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Protecting the Infrastructure with Thermal Spray Coatings—Technical Note*

T. Call and R.A. Sulit

Thermal sprayed aluminum and zinc provide long-term (>20 years to first maintenance) corrosion control coatings. However, this application is usually more expensive than painting or galvanizing if thermal spraying (metallizing) is not integrated into the design and fabrication phases of new construction and repair projects. Aluminum and zinc metallized coatings are tough enough to withstand fabrication, transportation, and assembly operations. The improved capabilities and productivity of metallizing equipment for aluminum and zinc spraying are a major factor in their current cost competitiveness. The net result is that the cost difference between metallizing, paint, and galvanizing is getting closer every day. Even though the initial application cost of metallizing may be higher, the life cycle cost (LCC) and average equivalent annual costs (AEAC) are lower than paint coating systems. Metallizing LCCs, when properly engineered into the construction schedule, are equal to or less than paint coating LCCs. This article summarizes some metallizing considerations for installing improved corrosion control coating systems in new construction and in maintenance and repair of infrastructure.

1. Introduction

THE European community has been taking advantage of the longevity of metallized coatings for over half a century. One of the major reasons for their extensive use in Europe is because the design goal for long service life accepts a higher initial construction cost for the higher performance metallized coating systems concomitant with reduced maintenance and repair costs. There is a greater expenditure on a structure and the coating system to protect it because most large structures outlive their design life. Blasting and painting costs coupled with current stringent environmental enclosure requirements have more than doubled the cost of painting large structures. Concurrently, the cost of metallizing has been substantially reduced, primarily through use of high-current arc spray machines.

The Federal Highway Administration (FHWA) and State Departments of Transportation (DOTs) are faced with the difficult and expensive task of installing improved corrosion control coating systems in new construction and in maintenance and repair of the existing infrastructure. Metallized coatings can meet this challenge of protecting infrastructure with economical and environmentally compliant coatings.

The outlook and approach to obtain the best LCC and AEAC, i.e., acquisition (construction) and operating (maintenance and repair) costs, are quickly changing in the United States to more closely reflect that of the Europeans. This is reflected in the passage of the $151 billion Intermodal Surface Transportation Efficiency Act (commonly called the 1991 Highway Bill or ISTEA),[1] which includes a mandate that the LCC be evaluated for all new construction of local, state, and federally funded projects. These LCC analyses should help bring the recognition and tradeoff of new technologies, including metallized coatings, in the construction, maintenance, and repair of infrastructure.

2. Design and Specification

Metallized coatings are now being considered during the design and development of specifications for new construction and for the update of maintenance and repair of existing infrastructure. The major quality and cost of metallizing can be controlled by its mode of delivery, as described below.

2.1 *Shop Metallizing*

Blasting and metallizing costs can be minimized and quality maximized due to better control of production and meeting environmental compliance requirements. This includes new construction and replacement components for maintenance and repair.

Key Words: cathodic protection, cost analysis, infrastructure, large-scale applications, metallization, thermal spray

T. Call, Douglas Call Company, 5714 Bayside Rd, Virginia Beach VA 23455; and **R.A. Sulit,** Sulit Engineering, 13203 Portofino Drive, Del Mar CA 92014. Presented at the 5th National Thermal Spray Conference (NTSC-93), Infrastructure Maintenance and Repair Session, 10 June 1993, Anaheim, CA.

***Editor's Note:** The following constants have been used to convert between English and Metric dimensions: 1 ft^2 = 0.0929 m^2; 1 lb/ft^2 = 4.89 kg/m^2; 1 mil = 0.025 mm.

Acronyms	
AEAC	Average equivalent annual costs
CP	Cathodic protection
DOD	Department of Defense
DOT	Department of Transportation
FHWA	Federal Highway Administration
ISTEA	Intermodal Surface Transportation Efficiency Act
LCC	Life cycle cost
TSC	Thermal spray coating
VOC	Volatile organic compound

Table 1 Aluminum and zinc spray rates and coverage of arc spray machines

Arc spray machine current, A	Aluminum		Zinc	
	Spray rate, lb/h (kg/h)	Coverage, $ft^2/h/10$ mil ($m^2/h/0.25$ mm)	Spray rate, lb/h (kg/h)	Coverage(a), $ft^2/h/20$ mil ($m^2/h/0.50$ mm)
200	12 (5.5)	70 (6.5)	46 (21)	45 (4.2)
500	30 (14)	175 (16)	115 (52)	110 (10)
1500	90 (41)	525 (49)	345 (157)	345 (32)

(a) $ft^2/h/20$ mil (or 0.51 mm) is the nominal coating thickness for cathodic protection on concrete.

