FINAL REPORT

STEEL BRIDGE PROTECTION POLICY

VOLUME III

METALIZATION OF STEEL BRIDGES: RESEARCH AND PRACTICE

FHWA/IN/JTRP-98/21

by

Luh-Maan Chang
Principal Investigator

and

Maged Georgy
Research Assistant

Purdue University
School of Civil Engineering

Joint Transportation Research Program
Project No.:C-36-26J
File No.:4-4-10

Prepared in Cooperation with the
Indiana Department of Transportation and
The U.S. Department of Transportation
Federal Highway Administration

Purdue University
West Lafayette, Indiana 47907

May 27, 1999

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JTRP-98/21		

4. Title and Subtitle	5. Report Date
Steel Bridge Protection Policy *Volume III of V: Metalization of Steel Bridges: Research and Practice*	May 1999
	6. Performing Organization Code
7. Author(s) Luh-Maan Chang, Maged Georgy	8. Performing Organization Report No. FHWA/IN/JTRP-98/21
9. Performing Organization Name and Address Joint Transportation Research Program 1284 Civil Engineering Building Purdue University West Lafayette, Indiana 47907-1284	10. Work Unit No.
	11. Contract or Grant No. SPR-2038
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.

16. Abstract

The study identifies various painting systems that are successfully used in Indiana's surrounding states and other industries. The identified systems are further screened and evaluated. After prudently comparing INDOT's inorganic zinc / vinyl system with the waterborne acrylic system, the moisture cure urethane coating system, and the 3-coat system of zinc-epoxy-urethane, the results show that the new 3-coat system fulfills INDOT's needs with the most benefits. Therefore, the 3-coat system is recommended to replace INDOT present inorganic zinc / vinyl system.

To deal with the problems facing the lead-based paint, a comparison between full-removal and over-coating alternatives is made. Results show that over-coating might provide a good protection for less than half the cost of full-removal; however it delays the lead full-removal process and does not completely solve the environmental problem.

The metalization of steel bridges is seemingly a potential protection policy. After reviewing standards and specifications on metalization, it is shown that metalization jobs require a higher degree of control. It suits on-shop practices, however, the initial cost is considerably high.

This study also describes a life cycle cost analysis that was done to determine an optimal painting system for INDOT. Herein, a deterministic method of economic analysis and a stochastic method of Markov chains process are used. The analysis not only reconfirms that the 3-coat system is the comparatively better painting system, but also generates an optimal painting maintenance plan for INDOT.

To assure the quality of paint material and workmanship after substantial completion of the painting contract, the development of legally binding and dependable warranty clauses is initiated in this study. The developed painting warranty clauses were primarily derived from the painting warranty clauses used by IDOT, MDOT, and INDOT's pavement warranty clauses. A comparative study was conducted on eleven essential categories. Among them, it was found that the warranty period, the definition of "defect", and the amount of the warranty bond all need further evaluation.

17. Key Words	18. Distribution Statement
coating, inspection, life cycle cost analysis, Markov Chains Process, metalization, painting, quality control, steel bridge, warranty Clauses.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	55	

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

CHAPTER I: INTRODUCTION	**1**
Historical Background	1
Why Reconsidering the Use of Thermal Spray Coatings Recently	2
Study Objectives	3
Study Methodology	3
CHAPTER II: BACKGROUND	**5**
Surface Preparation	5
Thermal Spraying Process	5
Flame spraying	6
Arc spraying	7
Thermal Spraying Materials	9
CHAPTER III: CONTEMPORARY RESEARCH IN THE UNITED STATES AND EUROPE	**12**
Research and Standards by the American Welding Society	12
Automation of the Thermal Spray Technology by USA-CERL	22
British Standard Code of Practice	23
CHAPTER IV: CONTEMPORARY PRACTICE IN THE UNITED STATES AND EUROPE	**27**
Practice in the United States	27
IDOT practice	28
MDOT practice	29
ODOT practice	29
ConnDOT practice	31
INDOT practice	35
European Practice	36
Merits of Metalization Compared with INDOT Conventional Painting System	37

CHAPTER V: REVIEW OF SPECIFICATIONS AND RECOMMENDATIONS **42**

General 42

Comparison and Recommendations 45

CHAPTER VI: SUMMARY AND CONCLUSIONS **53**

REFERENCES **54**

CHAPTER I
INTRODUCTION

The term thermal spray, or metalization, describes a family of coating technologies associated with the application of thick coating onto the bridge substrate in order to reduce or eliminate the debilitating effects of wear and corrosion. Within the region of application, the coating material -in either powder, wire, or rod form- is brought into a plastic or molten state. Afterwards, the coating material droplets are accelerated onto the steel surface. When the droplets impact into the surface, they form lenticular splats, Fig. (1), and form a coating layer. The coating is built to the desired thickness by multiple passes over the surface [1].

The terms, thermal spray and metalization, will be used interchangeably in this report.

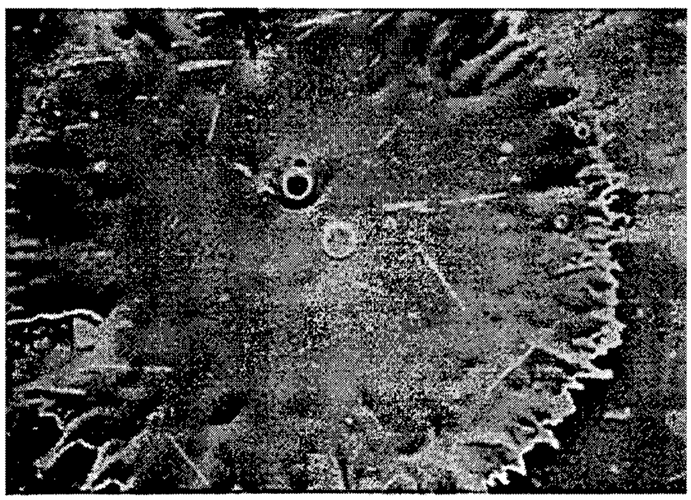


Figure (1). Splat structure.

Historical Background

Thermal spraying of bridges is not a new idea. Since the 1930s, zinc spraying has been extensively utilized in Europe, and in many countries zinc spraying is specified as the only corrosion protection system for new bridge construction. To date, several hundred bridges have been thermally sprayed to provide long-term corrosion protection. Table (1) lists several significant bridges, the year of metalization, and the last date when the coatings were inspected and found to be intact [1].

Table (1) Metalized Zinc Bridges

(Adopted from [1])

Structure	Coating system	Year metalized	Year last inspected
Kaw River (U.S.)	10 mils Zn	1936	1975
Ridge Avenue (U.S.)	10 mils Zn	1938	1984
Forth Road (U.K.)	3 mils Zn + 3 coats paint	1961	1975
Pierre-LaPorte (Canada)	5 mils Zn + 5 coats paint	1977	1985

1 mil = 0.0254 mm

Why Reconsidering the Use of Thermal Spray Coatings [2]

Recent changes in guidelines on the environmental impact of infrastructure maintenance have made it necessary for manufactures to reformulate paints to comply with lower volatile organic compounds (VOC) emissions requirements. In complying with these new VOC standards, many paint systems have suffered a reduction in long-term performance and an increase in required curing time. In addition, there are increasing demands for absolute enclosures around any maintenance site to capture all hazardous debris for the protection of workers and the environment. Class A containment enclosures are cumbersome, difficult to erect, and they greatly increase the difficulty of any maintenance task, increasing both project time and cost.

It is highly preferable to use the longest lasting protective coating available, which will not only decrease the number of maintenance cycles for a specific structure, but also minimize the level of effort required. A zinc/aluminum alloy, with its proven long-term performance record, provides a promising alternative. Basically, thermal spray process produces zero VOCs and requires zero curing time. Furthermore, thermal spraying can be applied at any temperature, as long as the minimum-above-dew-point requirement is satisfied, thus eliminating the need to cease work during the winter.

It is worth mentioning that INDOT has a previous experience of coating steel bridges with a zinc protective layer and which proved to be long lasting. About 30 years ago, INDOT galvanized the steel bridge that carries traffic of I-69 over 82nd street in Indianapolis. Recent evaluations of the galvanized bridge indicate that the coating system does not show signs of deterioration. Although being different in the way they are applied to the steel bridge surface, galvanization and metalization are not different in the way they protect the steel substrate. Both depend on covering the steel bridge with a zinc layer that acts as a barrier against steel corrosion. This layer is applied through hot-dipping of steel in case of galvanization and spraying in case of metalization. However, steel protection is essentially the same since the protection is provided through galvanic action at the zinc/steel surface as well as by the zinc ability to protect itself with its own corrosion byproducts. This protection process will be further explained in the report.

Study Objectives

Indiana Department of Transportation (INDOT) has become aware of the high potential of thermal spraying – metalizing – its steel bridges. At the time this research effort was initiated, the first metalization project in Indiana had been underway. This project comprises themetalizing of bridge I-65-123-4568B and which carries the traffic of old 45-52 over I-465. The study conducted by the research team in the area of metalization has the primary objective of investigating thermal spray – metalization – technology, relevant European and US standards, and the real-world practices for metalizing steel bridges. An extended objective is to provide the support for the decision making process made by INDOT personnel when choosing between different coating alternatives with metalization as one of them. The report provides a variety of information regarding metalization standards, research done in the past, current practices, and specifications in use in the area of metalizing steel bridges.

Study Methodology

As mentioned in an earlier section, the application of thermal spray coatings on steel bridges goes back to the 1930's. The technology itself is even older than that. Over the years, several research activities have been conducted to establish the standards that regulate the use and application of thermal spray technology in coating steel surfaces. Investigating the available literature and standards, which provide such information, constitutes the cornerstone of the current research effort.

Following the literature search, the degree of popularity associated with thermal spraying –metalizing – steel bridges was to be investigated. For such a purpose, several State Departments of Transportation were contacted. A special emphasis was given to the surrounding states and those states that have already established some experience in metalizing steel bridges. The fact that the first metalization project in Indiana was underway gave the chance to further investigate metalizing practices and interview the different personnel participating in this project. Finally, the different specification forms used by the contacted State Departments of Transportation have been obtained for study and analysis. This gave the opportunity to compare those forms with the one used by INDOT for Indiana's first metalization project. The comparison highlights those areas need to be reconsidered by INDOT in future practices.

Chapter II provides a general background of the metalization process. A review of the various equipment and materials are presented.

Chapter III presents the research activity conducted in the United States and Europe to standardize the application of the metalization coatings on steel substrates. This chapter provides an abridged form of the ANSI/AWS C2.18-93 standards, which are considered the reference standard for all metalization jobs in the United States. A review of the USA-CERL for automating the application process is provided. Also, the British standards are given in a brief form.

Chapter IV gives an overview of the popularity of metalization steel bridges in the United States. The results of the survey covering Indiana, Ohio, Illinois, Michigan and Connecticut are presented in detail.

Chapter V provides a general comparison between the already used specification forms in more than one state. Recommendations are given within some of the comparison areas that need to be taken into consideration by INDOT.

CHAPTER II
BACKGROUND

Surface Preparation

As with any coating, the surface must be properly prepared in order to insure coating adherence. In the case of thermal spray coatings applied in open atmosphere, the proper surface preparation is the roughening of the surface either by grit blasting or chemical etching in order to generate the asperities necessary for the mechanical bonding of the coating to the component surface [1].

Thick-sprayed metal coatings require a rougher surface than thin coatings, and aluminum requires a rougher surface than zinc of equal thickness. With any given abrasive, roughness may be increased somewhat by increasing the air pressure. As a rule, however, the required roughness is obtained by the selection of the proper abrasive [3].

Cleanliness of the surface is important regardless of the type and thickness of the coating metal. Fingerprints or other traces of moisture or contamination may result in practically no bond. Oil and moisture originating in the air used for the blast operation can cause trouble. Thus, additional oil or moisture separators are often required or specified in the compressed air lines. Occasionally, even the humidity of the air in contact with the area to be sprayed must be controlled [3].

Thermal Spraying Process

Thermal spraying is a line-of-sight process with optimum coatings being obtained when the angle of impingement of the molten droplets is perpendicular to the surface being coated [1]. Several thermal spraying techniques were developed over the years. The list includes flame spraying, plasma spraying, arc spraying, detonation -gun spraying, and high velocity oxy-fuel spraying (HVOF) [4]. Among all, flame and arc spraying were used on a broader scale for coating steel bridges [1].

Flame Spraying

Flame spraying, Fig. (2), is the oldest form of thermal spraying. In its simplest form, it consists of a nozzle assembly wherein a fuel (acetylene, hydrogen, propane, etc.) is mixed either with oxygen or air and undergoes combustion external to the nozzle. For materials in powder form, the powder is injected into the flame in a manner designed to optimize the heating of the powder. For materials in wire or rod form, the flame is concentric to the wire or rod in order to maximize the uniform heating of the wire rod. A coaxial sheath of compressed gases around the flame acts to atomize the molten particles and accelerate them toward the substrate [1].

