

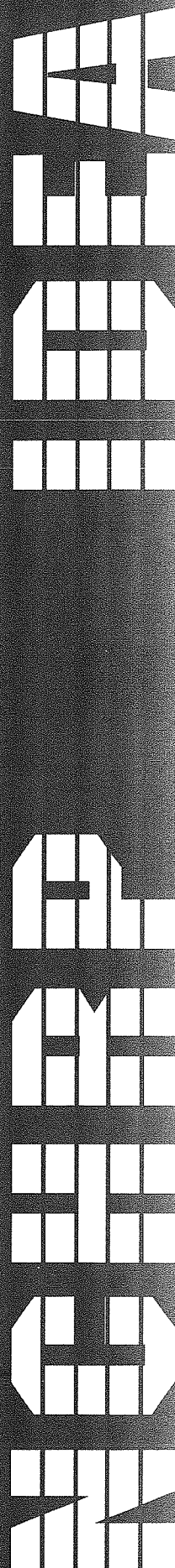
TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

IDEA *Innovations Deserving
Exploratory Analysis Project*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM



Report of Investigation



IDEA PROJECT FINAL REPORT

Contract NCHRP-94-ID023

IDEA Program
Transportation Research Board
National Research Council

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PAINT REMOVAL FROM STEEL STRUCTURES

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EXECUTIVE SUMMARY

DESCRIPTION OF THE INVENTION, THE ELECTROSTRIP™ PROCESS

EMEC Consultants invented a process to remove paint from steel structures without the need for abrasive blasting, using only benign chemicals, and collecting lead-containing debris to be used in a secondary smelter for lead production. The patented electrochemical method is called the ElectroStrip™ Process. By applying cathodic current

to a substrate, electrochemically assisted debonding of the paint is achieved. The environmentally benign electrolyte is contained in a liquid-absorbent material to which a counter electrode is attached. This combination, called ElectroPad™ and shown in Figure 1, often includes a liner, and is applied to the metal surface in the case of steel with magnets. After electrochemical treatment for ½ to 2 hours, the ElectroPad™ is removed and paint fragments recovered. No particles become airborne, a decisively advantageous feature for the removal of lead-based paint.

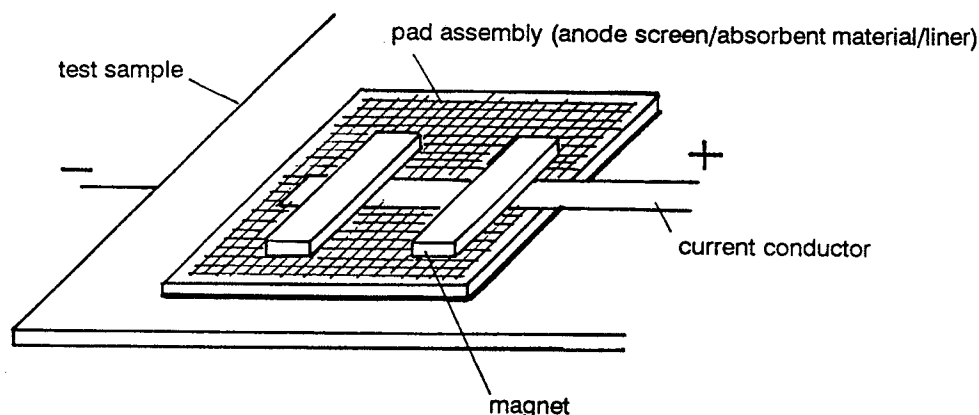


FIGURE 1 ElectroPad™ attached to metal surface.

EXPERIMENTAL RESULTS

Laboratory tests were conducted with specially prepared samples of reproducible characteristics and with field samples. Tests on bridges in the field followed with pads of 1- and 4-square-foot size. Despite cold weather, paint coatings debonded after 1½ hours of treatment. Pretreatment of the surface (scoring) was found to be essential to achieve complete debonding. The debonding process and the characteristics of the debonded paint depended on the nature of the coating. In most cases, the debonded coating adhered to the liner and could be easily collected.

An example of a field test is illustrated by Figure 2. The overpass is shown, then the test in progress, with a one-square-foot pad mounted to a girder, and with the equipment cart carrying the dc power source in the

background. The result is shown on the bottom. Horizontal score lines, 1 cm apart, can be seen in the treated area. Debonding was essentially complete. The removed ElectroPad™ is mounted to the right, showing the side that contacted the painted surface during the treatment. The paint coating was removed with the pad; the red color indicates the lead-based primer. In one corner, the paper liner is peeled back and the yellow-colored absorbent material is visible. To the left of the treated area, there are some marks from the characterization of the coating, as performed by KTA/SET Engineering.

PLANS FOR IMPLEMENTATION OF THE TECHNOLOGY

EMEC Consultants is a small business engaged in electrometallurgical, electrochemical and related

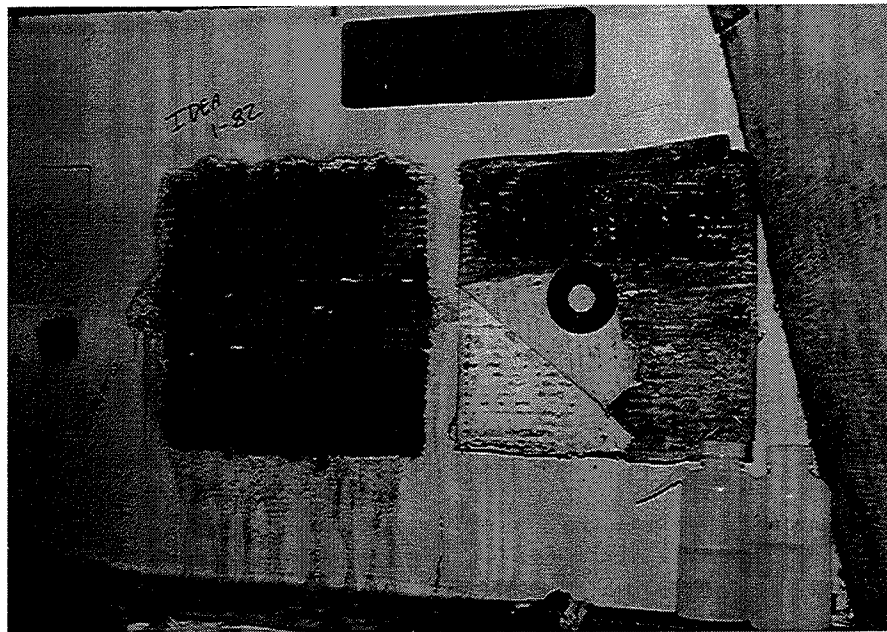
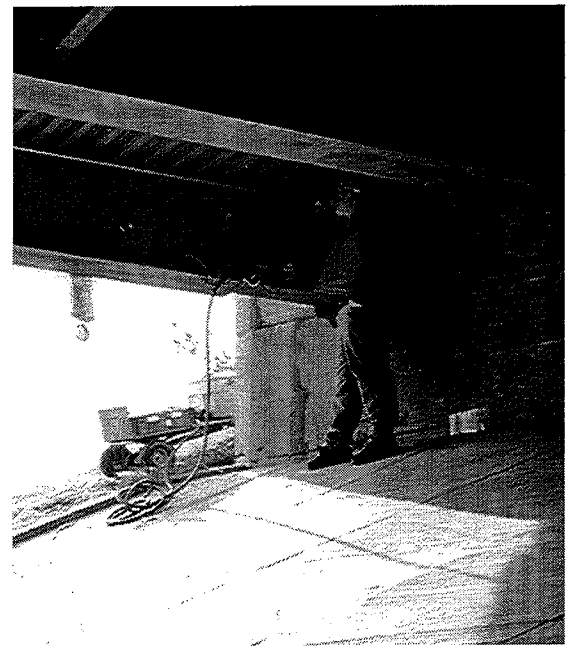
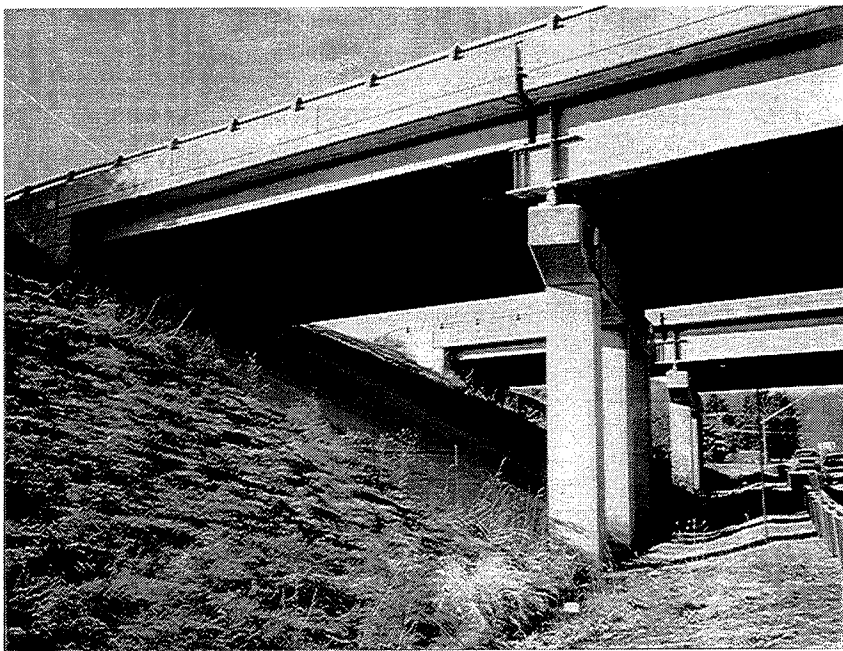