2.2 *Field Metallizing*

Blasting, metallizing, and environmental compliance costs are increased over shop metallizing. Field metallizing of *in situ* structures is currently more commonplace than shop metallizing because there are more existing structures than new construction. However with more stringent environmental specifications, metallizing is cost competitive with alternative coating systems.

The engineering properties, application processes, and optimization for metallizing coating systems for the preservation of steel and concrete are being incorporated into engineering guides for the design, construction, maintenance, and repair specifications. For example, the US Navy incorporated the specification and use of thermal spray aluminum in new construction ships and the repair and maintenance of ships in service in 1981.[2] The Steel Structure Painting Council issued their guide for metallic coating systems in 1991,[3] and The American Welding Society issued their process instruction for thermal spray coatings in April 1993.[4] Metallized coatings have a proven long-term performance record and have improved application productivity through high-current arc spraying machines.

3. Environmental Considerations

Environmental concerns are other areas that favor the use of metallized coatings. Reformulating paints to comply with the lower volatile organic compound (VOC) emission levels questions the long-term performance capabilities and the surface preparation and application requirements of the new compliant paint systems. Metallized coatings produce zero VOC, have no minimum application temperature, and have no cure time.

Noise and dust generation are inherent with metallizing. This is not uncommon when compared to other industrial processes like blasting and painting. Like painting, metallized coatings require a surface blasted to at least near-white metal finish with a 2 to 4 mil (50 to 100 μm) anchor-tooth profile. In shop situations, the dust from the blasting process is captured by the structural steel blast machine that incorporates self-contained dust collectors. For large-scale production spraying, a separate dust collector system would be necessary to capture the dust and over-spray from the metallizing process. Over-spray from the metal spray process can be recycled.

Most field recoating jobs require containment for the capture of all hazardous debris and for the protection of workers and the environment. This setup and operating cost is becoming more expensive and a larger fraction of the overall coating budget. Therefore, it becomes mandatory to find and use the best performance coating system for the intended service. Aluminum and zinc, with their proven long-term performance record, are very competitive in providing lower LCCs than the evolving compliant high-performance paint systems. The cost percentage of the metallizing feedstock and its application in relation to the overall coating job cost is declining and will be further reduced as environmental compliance requirements become more stringent.

Galvanizing has long been regarded as one of the most successful long-term coatings. Like metallizing, it uses a sacrificial coating to protect the less noble steel substrate. However, the galvanizing industry has its own environmental concerns. The cleaning or pickling process produces hazardous fumes and chemical waste. It is difficult to dip large or geometrically complex shapes. Zinc metallizing complements galvanizing. For galvanizing, where weight-to-surface ratios are greater than 30 lb/ft^2 (147 kg/m^2) or if the piece is longer than 40 to 50 ft (or 12 to 15 m, the longest size of a typical galvanizing tank), it is more economical and practical to metallize. Zinc metallizing is also used to touch up and repair galvanized surfaces removed during welding or damaged during transportation and erection.

4. Metallizing Process Considerations

Arc and flame spraying are the major production processes for metallizing steel and concrete components and structures in infrastructure and civil works. For the purpose of this article, high production rate metallizing for corrosion control will be addressed. Aluminum and zinc are the two most common metals used in the corrosion control arena. The most economical and productive way to apply these coatings is by arc spraying. This process feeds two wires together to form an electric arc. The molten material is atomized by jets of compressed air and sprayed onto the substrate.

Arc spray technology has seen some major improvements in the last 5 years, with several arc spray equipment manufacturers independently contributing major breakthroughs in several areas. The most significant contribution, for infrastructure metallizing, is the increased current capabilities of arc spray machines. The use of 200 A was the nominal current capacity of arc spray machines in the mid 1980s. In 1993, 500-A arc spray machines are in common use, and a 1500-A machine is in final development. Table 1 illustrates the nominal spray rates and coverage of these machines.