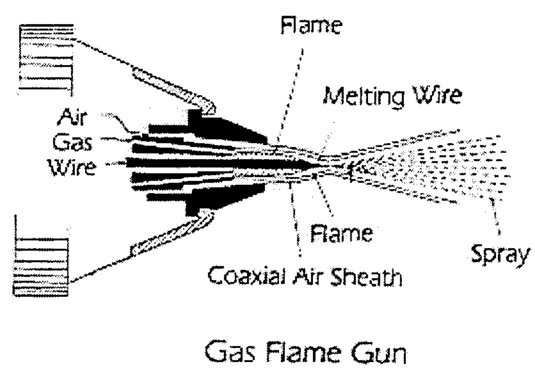


Fig. (2) Details of the Flame Spray Gun

- The main advantages of these processes are the low capital investment costs (a wire flame gun currently costs around $5,000 as reported by Lewis [21]) and the ease of operation. Because of the relatively small size of the equipment and the ease of operation, the process is field-portable, and there is little restriction to the size and complexity of components that can be coated [1].
- The main disadvantage, however, is that the particle velocities are relatively low and, therefore, the coating porosity can be as high as 20 percent [1].

Flame Spraying Parameters [4]:

- Oxygen to fuel ratio may vary from 1:1 to 1.1:1. The flame velocity is in the range of 263-328 ft/s (80-100 m/s).

- For powder guns, the powder particles used are usually in the range of 0.2 - 4.0 mils (5-100 μm) with the narrowest possible distribution of particle sizes to improve spraying efficiency. The powder feed rate varies from 0.1 to 0.2 Ib/min (50 to 100 g/min).
- For wire guns, the wire diameter ranges from 0.12 to 0.24 in. (3 to 6 mm).
- Spraying distance is in the range 0.4-0.8 ft (120-250 mm).

Arc Spraying

The electric arc process is illustrated in Fig. (3) and involves the continuous feeding of two wires into a device such that the wires converge at a point in space. The wires are held at different electrical potentials, such that an electric arc is generated between them. These wires are, in essence, consumable electrodes and are continuously melted. A jet of gas, usually compressed air, is used to atomize the molten material and accelerate the resultant droplets onto the component surface. It is not necessary for both wires to have the same chemical composition resulting in alloyed coating, however, adjustments to the feeding mechanism are necessary to compensate for these differences [1]

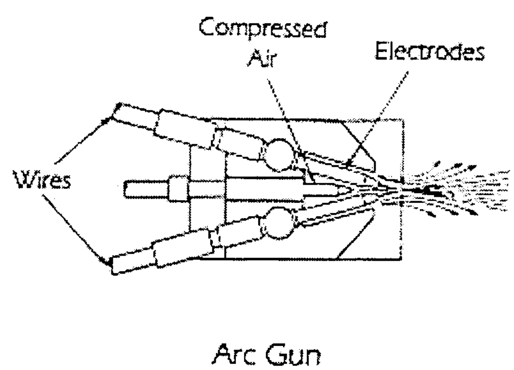


Fig. (3) Details of the Arc Spray Gun

- The main advantage of this process is that very high deposition rates are achievable [1]. Because of the high temperatures in the arc zone, the coatings have excellent adhesion and high cohesive strength, considerably higher those achieved with flame guns [19].

- Contrary to flame guns, arc spray guns require higher investment capital (an arc spray gun currently costs around $23,000 as reported by Lewis [21]). Also, the atomization process in arc spraying generates more fumes than other thermal spray processes.
- Additionally, this process frequently results in porosity levels of 25 percent by volume. However, the recent advances in the design of electric arc equipment have resulted in higher particle velocities and coatings of higher density [1]. A density level of 93% (only a porosity level of 7%) is achievable with the most advanced guns [22].

Arc Spraying Parameters [4]:

- All materials used are electrically conductive.
- The wire diameter is typically in the range 0.08 to 0.20 in. (2-5 mm).
- The molten particles formed of wires can reach velocities of up to 492 ft/s (150 m/s).
- Arc voltage is typically in the range 20-40 V, and an increase of voltage leads to an increase of droplet sizes.
- The deposition rate varies between 0.1-0.65 Ib/min (50-300 g/min).
- The spraying distance is in the range 0.15-0.55 ft (50-170 mm).

A comparison between the flame gun and the arc spray gun, is summarized in the following table:

	Flame Gun	**Arc Spray Gun**
Advantages	• Low capital investment cost. • Ease of operation. • Relatively small size of equipment. • More field-portable. • Little restriction to the size and complexity of components that can be coated.	• High deposition rates. • Droplet sizes can be controlled by changing the operating voltage. • Excellent adhesion and high cohesion strength.
Disadvantages	• Low deposition rate. • Particle velocities are relatively low, thus, coating porosity can be as high as 20 percent.	• High capital investment cost. • Atomization process generates more fumes than other thermal spraying processes. • Hard to manage in confined surfaces.

Thermal Spraying Materials [1]

The proper choice of coating materials may determine whether or not the desired goals are achieved. Historically, thermal spray coating systems have used pure zinc, pure aluminum, and zinc/aluminum alloys for applications involving corrosion protection of steel structures. Being metallic, the coatings offer additional protection in high-wear areas.

1. Zinc:

- Zinc provides long-term corrosion protection to steel through galvanic action at the zinc/steel surface as well as by its ability to protect itself with its own corrosion byproducts. Zinc has a lower oxidation potential than iron and will therefore preferentially corrode, preventing the steel from rusting.
- Being a reactive metal, zinc readily forms a protective corrosion-product film. When exposed to air, a very thin layer of zinc oxide forms. When exposed to moisture in the atmosphere, the zinc oxide reacts with the moisture to form zinc hydroxide. During the drying process, the zinc hydroxide reacts with carbon dioxide to form an insoluble zinc carbonate layer on the surface, providing excellent protection to the underlying zinc.
- Ductility of zinc aids in obtaining uniform coverage and provide increased tolerance of surface defects. [5]
- Zinc in considered of low cost compared to other metals.

2. Aluminum:

- Aluminum provides a barrier to the corrosion of steel by the formation of an inert aluminum oxide layer on the surface of the coating.
- When damaged, this coating is self-healing.
- Like zinc, aluminum has a lower oxidation potential than steel with respect to iron and therefore provides galvanic protection to the steel substrate.
- Unlike zinc, pure aluminum has not been extensively thermally sprayed onto steel bridges and structures although extensive use by the U.S. Navy indicates aluminum is more corrosion-resistant than zinc in marine environments. Fig (4) describes the estimated service life for aluminum thermal spray coatings.

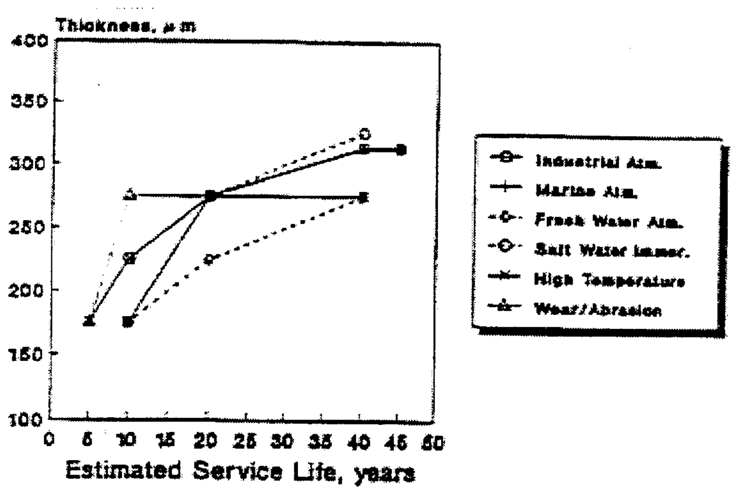


Fig. (4) Estimated Service Life for Al thermal spray coatings [1]

3. Zinc/Aluminum:

With the proven protection associated with zinc and the implied improved performance of aluminum in salt environments, alloys of zinc and aluminum have been developed.

- Initial work in Japan indicates that such alloys, particularly 85 percent zinc/15 percent aluminum alloy, have advantages over all-zinc coatings.
- This alloy has successfully been applied to steel bridges within the United States. Fig. (5) describes the estimated service life for Zn and 85/15 Zn/Al thermal spray coatings.

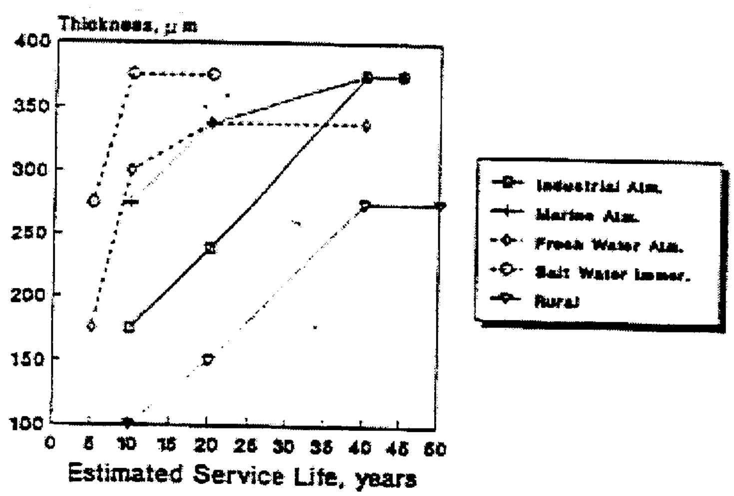


Fig. (5) Estimated Service Life for Zn and 85/15 Zn/Al thermal spray coatings [1]

4. Polymers:

Recently, the application of polymers such as ethylene acrylic acid (EAA) by thermal spray technology has been suggested for corrosion prevention on bridges. Unfortunately, unlike the metallic coatings described above, success has been limited for two reasons [1]:

- First, control of the substrate temperature is critical for adhesion and to date no definitive method for insuring the proper temperature has been proposed.
- Second, like most paint systems, these coatings are solely barrier coatings without any additional protective mechanisms such as those exhibited by the metallic coatings.

5. Sealers [1, 19]:

Although zinc, aluminum, and their alloys provide galvanic protection, additional protection can be obtained by sealing the porosity with acrylic urethanes, polyester urethanes, vinyls, phenolics, epoxy sealers, or thermally sprayed polymers. Although sealers and topcoats are not always necessary for zinc or aluminum coatings, because of the galvanic protection, a sealed coating offers an extended service life beyond that offered by an unsealed coating. This is primarily due to the sealing of pores against the penetration of moisture and external effects. In addition, a sealed coating generally gives a more pleasing appearance.

CHAPTER III
CONTEMPORARY RESEARCH IN THE UNITED STATES AND EUROPE

Thermal spraying of steel bridges in the US has started since 1936 when the Kaw River Bridge was coated with 10 mils (250 μm) of zinc [1]. Over the years, the performance of these coating systems was successful. This superior performance resulted into the initiation of an extensive research study by the American Welding Society (AWS) to investigate the protection of steel with thermal sprayed coatings. This effort eventually ended up with the introduction of the ANSI/AWS C2.18-93 standards.

Research and Standards by the American Welding Society

In 1974, the American Welding Society (AWS) completed a 19-year study of the corrosion protection afforded by wire-flame-sprayed aluminum and zinc coatings applied to low-carbon steel [6,7]. Originally, exposure periods of one, three, six, and twelve years of thermally sprayed steel panels were scheduled. However, the encouraging results of early inspections resulted in extending the test period to 19 years [7]. Results of the six-year and twelve-year inspections are reported in AWS publications C2.8-62 and C2.11-67, respectively.

The test sites were selected to provide a wide variety of environmental conditions. All locations were selected as ASTM test areas. No rural exposures were included; some degree of atmospheric contamination, either saline or industrial, exits at all sites. By the end of this study, the following conclusions were drawn [7]:

- Aluminum-sprayed coatings 3.0 to 6.0 mils (80 μm to 150 μm) thick, both sealed and unsealed, gave complete base metal protection from corrosion in seawater and also in severe marine and industrial atmospheres (Four types of sealing materials were used, including, wash primer, aluminum vinyl, clear vinyl, and chlorinated rubber).
- Unsealed zinc-sprayed coatings required 12 mils (300 μm) minimum-thickness for complete protection in seawater for 19 years. In severe marine and industrial atmospheres, 7.5 mils (230 μm) of unsealed zinc or 3.0 – 6.0 mils (80 μm to 150 μm) of sealed zinc are needed for 19-year protection.
- In severe marine atmospheres, the application of one coat of wash primer plus one or two coats of aluminum vinyl enhanced the appearance and extended the life of zinc

coatings at least 100%. With aluminum, the sealing system primarily enhanced appearance, because both systems showed no base metal rust after 19 years.