FIGURE 1 Field experiment on Pennsylvania Route 28, Exit 16

research and development. It plans to commercialize the ElectroStrip™ Process to support painting contractors as an environmental business. It is envisioned that EMEC Consultants provide supplies and equipment to conduct the ElectroStrip™ Process, act as consultant, and reprocess the spent ElectroPads™, thereby separating the toxic paint fragments to prepare them for use in lead smelting.

Work to refine process elements is planned for the near future. Consistently complete debonding on flat and irregular surfaces, mechanization of the scoring process, characterization of treated surfaces, identification of recycling requirements are among the issues to be addressed. The method will be practiced further on highway structures. Support for demonstration projects will be solicited.

IDEA PRODUCT: THE ELECTROSTRIP™ PROCESS

The ElectroStrip™ process is a novel, environmentally attractive and cost-effective approach to remove paint coatings from highway steel structures. Using a benign electrolyte solution, it achieves debonding of the paint by electrochemical polarization. It permits complete collection of lead-containing paint debris without any particles becoming airborne; the usual extensive precautionary measures are not necessary with this process, and the lead values can be recycled. It is amenable to efficient practice at any scale, by small and large contractors. A U. S. patent has been granted to EMEC Consultants.

To analyze the potential of the approach, painted samples were subjected to electrochemical treatment in laboratory and field experiments. Debonding was normally achieved within one hour of cathodic polarization. An arrangement, called the ElectroPad™, consisted of an optional paper liner, a pad of water-absorbent material, and a counter electrode mesh. It was held against the test object by means of magnets. After treatment, the ElectroPad™ was removed with the debonded paint.

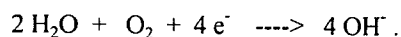
PRINCIPLES OF THE ELECTROSTRIP™ PROCESS

The project deals with an environmentally attractive and cost-effective approach to remove paint from steel structures. The ElectroStrip™ Process, our electrochemically assisted paint removal method, involves the use of electric current and benign electrolytes, non-caustic and free of any organic component. The approach

promises to be particularly useful in removing lead-based paints, as paint fragments can be collected and processed to reclaim the lead without toxic emissions into the air.

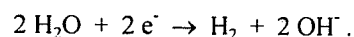
To remove paint coatings, steel surfaces are brought in contact with an aqueous electrolyte, e.g., with a neutral sodium sulfate solution. Direct current is then passed from a counter electrode to the work piece; for coherent coatings, this has to be facilitated by scoring the surface. The cathodic current results in debonding of the paint. Containment of electrolyte, placement of electrodes, and retention of paint fragments can best be achieved through the use of an "electric blanket", or ElectroPad™, a pad soaked with electrolyte, possibly equipped with a liner contacting the metal surface, and combined with a counter electrode mesh. Such an arrangement is shown schematically in Figure 1, its structure in Figure 3. To remove paint from steel, pads can be held in place by magnets that may also serve as current connectors. After use, the pads will be collected and processed by specialized personnel who separate the paint debris and prepare it for use in secondary lead smelting.

The process is related to cathodic debonding, a corrosion phenomenon observed on coated metals. Studies [1] have shown that paint delaminates from metal surfaces when a cathodic reaction occurs at the metal surface. It can occur under the coating of paint or at exposed areas of the metal. In natural corrosion, a portion of the area is anodic in nature and another portion cathodic; reduction of oxygen from the air is usually the cathodic reaction. This reaction results in the formation of local alkaline areas, according to



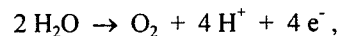
The localized pH change evidently attacks the bond between paint and metal, and the result is a cathodic delamination which has been observed on many coatings, such as alkyd, acrylic, epoxy, epoxy powder, bitumen, vinyl ester, fluorocarbon, polyester, polybutadiene, and polyethylene coatings. A study of the mechanism of the effect has been conducted on copper [2].

If only natural corrosion is involved, the process of paint delamination is usually very slow. In the envisioned electrolytically assisted paint removal process, the cathodic reaction is vastly accelerated by applying a cathodic current. The metal work piece is made of the cathode of an electrode couple and applied dc voltage. In this case, a cathodic reaction is forced at high rates, and hydrogen is evolved according to



This reaction also causes a local rise in pH, producing the same effect as applying a strong caustic solution to the metal surface, except that it occurs very locally at the interface between metal and coating. In the case of aluminum alloys, the normal dissolution in caustic media must be suppressed.

While the cathodic reaction causes localized pH increases, the overall solution remains neutral, as the reaction at the counter electrode is



and produces acidic ions to neutralize the hydroxyl ions formed at the cathode.

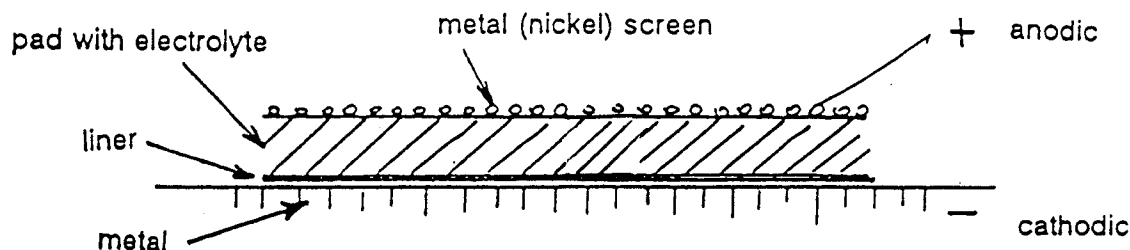


FIGURE 3 The "ElectroPad™" for electrochemically assisted paint removal.

The exact mechanism by which the bonding between metal and paint breaks down is not completely understood. The dissolution of oxide and a process similar to saponification have been mentioned as possibilities [2]. It is interesting that delamination of the paint starts in the immediate vicinity of a paint imperfection, then spreads over (or rather under) the entire surface, resulting in complete debonding of the paint; this is of great importance for the envisioned process.

PROCESS CONCEPT AND SIGNIFICANCE OF THE INNOVATION

It is envisioned that a painting contractor and a specialized environmental firm cooperate in practicing the ElectroStrip™ process. The painting contractor receives the ElectroPads™, ready for application, from the environmental firm. A series of pads are mounted and run

simultaneously. After debonding of the paint, pads are collected with the entire paint residue. They are returned to the environmental specialist who processes the pads to separate the paint debris and prepares it for use in secondary lead smelting. Pads and electrolyte are conditioned for reuse, if possible.

