, steel, and copper. Federal and state regulations now require stringent containment around the work area and tight control of the paint dust, debris, and spent abrasives. Any generated debris determined to be hazardous, as defined by the federal Resource Conservation and Recovery Act, must be disposed of in a legal and thoroughly documented manner. The owner of the structure is responsible for the ongoing disposition of the debris.

Issues Regarding the Removal of Lead Paint Systems from Highway Structures

In a recently published national study of lead paint removal from bridges, the number of structures painted in the two time periods 1986 through 1989 and 1993 through 1996 decreased 39 percent (4,377 in 1993-96 versus 7,150 in 1986-89) while the amount of money expended more than doubled ($400 million in the former period and $938 million in the latter) (Appelman, 1998). These figures reflect combined overcoat painting and full removal repainting efforts. The marked reduction in the number of structures painted reflects the environmental and worker protection regulations now in effect. Figure 1 shows that from 1990 to 1996 the number of bridges painted by the Virginia Department of Transportation (VDOT) has decreased by 86 percent (VDOT, 1998). The escalating costs of removing paint and repainting steel structures have significantly affected the budgeting of bridge coatings maintenance as the increased costs are contrasted by the even greater needs (National Cooperative Highway Research Program, 1997).

The principal causative factor in this decline is the cost of removing paint using traditional abrasives blasting. At the center of the increased cost of cleaning and repainting bridges are the expenses required to provide mandated systems to protect the environment and worker health (NCHRP, 1992, 1997).

One aspect of repainting older steel involves the presence (or absence) of mill scale. Mill scale is a product of steel production. It is an iron material approximately 50 to 100 μm thick that tightly adheres to the surface of steel. On older structural steel (before 1984 in Virginia), when lead-based paints were being specified, many owners (VDOT included) did not require that bridge steel be shot blasted as part of the fabrication process. Mill scale was left on the steel surface. Red lead paint, then the typical primer of choice, was (and still is) singularly effective in providing a strong, long-lasting bond to the steel. Life spans of 30 years or more were common for these systems.

New steel beams or girders are shot blasted at the fabrication facility to remove mill scale and provide surface profile. At VDOT, and typically elsewhere, zinc-rich primer paint is applied in the shop and the intermediate and finish coats are applied in the field. This ensures that the steel is prepared and protected in as effective manner as practicable as soon as possible after manufacture. For a period, even through many steel structures were shot blasted at fabrication, lead-based paint was still used, as was the bridge that was the subject of the current study.

Newer paint formulations, particularly the popular zinc-rich primers, are much less tolerant to surface contamination and the less-than-pristine conditions bridge repainting work encounters. Requirements for reduced volatile organic compound (VOC) emissions from paints have made the formulation of effective paint systems more difficult. Once the old coating system is removed, flash rusting and other surface contamination, both visible and microscopic, can contribute significantly to early paint system failures.

Thus, as the paint systems on older steel beams deteriorate, bridge owners are faced with having to make multiple decisions that are often unique to the bridge in question. On short spans (< 25 m), replacement of the structure may be the most economically viable choice based upon

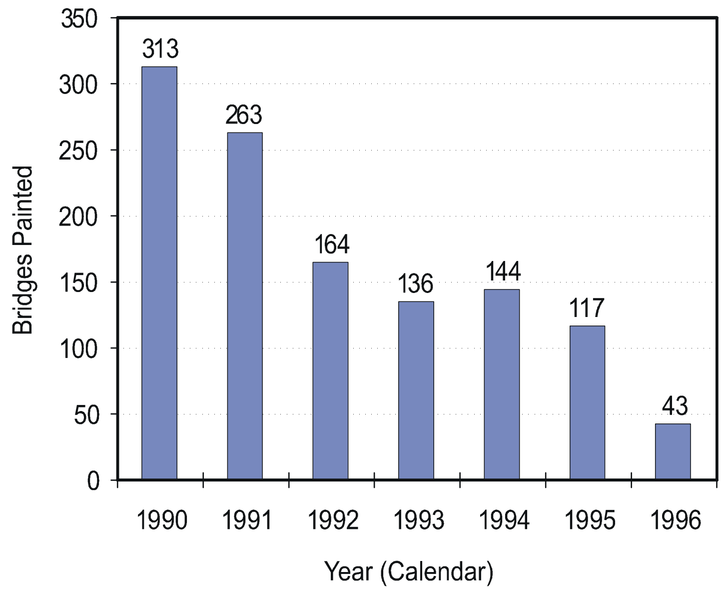

Figure 1. Steel Beam Bridges Painted by VDOT Annually

high unit costs for removal and painting for such short structures. Many structures in this length category are having their beams replaced with new steel or refurbished beams that have been galvanized. For longer spans, deciding whether to remove the existing paint completely, partially, or paint over the existing paint is a choice that should be weighed for cost-effectiveness. Making the right decision in a timely manner can possibly save many thousands of dollars for a particular bridge (Mickelsen & Haag, 1997).