Currently, throughputs for aluminum and zinc are on the order of 30 and 115 lb/h (14 and 52 kg/h), respectively, with some equipment capable of spraying 90 and 345 lb/h (41 and 157 kg/h) for aluminum and zinc. The net result is that metallizing

Table 2 Vinyl and zinc metallized coating life cycle costs

Coating system	Three-coat vinyl	Zinc (15 mil) with vinyl sealer(a)	Zinc (15 mil) with vinyl sealer
Maintenance interval, years	2	5	10
Current cost, \$/ft^2 (\$/m^2)	1.92 (20.7)	3.88 (41.7)	3.88 (41.7)
Net future value, \$/ft^2 (\$/m^2)	50.87 (547)	36.30 (391)	14.25 (153)
Net present value, \$/ft^2 (\$/m^2)	15.98 (1.72)	11.41 (123)	4.48 (48.2)
Average equivalent annual cost, \$/ft^2 (\$/m^2)	1.42 (15.3)	1.01 (10.9)	0.40 (4.42)

Note: The following calculations are used where n = number of years: Net future value (\$/ft^2) = NFV = (Current cost) × (1 + 4% inflation)^n. Net present value (\$/ft^2/yr) = NPV = (current cost) × (NFV) ÷ (1 + 8% interest). Annual equivalent annual cost (\$/ft^2) = AEAC = NPV × (8% interest) × (1 + 8% interest)^n ÷ [(1 + 8% interest) – 1]. (a) 15 mil = 0.38 mm.

Table 3 Nominal flame spray application cost for aluminum, zinc, and 85Zn-15Al

	Al	Zn	85Zn-15Al
Feedstock cost			
Required feedstock, lb/ft^2/mil (kg/m^2/0.025 mm)	0.0014 (0.0068)	0.005 (0.025)	0.0036 (0.0176)
Deposit efficiency	0.8	0.8	0.8
Coating thickness, mils (mm)	10 (0.25)	10 (0.25)	10 (0.25)
Spray rate, lb/h (kg/h)	12 (5.5)	45 (20.5)	40 (18.2)
Coverage, ft^2/h/mil (m^2/h/0.025 mm)	800 (74.3)	900 (83.6)	1110 (103)
Coverage for 10 mil thickness, ft^2/h (m^2/h)	64 (5.9)	72 (6.7)	89 (8.3)
Spray loss factor(a)	0.3	0.3	0.3
Required feedstock, lb/ft^2/10 mil (kg/m^2/0.25 mm)	0.06 (0.29)	0.21 (1.03)	0.15 (0.73)
Feedstock cost, \$/lb (\$/kg)	2.60 (5.72)	1.40 (3.08)	2.80 (6.16)
Feedstock cost per specified thickness, \$/ft^2 (\$/m^2)	0.15 (1.61)	0.29 (3.12)	0.42 (4.52)
Labor cost			
Spray gun crew	1.5	1.5	1.5
Labor rate, \$/h	40.00	40.00	40.00
Labor cost, \$/ft^2 (\$/m^2)	0.94 (10.12)	0.83 (8.93)	0.68 (7.32)
Overhead + direct + indirect costs			
Costs, \$/ft^2 (\$/m^2)	0.65 (7.00)	0.65 (7.00)	0.65 (7.00)
Total cost, \$/ft^2 (\$/m^2)	1.74 (18.73)	1.78 (19.16)	1.75 (18.84)

(a) Varies between shop and field.

contractors can spray more square feet per hour with fewer people. This reduces labor and overall job costs, making metallized coatings competitive with conventional paint coatings.

Table 2 illustrates the costs of a coating system designed for a tainter gate of a river lock.[5] The three-coat vinyl coating system LCC is compared with that of a 15-mil (0.38-mm) zinc coating, vinyl sealed, for three maintenance recoating intervals. In this table, n is the number of years, and the current inflation and interest rates in the United States are taken as 4 and 8%, respectively.