No ventilated enclosure is needed to operate the paint removal process. Environment and personnel are not exposed to airborne toxic debris or fumes. The owner of the structure can receive certification that the lead was recycled, thus eliminating future liability for this toxic component. In most cases, obstruction of traffic can be kept minimal. Noise levels are low. The process provides an attractive alternative to the present practice of removing paint from steel bridges by abrasive techniques. Used with paint containing lead, traditional methods often lead to unintentional environmental pollution, severe occupational hazards, and large volumes of hazardous waste.

Application of the new method of electrochemically assisted paint removal minimizes such hazards, as no airborne lead-containing particles are produced. It is projected that the ElectroStrip™ Process is cost-effective.

GOAL AND SCOPE OF PROJECT

The project was designed to demonstrate the feasibility of the envisioned approach of electrochemically assisted paint removal to remove lead-containing coatings from highway steel structures. The first stage comprised laboratory testing and experimentation on specially prepared steel plates and on field samples, and the design of prototype equipment for scale-up testing in the field. Field tests on highway structures were conducted in a second stage which included prototype testing.

EXPERIMENTAL RESULTS

OVERVIEW

Initially, tests were conducted in the laboratory. Some well-defined samples, of reproducible characteristics, were especially prepared for the investigation by

KTA/SET Environmental. Other samples were recovered from the field. These tests confirmed for a broader range of coating characteristics the results of earlier testing that indicated viability of the method.

Testing was extended to field experiments. Pads of one- to four-square-foot size were applied to the girders of five steel bridges. Results were also positive on this scale.

SELECTION OF TEST OBJECTS AND EXPERIMENTAL TECHNIQUE

Laboratory

Various samples of painted steel were available at EMEC Consultants. The coatings listed in Table 1 were characterized by KTA/SET Environmental. Field samples originated from the Coraopolis Bridge (buckle panels & I-beam), the West End Bridge, Pittsburgh (steel bridge girders), the Ewing Park Bridge, Elwood City (steel bridge railing), and a Fox Chapel Water Authority water tank (3 coating types, side walls and service door). For laboratory studies emphasizing reproducibility, KTA/SET Environmental prepared test plates consisting of a Carboline Subox III FD primer and a Carboline

TABLE 1 Characteristics of paint coatings on test samples

Sample	Average Coating Thickness (mils)	Tooke * (mils)	Coating Adhesion	Lead Content (wt %)	Generic ID	% Corrosion Present
Coraopolis Bridge	14.5 ± 2.4	4.0/7.5	0B	0.15	----	no corrosion
West End Bridge	8.2 ± 1.6	3/3 2.5/3	2B	22.2	Alkyd	» 10% corrosion
Ewing Park Bridge	11.3 ± 6.5	5/5 2.5/5 5/18 5/6/3.5	0B	27.2	Alkyd	<1% corrosion
Fox Chapel water tank (1)	9.4 ± 0.9	1.5/5/1/2	5B	12.8	unknown	no corrosion
Fox Chapel water tank (3)	3.8 ± 0.3	2.5/1	4-5B	43.5	unknown	no corrosion
KTA/SET test panels	9	4/5	see text	25 (in primer)	---	no corrosion

* The Tooke test involves the observation of a cut through the paint coating and gives data on number of coats and individual thicknesses; in the Table, the left number indicates the primer thickness, then follow values for intermediates, and the last number represents the thickness of the topcoat.

Carbomastic 15 low-odor topcoat on steel. The characterization data are shown in Table 1. They include: percent of corrosion present, total coating thickness and number of coats, adhesion (ASTM D3359), lead content, and generic identification of coating.

Testing was based on a standard test procedure, occasionally with slight variations. Samples were scored to facilitate initiation of the cathodic action. The two patterns used are shown in Figure 4. In fields of 10 cm x

10 cm, 0.5-cm wide stripes were separated by scratches applied with a knife blade. Cross-hatched patterns for pressure-tape testing were applied, consisting of 2 mm x 2 mm squares in early tests or 5 mm x 5 mm in later tests. The pattern was then covered by a 10 cm x 10 cm Sorb-X₂ pad (a material sold for the control of liquid spills) which was saturated with an aqueous 0.4 M Na₂SO₄ solution. A nickel Exmet screen was pressed against the pad and served as counter electrode. Magnets were used to hold the arrangement in place.

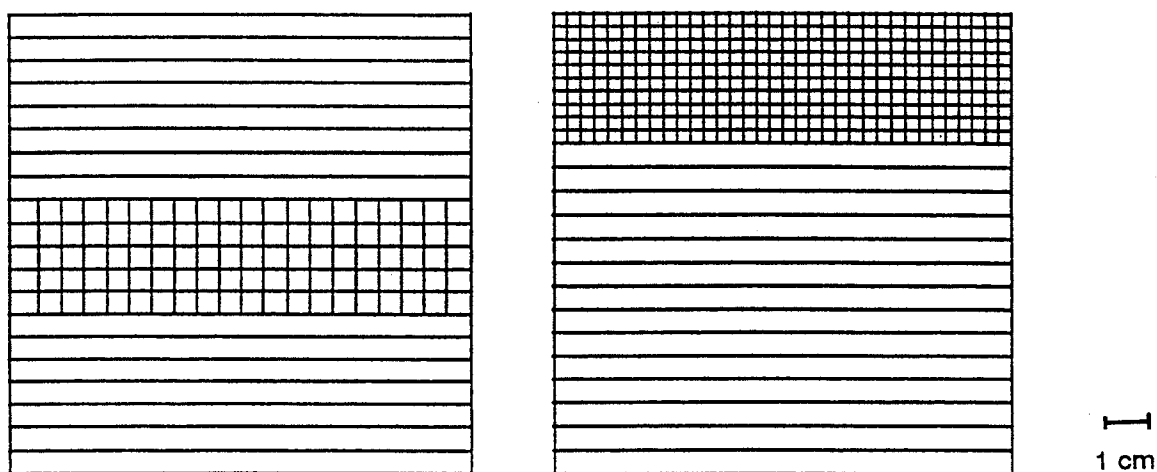


FIGURE 4 Scoring patterns used on test samples.

Tests were generally run for 10 minutes at a constant current of 7.5 A (75 mA/cm²) to achieve a steady voltage. After 10 minutes, the power supply was set to constant voltage at the stabilized value, in order to better represent a field trial which will be run at constant voltage rather than at constant current. Debonding rates could be correlated with the current (Ah) passed. Current was passed for a period typically ranging from 0.5 to 3 hours. Distilled water or electrolyte was added periodically to compensate for losses by electrolysis and evaporation.

At the end of the electrochemical treatment, the pad was removed and the degree of debonding examined. The cross-hatched area was tested with pressure-sensitive tape, in analogy to a commercially available test method (ASTM D3359) used to characterize paint coatings. In the striped areas, debonded paint strips were lifted off easily.

Variations in the testing included the use of a liner of filter paper between the Sorb-X₂ pad and the metal surface. This liner was introduced to facilitate the collection of paint fragments and extend the reusability of the pad material. Also, additions of wetting agents to the electrolyte were investigated.

Tested surfaces were usually horizontal, but other orientations (vertical and upside down) were also tested.

Field

Six sites consisting of bridges and overpasses were selected for field tests based on coating condition and accessibility. All sites were in Allegheny County and approval for testing was granted by the Pennsylvania Department of Transportation, District 11-0. The sites are listed below:

1. Route 28, Exit 16, overpass over SR 1028
2. Route 28, overpass over SR 1037 (Saxonburg Road)
3. SR 1031 bridge over Bull Creek
4. SR 1013 bridge over Deer Creek
5. SR 2058 bridge over Plum Creek
6. SR 2075 bridge over Pucketa Creek

These structures were characterized in the same manner as the laboratory samples by KTA/SET Environmental. Bill Corbett is shown in Figure 5 with a coating test pattern completed on a bridge girder. The data is presented in Table 2.



FIGURE 5 Coating characterization tests.