ElectroStrip™

The environmental and health-related complications and resulting costs in dealing with lead-based paint on structural steel and the indecision by owners in taking timely action are manifest in the decreasing number of bridges being painted. Alternative removal systems have been developed in an attempt to address the weaknesses of traditional abrasives blasting removal. The hazardous waste aspect and owner liability in perpetuity have been specific areas of concern. Because of these related regulatory requirements, many alternative paint removal methods have been developed to address one or more aspects of the regulations.

One such method is ElectroStrip™ (ElectroStrip), an electrochemical, cathodic reaction process that causes paint to debond from the surface. The patent for ElectroStrip (U.S. Patent No. 5,507,926) is held by EMEC Consultants, Export, Pennsylvania. Research in developing this method was funded by the National Cooperative Highway Research Program (NCHRP) Innovations Deserving Exploratory Analysis (IDEA) Program. ElectroStrip is a prototype process that is moving from the laboratory and small scale testing to the field trial stage. NCHRP-IDEA Project 23 (NCHRP, 1996) was the initial funding effort that led to the field trial of ElectroStrip, which was NCHRP-IDEA Project 38 (NCHRP, 1998), and its evaluation in this report.

The ElectroStrip process is driven by the application of low direct current (DC) voltage to the steel beam. The structural steel of the bridge serves as the cathode side of the reaction. An absorbent pad with imbedded screening is the anode. The pad is held against the painted steel surface with magnets. The passage of current is facilitated by the presence of a pH-neutral electrolyte saturating the pad material. The density of the current is initially 1,000 A/m^2, and it has decreased to about 500 A/m^2 by the end of the 90-min cycle. Figure 2 is a schematic representation of the process.

In order to take the laboratory-scaled ElectroStrip process to the level necessary to demonstrate real-world ability to remove bridge paint, equipment and practices modifications were necessary. A much larger DC rectifier was obtained. Additionally, preliminary equipment tests were conducted on a PennDOT bridge in the Pittsburgh area using multiple pads and the new rectifier and power delivery equipment. The bridge carried Route 28 over State Route 1037 (Saxonburg Road) (NCHRP, 1996, 1998). In addition, KTA-Tator, Inc., an industrial consultant with laboratory capability, conducted environmental and worker health monitoring of the ElectroStrip process during these multipad tests. The results of these tests are provided herein.

PURPOSE AND SCOPE

The purpose of this study was to document and evaluate the first production-level field trial using ElectroStrip to remove lead-based paint from a bridge. One interior beam of a three-span simple beam structure (VDOT No. 2066) in Arlington County, Virginia, was used in the trial. This bridge had 21 beams, with 7 beams per span.

METHODOLOGY

The ElectroStrip trial was included in a bridge painting contract awarded to Superior Painting & Contracting Co., Inc. (Baltimore, Maryland). The general contract called for the cleaning of the structural steel elements of the eastbound and westbound lane structures carrying I-66 over Westmoreland Street (milepost 68) in Arlington County using pressure washing with water ($\geq 3.45 \times 10^4$ kPa). Rust areas were to be hand/power tool cleaned in accordance with SSPC-SP2/SP3. One interior beam 19.5 m long with a variable depth of 0.91 to 1.42 m, representing approximately 74 m^2, on the three-span, simple beam structure carrying the eastbound lane was designated for full paint removal using ElectroStrip.

The methodology for this case study consisted of the following tasks:

1. Review paint removal technology in the literature.

2. Determine what comprises the existing paint system on the Westmoreland Street Bridge.

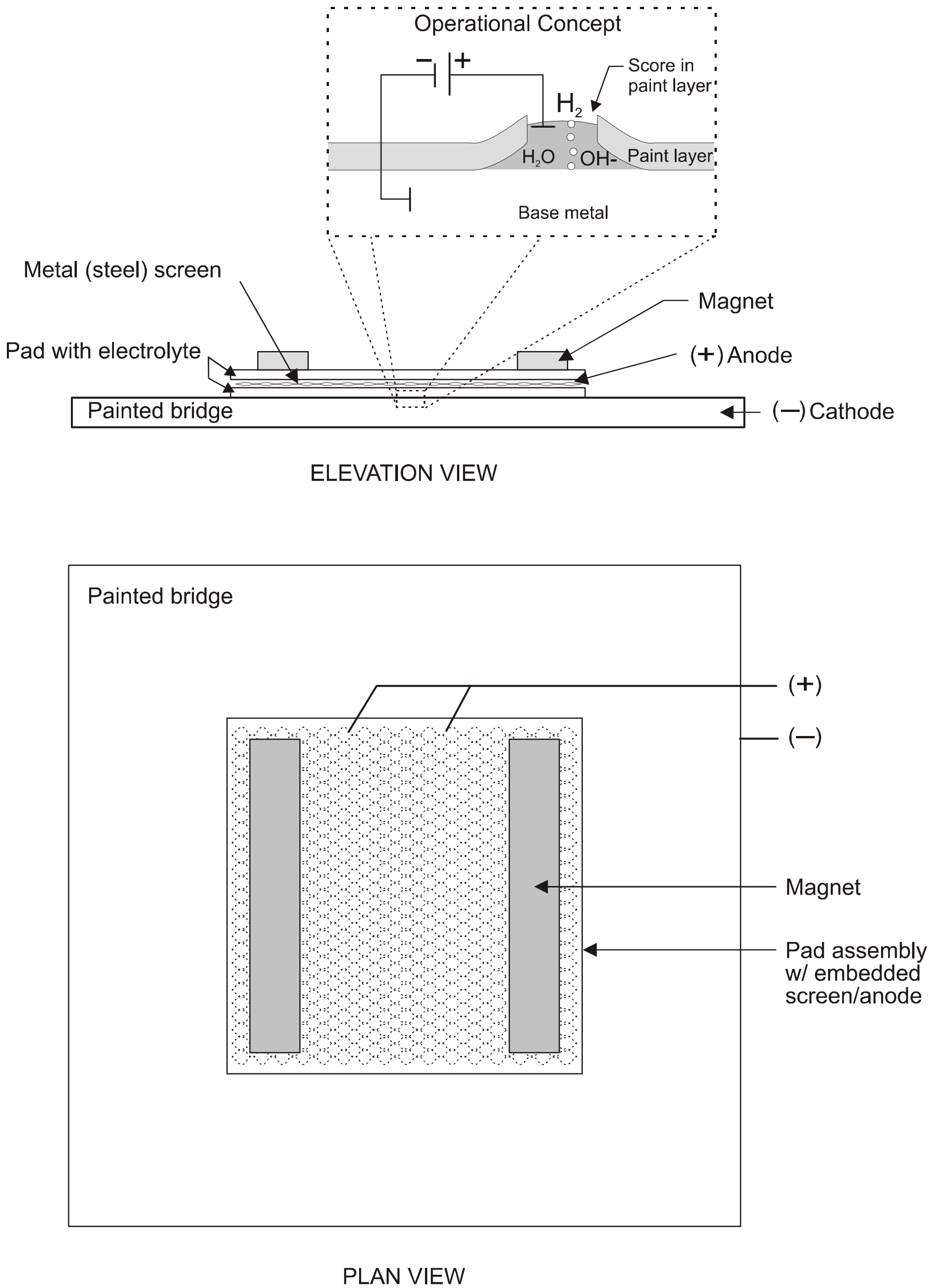

Figure 2. ElectroStrip Process

3. Monitor, document, and visually record the trial operations as to resources used, time expended, and environmental effects during the removal process.

4. Determine the effectiveness of the ElectroStrip process.

Review of Paint Removal Technology

The literature search was conducted through the use of the Transportation Research Board's Silver Platter, past issues of the *Journal of Protective Coatings and Linings,* and course materials for SSPC-C3, a course offered by the Society for Protective Coverings to certify lead workers/competent persons for supervising the removal of lead-based products.

Determination of Existing Paint System

The existing paint system was evaluated for composition (including lead content and other heavy metals), thickness, physical adhesion, and general condition in accordance with industry-accepted equipment and protocols.

Monitoring and Documentation of Trial Operations

The procedures used, the resources used, the time expended, and the environmental effects of using ElectroStrip were monitored during the removal process. Photography, still and video, was used to provide a record of the beam before and during the ElectroStrip trial. Inspection records were used for the approximate personnel-hours and beam areas stripped. Air quality was monitored using PM-10 and total suspended particulate (TSP) high-volume monitor devices. The worker exposure to lead was monitored using personal air sampling monitors on workers. The air quality and worker exposure monitoring was done under the supervision of a Certified Industrial Hygienist and in accordance with VDOT contract specifications.

Determination of Effectiveness of Removal Process

The measurement of the effectiveness of the ElectroStrip process was based on an observed estimate of the results of a particular run and was done in discussion with the VDOT inspector (certified by the National Association of Corrosion Engineers) who was always on site.

RESULTS AND DISCUSSION

Review of Paint Removal Technology

In the review provided here, abrasives blasting is discussed, and then alternative removal methods are discussed and compared with abrasives blasting (NCHRP, 1992, 1997).

Abrasives Blasting

Abrasives blasting is a very effective, productive, and desirable method for preparing painted steel for new paint. Costs increase significantly, however, when it is necessary to engineer, erect, and maintain a full containment "envelope" around the structural steel that needs to be cleaned. In accordance with federal, state, and local regulations, lead-based paint debris and lead-contaminated spent abrasives must not fall onto the ground or into the water below and around a bridge being cleaned for repainting. The integrity of containment, and the disposition of resulting waste and debris, from an environmental standpoint, is the purview of the federal Environmental Protection Agency.

