PROPERTIES OF THERMALLY SPRAYED ZINC COATING AFFECTED BY SPRAYING TECHNIQUE

GEIPLOVÁ Hana, PARAKOVÁ Markéta, NĚMCOVÁ Martina

SVÚOM Ltd., Prague, Czech Republic, EU

Abstract

The thermal spraying of metallic coating (zinc, Zn-Al15, etc.) from wire is suitable technique for surface treatment corrosion protection of large structures. This study was carried out to investigate and evaluate the properties of zinc coatings affected by spraying techniques - heated by electrical arc or flame. The panels with different coatings were exposed at atmospheric and accelerated tests. The article gives the overall evaluation of properties of these coatings.

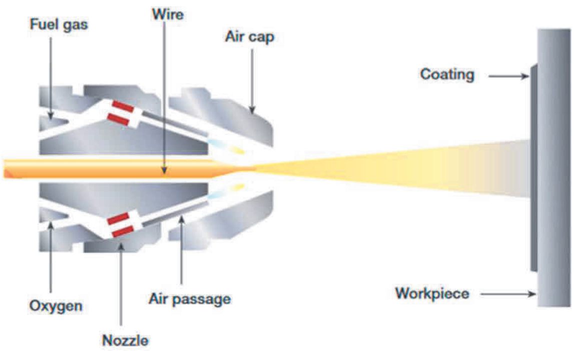
Keywords: Thermally sprayed coating, structure, adhesion, corrosion

1. INTRODUCTION

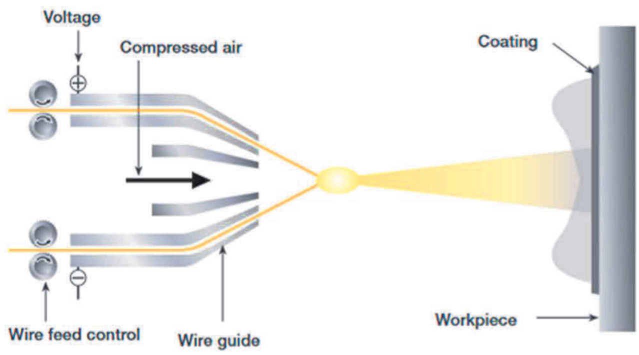
The thermal spraying of metallic coating (zinc, aluminium, alloy Zn-Al15, etc.) is suitable technique for surface treatment corrosion protection of large structures. Metal wire is fed in a nozzle where it melts. The as formed metal droplets are accelerated by the gas stream and strike the surface of the substrate. It cools down rapidly in contact with the steel surface and built coherent and structured coating. Various technologies can be used to deposit the appropriate surface protection that can resist under specific conditions.

In classical (developed between 1910 and 1920) but still widely used flame spraying technique, the particle velocities are generally low (< 150 $m \cdot s^{-1}$), and raw materials must be molten to be deposited. Flame temperatures and characteristics depend on the oxygen-to-fuel gas ratio and pressure. The process is less tolerant to inadequate surface preparation than electric arc spraying.

Electric arc spray is a form of thermal spraying where two consumable metal wires are fed independently into the spray gun. These wires are then charged and an arc is generated between them. The heat from this arc melts the incoming wire, which is then entrained in an air jet from the gun. This entrained molten feedstock is then deposited onto a substrate. Electric-arc spray offers advantages over flame spray processes. In general, theoretically, it exhibits higher bond strengths - adhesion. Substrate heating is lower than in flame spray processes due primarily to the absence of a flame touching the substrate. The electric-arc process is in most instances less expensive to operate than the other processes.



flame spray process



electric arc spray process

Figure 1 Process of heating at of wire

Material consumption and covering rate for these two spraying techniques were compared - **Table 1**.

Table 1 Typical spraying parameters

technique	flame sprayed			arc sprayed		
coating metal	zinc	aluminium	alloy Zn15Al	zinc	aluminium	alloy Zn15Al
material consumption (kg.m^{-2})	1.33	0.80	1.0	1.80	1.46	1.31
covering rate (m^2.hrs^{-1})	6	2.5	5	18	5	21
Note: The Zn and Zn-Al15 coatings were applied in 100 µm thickness, Al coating was applied in 200 µm thickness to obtain the same corrosion protective efficiency - see below.						