Tests at five sites were done with a 1 ft x 1 ft ElectroPad™ consisting of nickel Exmet sewn onto a Sorb-X₂ absorbent pad and a Whatman # 3 filter paper liner. The ElectroPad™ was saturated with 330 mL of 0.4 M sodium sulfate electrolyte and bagged at the laboratory for later field use. A one-square-foot area on the structure was scored at 10 mm intervals. ElectroPads™ were applied to the structures with ceramic magnets. Direct current was supplied by an Electronic Measurements TCR 20S90 power supply which in turn was supplied by a 4400 W portable generator. Current was limited to 80 A and

voltage generally to 12 V. One or the other was actually limiting depending on the resistivity of the pad which varied as electrolyte evaporated and was replenished. Conditions monitored were pad, bridge surface and air temperature, humidity, voltage, and current. Current was initially applied for 1.5 hours and resumed if the coating was not sufficiently removed. After pad removal, the surface was photographed, cleaned with dampened paper towels, and photographed again. Results are based on visual observation of percent coating removed.

TABLE 2 Characterization of Paint Coatings at Various Test Sites

Test Sites	Average Coating Thickness	Tooke (mils)	Coating Adhesion	Lead Content (wt %)	Generic ID	% Corrosion Present
Rt 28 Exit 16	5.3 ± 0.3 mils	2.5/1.0/0.5 2.5/2.5/0.5	3B	15.8	Alkyd	no corrosion
Rt 28 over SR 1037	8.0 ± 1.0 mils	6.0/2.5/<0.5 5.0/1.0/<0.5	2B	21.1	Alkyd	no corrosion
SR 1031 over Bull Creek	20.5 ± 2.0 mils	Coating too flexible to cut	4B	1.5	Alkyd	no corrosion
SR 1013 over Deer Creek	6.4 ± 0.5 mils	4.0/2.5/1.0 3.5/2.5/1.0	2B	14.8	Alkyd	no corrosion
SR 2058 over Plum Creek	4.8 ± 0.4 mils	2.5/2.5/1.0 2.5/1.5/0.5	3B	18.0	Alkyd	no corrosion
SR 2075 over Pucketa Creek	6.5 ± 0.9 mils	2.5/2.5/0.5-1 4.0/2.5/0.5	3B	17.7	Alkyd	< 0.03

EXPERIMENTAL RESULTS (LABORATORY DEBONDING TESTS)

Characteristics of debonding varied in the cases of the Coraopolis Bridge, West End Bridge, Ewing Park Bridge, test panels prepared at KTA/SET Environmental, and Fox Chapel Water Tank. In some cases, the top coat and primer stayed together and fragments of paint could be recovered. In other cases, the process produced a sludge that could be wiped away and collected.

In the case of the Coraopolis bridge samples, the top coat and primer stayed in tact and bonded together. The electrochemical process undercut the primer and broke the bonds between the primer and metal surface. Debonding rates for these samples in the standard test were determined to be 13.3 cm²/Ah at less than 12 V. These numbers were based on scoring lines spaced at 5 mm. When this spacing was increased to 10 mm the rate remained the same. An increase to 20 mm decreased the debonding rate to 10.7 cm²/Ah.

Wetting agents were added to the electrolyte to see if debonding could be accelerated. Additions of Jet Dry, a "spot free" household dishwasher rinsing agent, and Cascade dishwasher detergent did not noticeably affect the rate in standard tests. When 20 vol% Cellosolve, a

water-soluble solvent, was added, the debonding rate was not increased but the strips of removed paint coating were more pliable; this may be an advantage.

Other pad orientations (i.e. vertical, from below) were examined to see if there was any detrimental effect. A significant difference in the debonding rate was not found in the vertical test but a slight decrease was found in the upside-down test.

Various results obtained with Coraopolis bridge samples are compared on Figure 6. A Sorb-X₂ pad with 0.4 M Na₂SO₄ solution was used. A constant voltage between 8 and 12 V was applied to maintain a current of approximately 7.5 A for one hour. The first data set represents the fraction that fell off in the cross-hatched section during the scoring process; slight variations in procedure and local paint consistency could have a significant effect. The second data column represents the cumulative total of the first and the amount removed along with the pad; the next column shows the preceding total plus the amount removed with pressure tape. The last column indicates the degree of debonding in the test area, an area of 5-mm parallel scoring lines; this is not comparable to column 3 because of different debonding lengths and cleaning methods.

Tests were run for 1 hour at 8-12 V in a 0.4 M Na_2SO_4 solution. The grid pattern consisted of 5 x 5 mm squares.

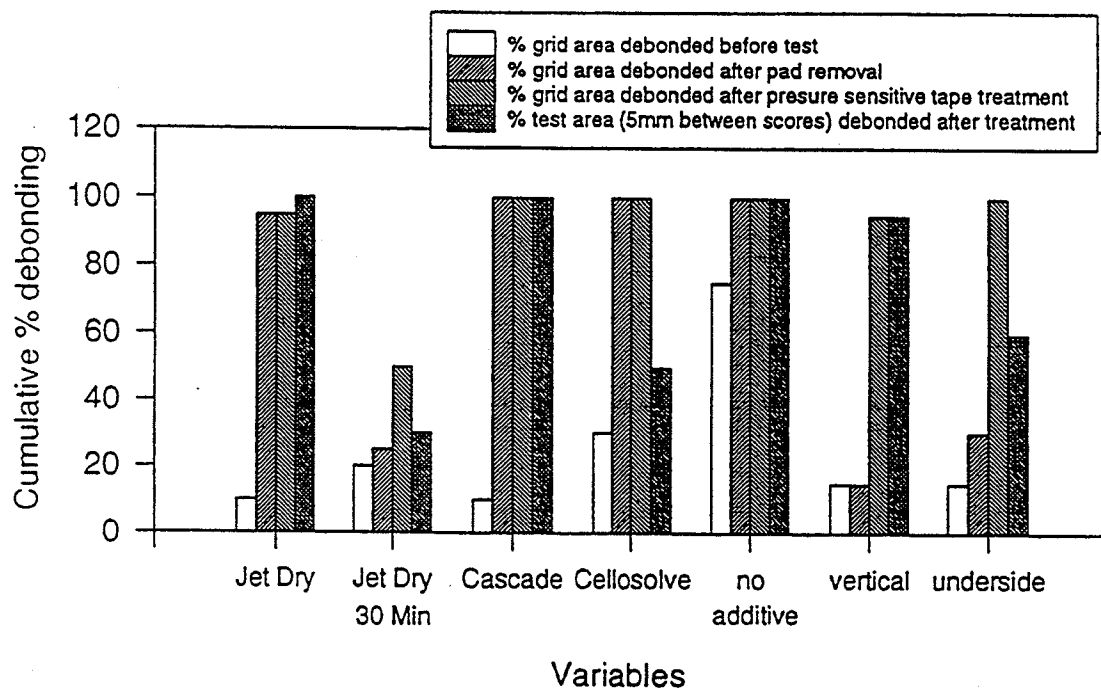


FIGURE 6 Effects of additives and test configuration on debonding rates.
(Coraopolis Bridge samples)

Test ran for 1 hour at a current density of 75 mA/cm^2 .



FIGURE 7 Experiment # IDEA-1-23: Condition of West End bridge sample after pad removal.

In the case of the West End Bridge samples, the coating system was microcracked to the point that scoring was not needed to obtain a conductive path. Application of the electrochemical process reduced the coating to a sludge that could be wiped away or collected easily. This behavior is shown in Figure 7 (Experiment # IDEA-1-23). This one-hour test was run at 77 mA/cm^2 . In the areas in which the paint was not removed, plastic thermocouple

sleeves blocked the current from going through the microcracks. In repeat tests where the sleeves were not used, all paint was removed.

Figure 8 shows that wetting agents did not help the debonding, and different orientations such as vertical and upside-down positioning did not hinder the process.