- Thin coats of aluminum perform better because they have less tendency to develop pits and blisters and therefore extended life is expected.
- Where aluminum coatings showed damage such as chips or scrapes, corrosion did not progress, suggesting the occurrence of galvanic protection.
- The corrosion protection afforded by zinc and aluminum coatings is not affected by the method of surface preparation used for this test. Six types of surface preparation materials were used; including coarse silica sand, coarse silica sand and steel flash, fine silica sand, fine silica sand and steel flash, chilled iron grit, and chilled iron grit and steel flash. For large parts, or where coating thickness will exceed 6.0 mils (150 μm), a coarse abrasive is recommended.

In 1993, the AWS issued a *Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites*, **ANSI/AWS C2.18-93** [8]. This guide is now considered the definitive document for preparing specifications for bid documents in the United States [6]. This guide is modeled on the thermal spray method of MIL-STD-2138A(SH), *Metal Sprayed Coating Systems for Corrosion Protection Aboard Naval Ships*.

The guide is divided into 14 sections; titled:

1. General
2. Safety
3. Job and Contract Description
4. Background and Requirements
5. Materials
6. Equipment for Thermal Spray
7. Quality Control Equipment
8. Application-Process Method
9. Maintenance and Repair of Thermal Spray Coatings
10. Records
11. Debris Containment and Control
12. Utility Services
13. Work Procedures and Safety

14. Warranty

In addition, four annexes are attached to the original standards, including;

1. Sample Job Control Record (JCR).
2. Recommendations for the selection of thermal spray coatings of Aluminum and zinc and their composites.
3. Thermal spray operator qualification and certification.
4. Sample thermal spray operator qualification form.

1. General

The scope of the guide is defined as explained in the preceding section. The guide defines four abrasive blast-cleaning methods for various surface finishes. Those standards were developed by the National Association of Corrosion Engineers (NACE) and the Steel Structures Painting Council (SSPC). The list includes:

- SSPC-SP 5: *White-Metal Blast Cleaning.*
- NACE No. 1: *White-Metal Blast-Cleaned Surface Finish* (NACE No. 1 is comparable to SSPC-SP 5)
- SSPC-SP 10: *Near-White-Metal Blast Cleaning.*
- NACE No. 2: *Near-White Blast Finish* (NACE No. 2 is comparable to SSPC-SP 10)

2. Safety

The basic precautions for thermal spraying are essentially the same for welding and cutting. This is described by several standards, e.g., ANSI/ASC Z49.1, *Safety in Welding and Cutting*.

The guide gives special attention to <u>the explosive nature of the metal dust</u>. Several requirements are cited including;

- Adequate ventilation in the thermal spray work area
- Partial or complete containment of the work site and safe disposal of the used blasting media and thermal spray overspray.
- Special fine overspray collectors to be used in shop-environments.
- Additional precautions to be taken in case of the extremely hot conditions of thermal spray operation.

In addition, a special section addresses the handling of aluminum and zinc powders.

3. Job and Contract Description

This section addresses the thermal spray boundary (TSB), job control record (JCR), selection of thermal spray coating (TSC), TSC inspectors, and TSC operator qualifications. The TSC operator qualification criterion is presented in ANSI/AWS C2.16-92. The TSC inspector, at a minimum, should meet the knowledge and skill requirements of the same standards. A Job Control Record (JCR) covers the essential job information and the QC check points in six areas:

- TSC contractor (TSCC),
- Purchaser's invoice,
- TSC type and requirements,
- TSC operators qualifications,
- blasting and thermal spray equipment, and
- Nine QC checkpoints presented later in the application-process method (refer to section 8 of the same standards for a complete description).

4. Background and Requirements

The following job requirements should be described in sufficient detail:

- TSC feedstock material.
- TSC minimum inspection and end-item acceptance criteria.
- TSC work process requirements.
- TSC inspector qualification.
- TSC operator qualification.
- Job Schedule.
- Concurrent work on the job site that may cause mutual interference.
- Job site work permits, access permits, safety, etc.
- Containment and disposal of waste and paint debris.
- Applicable Federal, State, County, City, or union regulations.
- Other information needed for the planning and completion of the thermal spray job.

5. Materials

Aluminum, zinc, 85 zinc/15 aluminum are available in both powder and wire form. Generic thermal spray wire and powder material classification and specifications may be found in MIL-W-6712.

6. Equipment for Thermal Spraying

Any thermal spray gun to be used should satisfy the following:

1. Spray for 3 minutes without sputtering or shutdown.
2. Start and stop spraying for eight *10-second spray, 5-second off* sequences without fusing or sputtering.

This proof of equipment quality should be demonstrated only during the initial or preliminary trials, not on a daily check basis.

7. Quality Control Equipment

The following QC equipment is to be used before and during the thermal spraying process.

Surface Preparation

- 10x Magnifier or Loop for visual inspection of metal finish.
- Small glass or plastic container (4 oz) for the testing of blasting media and a clean white cloth squares to detect moisture and contamination in the compressed air.
- Profile replica tape, 1.6-4.4 mils (40-110 μm) for anchor-tooth measurements, spring anvil micrometer for measuring the profile tape, and dial surface profile gage for measuring the anchor-tooth depth.

TSC Application

- Contact or infrared pyrometer to measure substrate temperatures.
- Psychrometer or an equivalent digital humidity measurement instrument.
- Magnetic pull-off or electronic thickness gage.
- 2 in. X 4-8 in. X 0.05 in. (50 mm X 100-200 mm X 13 mm) mild steel for bend coupons.
- Sealable plastic bags to encase bend coupons and other QC samples collected during the job.

8. Application-Process Method

Surface Preparation

The steel substrate must be prepared according to SSPC-SP 10 (near-white-metal finish) as a minimum. Angular blasting media, e.g., steel grit, mineral slag, and aluminum oxide, should be used to cut a 2-4 mils (50-100 μm) anchor-tooth profile to ensure the mechanical anchorage of the TSC. For TSC's greater than 12 mils (300 μm), use profile depth approximately one-third the TSC thickness. Blast angle should be as close to perpendicular as possible but in no case greater than ±45° to the work surface.

New Steel Substrate

The surface should first be degreased using steam cleaning, solvent washing or detergent washing. Afterwards, certain areas of the substrate are to be masked if fall under any of the following categories:

- All fit and function surfaces.
- Overspray-control areas.
- The non-TSC area beyond the TSB.

A near-white-metal finish should be reached using a mechanical (centrifugal wheel) and pressure-pot blast cleaning equipment. Suction blasting is not allowed. The requirements of the surface profile are as listed in the previous section. The abrasive blasting media and method is to be tested according to one of the following inspection procedures:

- SSPC-Vis 1-89, *Visual Standard for Abrasive Blast Cleaned Steel,*
- NACE TM0170-70, *Visual Comparator of Surfaces of New Steel Air Blast Cleaned with Slag Abrasive*, or
- NACE TM0175-75, *Visual Comparator of Surfaces Centrifugally Cleaned with Steel Grit Abrasive.*

Contaminated Steel Substrate

A contaminated steel substrate requires more intensive surface preparation than new steel. The surface should be degreased using hydroblasting, steam cleaning, solvent washing, or detergent washing. The masking procedure, blast equipment, blast media, and surface finish and profile are the same as for new steel. However, the blasting procedure should be followed by a 24 hours wait-period until the occurrence of the rust bloom. If there is no rust or light-rust bloom, the substrate area that will be thermally sprayed within the next 6 hours re-anchor-tooth blasted to SSPC SP-5 finish and a $2.0 \times 10^{-3} - 4.0 \times 10^{-3}$ in. (50-100 μm) angular profile. If there is heavy rust bloom (dark brown or black color), other cleaning methods should be continued, e.g., wet abrasive, high- and ultra-high-pressure water, or thermal charring singly or in combination, to remove the contamination. A thermal cleaning method may be used with caution of fire hazards (Refer to ANSI/AWS C2.18-93 original standard for more detail).

Post-Blasting Period

The surface temperature should be at least 10°F (5°C) above the dew point. Time between the completion of the final anchor-tooth blasting and the completion of the thermal spraying should be no greater than six hours for steel substrate. This is primarily to prevent flash rusting from developing prior to the application of the TSC. If rust bloom, blistering, or degraded coating appears at any time during the application of the TSC, the spraying should be stopped immediately and the TSC inspector must evaluate the error thoroughly. Then, all the proper remedial actions are to be taken. The 6-hour holding-period can be extended in low-humidity environments or in enclosed spaces using industrial dehumidification equipment according to the manufacturer standards and after checking the results of the bend coupons and tensile bond coupons or both. When specified by the purchasing contract a flash-coat of TSC equal to or greater than 1 in. (25 mm) may be applied within 6 hours. This can extend the holding period for another 4 hours.

Thermal Spraying

After setting-up the thermal spray equipment, the process should start as soon as possible after the final anchor-tooth and completed within the 6-hour holding period. Table (2) presents the nominal standoff and spray pass width values. The surface must meet the temperature to the dew point requirement listed above.

Table (2) Flame- and Arc-Spray Standoff Distances and Spray-Pass Widths (Nominal)

Thermal Spray	Perpendicular Standoff, in. (mm)	Spray-Pass Width, in. (mm)	
		Regular Air Cap	Fan Air Cap
Flame Wire	5-7 (130-180)	0.75 (20)	Not Available
Flame Powder	8-10 (200-250)	2 (50)	3-4 (75-100)
Arc Wire	6-8 (150-200)	1.5 (40)	3-6 (75-150)

Prior to thermal spraying the surface, complex geometries where overspray cannot be eliminated, an overspray-control area should be established and proper masking to be done. The following execution sequence is to be followed:

- For flame spraying, the initial 1-2 ft^2 (0.1-0.2 m^2) should be preheated to approximately 250°F (120°C) to drive off residual moisture and reduce the temperature differential between the sprayed metal and the substrate.
- All start-up and adjustment of the spray gun should be made off the surface to be thermally sprayed
- The specified coating thickness should be applied in several perpendicular overlapping passes. The coating tensile bond strength is greater when the spray passes are kept thin. Laying down an excessive thick spray pass will decrease the ultimate tensile-bond strength of the coating.
- The total coating thickness is to be measured from the peaks of the anchor-toothed profile.

Sealing

Seal coats should be applied as soon as possible after the TSC has been applied and before visible oxidation of the TSC occurs The application process of the sealer should be within 8 hours for zinc and zinc alloys TSCs and 24 hours for aluminum TSC. Seal coat(s) should only be applied to clean dry TSC surfaces. If moisture is present, the steel should be heated to 250°F (120°C) to remove the moisture prior to the seal coat application. Intermediate and topcoats, if any, are to be applied according to the contract specifications.

The application of the thermal spray coating is to be checked against nine QC checkpoints. The list includes:

1. Oil and grease contamination.
2. Masking.
3. Clean, dry air.
4. Clean blasting media.
5. Near-white-metal finish and anchor-tooth profile.
6. Thermal spray equipment set-up.
7. TSC application.
8. Seal coat thickness.
9. Intermediate and topcoat thickness.

9. Maintenance and Repair (M&R) of Thermal Spray Coatings

Inspection and maintenance should be made on a scheduled basis responsive to the operating environments, duty cycle, severity of service, and estimated coating service life before maintenance repair and re-coating. Table (3) lists the required procedures depending on the degree of damage and wear, and the size of the damaged area. The possible coating failures are classified into two groups:

- Coating failure on which the steel substrate is NOT exposed to the surrounding environment.
- Coating failure on which the steel substrate is exposed to the surrounding environment.

Table (3) Maintenance and Repair (M&R) Actions for TSCs

(The √ symbol indicates a required M&R step for the corresponding coating failure as denoted in column heads)

M&R Step	Steel Substrate Not Exposed		Steel Substrate Exposed	
	Area ≤ 0.1 m^2	Area ≥0.1 m^2	Paint Repair	TSC Repair
Solvent Clean	√	√	√	√
Flexible-Blade Scrape	√			
Hard-Blade Scrape			√	√
Hand-Brush Clean	√			
Abrasive Brush Blast		√		
Power Tool Clean			√	

White-Metal Blast				√
Feather 2-3 in. Border	√	√	√	√
Lightly Abrade	√			
Apply TSC				√
Seal and Topcoat	√	√	√	√

10. Records

The TSCC should use a JCR to record the production and QC information required by the Purchaser in addition to its own Quality Assurance Program.