The basic requirements of these coating are given in standard ISO 2063 which is under revision (FDIS in 03/2017):

- ISO 2063 - 1 Part 1: Planning of the corrosion protection system - Component design considerations and quality requirements
- ISO 2063 - 2 Thermal spraying - Metallic and other inorganic coatings - Zinc, aluminium and their alloys - Part 2: Conditions for execution of corrosion protection works by thermal spray processes

A high standard of surface preparation is required to develop the optimum thermo-mechanical bond required for metal sprayed coatings. Steel surfaces to be arc sprayed with zinc or aluminium or to be flame sprayed with zinc should be abrasive blast cleaned to at least Class Sa 2½ to produce a sharp angular profile of at least 50 µm. Steel surfaces to be flame sprayed with aluminium or aluminium alloys should be abrasive blast cleaned to Class Sa 3 to produce a sharp angular profile of at least 75 µm. On the surface with higher cleanness may be expected higher adhesion of thermally spray coating.

The coating material and the required coating thickness are to be selected and specified concerning to the expected corrosivity, the required design life and construction design. Thermal spraying can provide thick coatings, approx. thickness range is 100 to 300 µm. Coating quality is usually assessed by measuring its porosity, oxide content, macro and micro-hardness, bond strength and surface roughness.

The microstructure of the coating formed by the piling up of these particles depends on (i) particle impact parameters (particle temperature, molten state, velocity and size), (ii) substrate conditions (shape, roughness, surface chemistry...), (iii) the temperature control of substrate and coating before (preheating) during and after (cooling) spraying and (iv) the spray pattern.

The flame sprayed coating displayed the lower adhesion value than the arc sprayed coating according to ISO 2063-2 - **Table 2**. These values are specified in standard for the first time.

Table 2 Typical values of the pull-off strength (MPa)

coating metal	flame sprayed	arc sprayed
zinc	5	6
aluminium	10	10
alloy 15Al85Zn	6.8	7.2

There are available only a few empirical data about the corrosion resistance of these coatings in various atmospheric environment [1, 2]. In ISO 2063-1 there are reference to ISO 9223, ISO 9224 or ISO 14713-1, but the thermally sprayed coating have a very porous structure which affect he corrosion behaviour, too.

2. ALUMINIUM-ZINC THERMAL SPRAYED COATING CHARACTERISTICS

In recent decades, binary zinc-aluminium (Zn-Al15) alloy coatings have been used instead of zinc and/or aluminium in most atmospheric applications. Alloyed zinc-aluminium coating is applied by an alloyed wire of 85% zinc and 15 % aluminium by weight. The cross sections of the 85/15 coating lead to the discovery of a two phase, evenly distributed coating structure consisting of large elongated particles containing mainly aluminium surrounded by tiny particles of zinc. Aside from the benefits of having a dual phase coating 85/15 sprayed by both flame and electric arc metalizing equipment produces a denser coating than pure zinc or aluminium.

Zn-Al15 alloy coating on the steel has the same excellent electrochemical cathode protection features of thermal spraying Zn coating, but also has high corrosion resistance characteristics of thermal sprayed Al coating [3]. The zinc, aluminium and Zn-Al15 alloy coatings with coating thickness of 50, 100 and 150 μm had been exposed at accelerated laboratory corrosion test - salt spray test according to ISO 9227. The Zn-Al15 alloy coating shows the best behaviour in this condition - **Table 3**.

Table 3 Result of salt spray test - time to corrosion of substrate (red rust) occurrence (hrs)

coating	time (hrs)		
	50 (μm)	100 (μm)	150 (μm)
Zinc	300	600	1522
Aluminium	540	-*	-*
Zn15Al alloy	492	1080	1716
Note: Only white corrosion products formed.			

3. EXPERIMENTAL

3.1. Material and methods

Zinc coating was deposited on steel panels 150 x 100 x 3 mm. The substrate surface before deposition was grit blasted to create an anchor tooth profile, min. 75 μm.

Alloyed coating was deposited using Zn-Al15 wire flame spray device (AD3 gas) - number 98 and electric arc device Margarido M45 - number 99. The thickness of the deposited coating was ca 120 - 130 μm.