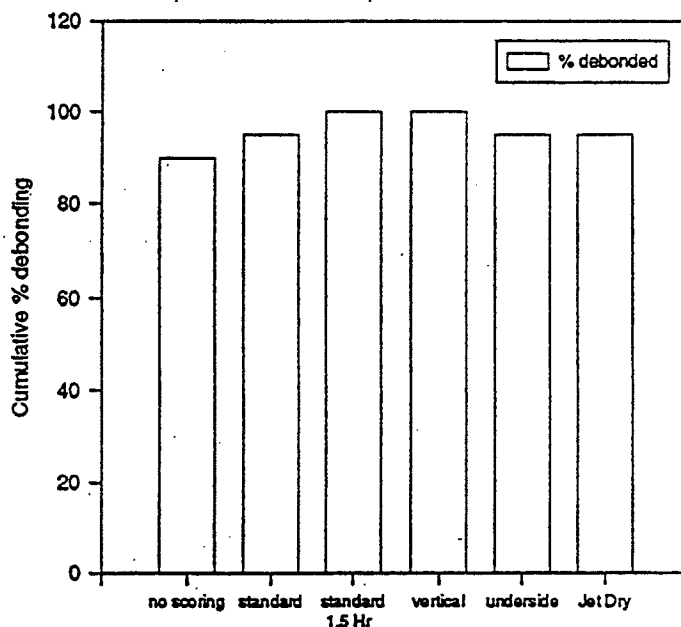


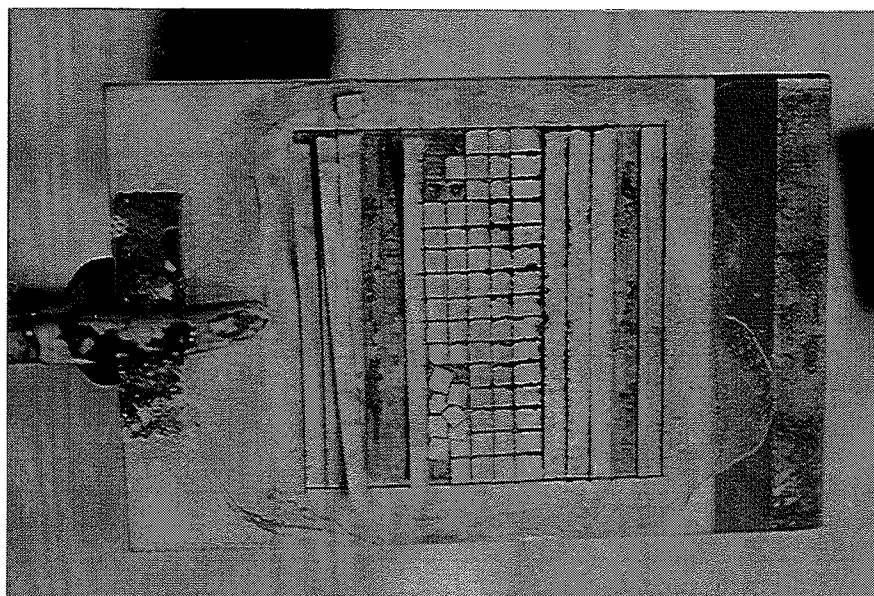
FIGURE 8 Results of debonding tests on Westend Bridge samples.

The test panels prepared by KTA/SET exhibited a different debonding behavior. In this case, the top coat stayed intact but the primer was dissolved away from under it. Figure 9 shows two tests, one after pad removal in which a non-adherent coating can be seen, and the other after a light putty knife scraping and wiping with a damp paper towel. These samples needed two to three hours for coating removal, which is much longer than the times needed on the field samples.

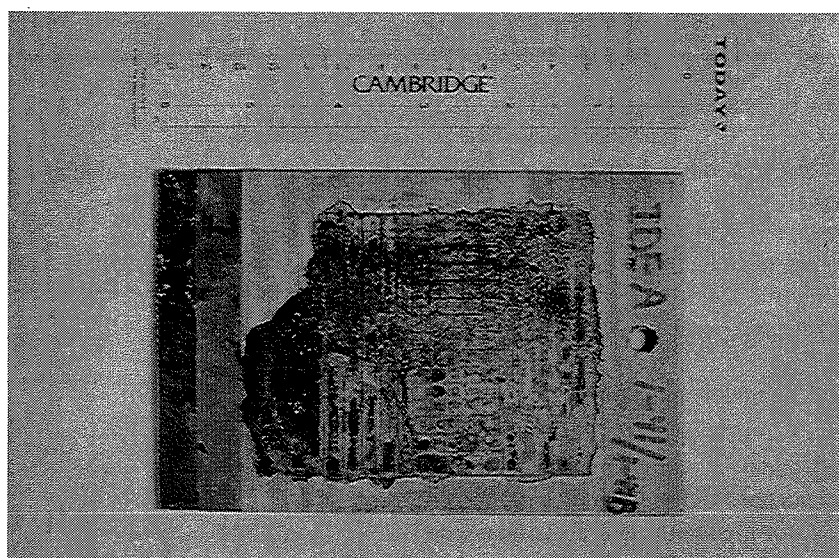
Table 3 lists the conditions for paint removal with the KTA/SET test panels and lists the percent coating removal for areas with the grid and test pattern, respectively. The grid pattern results are based on a modification to ASTM D3359, Standard Test Methods for Measuring Adhesion by Tape Test. In this method, a cross pattern as shown in Figure 4 is scored in the coating, then a pressure-sensitive

adhesive tape is applied over the pattern and removed to evaluate paint adhesion by comparison to standards. In our debonding test, the cross cuts also serve to initiate the current action. We applied the tape after electrochemical testing and examined the percent of coating removed.

One problem with modifying ASTM D3359 for our purpose is that upon application of the tape residual electrolyte under debonded paint is squeezed out and decreases the adhesion of the tape. We believe that the data is valid as a comparison between treated samples, but it should not be compared to the test pattern removal data that was obtained by lightly scraping and water-washing the remaining test area, also shown in Figure 4; this area had different removal rates due to longer distances between scoring lines.



After pad removal (Experiment # IDEA-1-42)



After light scraping and wiping with a dampened paper towel (Experiment # IDEA-1-41b)

FIGURE 9 Testing with samples prepared by KTA/SET Environmental.

TABLE 3 Experimental Data for KTA/SET Test Panels

Test #	Comment	Volt	Current range:Ave. current (A)	Temp range (°C)	Time (Hr)	Grid pattern % coating removal [*]	Test pattern % coating removal ^{**}
1-36		6	5.5-2.5 : 3.8	44-52	1	85	10
1-37		5.5-7	5.5-2.5 : 3.7	41-59	1.5	90	20
1-38	wetting agent ^t	7	5.5-2.5 : 3.5	48-63	1.5	65	20
1-39	higher voltage	12.5	10-1.5 : 3.4	74-97	1.5	95	65
1-40	vertical	12.5	14-1.0 : 3	64-93	1.5	85	30
1-41a		12	14-1.0 : 3.7	46-94	2	100	80
1-41b		8.5	15-3.5 : 7.5	58-76	1 ^{***}	100	100
1-42	upside down	10	14-1.5 : 4.4	40-92	2.5	100	100
1-43	wetting agent ^t	7	14.5-1.5 : 3.4	38-93	2	20	75
1-44	10mm spacing	9	10-1.5 : 3.6	48-77	2.5	50	60
1-45	20mm spacing	9	11.5-1 : 2.9	43-73	3	40	10
1-46	sparked	10 ^{tt}	7-0.2 : 2.2	26-72	2.5	--	50
1-48	20mm vertical	10	9.8-1.5 : 2.5	45-79	3	80	30
1-50	20mm Jet Dry	10	8-1 : 2.3	43-77	3	40	10
1-51	0 °C	10	16-1 : 2.7	33-87	3	50	85

* removed by pressure tape ASTM D3359

** percent of test area, other than grid pattern area, that was cleared to bare metal after lightly scraping and wiping with a wet paper towel

*** 1-41b is a continuation of 1-41a with a new pad and liner

t Jet Dry (dishwasher spot free rinse)

tt needed 35 V to initiate reaction

Once again, adding wetting agents or applying the test in different orientations did not significantly affect the rates. As expected, for a coating with no holidays or pinholes, the rate of removal decreased as the scoring distance increased. One other significant comparison in this table is the current range to average current relationship. The current range was large but the average current was toward the low end. As the tests got longer, the average got closer to the low range point. This effect was produced by a current decay (Figure 10) that was observed in all the tests.