11. Debris Containment and Control

The TSCC and the purchaser should coordinate the specific requirements, responsibilities and actions for the containment, collection and removal of the debris produced by the TSCC and its subs.

12. Utility Services

The utility services and the time they are required for use by the TSCC should be listed.

13. Work Procedures and Safety

The purchaser shall provide its standard operating and safety procedures and compliance requirements to the TSCC who should follow it.

14. Warranty

The TSCC shall warrant the quality of its workmanship as mutually agreed to by the purchaser and the TSCC.

Automation of the Thermal Spray Technology by USACERL [2]

In 1991, the U.S. Army Corps of Engineers initiated a study through the Construction Productivity Advancement Research (CPAR) Work Unit. The work was conducted in cooperation with the State University of New York (SUNY) at Stony Brook, NY. The objective of this CPAR project was to develop, demonstrate, and transfer to the technical coatings industry an automated thermal spray technology for field applications to civil works infrastructures. The major incentive for developing such an automated system is the need to deal with lead-based paints already existing on a large number of the steel bridges all over the US. The probable dangerous effects of those materials on the repair crews and the surrounding environment in case of a deficient and /or slow manual procedure necessitate the automation of the whole process.

The Automated Thermal Spray System (ATSS) utilizes a triaxial array of linear motion actuators to form a robot capable of performing preprogrammed sequences. The ATSS positioning system is designed to eliminate many difficulties, e.g., physical demands on workers, surface inaccessibility, normally encountered in such work. A three-axis positioning system maneuvers a vacuum blasting head, thermal spray gun, and video camera to locations on the structure at the appropriate standoff distance for each component. The system may be operated through remote control or can be programmed for specific motion.

A two-wire electric arc thermal spray system (Hobart-Tafa Arc Spray Model 9000, Tafa, Inc.) was chosen for depositing alloy coatings onto the structures. Criteria for selecting this type of a system were quality of the coatings produced deposition rates, automation capability, logistical support requirements, materials sprayed, and operating costs. The operator can remotely adjust the wire feed rate between 0 and 3000 ft/hr (0-0.25 m/s) to control the deposition rate and deposit thickness.

The surface was cleaned according to SSPC-SP 5. To avoid the necessity of using expensive full-enclosure technologies, a vacuum blasting system (LTC 1060-B, LTC Americas, Inc.) was chosen for surface preparation. Testing by North Carolina State University on a bridge, whose coatings contained 18.4 percent lead by weight, demonstrated the effectiveness of this system in removing and containing the lead. Also, in 1990-test conducted by the Illinois DOT, the system was proved to be effective on a production scale. Although the TLC 1060-B is not accepted by all state departments of transportation as a substitute for the Class (A) enclosures currently specified for environmental controls, it still provides the level of dust containment required by the EPA.

On 9 December 1994, a field test of ATSS was performed on bridge No. 1056230 over County Route 58, Long Island. The test included a field setup procedure, grit blasting to remove lead-based paint from part of the structure, and thermal spraying of the exposed steel substrate. Both the grit-blasting nozzle and the thermal spray gun were mounted on the ATSS and controlled from the ground. By the end of the process, engineers from USACERL judged the coating to be acceptable for corrosion-protection purposes. The demonstration made it clear that the prototype ATSS could not perform a comprehensive real-world project without a support crew. However, the demonstration results do prove the feasibility of using an automated platform for blasting and thermally spraying steel substrates in field conditions.

ATSS requires only a three-person crew for operation. Engineers observing the demonstration estimated that a three-person crew with a few days of ATSS experience could set up a site in 1 hour and change the location of the system in 5 minutes. Assuming that the equipment is operating properly, the work crew could average 6 hours of continuous ATSS operation per day. The average coating time for the prototype ATSS is 5 minutes for every 4 ft^2 (0.4 m^2) of surface area. Therefore, the maintenance crew could cover 290 ft^2 (27 m^2) per day. The average cost for that is \$5.20/ ft^2 (\$56/m^2). Table (4) lists estimated ATSS operating costs, including all materials and consumable parts.

Table (4) ATSS Estimated Operation Cost

Element	**Cost**
3-person maintenance crew [\$25/hr]	\$600/day
Wire [400Ib (180 Kg)]	\$800/day
Consumables	\$50/day
Grit blast media	\$50/day
Average cost	*\$5.20/ft^2 (\$56/m^2)*

British Standards [9]

The British code of practice for "Protective coating of iron and steel structures against corrosion" was published in October 1977 and last amended in November 1993. In general, this code of practice represents a generalized procedure for choosing the most appropriate coating system for a certain application. Nevertheless, metalization has been introduced as one of the basic protective coating for steel works.

The structure of the code of practice is highly dependent on the definition of the environment on which the steel structure exists. Consequently, clear definitions of all the possible environments are listed in greater detail. The list includes exterior exposed, non-polluted inland, polluted inland, non-polluted coastal, etc. Although the definition of environment and recommendations for coatings are primarily related to the conditions in the U.K., the environmental categories developed in such a way to cover all possible occurrences. The only limitation mentioned is the applications of those standards in high-temperature areas where the environments are more corrosive than usual.

Four methods for applying metallic coatings are represented; including hot-dip galvanizing, sherardizing, electroplating, and metal spraying. The code, however, gives special attention to metal spraying. The major points to be pinpointed in the code of practice are:

- The metals commonly used for spraying structural steel are zinc and aluminum.
- The surface is to be prepared according to British Standards (BS-2569) and the process is especially economical when the area/weight ratio is low.
- All grades of steel can be sprayed. The steel surface remains cool and there is no distortion nor is there any effect on the metallurgical properties of the steel.
- The zinc coatings thickness can be determined as a function of the surrounding environment according to Fig. (6)
- Coating thickness less than 4 mils (100 μm) is not usually specified unless the sprayed metal is to be sealed or painted immediately.
- For most atmospheric environments, there is no advantage in spraying aluminum to a thickness greater than 6 mils (150 μm).
- Using a sealer aids in filling the metal pores and smoothes the sprayed surface, improves the appearance, and life of a sprayed metal coating. It also simplifies the maintenance, which then requires only the renewal of the sealer. Sealers should be applied immediately after spraying the metal coating.

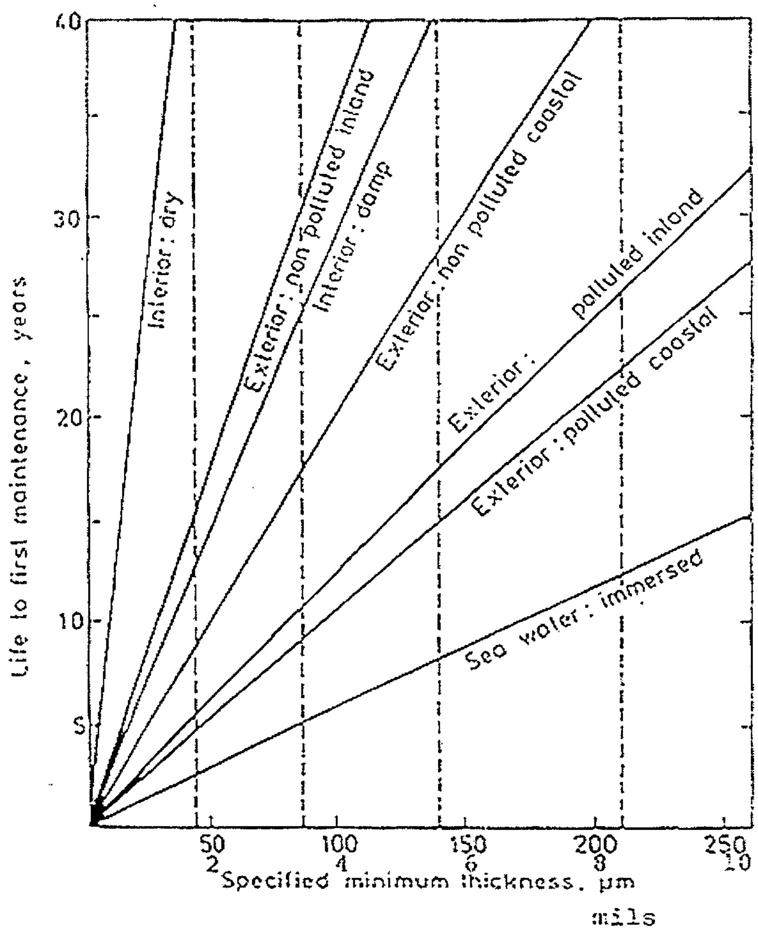


Fig. (6) Typical lives of zinc coatings in selected environments

- Metal-coated steel is painted only when: a) the environment s very acid or very alkaline, b) the metal is subject to direct attack by specific chemicals, c) the required decorative finish can be obtained only by paint, or d) when additional abrasion resistance is required.
- Generally one or two coats of paint may be sufficient except in abnormally aggressive environments. Sealed sprayed metal is usually preferable to painted sprayed metals.
- Appropriate paints usually have longer life on metal coatings than on bare steel.
- Most paints, other than drying oils, are suitable for application to zinc-coated steel.
- Dry-film thickness gages using the magnetic flux or eddy current principle are usually used for the measurement of the metallic coating.

- The code of practice includes an inspection guide that defines the potential defects, how they can be inspected, the most likely cause(s), and the suggested actions. The following table summarizes those information associated with metal-sprayed coatings.

	Potential defects	**How determined**	**Likely cause**	**suggestions for action**	**Notes**
1	Thin coating	Instrumental	Incorrect processing	Reject, reprocess where possible or agree additional coats provided that surface has not become contaminated.	
2	Random bare spots	Visual	Incorrect processing	Reject if areas are large or are the result of unsatisfactory preparation, but by agreement small areas can be made good by adequate surface preparation and suitable zinc-rich paints, low melting point alloy sticks, or metal spray.	Small items, such as fasteners should be returned to the processor.
3	Corrosion products	Visual	Poor storage conditions or even-long period before further treatment	Reject all rusted metal and any from which a substantial part of the coating has been lost. Obtain fresh suppliers or completely re-treat as specified	
4	Unsatisfactory adhesion	Instrumental	Incorrect processing	Reject	

CHAPTER IV
CONTEMPORARY PRACTICE IN THE UNITED STATES AND EUROPE

Practice in the United States

The successful performance of metalization coatings constitutes only one face of the coin. For the same surface area, the costs associated with metalization are higher than those of a conventional coating system. If the two systems are considered as potential candidates for a certain job, the decision-maker will face the dilemma of choosing between the relatively lower cost of a conventional coating and the longer lifetime expectancy of a metalization coating.

A survey was conducted to investigate the degree of popularity of metalizing steel bridges among various states. The primary purpose of the survey was to identify the extent to which each of the contacted states consider metalization as a promising coating system even with its relatively higher initial costs. The survey covered Illinois, Michigan, Ohio, Connecticut, and Indiana. The choice of the aforementioned states was dependent on two main parameters:

- Being located in the Midwest area, and/or
- Having experience with metalizing steel bridges.

The first group includes Illinois, Michigan, Ohio, and Indiana. The second group includes Connecticut and Ohio. As can be noted from the classification that, while Ohio is one of the Midwest states, it has established noticeable experience in metalizing steel bridges.

The survey interestingly showed the diverse opinion regarding the potentiality of metalizing steel bridges between the states of the Midwest. Illinois Department of Transportation (IDOT) is currently investigating the use of metalization in protecting steel bridges in a similar fashion to Indiana Department of Transportation (INDOT). The first bridge was metalized in Illinois in 1997. On the other hand, Michigan Department of Transportation (MDOT) is quite a bit conservative regarding the metalizing of its steel bridges. The currently used painting system in Michigan is giving satisfactory performance in terms of both its initial cost and lifetime expectancy. This causes MDOT to be unsure about the effectiveness of metalizing its steel bridges.

Ohio is the only state in the Midwest area that adopted metalization since the 1980's. Ohio Department of Transportation (ODOT) believes metalization to be a successful coating system that will even gain more success in the future. ODOT has partially metalized 10 bridges up-till-now. The current trend is to go for metalizing complete bridges in the future.

Connecticut Department of Transportation (ConnDOT) opinion is not much different from ODOT. However, ConnDOT approach for investigating the effectiveness of metalizing steel bridges was quite different. ConnDOT conducted a study, sponsored by the FHWA, to investigate the applicability, performance, and cost-effectiveness of metalizing steel bridges in Connecticut. The Department conducted extensive experiments on a sample of four steel bridges. The experimental stage has already finished and the department established its specification forms. A complete information about the findings of such investigation will be explained in greater detail in the following sections.