3.2. Atmospheric corrosion test

Test site Kopisty, performed according to ISO 8565 is located in Northern Bohemia region, near to Most city, where heavy industrial pollution was in past (~ 100 μg $SO_2 \cdot m^{-3}$). On-site measurement of environmental data (temperature, relative humidity, rain, air pollution, etc.) was done during the exposure and statistically treated on yearly average values (**Table 4**). The atmospheric corrosivity of localities was regularly estimated according to ISO 9223 for zinc and aluminium, too. Based on coupons´ yearly corrosion loss, the corrosivity of atmosphere at the test site is estimated by degree C2 for zinc (4.69 $g \cdot m^{-2}$) and degree C1 aluminium (0.23 $g \cdot m^{-2}$) according to ISO 9223.

Table 4 Selected average annual environmental parameters at test site

T (°C)	RH (%)	SO_2 ($\mu g \cdot m^{-3}$)	NO_x ($\mu g \cdot m^{-3}$)	rain (mm)	pH of precipitation
10.1	76	17	26	527	5.4

3.3. Evaluation of exposed panels

The samples had been visually evaluated after each years of exposure. The coating applied by flame spraying showed from the 1st year of exposure some visually non-uniformity - white spots. After 4 years of exposure the samples had been withdrawal for detailed evaluation. For clarification of the corrosion behaviour of the coatings, the corroded surfaces were examined with 3D digital microscope Keyence HVC-5000 (**Figure 2**). The microstructure of coatings was studied on cross sections of coatings (**Figure 3**).