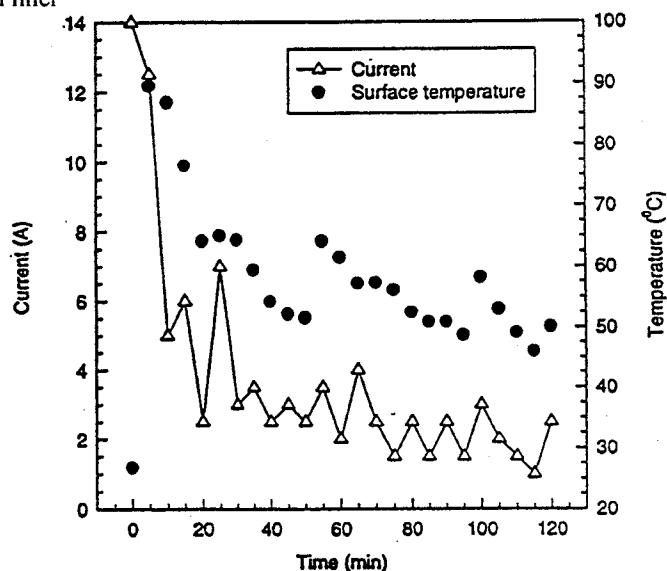


FIGURE 10 Current and temperature with time, for Experiment # IDEA-1-41, run at 12 V. Current spikes are due to periodic water or electrolyte additions.

Our explanation for this current decay is illustrated schematically in Figure 11. Initially in the tests, the conductive area was at the scoring marks or the microcracks. As the test proceeded and the coating was debonded, a nonconductive layer, possibly iron hydroxide, is thought to have formed on the newly exposed metal surface. This would mean that the remaining conductive surface and electrochemically active area was limited to the zone between the unbonded and bonded coating, which was continually progressing but decreasing in size, resulting in an increasing overall resistance and, consequently, lower current.

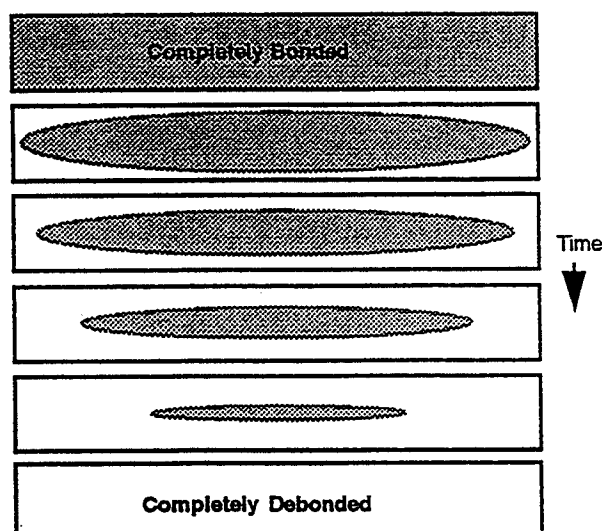


FIGURE 11 Debonding pattern of individual paint strips developing with progressing time, for samples with undamaged topcoats.

The Ewing Park bridge samples, although relatively small in size, had extremely varied coating characteristics over the surface. The coating thickness ranged from 5 to 25 mils. There also seemed to be a lot of rust and spots of a tar-like substance on the metal surface under the coating. Removal times were approximately 3 hours at voltages between 8 and 12 V. Adding wetting agents or applying the test in different orientations did not significantly affect the rates.

The Fox Chapel water tank (1) coatings debonded like the Coraopolis bridge coatings, with the topcoat and primer staying intact and bonded together. The electrochemical process undercut the primer and broke the bonds between the primer and steel substrate. The removal time was approximately one hour and the process left easily recoverable paint fragments.

In tests done on all samples, it was found that low temperatures approaching 0 °C (with laboratory samples placed on a block of ice) could be accommodated simply by ohmic heating produced when raising the potential a few volts. Even though the samples were small, it was believed that since this heating was right around the coating, it would still work on a large bridge despite its great heat sinking capabilities.

EXPERIMENTAL RESULTS (FIELD DEBONDING TESTS)

Tests were conducted on five bridges, with the permission of the Pennsylvania Department of Transportation. An example of a test is illustrated on Figure 2 (Executive Summary). Results on tests completed on the five bridges are presented below.

Rt 28 over SR 1037 (Saxonburg Road)

Figure 12 shows the bridge, a test in preparation, and the results after removal of the pad.

The conditions at the start of the test were as follows: air temperature -1.1 °C, surface temperature -6.6 °C, relative humidity 90%. The voltage used was normally between 12 and 14 V. Current was applied for 1.5 hours. In this coating, the paint/primer system was undercut and adhered to the filter paper liner. This adherence seems to be caused by the topcoat softening to the point where it penetrated into the top layer of the fibrous filter paper forming some mechanical bond. When the ElectroPad™ was removed at the end of the process, the coating was removed with it and could easily be collected. After some residual primer was removed with a moistened paper towel, it was estimated that more than 95% of the test area was stripped to a bare metal/millscale surface. It appeared that the remaining five percent could be readily attributed to imperfect scoring. Since the undercutting of the coating is a function of time, a bad scoring line may double the time needed to debond that localized area.

Rt 28 Exit 16

The conditions at the start of the test were as follows: air temperature 10.0 °C, surface temperature 9.6 °C, relative humidity 31%. The voltage used was normally between 10 and 12 V. Current was applied for 1.5 hours. This coating system debonded like the coating of the Rt 28 over SR 1037 overpass. Nearly all of the test area was stripped to a bare metal/millscale surface, as shown

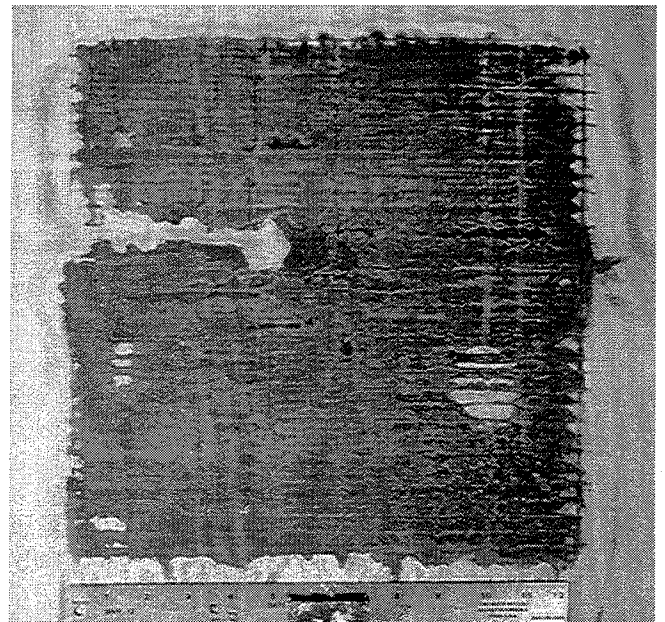
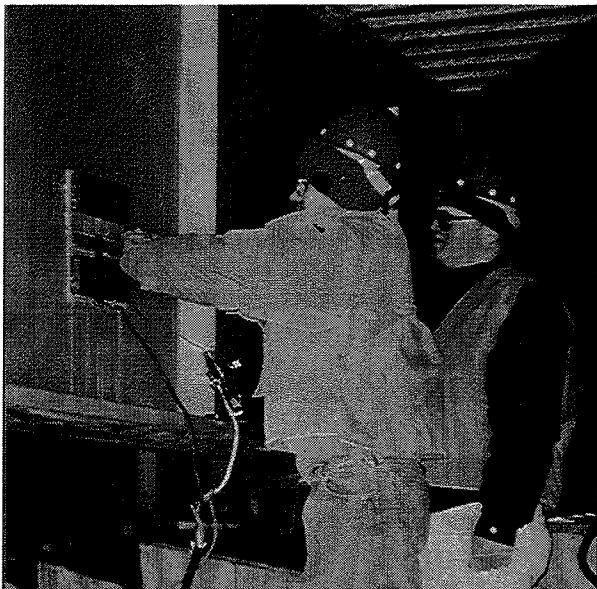
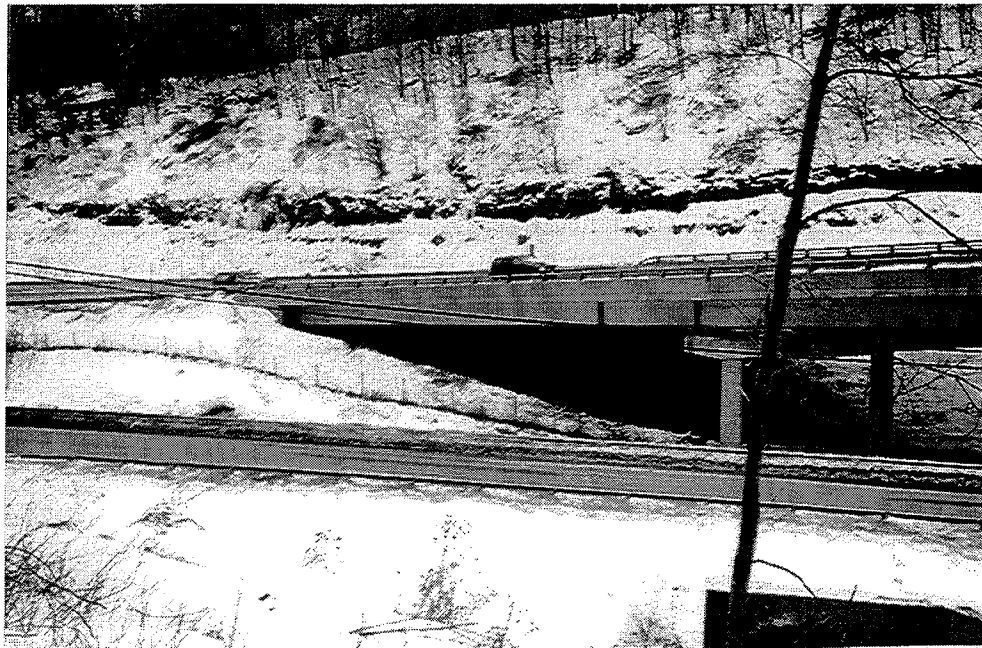