Associated with this type of removal process is a higher worker exposure to and possible contamination from the presence of lead and other hazards in the paint being blasted from the steel. To protect the workers inside and outside the containment of the structure being cleaned, rigorous health monitoring and hygiene procedures must be put in place and complied with. Federally, the Occupational Safety and Health Administration sets the regulations for exposure limits and polices the work to ensure compliance.

The reason abrasives blasting is such a desirable method for removing paint from structural steel, in spite of its expense, is the surface profile, or roughness, it imparts to the metal surface. In the process of removing the coating, the abrasive grit pits the metal to a depth between 25 and 75 µm, depending on the grit media used and the type of steel. The profile created helps physically anchor the paint to the metal. This is an important quality. It is especially so for steel that has not had the mill scale removed before the initial coat of paint. A weak physical bond between paint and metal leads to premature failure of the paint system, no matter how carefully the paint is applied. Other factors contribute to paint failure, to be sure, but the integrity of the paint-metal bond is critical.

Abrasives blasting does have disadvantages. The process of forcefully impinging the grit particles against the painted surface removes most of the paint from the surface; however, there are instances when the particles fold over peaks in the profile, entrapping minute particles of paint. Surface contaminants such as chloride salts may also be entrapped and shorten the life of the new coating.

In terms of the actual process of abrasives blasting, there is a large requirement for support equipment in addition to other "overhead." Such requirements include air compressors; ventilation/air handling/filtration machinery; abrasive media storage, recycling, and waste containers; and storage for the blasting-related tools (hoses, nozzles, helmets, suits, etc.). For worker safety and hygiene, requirements include changing areas, showers, lunches, and monitoring.

Water Jetting/Spraying Under a Variety of Pressures

The advantages of these techniques are that they lend themselves to recycling, the debris amount is less than with abrasives blasting, they are fairly quiet, the degree of containment required is less than with abrasives blasting, the work environment for workers is more comfortable than with blasting, the worker exposure to lead is reduced compared to blasting, surface contaminants (ions of chlorine and sulfate) are reduced significantly if not eliminated, and complete paint removal (SSPC 10, near white metal, typical) is possible.

The disadvantages of water jetting include the fact that the cleaned surface flash rusts rapidly after the paint has been removed, containment and collection of waste are issues, as a zero emission condition is difficult (i.e., expensive) to achieve, it does not impart a profile unless an abrasive is mixed in with water (which adds to the debris amount), and the ability of the water to be recycled is questionable, especially at high and ultrahigh pressures.

Chemical Strippers

Advantages of using chemical strippers are that the method is quiet, there are no airborne contaminants, the containment requirement is substantially less, the lead exposure hazard to workers is significantly less, and the debris volume is reduced.

The disadvantages of using chemical strippers are that they are hazardous; corrosive chemicals must be dealt with, which creates a unique set of worker safety guidelines; the steel must be pressure washed after the chemical has been applied; flash rusting of the bare steel readily occurs; and the method is more costly because of the reduced production rate, increased materials costs, and debris disposal issues. In addition, chemical stripping imparts no surface profile to the bare steel.

Air Blasting with Other Media

Paint removal using other types of blasting media (e.g., walnut shells, sponges, plant starch, carbon dioxide ice pellets) has unique advantages. It is particularly beneficial for use on more sensitive and otherwise exotic substrates such as aircraft where the metal may be thinner or the substrate may not even be metal. By virtue of there being “natural” products and by-products, these media also have the cachet of being more environmentally friendly and even beneficial.

The disadvantages of using these methods are more numerous. Being somewhat exotic, the equipment necessary to use them is often more expensive, with unique parts. This translates often into higher equipment costs and reduced production rates. The debris issue is still prevalent. Further, surface contamination can still be a problem. Very little, if any, surface profile is created, particularly on steel.

Chemical Additives in Combination With Traditional Abrasives That Render the Lead Compounds Nontoxic and Nonhazardous (Blastox™, Pretox™, Leadx™)

The advantages of this category are potentially significant. The resulting blast debris is not considered a hazardous waste since the lead in the paint removed is chemically stabilized. The debris can be disposed of in a standard landfill or, in the case of Blastox™ and Pretox™, used as feedstock in the manufacturing of cement. In addition, with conventional blast media, surface profile is created. Conventional equipment is used, and it can be used with all blast media. Record keeping and reporting requirements are reduced.

The disadvantages are that worker exposure is the same as with conventional blasting, as are the containment issues. There is an additional expense because of the cost of the material. Recycling of spent abrasives is a problem and is not well documented.

Composition of Paint System on the Westmoreland Street Bridge

The paint on the Westmoreland Street Bridge consisted of an apparent two-part alkyd paint system that had a combined composition as described in Table 1.

Table 1. Composition of Paint on Westmoreland Street Bridge

Element	PPM[a]	%
Lead	167217	16.7
Chromium	11720	1.17
Aluminum	649	0.06
Copper	12.4	<0.01
Cadmium	<2	<0.01

[a]Parts per million via atomic absorption, using EPA SW-846 test protocols.