IDOT Practice [10, 11, 20]

IDOT has started investigating metalization as a possible candidate for coating its steel bridges, lately. Based on the current increased interest in applying metalizing technology to protect bridge steel, IDOT performed a demonstration project on the new steel installed to carry Interstate 80 over U.S. Route 30. This bridge consists of two similar parallel spans, one painted with inorganic zinc, epoxy and polyurethane paint system while the twin span is metalized. The bridge elements are totally metalized on-shop before being transported to site. The metalized coating was left unsealed except for the facia beams, which were sealed with epoxy and polyurethane system.

IDOT shows an interest in investigating the use of metalization in coating steel bridges and how much this system can be effective. Still, a major concern thought of, is the high initial costs of metalization. The total bid price for metalizing the steel was $9.18/ft^2 ($99/m^2). Productivity is another concern as the metalization of the steel covered a period of approximately six weeks. Initial production rates were hampered due to problems with power supply and communication between the metalization contractor and the fabrication shop. Initial production rates were estimated as 77 ft^2/hour/gun (7.2 m^2/hour/gun). However, after the initial two weeks of operation, the production rates had more than doubled, so that a final average production rate of 179 ft^2/hour/gun was recorded (16.6 m^2/hour/gun). A typical painting application rates are 1250 ft2/hour/applicator (115 m^2/hour/applicator) for a single coat, i.e., approximately 420 ft2/hour/applicator (39 m^2/hour/applicator) for a complete three coat painting system, after neglecting drying time. This shows the relatively slower rate for metalizing steel bridges in comparison with paint application.

MDOT Practice [12]

Michigan Department of Transportation (MDOT) prefers being slower in terms of changes. This causes the Department to be conservative regarding the use of metalization. Currently, the painting system used in Michigan is quite successful and giving satisfactory results, which diminishes the need to seek another coating system. At the same time, using metalization is believed by Dave Long to have some disadvantages that are not overcome yet by the industry.

Compared to the conventional painting systems, metalization is quite expensive. Even with its long expected lifetime, its cost-effectiveness is questionable. First, some of the currently used painting systems can last for many years, competing with metalization to some degree, while being relatively cheaper. Secondly, the specifications for metalizing a steel bridge are stringent and sometimes difficult to satisfy. Before metalizing the steel substrate, the surface is required to be sand blasted near white. This condition is not always guaranteed. With any complicated surfaces, the preparation process can be very time consuming in order to satisfy those requirements. The cost effectiveness is still the dominating factor in taking the decision and whenever the metalization costs go down, MDOT may reconsider its use.

ODOT Practice [1, 13, 14]

Ohio Department of Transportation has started metalizing some of its steel bridges since 1985. The records show that about 10 bridges have already been metalized, partially or totally. Table (5) lists the major metalization jobs in Ohio during the last ten years, accompanied with the year of application and the cost per square feet.

Table (5) Major metalization jobs in Ohio (1985-now)

Bridge ID **County-Route-Section**	**Year of application**	**Cost/square feet**
MRW-229-0118	1985	$10.09
MRW-71-1687	1986	$8.28
MAD-161-0151	1987	$9.00
DEL-71-1429	1988	$8.68
MAR-23-1362	1991	$14.66
LAW-7-1622	1994	$18.60
HIG-138-1372	1995	$17.50
SCI-348-0601	1996	$15.00

Generally, ODOT is not experiencing any problems with its currently used painting system, causing the initiation of this metalization activity of some of its steel bridges. Metalization is another successful system that can be used when painting the bridge is not appropriate. Some examples, given by Mike McColeman [13], are the high-traffic-volume bridges where there is bad need to complete the coating process in a shorter period of time. Compared with painting, metalization takes less time since there is no curing time. In addition, this situation requires the coating system to last ultra number of years, which is achievable with the use of metalization.

Up-till-now, no new bridges have been metalized in Ohio. All the metalization jobs were accompanied with partial or total rehabilitation activities of existing bridges. Metalization was extremely successful especially with the *partial rehabilitation activities*. McColeman reports that ODOT has experienced various problems with the rust-sensitive areas of its steel bridges, e.g., expansion joints. It is common that water rests beneath those spots causing an extensive rusting condition of the bridge members. By partially metalizing those spots, after the proper rehabilitation, most of the rusting problems have been overcome. This may constitute the most efficient application of metalization. Lewis [21] further reported that Ohio is moving towards metalizing the rust-sensitive areas as a common practice in the state.

The current practice of Ohio is to sand blast the surface until white. Afterwards, the metalization coat, which is composed of 85%Zinc-15%Aluminum alloy, is applied to the cleaned surface. ODOT prefers to apply a top sealer on the metalized areas of the bridge. Some of the main reasons are:

- It makes the system last longer.
- It maintains good esthetics of the bridge.
- It facilitates the inspection process.
- It keeps the metalization coat from getting oxidized.

Currently, metalization costs about \$16.5/ft^2 (\$175/m^2) of the metalized area. This includes a complete process starting from the removal of the existing paint system to the application of the outer sealer over the metallic coating. Mike McColeman believes that the high costs are only temporary. ODOT experienced the same situation before when applying the then new painting system. With the old painting system, the costs averaged \$3/ft^2 (\$32/m^2). Switching to the new system, which is composed of organic zinc, epoxy, and urethane, the costs jumped to \$12/ft^2 (\$130/m^2). Now, and after ten years, the costs of the new system are only \$4/ft^2 (\$43/m^2) (it is worth mentioning that the EPA requirements in Ohio are not very stringent, i.e., a 100% containment system is not required yet). In a short time, these requirements will become mandatory which will increase the cost of the current painting system). Thinking about metalization the same way, if metalization is taken more seriously by the industry, the associated costs will drop maybe to only half value in a short period of time.

McColeman highlighted a major advantage of metalizing steel bridges. The metalization process is more flexible than conventional painting. Metalization can be applied in a wide range of temperatures and humidity. This can not be done with a conventional painting system especially during the snow season. He also pinpointed that one possible problem with metalization is to get the required thickness. However, the recent advancements in the metalization equipment noticeably facilitated the process. McColeman described metalization as a user-friendly process and several successful applications of metalization with both flame spray and arc spray have been experienced in Ohio. Generally, arc spray is easier to use for all present applications.

ConnDOT Practice [5,15,16]

In the mid 1980's, ConnDOT initiated a research project sponsored by the FHWA to evaluate various alternative coating systems that may replace the banned lead-based coating systems. It was determined that the coating replacement process would be the focus of the research project. Two coating systems were chosen for the extensive evaluation through the project: metalization and organic zinc-rich primer coats.

The metalization system contains three separate coats, beginning with a pure metal primer applied by a thermal spraying process. The 85% zinc-15% Aluminum alloy was selected as the primer material. This composition is identified as the optimum mixture for the protection of steel in harsh industrial and salt-sprayed environments. The primer is then coated with both a sealer and a topcoat, which act as an environmental barrier. The sealer used for the study is a clear epoxy material that penetrates into the pores of the metalizing and provides a surface that is compatible with the topcoat material. The topcoat for the system is acrylic-modified, aliphatic urethane, which provides resistance to abrasion and ultraviolet degradation.

In order to evaluate the coatings on prevalent bridge types, four typical highway bridges, each containing I-beam girders and three spans were selected for the study. These conditions allowed each bridge to have one span coated with the metalization system, one span painted with the organic-zinc rich system, and the third span designated as a control. The control spans were coated with ConnDOT's standard paint system at the time the project was initiated. This arrangement facilitated an evaluation of the relative effectiveness of both experimental systems, as well as the control, under similar exposure conditions at each location.

The final examination of the four bridges was performed in July 1995; seven years after the first bridge was coated. The bulk of the field evaluation activities consisted of visual inspections, which were performed annually to identify any coating deterioration, or rusting. A primary focus of the evaluation was to identify any installation problems with the coatings, which may have lead to premature failure, and to test the systems in critical areas where failure usually begins. The short-term performance of the coatings in these areas could then be used to estimate long-term service lives of the whole system.

The overall performance of the metalizing system has been excellent to date in nearly all areas of the four test sections. One localized area in the metalizing section of a certain bridge has begun to show rust staining. When the coatings were four years old on that bridge, rust stains began to appear under a leaking expansion joint. A close examination of the area revealed that this area was not properly blast cleaned, and metalizing was applied over fairly severe laminar rust. The remainder of the metalizing section on the same bridge is free of rusting, peeling, fading, or cracking. The metalizing sections on the other bridges are completely free of any deterioration. This supports the fact that any substandard preparation will inevitably cause premature coating failure.

The study showed that the maintenance-free service life of a bare 85%Zn-15%Al metalized coating on a typical bridge is predicted to be in the range of 25 -40 years. The use of a sealer and topcoat over the metalizing is expected to increase this life an additional 15-20 years, making the estimated maintenance-free life in the range of 40-60 years for the complete system. When deterioration is observed, it has been reported that touch-up, or replacement of the topcoat may be performed to further extend the ultimate service life of the original coating. The above service life predictions are longer than those of typical paint systems, including the organic zinc primer.

After the end of the research project, a group of bridge was identified as good candidate for a metalizing coating system. The decision was also supported by the indications that metalizing costs have come down since the experimental installations. The project include five local road bridges, which all are in good condition with the original paint in poor condition. The following table shows the lump sum prices, per bridge, for the bid item, "Abrasive blast cleaning and field metalizing of structure." Prices for containment, collection, and disposal of surface preparation debris are paid under separate work items, and are not included in Table (6). The bid prices received for debris containment, collection and disposal items are consistent with the statewide averages. The average values for those items are $\$5.11/ft^2$ ($\$98/m^2$) for containment and collection and $\$0.56/ft^2$ ($\$6/m^2$) for disposal.

Table (6). Bid Prices for Field Metalizing System

Bridge Number	Location	Lump sum for metalizing System	Steel Surface Area		Unit Price	
			ft^2	m^2	$\$/ft^2$	$\$/m^2$
00244	Whipporwill Road over I-95	$134,000	12,900	1200	$10.39	$111.67
00246	Four Mile River Road over I-95	$107,000	10,600	985	$10.09	$108.63
00247	Route 449 over I-95	$160,000	16,150	1500	$9.91	$106.67
00249	Society Road over I-95	$108,000	10,200	950	$10.59	$113.68
00303	Moosup Pond Road over I-395	$134,000	13,100	1220	$10.23	$109.84
	Total/Average	**$643,000**	**62,950+**	**5855**	**$10.21**	**$109.82**

Using the provided surface-area-estimates, the project average for the complete three-coat metalizing system is $\$10.21/ft^2$ ($\$109.81/m^2$). Eric Lohery [15] mentioned that the unit installation prices have become lower than those paid for the experimental sections, indicating that metalizing production rates may be improving. The additional unit costs of containment, collection and disposal cause the total unit cost to rise to $\$16/ft^2 \sim \$17/ft^2$ ($\$172/m^2 \sim \$183/m^2$). The painting system currently in use in Connecticut costs $\$12/ft^2 \sim \$13/ft^2$ ($\$129/m^2 \sim \$140/m^2$). Compared with the costs of metalizing a steel bridge, the difference is not huge. Lohery pinpointed that this difference can even be reduced in case of on-shop operation where several site mobilization problems can be overcome. He added that the costs of metalization would drop down even more in the future.

Currently, a new bridge is being metalized on-shop. The specifications for that bridge state that it has to be metalized with 85%Zn-15%Al alloy, then an epoxy sealer and a urethane topcoat are to be applied on top of the metallic coating. In the past, flame guns were more common but the recent practice is to use arc guns, which have become more applicable.

INDOT practice [17,18]

INDOT has recently completed the metalization of one of its steel bridges. This is considered the first experience of metalizing bridges in Indiana. The project started in April 1997. The bridge carries the traffic of Lafayette Road over I-465 in the northwestern side of Indianapolis. The structural system of this bridge is composed of seven beam girders in each direction of the traffic flow. Earlier than the metalization job, the bridge has undergone a major rehabilitation activity including the full replacement of the outer beams in each direction and several remedial works for the rest of the bridge. When the rehabilitation activity was completed, the bridge was fully metalized by *Metalization Master, Inc.*, Ohio. Afterwards, it was covered with a clear sealer for the whole surface area. The contract value of the items: cleaning the surface and metalizing the bridge is $186,000.

Discussions with Dale Eastin indicated that no qualification certificates were required from the contractor. The contract, however, states that the workers are required to prepare sample plates metalized with the same material and equipment specified in another provision of the contract. Those plates are to be tested by the engineer for approval prior to commencement of contract works.

Eastin highlighted the fact that metalization requires more stringent specifications for surface cleaning compared with conventional painting systems. The contract for this particular project requires the surface to be blast cleaned according to SSPC-SP 5 (white surface cleaning). The work was carried out in a block pattern of an area of 2 ft^2 (0.2 m^2). The specifications require the surface to be metalized within a period of 4 hours following the surface cleaning. This strict requirement constituted no problem for either the metalization applicator or the inspector because of the small area of the block pattern.