5. Thermal Spray Coating Cost Estimate

Thermal spray coating (TSC) costs can be estimated by:

$$\text{TSC (cost)} = W \times C + (N \times L)/R + A(\$/\text{ft}^2)$$

where W is the weight of the feedstock (lb/ft^2); C is the cost of TSC feedstock material (\$/lb); N is the number of persons in spray gun crew; L is the labor rate (\$/h); R is the coverage rate/spray gun crew (ft^2/h); and A is the overhead + direct costs + indirect costs (\$/ft^2).

Using the nominal spray rate and coverage information for ⅛-in. wire from AWS C2.18-93 and market feedstock costs, Table 3 compares the cost of flame sprayed aluminum, zinc, and 85Zn-15Al, and Table 4 details the cost for comparable arc-sprayed (500-A current) coatings. A spray gun deposit efficiency of 80% and a 30% spray loss factor were assumed. The 30% spray loss factor is used to estimate the loss from manual spraying in both shop and field work. It can be significantly reduced with simple low-cost fixturing and automation to complex robot manipulators depending on the component geometry and quantity to be metallized. For the assumptions made in Tables 3 and 4, the arc-sprayed aluminum, zinc, and 85Zn-15Al costs are 30, 25, and 7% less costly than the equivalent flame sprayed coatings.

6. Applications

Metallized coatings currently are used on an international basis to protect a wide variety of structures. Metallizing prices have decreased by approximately 20% in the past few years on large-scale jobs. Contributing factors include more jobs being

Table 4 Nominal arc spray application cost for aluminum, zinc, and 85Zn-15Al

	Al	Zn	85Zn-15Al
Feedstock cost			
Required feedstock, lb/ft^2/mil (kg/m^2/0.025 mm)	0.0017 (0.0083)	0.0054 (0.0264)	0.0049 (0.0240)
Deposit efficiency	0.7	0.7	0.7
Coating thickness, mils (mm)	10 (0.25)	10 (0.25)	10 (0.25)
Spray rate, lb/h/100 A (kg/h/100 A)	6 (2.7)	23 (10.5)	20 (9.1)
Coverage, ft^2/h/mil/100 A (m^2/h/0.025 mm/100 A)	350 (32.5)	430 (40.0)	410 (38.1)
Spraying current, A	500	500	500
Coverage for 10 mil (0.25 mm) thickness, ft^2/h (m^2/h)	123 (11.4)	151 (14.1)	144 (13.4)
Spray loss factor(a)	0.3	0.3	0.3
Required feedstock, lb/ft^2/10 mil (kg/m^2/0.25 mm)	0.08 (0.39)	0.26 (1.27)	0.23 (1.12)
Feedstock cost, $/lb ($/kg)	2.60 (5.72)	1.40 (3.08)	2.80 (6.16)
Feedstock cost per specified thickness, $/ft^2 ($/m^2)	0.21 (2.26)	0.36 (3.88)	0.65 (7.00)
Labor cost			
Spray gun crew	1.5	1.5	1.5
Labor rate, $/h	40.00	40.00	40.00
Labor cost, $/ft^2 ($/m^2)	0.49 (5.27)	0.40 (4.31)	0.42 (4.52)
Overhead + direct + indirect costs			
Costs, $/ft^2 ($/m^2)	0.55 (5.92)	0.55 (5.92)	0.55 (5.92)
Total cost, $/ft^2 ($/m^2)	1.25 (13.46)	1.31 (14.10)	1.62 (17.44)

(a) Varies between shop and field

Table 5 Infrastructure applications and owners

Description	Owner
Steel bridge beams and girders	State DOTs, FHWA
Concrete rebar	State DOTs, FHWA
Concrete parking garages (cathodic protection)	City municipalities, private authorities
Dam locks and sluice gates	Army Corps of Engineers
Offshore oil platforms	Oil companies and operators
Potable water towers	City municipalities
Pier and wharves	State DOT, municipalities, DOD
Railroad cars and bridges	Railroad companies
Structural steel	Buildings and facilities for all industries
Concrete-reinforced structures	State DOTs, FHWA
Steam and black liquor recovery boilers	Power generation, pulp and paper