The thickness of the paint on the beam used in the trial (Beam 2) was 184 μm (Defelsko Positector 6000 electronic gage; protocol SSPC-PA 2). Table 2 shows the dry film thickness of the paint on several beams. When compared with the thickness of the paint on the trial beam, the other readings compare very favorably.

Table 2. Thickness of Paint

Location	Red Primer (μm)	Buff Topcoat (μm)	Total Dry Film Thickness (μm)	Gage Type
Beam 2, East Abut.[a]			184.0	Electronic
Beam 4, East Abut.	177.8	127	284.8	Tooke
Beam 5, East Abut	76.2	127	183.2	Tooke
Beam 5, East Abut			190.0	Electronic
Beam 5, East Abut			203.2	Electronic
Beam 5, East Abut			185.4	Electronic

[a]Beam 2 was the trial beam. For the bridge, the beams are numbered 1 through 7, outside EBL to inside EBL, or south to north.

The data in Table 3 represent the paint adhesion on Beams 4 and 5 measured in accordance with ASTM D-4541. They are meant only as representative examples, as no readings were taken of the paint on the trial beam. The pull-off test readings indicated good adhesion, with the two layers failing cohesively rather than delaminating between the primer and steel or the topcoat and primer. The data in Tables 2 and 3 reflect the conditions *typical* of the paint system on the bridge.

Table 3. Paint Adhesion

Location	Paint	Adhesion (MPa)	Failure Mode
Beam 5, East Abut.	Topcoat	2.8	100% cohesive in topcoat
Beam 5, East Abut.	Topcoat	3.1	100% cohesive in topcoat
Beam 5, East Abut.	Topcoat	3.1	100% cohesive in topcoat
Beam 4, East Abut.	Primer	3.5	100% cohesive in primer
Beam 4, East Abut.	Primer	4.1	100% cohesive in primer

The general condition of the paint on both structures involved was mixed: the red lead primer was in good condition with very tight adherence (with the exception of approximately 5 m^2 of rust indicated on the north fascia beam of the companion westbound lane bridge). The existing topcoat paint layer was severely peeling on most of the beams and diaphragms of both structures. There were also areas of significant rust on the companion, parallel structure (westbound lane).

Monitoring and Documentation of the Paint Removal Process

The contractor elected to do the ElectroStrip portion of the work first and by itself. The work began on May 11, 1998, and concluded on May 19. The contractor provided a crew of two laborers, scaffolding, and establishment of traffic control on Westmoreland Street. Dr. Rudolf Keller and two technicians led the ElectroStrip contingent. Over the course of 7 workdays from May 11 to May 19, 1998, the contractor and the ElectroStrip personnel removed the paint from the 74-m^2 surface of the target beam. The team worked from approximately 7:00 A.M. to 4:30 P.M. each weekday. There was no work done on Sunday.

To prepare a coherent paint coating for removal, it must be scored through to the substrate. This allows the reaction to be more effective in debonding the paint. For effective use, score lines or marks must be 1 cm, or less, apart. For this trial, an electrically driven Roto-Peen tool was especially fitted with star wheels of the requisite separation. The Roto-Peen tool was also connected to an approved high-efficiency particulate air (HEPA) vacuum device for environmental and worker protection purposes.

An electrical rectifier of sufficient capacity is needed to convert the 480 VAC, 3Ø input power to the low DC voltage–high amperage electrical energy needed to drive the electrochemical reaction. The rectified power is supplied to the structural steel via heavy cables and large aluminum or copper bus bars.

The work sequence was as follows:

1. preparing (scoring) the surface of the beam using the specially configured Roto-Peen tool

2. placing the ElectroPad™ material saturated in electrolyte on the prepared steel (The pads were held against the steel by permanent magnet strips mounted to stiff plastic tile grids having the same dimensions as the pads; approximately 5.6 m² of pads were set up per trial.)

3. making the electrical connections between the pad anode screen and the DC bus bars

4. energizing the pads (18 VDC at 3,000 A initially)

5. monitoring the pads while they were energized and keeping them moist with the pH-neutral electrolyte solution (sodium sulfate)

6. after 90 minutes, de-energizing the circuit; disconnecting the leads; and removing magnets, backing, and pads

7. wiping down the area treated with water-moistened paper towel–type material

8. using a washer/vacuum/recycling device on the treated surface area

9. using power or hand tools on areas where the paint was not removed and recycling wash.

Table 4 provides a summary of the work schedule and the results obtained.