More than one constraint related to the weather has been taken care of while metalizing the bridge. Eastin mentioned that the surface is required to be completely free of surface moisture to guarantee a successful job. The application of the metalizing coating is subjected to the same restrictions found in painting contracts. He also added that the contractor used to completely stop the work in case of a rainy weather. This is done so as not to affect the quality of the metalizing coating.

The metalizing coating applied on the bridge is composed of 85% zinc / 15% aluminum. This alloy was used to cover the whole surface area of the bridge with no exceptions. Eastin mentioned that the contract provisions require a specific type of arc spray guns to be used in metalizing the bridge. Although a sample arc spray gun is specified, equally approved products can be used instead if the specified equipment is not available to the contractor. The engineer must examine the specifications of any submitted gun to check its compliance with those of the cited one. On one occasion, the contractor submitted a request for the use of different spray gun, which was basically a flame spray gun. The engineer refused this request since the gun does not comply with the specifications.

Eastin added that the production rate of metalizing the bridge was slower than what is common in painting practices. The authors believe this to be a consequence of the small area of the block pattern. This process is much different from painting practices where larger areas of the surface can be painted at the same time. Although metalization requires no time for curing, this seemed to be ineffective in determining the actual production rate. The truly effective factor was the surface area of the substrate to be coated at each step in metalizing the bridge.

Eastin cited that having several applicators and/or working shifts could positively influence the production rate. For this particular project, the work was done initially on two shifts where the rate seemed to be convenient for practical purposes. Afterwards, the road closure problems mandated switching to only one shift and since then the rate slowed down drastically until the end of the project.

Following the application of the metalization coating, the bridge was covered with a clear sealer. No topcoat is specified as part of the contract for this particular project. In spite of the benefit of extending the service life of the coating, Eastin believes that covering the metalization coating with the sealer had a counter effect on the appearance of the bridge.

Eastin also added that metalization requires no additional environmental precautions than those associated with painting. The absence of VOCs in the metalizing coating gives it a lot of credit. However, the major problem encountering the application of any coating is the removal of the old paint that in most cases contains lead compounds. Therefore, the main concern is the disposal of the surface cleaning waste, which is very similar to painting practices. This makes both painting and metalization very similar in terms of the environmental control.

EUROPEAN PRACTICE

During 1995, the FHWA Office of International Programs commissioned a team of U.S. experts to pursue technology transfer of steel bridge maintenance coating methods with the European highway community [6]. The tour covered several European countries including

Switzerland, Germany, the Netherlands, and the United Kingdom. Metalization has been thoroughly investigated especially because of its widespread use in some of those countries. The following sections present the general findings of the tour regarding the metalization practices.

The degree of usage of the thermal spray technology varied greatly among the different visited European countries. Switzerland and the Netherlands showed minimal, if ever, usage of the system in spite of the fact that thermal spray technology was initially developed in Switzerland in 1890. The Germans are also infrequent in using the technology on a nationwide level. However, Germany has its own thermal-spray specifications. In the UK, France, Belgium, and the Scandinavian countries, thermal spray has been used on a greater scale and it is considered the preferred protection system.

In the UK, over 90% of all new steel bridge construction uses thermal spray technology. In 1994, between 32 and 38 million ft^2 (3 and 3.5 million m^2) of steel were protected by thermal spray. Of this, 27 million ft^2 (2.5 million m^2) were protected by zinc and the reminder by aluminum. Those numbers surely does not address only steel bridge protection but rather several applications including offshore structures, buried pipelines, and lighting columns in addition to the ordinary steel bridges.

Merits and Shortcomings of Metalization Compared with INDOT Conventional Painting Systems

Metalization coatings are known of their ultra long lasting corrosion protection. This is provided primarily through the galvanic protection of the steel surface. The zinc-rich primers used in painting systems can provide some degree of galvanic protection but **never** the same as metalization. This gives metalization coatings the advantage of lasting for many years beyond those expected of any paint system. The expected service life of a sealed metalization coating with an appropriate topcoat can vary between 40-60 years as reported by Lohery [5]. When deterioration is observed, touch-up or replacement of the topcoat may be performed to further extend the ultimate service life of the original coating [5].

The cost-effectiveness of a coating system is minimized when the life expectancy of the coating is matched to the remaining design life of the bridge [5]. This makes metalization coatings a promising candidate for application on new or newly rehabilitated bridges. Under those circumstances, the bridge is expected to last for several years. With the ultra long lifetime expectancy of metalization coatings, this optimal condition can be satisfied. The ordinary zinc-rich systems cannot provide a similar performance for this kind of an extra long time.

The cost of metalizing a steel bridge may be the primary barrier of applying this technology on a wider scale. It is important to realize that the cost of metalizing a new bridge is less than that of an existing bridge. With the latest changes in the environmental and health requirements regarding the removal of existing lead-based paints, a significant cost item is associated with this process. The costs of containment, collection of debris and waste disposal are not present for the case of a new bridge.

A cost comparison of three coating alternatives used by INDOT is illustrated in table (7). This comparison includes vinyl, 3-coat system, and metalization. The comparison is dependent upon data from bridges that have been coated over the last three years. This comparison, however, is not intended to give sound cost figures, rather some guidance regarding the approximate costs associated with using each of the three coating systems according to INDOT practices.

Table (7) shows clearly that the cost of metalizing a steel bridge is substantially higher than the other two alternatives. The organic zinc / vinyl coating system costs \$1.87/ft^2 (\$20.1/m^2) and \$2.16/ft^2 (\$23.3/m^2) for surface cleaning and painting two sample bridges contracted in 1997. Adding other cost items like mobilization, traffic control and pollution control increases the final costs to \$2.68/ft^2 (\$28.8/m^2) and \$2.92/ft^2 (\$31.4/m^2) respectively. On the other hand, the 3-coat system costs \$2.16/ft^2 (\$23.3/m^2) and \$3.11/ft^2 (\$33.5/m^2) for surface cleaning and painting two sample bridges contracted in 1998. Adding other cost items like mobilization, traffic control and pollution control increases the final costs to \$3.07/ft^2 (\$33.0/m^2) and \$4.10/ft^2 (\$44.1/m^2) respectively. Finally, the costs associated with metalizing the demonstration bridge and which was contracted in 1995, subtotal \$15.69/ft^2 (\$169/m^2) for the surface cleaning and metalizing the bridge. The total costs go up to \$18.65/ft^2 (\$201/m^2) after adding the traffic maintenance and pollution control.

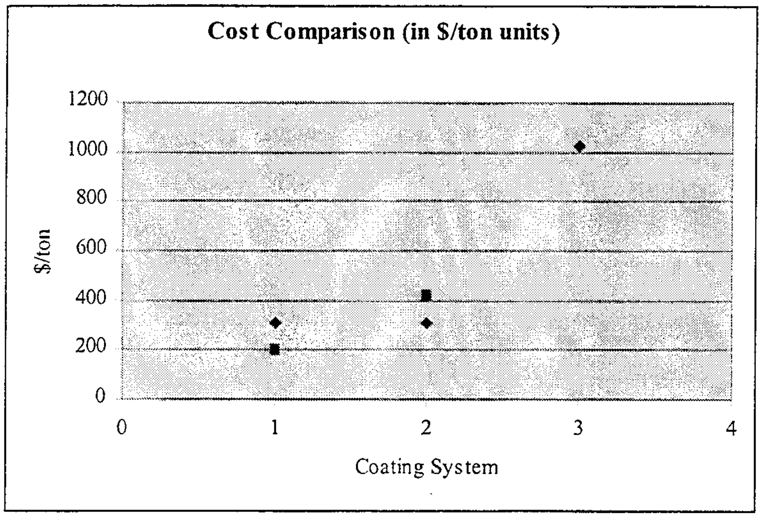
Table (7) Cost Comparison of alternative coating systems

Item	Vinyl			3 Coat System			Metalization	
Contract Year	1997	1997		1998	1998		1995	
Bridge Number	I-69-91-4783	I-69-113-4502		I-69-95-04768	I-69-110-02266NB		I-65-123-4568B	
Location	91 mile marker I-69 Huntington Co.	113 mile marker I-69 Allen Co.		95 mile marker I-69 Allen Co.	110 mile marker I-69 Allen Co.		Old 45-52 over I-465	
Cost/bridge (all items)	$20,000	$23,000		$27,000	$33,000		$185,728	
Cost/bridge (clean and coat steel)	$14,000	$17,000		$19,000	$25,000		$156,218	
Bridge Tonnage (MG)				79	71			
Bridge Tonnage (Ton)	65	84		87.10	78.28		181	
Number of beams	12	8	4	12	14	7	14	7
Length of beam (ft)	65	67.75	67.75	75.86	43	54	34.58	76.08
Type of beam	36 WF 135	36 WF 160	36 WF 170	36 WF 160	30 WF 108	30 WF 108	36 WF 194	36 WF 194
Width of flange (in)	11.95	12	12.03	12	10.745	10.475	12.115	12.115
Beam depth (in)	35.55	36.01	36.17	36.01	29.83	29.83	36.49	36.49
Surface Areas		5244.82	2632.36		4955.82	3084.37	4741.78	5215.96
Estimated surface area to be coated (ft^2)	7473.13	7877.19		8808.98	8040.19		9957.74	
Cost in $/ton (all items)	$307.69	$273.81		$309.99	$421.56		$1,026.12	
Cost in $/ton (clean and coat steel)	$215.38	$202.38		$218.14	$319.37		$863.08	
Cost in $/$ft^2$ (all items)	$2.68	$2.92		$3.07	$4.10		$18.65	
Cost in $/$ft^2$ (Clean and coat steel)	$1.87	$2.16		$2.16	$3.11		$15.69	

Fig. (6) further illustrates the cost comparison between the three alternative coating systems. Both charts demonstrate the high costs associated with metalizing a steel bridge. A point need to be examined is the reliability of using \$/ton vs. \$/ft^2 as an estimate of the cost of coating steel bridges. Considering the second sample bridge coated with the 3-coat system and the metalization bridge as shown in table (7), the two bridges are significantly different in terms of their tonnage. The metalization bridge is more than twice heavier than the 3-coat system bridge. While this is true, the difference in their surface areas are much less significant. The metalization bridge is only 25% larger in terms of surface area. Since the coating of a steel bridge is a function of its surface area rather than its tonnage, the use of cost estimates depending on the bridge tonnage can be quite misleading. While the metalization bridge is only 2.4 times more costly than the 3-coat bridge if the tonnage estimate is used, this ratio jumps to 4.5 times if the surface area estimate is used.

The previous experience of metalizing steel bridges in Ohio [13] attracts the attention to the applicability of metalizing only the highly rust-sensitive areas of the steel structure. Most of Ohio's practice was to partially metalize steel bridges especially those areas of the bridge having higher potential for rusting. Although this may provide a higher unit price of the metalized surface, a better performance of the whole coating system can be obtained.

Finally, the costs of blast cleaning and metalizing steel bridges have noticeably decreased over the past few years. This gives an indication that they may even drop down more in the future and make metalization a real competitor to conventional paints. Lohery [5] reported that the costs associated with the recent metalization jobs in Connecticut are lower than those of the late 1980's and early 1990's. A similar conclusion can be drawn from the latest three metalization projects in Ohio, presented in table (6), where the unit cost dropped down from \$18.60/ft^2 (\$200/m^2) to \$17.50/ft^2 (\$188/m^2) then to \$15.00/ft^2 (\$161/m^2) over a period of three years.



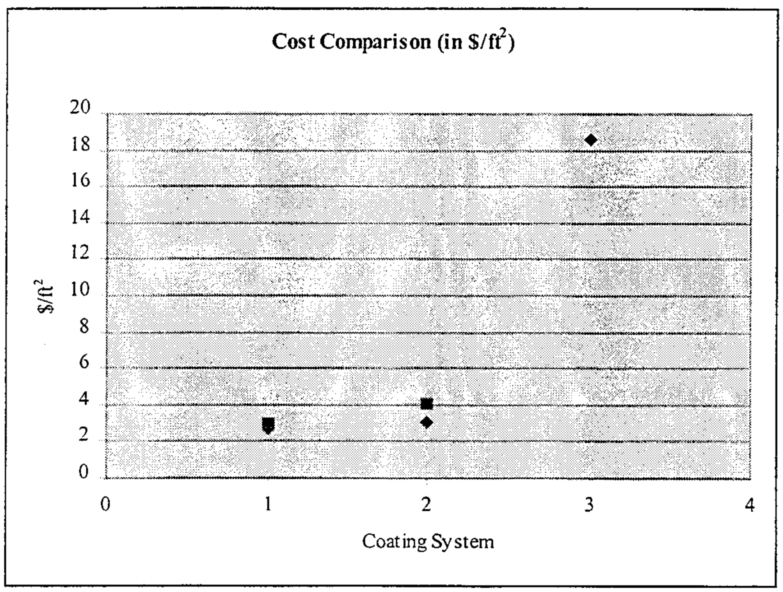


Fig. (6) Cost of coating sample bridges using 3 different alternatives

CHAPTER V

REVIEW OF SPECIFICATIONS AND RECOMMENDATIONS

General

A couple of standards have been presented throughout this report that regulates the application of thermal spray coatings on steel bridges. The existence of standards does not, however, constitute all what is needed to guarantee a successful job. Whenever the specifications of a certain job are prepared, several issues must be taken into consideration including the constraints on the operation, the pitfalls of the previous jobs need to be avoided, etc. The survey previously presented in chapter IV gave the author the chance to examine several specification forms that are in practical use by Connecticut, Ohio, Illinois and Indiana.