Table 6 Selected bridge metallizing jobs

Structure	Coating system	Year metallized	Last year inspected(a)
Kaw River (US)	10 mils Zn	1936	1975
Ridge Avenue (US)	10 mils Zn	1938	[redacted]84
Menai Straits (UK)	6 mils Zn + 3 coats paint	1938	1968
Southwest Trafficway (US)	10 mils Zn	1950	1975
Vilsund (Denmark)	4 to 6 mils Zn + 3 coats paint	1951	1974
Djupfjord (Norway)	6 mils Zn + 1 coat paint	1958	1970
Conway Arch (UK)	4 mils Zn + 1 coat paint	1959	1970
Forth Road (UK)	3 mils Zn + 3 coats paint	1961	1975
Pierre-Laporte (Canada)	5 mils Zn + 2 coats paint	1977	1985

Note: 1 mil = 0.025 mm.
(a) All structures in excellent condition when last inspected.

let for bid and more metallizing contractors using higher spray rate production equipment. All of these factors have helped to establish metallizing as a cost-effective alternative to painting and galvanizing. This is a trend that will continue for several reasons. For instance, as reports of successful metallizing projects circulate among the specifying authorities (DOT, DOD, Corps of Engineers, architectural and design engineers, corrosion engineers, etc.), their use will become more widespread.

In addition to the protection of steel surfaces with metallized coatings, another very large potential use of metallized coatings exists for spraying concrete surfaces with zinc and other materials to protect embedded reinforcing bars from corrosion. Cathodic protection (CP) using thermal spray coatings to protect reinforced concrete has been used in the United States since the 1970s. There have been many advances in this field, one of which is the use of metallizing equipment (primarily arc spray) to apply the electrically conductive anode to the surfaces of the concrete structure. These concrete structures include bridge decks and substructures, parking garages, piers and wharves, offshore oil platform legs, bulkheads. etc.

Oregon and Florida DOTs are successfully implementing arc-sprayed zinc coatings into their bridge maintenance and repair budgets and programs. Virginia, Texas, North Carolina, and other states are beginning to implement metallized coatings into their CP maintenance and repair programs as well. This is an area of great interest to both DOTs and the metallizing community. If this trend continues, and all indications are that it will,

Table 7 Recent zinc metallizing applications

State	Structure type	Coating	Function	Area, ≈$10^3 \times ft^2$	Area, ≈$10^3 \times m^2$
Virginia	4 steel	Zn	Corrosion control	24	2.2
	1 concrete	Zn	Corrosion control	0.8	0.26
Ohio	3 steel	Zn	Corrosion control	80	7.4
	3 steel	85Zn-15Al	Corrosion control		
Pennsylvania	1 steel	Zn	Corrosion control	2	0.19
Connecticut	1 steel	Zn	Corrosion control	2	0.19
Florida	6 concrete	Zn (15 to 20 mil)(a)	Cathodic protection	140	13
Oregon	2 concrete	Zn (18 to 22 mil)(b)	Cathodic protection	102 and 190	9.5 and 17.7

(a) For passive cathodic protection. (b) For a distributed anode for impressed current cathodic protection.

metallizing will play a vital role in the maintenance and repair and up-grading of the infrastructure.

Table 5 presents a brief list of applications and their owners, whereas Table 6 lists selected steel bridge metallizing jobs. Table 7 lists recent State DOT zinc metallizing jobs.

7. Conclusions

This technology that has evolved over the course of the 20th century has had a very long and successful track record. It has been used to spray everything from very large plate girders to relatively small bearing pads and rebar. Aluminum and zinc, among other metals, have been sprayed for a variety of service uses and operating environments. The thermal spray process has demonstrated a breadth of applications that cover a wide range of protective coatings. With environmental and economic concerns playing a larger role in the coating specifiers and owner's agenda, metallized coatings should become a major consideration in their planning and increased use.

The authors are in close communication with many owners, users, and specifying authorities and would welcome comments, questions, or ideas concerning the continued and expanding use of metallized coating systems to protect infrastructure and civil works. They encourage other DOT, municipalities, DOD, and owners of similar concrete structures to contact the officials in Oregon and Florida DOTs to discuss their issues and accomplishments and lessons learned from the Oregon and Florida programs.

Editor's comment: The *Journal of Thermal Spray Technology* encourages and welcomes any case histories in this and other application areas of thermal spray practice.

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