Table 4. Summary of ElectroStrip Project Activities

Date	Weather	Temp. (° C)	Relative Humidity (%)	Personnel-Hours Worked	Area Stripped (m²)	Comments
05/11/98	Rain	N/A	N/A	18.0	0.0	EMEC Consultants set up their equipment and supplies
05/12/98	Rain	N/A	N/A	72.3	11.15	Site prepared: scaffolds, bus bars, cabling, etc.; 2 runs made
05/13/98	Partly cloudy to sunny	19.0	70.0	38.25	16.71	3 runs: first 2 poor; third good; some areas recorded and retreated
05/14/98	Sunny	18.9	94.0		16.71	3 runs: first 2 are redos; third new
05/15/98	Sunny	23.3	59.0	25.0	11.15	2 runs; demo/open house
05/16/98	Sunny	30.0	57.0	6.0	5.57	1 run; paint contractor did not show; several surface tests done
05/18/98	Sunny	27.2	51.0	16.09	11.08	2 runs; scaffold cable damaged; further work curtailed.
05/19/98	Sunny	28.9	48.0	25.33	5.57	1 run (last); power wash; remove rigging, etc.; some power tool cleaning
Total				200.97	77.94	[Surface area exceeds 74 m² because of retreatments.] Based on total surface to be cleaned, overall production rate was 0.37 m²/personnel-hour

The equipment used for the paint removal operation consisted of the following:

- diesel-powered generator (125 kVA generator; 480 VAC, three phase)
- trailer-mounted 4,000-A rectifier
- heavy-gage electrical wiring
- solid aluminum bus bars (approximately 800 mm in width by 2 m in length by 30 mm in thickness)
- miscellaneous equipment and supplies necessary to the process.

Especially initially, there were loud, rapid detonations of, apparently, hydrogen off-gassing as the reaction progressed. The most frequent and loudest "bangs" occurred in the first 30 minutes. The frequency and intensity diminished considerably after that point. In the last 30 minutes, there was very little reaction detonation. According to the developer of the process, these detonations were "normal." He indicated that similar detonations had occurred during the Pennsylvania trial. Noise level readings were not taken, but even the loudest explosions did not seem to be unacceptably loud for envisioned uses of the process. A subsequent change in the pad placement technique appeared to reduce the frequency and intensity of the noise problem.

The fog was apparently a product of recondensing water vapor resulting from the heating of the electrolyte in combination with a particularly humid, rainy, and cooler day. In drier, warmer weather conditions later in the week, there was very little, if any, fog. The process did elevate the surface temperature. Surface temperature increased from 20.0 ºC before the removal to 54.4 ºC after the removal, an increase of 172%.

Effectiveness of Removal Process

General

The runs made with the smaller generator yielded very poor results, i.e., 50 % or less effective paint removal. When the larger generator was used, the results increased significantly. The first run with the larger generator was approximately 90% effective in removing paint. Subsequent trials were less effective (but were still more effective than the first series with the smaller generator). The range was from 90% to approximately 70%. Generally, the trial went very well. The real slowdown was caused by the need to change the generators. The weather was sufficiently varied (cool/damp to hot/humid) to determine that it was not a factor in removing paint with ElectroStrip.

The surface profile on the steel substrate after the paint was removed was measured using Press-O-Film tape. A 56-μm peened surface was measured. This value was consistent with similar measurements taken by others during the trial.

Surface contamination by microscopic chemicals (particularly ions of sulfate and/or chloride) imbedded in the surface irregularities of the steel beams had been a concern in using ElectroStrip. The presence of such ions interferes with the bond between the paint and substrate. It appreciably shortens the life of new paint, no matter what system is used. Measurements taken before and after the process indicated that the levels of chloride (Cl^-) and sulfate (S^-) ions did not change. The data indicated that the level of each returned to the preprocess level at the completion of the paint removal procedure. The sulfate values increased from 8 $\mu g/cm^2$ preprocess to 160 $\mu g/cm^2$ after the pads were removed but before the steel was cleaned with the recycling washer/vacuum (Table 6). This was expected because of the use of sodium sulfate (Na_2SO_4) as the electrolyte that facilitates the electrochemical process. Further study of this aspect of the process is warranted, particularly on painted steel with known and well-defined chloride contamination.

Table 6. Surface Contamination

Surface	Cl^- ($\mu g/cm^2$)	S^{-2} ($\mu g/cm^2$)	Fe^{+2} ($\mu g/cm^2$)	Conductivity ($\mu S/cm$)
Untouched paint	0-2	8	0	360
Pads removed/steel scraped	0-2	30	0	530
	DNM[a]	24	DNM	350
	DNM	160	DNM	330
	DNM	24	DNM	DNM
	DNM	96	DNM	DNM
	DNM	56	DNM	DNM
After pressure wash	0-2	8	DNM	18
	DNM	8	DNM	25
	DNM	DNM	DNM	52

[a]DNM = did not measure.

Absence of Flash Rust

Following the use of the ElectroStrip process, there was no flash rust or rust bloom on the beam. Flash rust (iron oxide) typically occurs within hours after the paint is removed, especially after power washing. This lack of flash rust was noticed in earlier, smaller trials used to test the pad design and other aspects of the process. There was, in contrast, flash rust on areas where the paint was removed by power tooling. VDOT specifications require that bridge steel to be repainted is free of visible rust.