This chapter provides a general review of the specification forms used by the four states. It is worth mentioning that the form used by Illinois is slightly modified to match with the on-shop practice. This form has been used only once in a similar fashion to INDOT's form. Both forms used by ConnDOT and ODOT have been used on a broader scale and for longer period of time. The review process has the following set of objectives:

- To identify the various constituents of the specification forms.
- To compare and highlight the differences and give any justifications with the aid of the AWS or British standards.
- To pinpoint those items not in use by INDOT and give the reasons why they need to be reconsidered, if any.

Table (8) represents the major items cited by the four specification forms in use by ConnDOT, ODOT, IDOT and INDOT [11, 14, 16, 18]. Those items can be classified into the following nine categories:

1. Documents to be submitted with the bid proposal.
2. General information.
3. Materials handling.
4. Construction-related issues.
5. Surface preparation.
6. Metalization Process.

7. Paint coats applications.
8. Site Management.
9. Payment.

Items marked with √ symbol, in correspondence with a certain state, indicate that this item was cited in the specification form of the denoted state with some degree of detail. If a certain item is not marked with √ symbol, that does not imply that it is not applicable for that state since several regulations and contract requirements are included in the specification book published by the Department of Transportation. It is important to realize that this comparison is limited to the specification forms provided by the four State Departments of Transportation and which are used in metalizing their steel bridges.

Table (8) Comparison between specification forms used by Connecticut, Ohio, Illinois and Indiana

	ConnDOT	ODOT	IDOT	INDOT
Documents to be submitted with the bid proposal	√			
General Information	√	√	√	√
Materials used				
Primer type	√	√	√	√
Sealer type	√	√		√
Intermediate coat type			√	
Topcoat type	√		√	√
Materials acceptance criteria	√			
Materials field history	√			
Materials Handling				
Submittal of test samples	√			√
Packaging and labeling of materials	√	√	√	
Construction-related issues				
Safety	√			√
Contractor qualifications	√		√	
Applicator qualifications	√		√	
Supervisor experience		√		
Safety equipment	√			
Spray equipment	√	√	√	√
Inspection equipment	√	√		
Pneumatic equipment	√	√	√	
Storage of paints	√			

Surface Preparation				
Solvent cleaning		√	√	√
Standards of surface preparation	√	√	√	√
Grit type	√	√	√	√
Grit Contamination testing	√	√	√	
Grit specifications	√			
Profile depth	√	√	√	√
Measurement of surface profile	√	√	√	√
Test section and acceptance standards		√	√	
Containment and waste disposal		√	√	√
Metalization Process				
Process Description	√	√	√	√
Temperature constraints		√	√	
Moisture constraints	√	√	√	√
Wind constraints			√	
Area of metalized substrate	√	√		√
Dry film thickness	√	√	√	√
Thickness acceptance criteria	√		√	
Test section or test plate	√	√	√	√
Adhesion strength testing	√	√		√
Repair of damaged areas	√	√	√	√
Inspection access		√		
Paint Coats Application				
Sealer	√			√
Intermediate Coat			√	
Topcoat	√		√	√
Site Management				
Manufacturer Technical Advisor on Site	√			√
QC/QA Program			√	√
Bend test				√
Payment				
Method of payment	√	√	√	√

Each of the previously listed categories will be discussed in further detail with special emphasis on the surface preparation and metalization process categories due to their relevant importance.

Comparison and Recommendations

1. Documents to be submitted with the Bid Proposal

The on-site metalization jobs require the full removal of the existing paint before the application of the coating on the cleaned substrate. With the fact that most of the existing paints contain lead, ConnDOT explicitly requires the contractors willing to apply for the metalization job to be qualified according to the SSPC, Painting Contractors Certificate Program (PCCP), QP-1 and QP-2. This case has not been experienced in all other forms. However, this condition is irrelevant to the metalization job and may be required as a general pre-qualification condition of all contractors regardless the coating type.

2. General Information

This section is represented in all four forms and comprises a general description of the contract job. The degree of detail differs from one state to another but, in general, this section describes the scope of work and those areas need to be covered. The scope of work may differ indicating whether a sealer and/or a topcoat are required or not. The benefits of applying a sealer and topcoat have been thoroughly examined in both chapters III and IV.

3. Materials Used

This section primarily defines the type of materials used in carrying out the contract works. ConnDOT has supplementary subsections that handle the materials acceptance criteria and the documents required from the contractor to demonstrate the successful use of any of the proposed coating materials. Detailed quantitative requirements are given for each of the three coats, i.e., primer, sealer and topcoat. No similar requirements are experienced in ODOT, IDOT and INDOT forms.

All states require the use of 85% zinc – 15% aluminum wire for the application of the primer. This coincides with ANSI/AWS C2.18-93 standards presented in Chapter III. The combined benefits of using the zinc/aluminum alloy were given in greater detail in chapter II. In terms of the outer coats, ODOT requires the application of only a clear sealer to cover the primer. Connecticut and Illinois specifications require the application of both a sealer (an intermediate coat) and a topcoat. The materials used are identical between the two states where an epoxy sealer and a urethane topcoat are required. The two-coat system required by IDOT specifies a list of manufactures and relevant products to be used by the contractor. A more generalized form was used by INDOT in its first metalization project. A variety of painting coats is identified as candidates for the outer coats.

4. Materials Handling

All specification forms except for the one used by INDOT give a detailed description of the packaging and labeling procedure of the materials on site. Only an implicit wording is used by INDOT. On the other hand, the submittal of the test samples of all material types to be used in the contract is only stated explicitly in ConnDOT and INDOT forms. This subsection requires the contractor to submit all test samples for the coating wire, sealer, topcoat and grit material prior to beginning of the contract works.

5. Construction-related Issues

Several construction-related issues relevant to the metalization job are stated in explicit terms within the specification forms. ConnDOT's form is the richest compared to the other three forms. The different items within this section include: safety, contractor qualification, applicator qualification, supervisor experience, safety equipment, spray equipment, inspection equipment, pneumatic equipment and storage of paints.

Due to the special experience required from the contractor, both ConnDOT and IDOT mandate contractors applying for the job to show evidence of previous experience in metalizing steel bridges. ConnDOT requires a minimum of three bridges / structures in the three years preceding the job in hand. The documentation should list the agency, location, amount and date of application of the metalization coating. IDOT requires a minimum of five years experience. ODOT adopts a different terminology where all metalization jobs are to be performed under the direct supervision of an experienced person in the field of metalization. Similar requirements for qualification are to be submitted indicating the details of such experience.

The applicator should also be highly qualified to apply the metalization coating. Both MIL-standards (DoD STD-2138) and ANSI/AWS C2.16-92 establish qualification criteria for the metalization coating applicator. In a briefed form, the ANSI/AWS C2.18-93 includes an annex to cover the same topic; refer to chapter III. ConnDOT specification requires the contractor to submit an evidence indicating that the proposed metalization applicators are fully qualified according to the ANSI/AWS C2.18-93 or DoD STD-2138 to perform the work. IDOT limits the acceptance qualification criterion to the ANSI standards. The specification form of IDOT states that any operator who does not show evidence of qualifications according to ANSI/AWS C2.18-

93 shall not be allowed to spray. INDOT specification form does not enforce any similar requirement.

The safety issues are highlighted by ConnDOT, ODOT and INDOT. ConnDOT addresses the site-related safety issues while ODOT and INDOT concentrate on the applicator's safety issues. INDOT specification form requires a clear reference to all-applicable Federal and local safety regulations for future practices.

In terms of the various types of equipment used in the operation, ConnDOT gives a thorough description of the requirements for safety, spray, inspection and pneumatic equipment. The inspection equipment category is also described by ODOT. A complete reference for the inspection equipment can be obtained from the ANSI/AWS C2.18-93 standards in chapter III. INDOT specification form describes the requirements for the spray equipment only. A rigorous requirement of an arc spray gun is specified. Contrary to that, ConnDOT and IDOT specify either an appropriate arc or flame gun to be used. This generalization requires higher degree of control from the engineer. Due to the varying details of the surface, this generalization may become a necessity to overcome the drawbacks of overspray as defined by ANSI/AWS C2.18-93 in chapter III.

6. Surface Preparation

The surface preparation is the key element for a successful metalizing job. The comparison between the different specification forms reveal that several items has been addressed including: solvent cleaning, surface preparation standards, grit type, grit testing, grit specifications, profile depth, measurement of surface profile, test section, and containment and waste disposal.

Table (9) represents a brief comparison of the surface preparation related standards for all investigated states:

Table (9) Comparison of surface preparation and profile depth standards among the different sates

	ConnDOT	ODOT	IDOT	INDOT
Surface Preparation	SSPC-SP 5	SSPC-SP 10	SSPC-SP 10	SSPC-SP 5
Profile Depth*	2.0-4.0 mils	1.0-3.5 mils	2.0-4.0 mils	2.0-5.0 mils

* 1 mil = 0.0254 mm

Both SSPC-SP 5 (White Metal Blast Cleaning) and SSPC-SP 10 (Near White Metal Blast Cleaning) are identified by ANSI/AWS C2.18-93 as appropriate surface cleaning standards for metalization jobs; refer to chapter III for more detail. The costs associated with cleaning the surface according to SSPC-SP 5 are higher than those for SSPC-SP 10. The SSPC-SP 5 standard, which was used on Indiana's first metalization project, can be altered with SSPC-SP 10 without violating the ANSI/AWS C2.18-93 standards. If a higher quality job is pursued, the more stringent specification may become more appropriate.

In terms of the ANSI/AWS C2.18-93 standards, the profile depth is required to be in the range 2.0 - 4.0 mils (50-100 μm). The relatively high upper limit required by INDOT specification form is not mandatory according to the ANSI standards. The only different case defined by the ANSI/AWS C2.18-93 is for those metalization coatings in excess of 12 mils (300 μm) where the profile depth is required to be one-third of the coating thickness. IDOT clearly states that if any measurement falls outside the 2.0 – 4.0 mils (50-100 μm) range, the surface preparation will be considered unacceptable. This implies the inconvenience of the relatively large profile depth as well as the small one.

The material used for the blasting process has been limited to recyclable steel grit for both ConnDOT and ODOT. IDOT and INDOT give a more flexible range of possible blasting materials to be used in surface cleaning. INDOT specification form does not include any measurement of the possible grit's oil contamination. All other forms have explicitly described the process of contamination testing. ConnDOT specification form, among all the investigated forms, provides a detailed specification of the grit material to be used in the surface cleaning process. This includes measures such as Rockwell C hardness and the percentage of breakdown of the original material after a certain number of uses.

IDOT and ODOT specification forms mandate the contractor to prepare a test section on a representative section of the steel structure. This test section is prepared using the same equipment and procedure for surface preparation. IDOT test section is of an area of 11 ft^2 (1.0 m^2) while the one of ODOT varies between 20-30 ft^2 (1.9-2.8m^2). After the test section has been accepted by the engineer, the contractor is allowed to proceed with the process. A similar requirement is provided by ConnDOT but in a less detailed fashion. The ANSI/AWS C2.18-93 provides several procedures for the testing of the blast-cleaned section of the substrate such as SSPC-VIS 1-89, refer to chapter III for more detail. A different testing procedure is adopted by INDOT where the effectiveness of the blast cleaning is qualified by performing three bend tests as explained later.

7. Metalization Process

The metalization process following the surface preparation cannot be conducted unless certain requirements of the surrounding environment are satisfied. The major constraints listed by the four specification forms are those related to temperature, humidity, surface temperature and wind. Table (10) represents a comparison of the values of those various constraints among the different specification forms. It is important to recognize that some of the unlisted constraints may be cited as general conditions for coating steel bridges in the specification book.