FIGURE 12 Test at Route 28 overpass over Saxonburg Road.

in Figure 12. As a result of the low humidity, the pad needed to be replenished with water more often.

A larger four-square-foot area was also tested at this site. In this case the ElectroPad™ was assembled on site, i.e. the SorbX pad (2 ft² x 2 ft²) and the strips of nickel anode screen were not sewn together. Two current collectors were used. The assembly was held together and pressed to the bridge by magnets. We expected to have 240 A DC (60 A/ft²) available but due to generator problems only 150 A (37.5 A/ft²) was obtained. The ohmic heating at this level raised the pad temperature only to 40 °C, thus the reaction rate was lower than that normally obtained when the pad is heated to around 80 °C. This test was run for 3 hours to compensate for the low current density. Removal of the pad revealed that all of the areas in the vicinity of the support magnets were completely debonded and the areas in between the magnets were not. This indicates that either the counter electrode was not in good contact with the absorbent pad because it was not sewn to the pad, or the magnets were spaced too far apart. It is believed that both factors contributed to this effect.

SR 2075 over Pucketa Creek

The conditions at the start of the first test were as follows: air temperature 3.5 °C, surface temperature 6.4 °C, relative humidity 83%. Of the two tests performed at this site, one was conducted on a flat web surface of a stringer beam, and the second pad started on the web surface and was folded around to the bottom of the lower flange, covering an inside corner and two outside corners. The voltage used was between 11 and 14 V. Current was applied for 1.5 hours. This coating system debonded like the one of the Rt 28 over SR 1037 overpass. Again, more than 95% of both test areas was stripped to a bare metal surface. The paint debonded well from the corners. Although this coating contained 17.7% lead, there was a noticeable blast profile in the metal and no millscale was present.

Figure 13 shows Pucketa Creek Bridge and testing in progress; current is supplied to a pad folded over the edge of the lower flange and a thermocouple is mounted to the body of the beam. The ElectroPad™ is removed in Figure 14. The liner is partially folded over to show the absorbent material. The results of two tests can be seen in the lower part of Figure 14.

Pucketa Creek is the location closest to EMEC Consultants' laboratory, and this bridge is well suited for more extensive future testing.

SR 1031 over Bull Creek

The conditions at the start of the test were as follows: air temperature 0.5 °C, surface temperature 1.0 °C, relative humidity 90%. The voltage used was normally between 9 and 11 V. Current was applied for 1.5 hours.

This coating system consisted of 5 layers and had an average thickness of 20 ± 2 mils. It was also different from others in that at least the top coat was brushed on and was very rubbery. The first of two tests was run for an hour at 20 V with only a low current. It seems that the thick, rubbery coating resealed after having been scored with a razor blade. The pad was removed and some of the scores were widened so that about a 1 mm strip of paint was removed. The test was restarted and run for another hour. Widening the scoring fixed the problem and normal currents were obtained. Forty percent of the coating was removed at the end of the test. This number is deceiving because, since the paint was so rubbery, a small bonded area could hold a large piece of coating even though most of the piece was debonded.

In the second test, all scores were made by removing coating strips of approximately 1-mm width. The test ran for 1.5 hours and 70% of the coating was removed. Again this number is deceiving for the same reason as above. Using a tungsten carbide blade with 30° tip rather than a razor blade should solve these scoring problems.

SR 1013 over Deer Creek

The conditions during testing were as follows: air temperature rising from 5.3 to 20.6 °C, surface temperature from 5.6 to 19.2 °C, with the relative humidity falling from 49 to 36%. This coating system debonded like the coating of the Rt 28 over SR 1037 overpass. Because the air was relatively dry, the pad needed to be replenished with water more often.

In the 1-ft² test, the voltage was normally between 10 and 13 V and the test was run for 2 hours. The main difference, when compared to other tests, was the use of a thicker copper current collector. This evidently caused uneven pressure on the pad (the magnet holding the copper did not push down the pad as well in areas immediately adjacent to the copper) and resulted in incomplete debonding in less pressured areas. A total of 85% of the coating was removed.

In the 4-ft² test, the voltage was normally between 7 and 10.5 V and the test was run for 3 hours. As in the

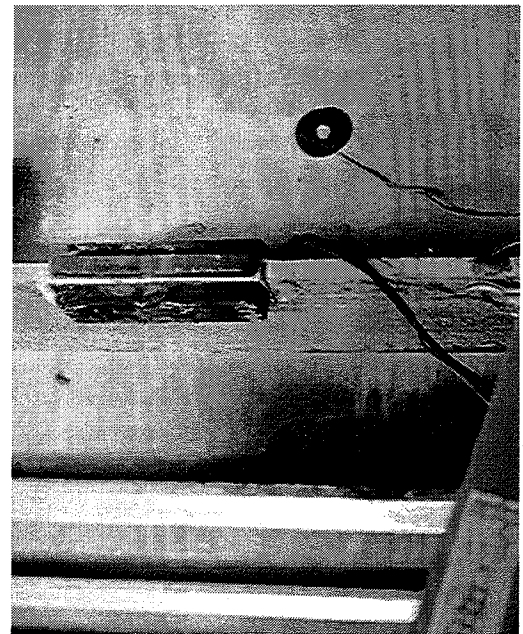


FIGURE 13 Field experiment on Pucketa Creek Bridge in New Kensington.