Current thinking (NCHRP, 1998) is that the ElectroStrip process so negatively charges the substrate that rusting is inhibited for a prolonged period. There is also the possibility that a minute amount of lead is reduced from the paint and plates the steel, providing protection from oxidation. Two wipe samples showed that after ElectroStrip, the amount of lead on the surface was 0.23 $\mu g/cm^2$, and that after ElectroStrip and a light water rinse, the amount was 0.08 $\mu g/cm^2$. It is also possible that the lead measured was from the steel itself. Researchers at Lehigh University and the University of Pittsburgh are planning to investigate the lack of flash rust, as well as other aspects of ElectroStrip (NCHRP, 1998).

Another question going into the trial was the effect of the process on surface rust. This trial, as well as earlier trials in the laboratory**,** indicated that the rust was converted to magnetite. This is consistent with the chemistry involved in this situation (Deer, Howie, & Zussman, 1966). Although samples of the rusted areas cleaned with ElectroStrip were not taken, the locations were referenced and photographed. They will be monitored for paint adherence, along with the rest of the beam in this trial.

Production Rate

As the trial progressed, the effectiveness of the process diminished, although the efficiency of the pad removal and installation turnaround increased. It was determined that the plastic tile grids were becoming less effective in holding the anode pads uniformly flat against the steel. It was speculated the heat cycles were causing the tiles to warp, albeit slightly, enough to make the subsequent removal runs not quite as efficient as the first several.

Although production rates for this trial were not as good as with more conventional methods, ElectroStrip would seem to be more competitive than is otherwise apparent. The set up and take down time for the ElectroStrip equipment was minimal. Two hours elapsed time was the documented interval from the arrival of the equipment to the point the process was ready to be started. A conventional setup for an abrasives blasting job on the same structure would require significantly more time. It is estimated at least 1 day would be required to set up traffic control, place and rig the compressors and air handlers and dust and debris collectors, set the scaffolding, and do all the preoperational testing for negative air pressure in the containment. A high-pressure water blasting setup might entail a somewhat shorter time, but there is still more ancillary equipment (e.g., water supply and waste water storage tanks, containment shrouds) that is larger and bulkier than that required by the ElectroStrip process. Secure storage for spent abrasives, wastewater, and accumulated paint debris, depending upon the process used, is another factor favoring ElectroStrip. The more conventional methods would require considerably more room to accommodate the waste stream generated.

Environment/Worker Health

The volume of debris generated was much smaller than that generated by more conventional methods. The debris was also more able to be recycled. This project generated 0.62 m^3 (three 55-gal barrels) of solid debris that was disposed of properly with the contractor's other wastes; 208.2 L (two 55-gal barrels) of wash water was also generated. A beam with the same area as the one used in this study would typically generate about 1.67 m^3 (eight 55-gal barrels) of debris and spent abrasives if it were to be cleaned to bare metal by abrasives blasting (Neal, 1998).

Based upon the certified worker exposure and high-volume ambient air monitoring done on this project and previously (Tables 6 and 7), it would appear that the respirator requirements would be satisfied with a half-face, lead-dust filter cartridge combination. Disposable clothing, gloves, etc., are further indicated. The sampled worker exposure is low considering the amount of lead contained in the paint analysis (Table 1).

Table 6. Airborne Lead Concentration (μg/m³)

Work Site	Actual	8-Hr Time Weighted Average
Route 28 ElectroStrip (5/6/98)[a]		
Foreman	5.1	4.6
Technician	18.2	16.5
Assistant	28.1	25.3
Work Area Monitor 01	5.8	5.1
Work Area Monitor 02	5.4	4.7
Work Area Monitor 03	4.4	3.9
Work Area Monitor 04	4.6	4
Westmoreland Street ElectroStrip (5/12 and 5/13)[b]		
Power tool scoring (vacuum shroud)	64.4	48.3
Power tool scoring (vacuum shroud)	9.3	7
Work Area Monitor 5/12/98	5.2	3.9
Work Area Monitor 5/13/98	13.7	12
Power tool paint removal	223.7	179.4
Support assistant	33.8	26.7

[a]This information is in a letter from S.T. Liang, of KTA-Tator, Inc., to R. Keller, of EMEC Consultants, dated May 14, 1998.
[b]This information is in a letter from R.T. Leighton, of Leighton Associates, to B. Fourtinakis, of Superior Painting & Contracting Co., Inc., dated June 10, 1998.

Table 7. High-Volume Air Quality Monitoring[a]

Date	Location	TSP-Lead(μg/m³)	PM-10 Respirable Dust (μg/m³)
5/11/98	100 ft S of bridge (background)	<0.07	23.21
5/12/98	60 ft SE of bridge	<0.05	15.13
5/13/98	60 ft SE of bridge	<0.07	74.94
6/08/98	45 ft S of bridge (downwind)[b]	0.82	29.31

[a]The information provided in this table is in a letter from R.T. Leighton, of Leighton Associates, to B. Fourtinakis, of Superior Painting & Contracting Co., Inc., dated May 18, 1998.
[b]After ElectroStrip trial during power/hand tool cleaning.