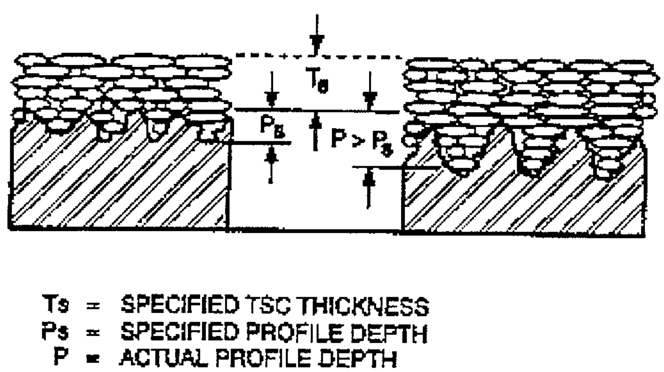
Table (10) Weather conditions standards among the various states

	ANSI	ConnDOT	ODOT	IDOT	INDOT
Air/Steel Temperature (minimum)	N/A	N/A	40°F (4°C)	40°F (4°C)	N/A
Humidity (maximum)	N/A	80%	85%	85%	N/A
Steel Surface Temperature (minimum *difference* above dew point)	10°F (5°C)	5°F (3°C)	5°F (3°C)	5°F (3°C)	5°F (3°C)
Wind (maximum)	N/A	N/A	N/A	15 mph (24 Km/hr)	N/A

The ANSI/AWS C2.18-93 requires the steel surface temperature to be at least 10°F (5°C) above the dew point. All forms adopt a value of 5°F (3°C), which is less than the allowed value according to the ANSI standards. The remaining constraints are not defined by the ANSI standards. The air and steel temperature are required by both ODOT and IDOT specification forms to be above 40°F (4°C) for the successful application of the metalization coating. A similar case is experienced with humidity when both forms require the humidity to be below 85%. The corresponding constraint of ConnDOT specification form is more stringent where the humidity level is not allowed to be above 80%. Only IDOT specifies the maximum wind limits to be 15 mph (24 Km/hr).

The process of applying the metalization coating is carried out on a block pattern as required by all specification forms. The area of the block pattern varies dramatically from one form to another. ConnDOT requires this area not to exceed 9 ft^2 (0.8 m^2) while IDOT limits the block pattern area to 4 ft^2 (0.4 m^2). Both ODOT and INDOT specification forms require the block pattern area not to exceed 2ft^2 (0.2 m^2). The higher area set by ConnDOT specification form provides a possibility for a relatively higher application rate of the metalization coating. As explained earlier in chapter IV, the application rate of the metalization coating in INDOT's first metalization project was slow. The applicability of larger areas of the block pattern makes it possible to obtain higher application rate of the process.

Regarding the metalization coating thickness, both ConnDOT and ODOT requires the thickness to be in the range of 6.0 – 8.0 mils (150-200 μm). IDOT and INDOT raise those limits such that the coating thickness becomes in the range of 8.0 – 10.0 mils (200-250 μm). The ANSI/AWS C2.18-93 Standard requires that the total coating thickness should be the specified thickness (T_S) over the anchor-tooth profile (P_S). If the profile is greater than P_S, then the thickness over the deeper profiled area should approximately equal T_S measured from the peaks



of the anchor-tooth profile, see Fig. (7)

Fig. (7) Measurement of the Thermal Spray Coating (TSC) Thickness

According to the Steel Structures Painting Council Specification Standard (SSPC-PA 2), if the steel surface is roughened, as by blast cleaning, the "apparent" or effective surface that the gage senses is an imaginary plane located between the peaks and valleys of the surface profile. For this reason, thickness would appear to the gauge to be greater than it actually is above the peaks. Sections 2.2 and 2.3 of the aforementioned standard provide a correction procedure for this effect of the surface profile.

The correction procedure can be used for the calibration of the gage such that it measures zero thickness for cleaned surfaces. If this correction procedure is not pursued, the specification of metalization coatings should account for the difference between the effective plane of measurement and the peaks of the anchor-tooth profile. In reality, this distance is much less than the peak-to valley distance. A typical sand blast profile, 2.8 mils (70 μm) maximum height, increased Mikrotest readings on a 4 mils (100 μm) coat by only 0.5 mils (12.5 μm), as reported by SSPC [3]. Taking half the distance between the peaks and valleys, i.e., ½ of the profile depth, as representative of the gage bias will be on the conservative side. This value can be added to the required metalization coating thickness (T_S) to represent the thickness need to be stated in specifications if the gauge calibration will not be pursued. With the previous argument, half the value of the anchor depth should be added to the minimum required metalization coating to account for the gage bias. Accordingly, specification should require a coating thickness of 8-10 mils (200-250 μm) to entirely satisfy the ANSI/AWS C2.18-93 Standard.

When the application process is done, the adhesion of the coating should be measured by the engineer to ensure the proper coating of the steel substrate. ConnDOT specified the ASTM D4541 as the standard procedure for the measurement of the degree of adhesion to the substrate. ODOT, IDOT and INDOT specify a different procedure where the engineer removes a part of the coating using a knife or chisel to test the relative degree of adhesion.

8. Paint Coats Application

ODOT specification form does not provide any section that handles this topic. The rest of the investigated forms describe it with varying degrees of detail. As explained earlier, both ConnDOT and IDOT use the same type of paints for the two-coat system. Table (11) represents the thickness of each paint coat in mils among the various specification forms.

Table (11) Painting thickness standards among the various states

	ConnDOT	ODOT	IDOT	INDOT
Sealer / Intermediate coat thickness (mils)*	1.0 – 2.0	N/A	2.5 – 4.0	0.25 – 0.50
Topcoat thickness (mils)*	3.0 – 5.0	N/A	2.0 – 4.0	N/A

* 1 mil = 0.0254 mm

Incorporating the values of the metalization coating thickness, the total thickness can be obtained. Table (12) represents the values of total thickness used by the four states.

Table (12) Composition of the coating system thickness among the various states

	ConnDOT	ODOT	IDOT	INDOT
Metalization coat (mils)*	6.0-8.0	6.0-8.0	8.0-10.0	8.0-10.0
Paint coats (mils)*	4.0-7.0	N/A	4.5-8.0	0.25-0.50
Total coat (mils)*	10.0-15.0	N/A	12.5-18.0	8.25-10.5

* 1 mil = 0.0254 mm

A major item associated with this topic is the time constraints on the application of the paint coats. ConnDOT and INDOT specification forms address this issue in more elaboration. The time constraints set by INDOT are more stringent than ConnDOT. While INODT form requires the sealer to be applied the same day as the metallic coating, ConnDOT form allows a 72-hour period on which the sealer should be applied. Regarding the topcoat, a range of 1-5 days is specified by INDOT form while ConnDOT form extends this range to 1-10 days.

9. Site Management

The QA/QC program of the metalization process has been described by the ANSI/AWS C2.18-93 in great detail. Refer to the original standards for more information.

Both ConnDOT and INDOT specification forms require the existence of a manufacturer's technical advisor. ConnDOT mandates that the contractor obtains the services of a qualified technical advisor, employed by the coating manufacturer. The technical advisor shall assist the engineer and the contractor in establishing correct application methods for the metalization coating, sealer and topcoat. INDOT specification form requires this assistanceunder a limited circumstances whenever the applicator of the metalization coating has a working experience with the used gun for less than two years.

10. Payment

The method of payment for ConnDOT, IDOT and INDOT is based on a lump sum basis. Only ODOT adopts a square foot bid method of measurement. The surface area is measured according to a formula based on the nominal surface area of the steel beams. In case of a truss structural system, a lump sum basis is used instead.

CHAPTER VI
SUMMARY AND CONCLUSIONS

Metalizing steel bridges is a promising protection policy that has a high potential for success in the future. Several State Departments of Transportation has become more interested in investigating this technology in greater detail. The first metalization project in Indiana was carried out in April of 1997. Metalizing this particular bridge followed a complete rehabilitation activity of the steel superstructure. This project is regarded as a basic step in the experimental stage of metalizing steel bridges in Indiana.

The survey conducted to investigate the popularity of metalizing steel bridges in the US indicated that both ODOT and ConnDOT have gained a lot of experience in this field during the past ten years. A major potion of ODOT experience comprises the partial metalization of the rust-sensitive areas of the structure. This application can be successful in extending the ultimate service life of the existing coating system.

Lohery [5] reported that the cost-effectiveness of a coating system is maximized when its ultimate service life coincides with the remaining service life of the overall structure. This makes metalization coatings a promising candidate for coating new or newly rehabilitated bridges. Other conventional painting system cannot provide such an ultra-long surface protection offered by metalizing and that varies between 40 and 60 years.

A thorough review of the standards and specifications regulating the application of metalization coatings has been presented throughout this report. The ANSI/AWS C2.18-93 indicated that metalization jobs require higher degrees of control, which suits on-shop practices. A complete process of surface preparation, metalization and application of paint coats is attainable on-shop. The latest metalization job in Connecticut is being totally carried out on-shop where the structure is fabricated and then coated with the three-coat system. After being erected on-site, further field touch-up will be performed to repair any coating damage.

The primary barrier facing the metalization of steel bridges is the high installation costs of the system. However, distributing the installation costs over the expected long life span of the system can provide a more realistic estimate of the real cost. Another factor to consider is that the costs of metalization have decreased over the last ten years allowing higher competitiveness of metalization against all conventional paint systems. If the trend continued in the coming years, metalization could become even more competitive while providing a superior performance over an ultra long lifetime, *if properly applied according to the established standards*.

REFERENCES

1. Bernecki, T. F., Nichols, G. M., Prine, D., Shubinsky, G. and Zdunek, A., "Issues Impacting Bridge Painting: An Overview," FHWA, Report No. FHWA/RD/94/098, pp. 89-102, August 1995.
2. Benary, R., Ganertz, R., Herman, H. and Hock, V. F., "Automated Thermal Spray Technology for Rehabilitation and Maintenance of Civil Works Infrastructures," USACERL, Technical Report 96/Draft 3, June 1997.
3. Oechsle, S. J. and Childs, J. N., Jr., "Thermal Sprayed Coatings," Steel Structures Painting Council (SSPC), Steel Structures Painting Manual, Vol. 1, Good Painting Practice, 3rd edition, Chapter 20, 1994.
4. Pawlowski, L., "The Science and Engineering of Thermal Spray Coatings," John Wiley & Sons Ltd., England, 1995.
5. Lohery, E., "Field Evaluation of Zinc-based Protective Coatings for Structural Steel," State of Connecticut, Department of Transportation, Report No. FHWA-CT-RD-1084-F-95-1, October 1995.
6. "FHWA Study Tour for Bridge Maintenance Coatings," FHWA's scanning Program, pp. 28-30, January 1997.
7. "Corrosion Tests of Flame-Sprayed Coated Steel: 19-year Report," American Welding Society (AWS), Miami, FL, 1974.
8. "ANSI/AWS C2.18-93: Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites," American Welding Society (AWS), Miami, FL, 1993.
9. "BS 5493:1977: Code of Practice of Iron and Steel Structures Against Corrosion," British Standards Institute, London, UK, 1977.
10. Gregowicz, T., Illinois Department of Transportation, Springfield, Illinois, (217) 524-3321, May 1997.
11. "Metalizing Structural Steel," Illinois Department of Transportation, Springfield, Illinois, September 1996.
12. Long, D., Michigan Department of Transportation, Lansing, Michigan, (517) 322-6138, May 1997.

13. McColeman, M., Ohio Department of Transportation, Columbus, Ohio, (614) 466-4038, May 1997.

14. "Metalizing Steel Structures," Ohio Department of Transportation, Columbus, Ohio, March 1994.

15. Lohery, E., Connecticut Department of Transportation, Newington, Connecticut, (860) 594-

16. "Specifications of Metalized Coating System," Connecticut Department of Transportation, Newington, Connecticut, October 1995.

17. Eastin, D., Indiana Department of Transportation, Indianapolis, Indiana, Field Trip, August 1997.

18. "Thermal Sprayed Metallic Coating System," Indiana Department of Transportation, Indianapolis, Indiana, Contract No. B-21621, April 1997.

19. "Metals Handbook," American Society for metals, Metals Park, Ohio, 1985.

20. Kogler, R. A., Brydl, D., and Highsmith, C. "Recent FHWA Experience in Testing and Implementing Metalized Coatings for Steel Bridges," Corrosion 98, Paper no. 499, 1998.

21. Lewis, C., "Metalization Seminar," Training Conference Center, Center South, Indiana Department of Transportation, Indianapolis, 14 August 1998.

22. Lewis, C., Applied Coatings, Inc., Columbus, Ohio, (614) 276-4100, August 1998.