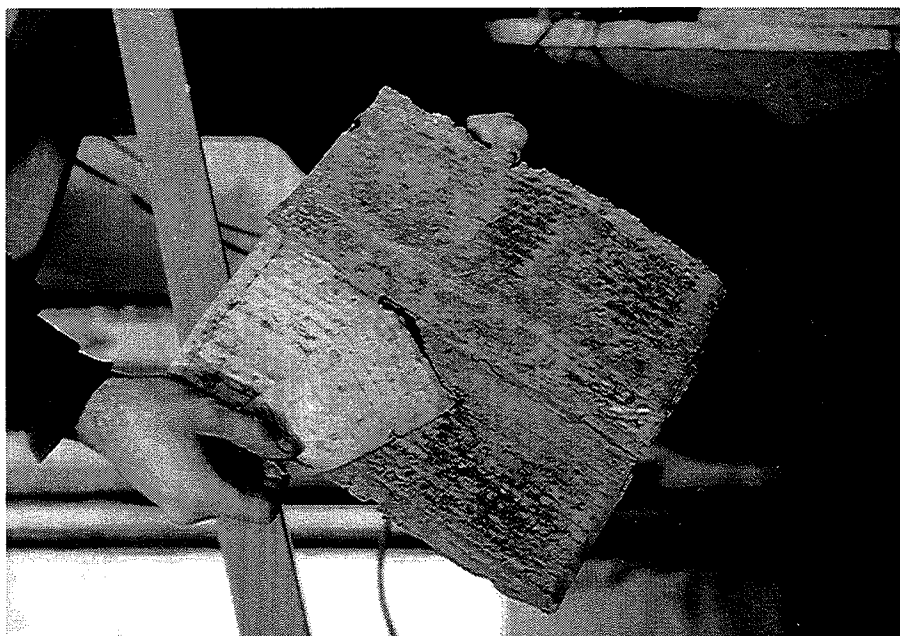


FIGURE 14 Results of tests at Pucketa Creek bridge.
Removed ElectroPad™.
One-square-foot test and wrap-around test.

last large test, we could not obtain the desired cathodic current density due to equipment problems. Despite the low current density of 37.5 A/ft^2 , 80% of the coating was removed, and the remaining coating was situated between magnets, as in the previous test.

Summary

In the experiments at all five field objects, paint debonding was achieved within one to two hours. When it was incomplete in some areas, it was most likely due to imperfect scoring or insufficient contact between the pad and steel surface at that location. We could not identify a basic reason why debonding could not be complete. One of the efforts following this present study has to address the achievement of complete debonding with consistency.

STUDY OF COUNTER ELECTRODE

Nickel Exmet screen electrodes were used to evolve oxygen at the counter electrode. These electrodes were not fully stable. To gain background information on the stability of the material, potentiostatic polarization curves were taken with a $0.4 \text{ M Na}_2\text{SO}_4$ solution, the electrolyte primarily used in our studies. An example is shown in Figure 15. It clearly displays a passive region, presumably with oxygen evolution setting in at 1 V versus the reference electrode used. Different electrolytes, presumably with lower nickel solubility, were tried. K_2SO_4 and a mixture of Na_2SO_4 and Na_2SiO_3 electrolytes showed no benefits. A $0.4 \text{ M Na}_2\text{SiO}_3$ solution helped passivate the anode but at the cost of a much higher voltage needed to evolve oxygen.

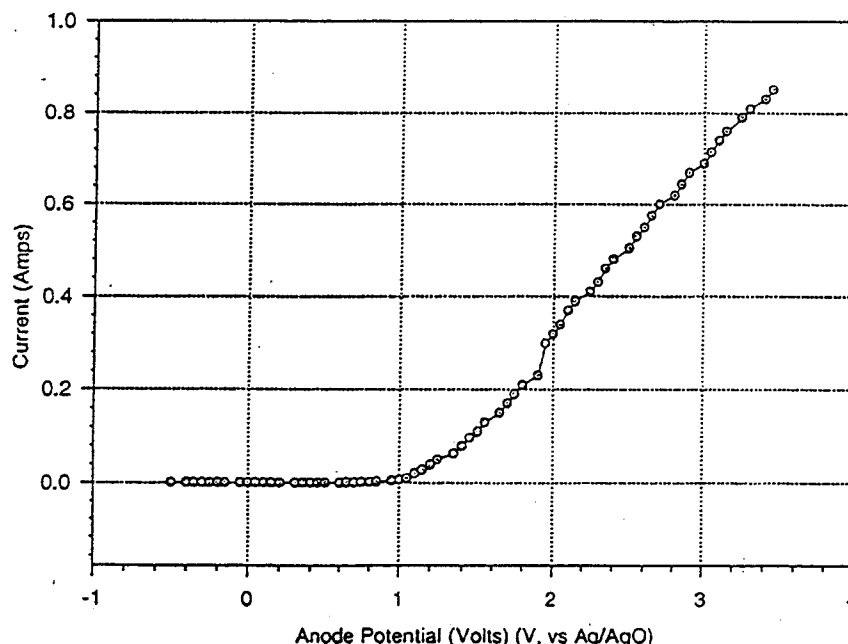


FIGURE 15 Anodic polarization curve for Exmet nickel electrode.

Recovery of the paint from the pads appears feasible.

The surface of the metal after paint removal was not examined in detail. It appeared protected from immediate rusting, possibly by the passivating layer.

Alternate anode material candidates were 304 stainless steel, Inconel, titanium, and Elgard anode mesh (titanium with a mixed metal oxide coating). Of these, only the Elgard material outperformed nickel; in a three-hour test, the Elgard counter electrode experienced no measurable weight loss.

Studies on the behavior of the counter electrode should be extended to assure adequate life of the electrode. This was, however, beyond the scope and means of the present contract.

ASSESSMENT OF HYDROGEN EMBRITTLEMENT POTENTIAL

A study by Dr. T. D. Burleigh addressed the possibility of steel highway bridges becoming affected by hydrogen embrittlement upon removal of paint involving cathodic treatment. He concluded that common structural steel parts are not susceptible to hydrogen embrittlement, with the

possible exception of newer high-strength bolts, ASTM A490.

CONCLUSIONS

Overall, laboratory and field debonding tests were successful. It appears that an attractive method to debond paint from steel structures and to collect the lead-containing paint fragments quantitatively can be developed.

The ElectroStrip™ Process is a promising concept. Compared to traditional practice of abrasive blasting, it offers the following advantages:

- reduced environmental and occupational hazards because no paint fragments become airborne,
- no production of hazardous waste,
- shifting of responsibility for handling of hazardous waste from painting contractor to environmental specialist,
- low equipment cost to painting contractors,
- competitive cost at small and large scale,
- reduced requirements to restrict traffic flow, and low noise levels.

In further development of the process, short-range goals will be: (1) consistent complete debonding of the paint under each pad, (2) adjusting treatment methods to accommodate irregular surface geometries (e.g. protruding nuts and bolts), (3) developing an efficient and reliable scoring tool.

Commercial scale equipment and operating procedures must be developed. A practical scoring tool is needed and improvements of the ElectroPad™ prototype are desirable. A strategy for applying a multitude of pads needs to be generated. Recovery of paint residue and reconditioning of ElectroPads™ need to be addressed.

The process should be practiced on large areas. Demonstrations on highway structures are being planned.

INVESTIGATOR PROFILE

EMEC Consultants is a sole proprietorship founded in 1984. It is a small business presently employing seven full-time employees, including Dr. Rudolf Keller, its proprietor and Principal Investigator of the project. EMEC Consultants is engaged in contractual research and development in electrometallurgy, electrochemistry and related areas. Several retirees of ALCOA Laboratories participate as part-time advisors on a regular basis. EMEC Consultants maintains a laboratory of 3,200 square feet at the Schreiber Industrial District in New Kensington, Pennsylvania.

Dr. T. David Burleigh of Burleigh Corrosion Consultants and on the staff of the University of Pittsburgh played a key role in the invention and the development of the ElectroStrip™ Process. KTA/SET Engineering provided support as a consulting firm specializing in the environmental aspects of removal of coatings and repainting of structures.

A new entity, EMEC Technologies Corporation, is being planned to foster implementation of the technology under development. This new entity will acquire exclusive rights from EMEC Consultants to practice and license the patented ElectroStrip™ technology.

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- [2] J. M. Atkinson, R. D. Granata, H. Leidheiser, Jr., and D. G. McBride, "Cathodic delamination of methyl methacrylate-based dry film polymers on copper", *IBM J. Res. Develop.* **29** (1), 27-36 (1985).