Project Costs

Table 8 provides the contract items and bid prices (two structures; >3,400 m² surface area; ElectroStrip trial represented ~2%) related to this project.

Table 8. Project Costs

Project Bid Total		$189,000
Prepare & Paint Str. 2066		63,940
Environmental Protection	8,000	
Disposal of Material (Str. 2066)	2,000	
ElectroStrip Labor	10,800	
EMEC Consultants fee	60,000	
Total Removal Costs		$80,800 ($1,092/m²)

On a unit cost basis, this does not compare well with national costs of traditional abrasives blasting. Full removal costs for a girder are from $29.24/m² to $177.54/m², with a median cost of $65.10/m² and an average cost of $83.89/m² (Society for Protective Coverings, 1997). On the other hand, this was a trial of a new method. The beam used in the trial represented only 4.4% of the total painted steel surface on the structure. The unit costs are, therefore, not comparative with those of other removal methods. A larger, full-scale operation would be more appropriate for such comparisons.

Summary

The overall efficiency of ElectroStrip was not well defined because of the initial mechanical and operational problems. In terms of production, the potential for greater efficiency was identified. Suggestions for changes and improvements that might be made to help make the process more efficient and productive were discussed with Dr. Keller. These included pad material in larger sizes, a better backing grid that was more effective in pressing the anode pad against the steel, and the use of braces rather than magnets to hold the pad material against the steel. Changes in the anode material were also being considered. The anode material for this trial was mild steel screening.

The need to produce large-scale, consistent results in an efficient manner, i.e., show that ElectroStrip is a competitive alternative to conventional methods, spurred the consultants to deal with the problems associated with production rate with some success. The process, as presently configured, is somewhat slow to implement. The time needed for the installation of the pads, the energizing period, and the removal processes was more than with more conventional methods. However, this trial was an evaluation of a process that is still in a prototypical phase. A larger scale trial with a much larger rectifier and power source could yield much more encouraging results with a significant increase in efficiency.

In some locations, bridge repainting involving paint removal might have to be done at night because of traffic conditions and restrictions. Even then, there are bridge situations that could not tolerate full removal using conventional methods because of environmental concerns and restraints, i.e., noise levels and proximity to sensitive areas or features such as hospitals, public water supplies, and residential areas. ElectroStrip, because of its relatively quiet and very clean process, would seem to be a good fit for locations with sensitive aspects, environmental or otherwise, that would hamper more conventional paint removal methods. Given those types of restrictions, ElectroStrip may be the most economical and productive method available when all factors, including public and private liability exposure and quality of life, are considered.

CONCLUSIONS

- ElectroStrip removes lead-based alkyd paint from structural steel, although refinements in the procedure are required and further studies on additional paint systems are warranted (e.g., epoxies, moisture-cured urethanes).

- The measurable airborne emissions from the ElectroStrip process are very low.

- Workers using ElectroStrip, based upon trials to date, are exposed to lower levels of airborne lead than other methods.

- ElectroStrip has several advantages over conventional removal methods:

  — The amount of equipment needed and the overhead are relatively low compared with other removal techniques.

  — The cost of containment is minimal (ground tarps, typically) compared with abrasives.

  — Far less debris is generated than with abrasives blasting or water jetting.

  — The steel substrate is not further contaminated in spite of the use of a sulfate-based electrolyte. The cleaned and washed substrate does not appear to have any residual ions present that might affect paint adherence.

  — There is no immediate flash rusting of the cleaned steel surface. This may be beneficial in terms of paint performance, but its actual effect is unknown at this time.

- Further refinements in the process and the components are necessary to make the system more viable.

RECOMMENDATIONS

1. The developers of ElectroStrip should increase the productivity and efficiency of the process through providing the following:

   - larger pads for more efficient handling

   - more effective pad backing material to achieve a more effective and consistent paint debonding reaction

- more effective anode connectors to provide more efficient electrical energy transfer to the pads during the debonding reaction

- refinements in the power delivery system to minimize losses due to bus bar interconnection and cable-bus bar interface

- a larger rectifier to provide more coverage area per run.

2. Additional studies should be done to investigate and follow up on the paint life and holding qualities of bridge steel on which ElectroStrip has been performed, especially in light of the fact that flash rusting is not immediately propagated following paint removal.

3. Additional studies should be done using ElectroStrip on other types of paint systems, including highly aluminized paint topcoats.

4. Further research should be done using ElectroStrip to remove paint from items other than bridges (e.g., traffic sign and signal supports).

5. Further research and comparisons with other paint removal techniques should be done to assess more fully the costs associated with the various methods.

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