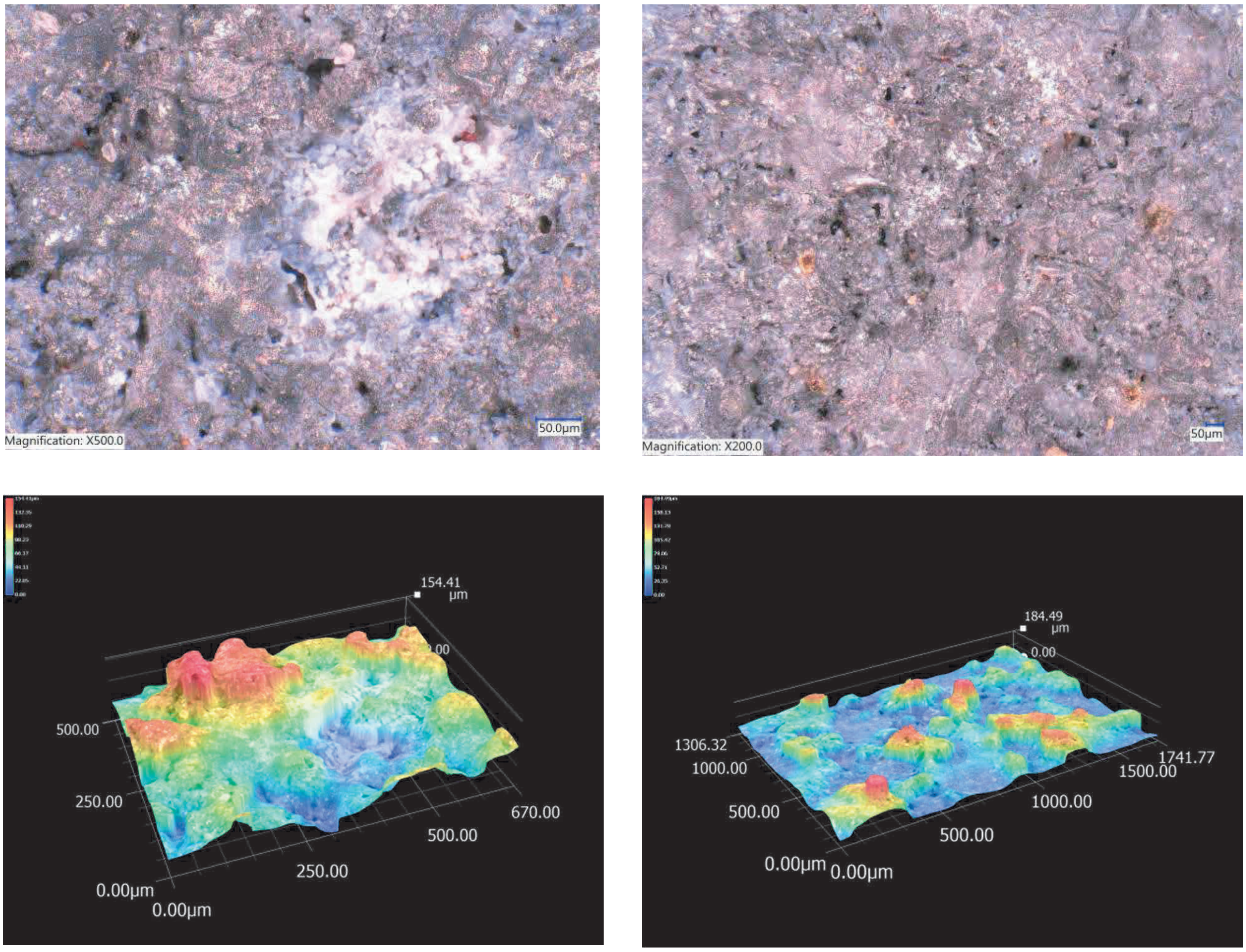


Figure 2 Details of Zn-Al 15 coatings after 4 years exposure- flame spray (left) and arc sprayed (right)

The pull-off test was done for non-exposed and exposed coatings according to ISO 4624 by hydraulic pull off tester P.A.T. model GM01, Surftec of **Table 5**.

Table 5 Adhesion of thermally sprayed coatings (MPa)

coating	non-exposed	exposed
flame sprayed	9.6	10.7
electric arc	9.2	8.6

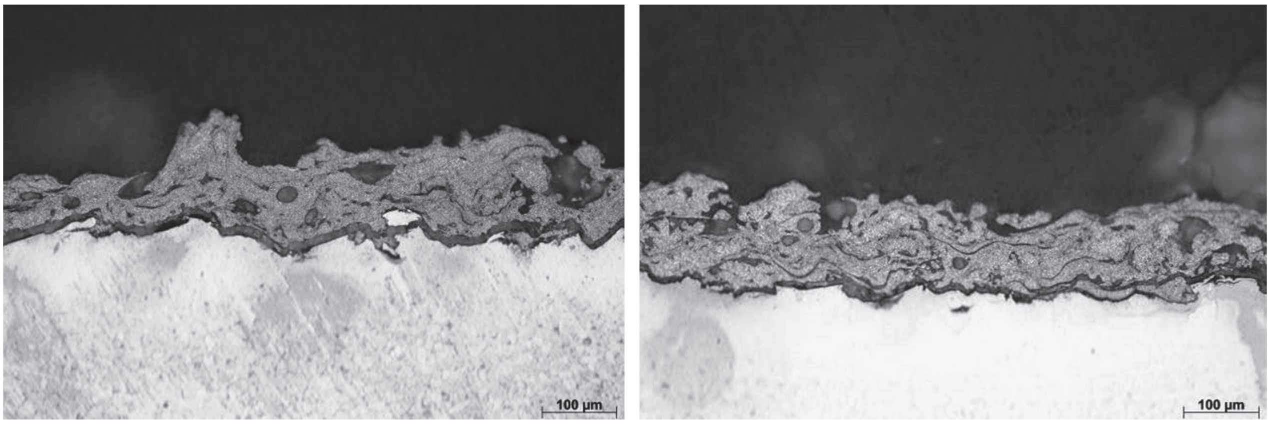


Figure 3 Microstructure of exposed coatings **-** flame spray (left) and arc sprayed (right)

4. DISCUSSION

The 4 years exposure in industrial atmosphere with ca 15 µg.m^{-3} of SO_2 is not long enough to show some significant differences between corrosion resistances of thermally sprayed Zn Al15 coatings, but some first symptoms had been seen.

As the surface of flame sprayed coating are rougher and porous the white corrosion products formed in pores of it (**Figure 2**).

The adhesion values for thermally sprayed coating are newly specified in ISO 2063-2. Values measured on exposed panels show the adhesion of both coatings were higher than specified and slightly higher for flame sprayed coating. After 4 years the values changed minimally.

5. CONCLUSION

From corrosion laboratory and field tests and spraying parameters it can be conclude that Zn Al15 thermally sprayed coating is the more economical than double spraying of zinc and aluminum coats for long life corrosion protection. The results of describe tests of the spraying techniques on testing samples do not shown widely differences.

For large structures with required long-term durability the thermally sprayed coatings followed by the application of paint systems. Several bridges in the Czech Republic were protected many years ago against corrosion by ZnAl15 thermal spraying + paint system (Plesna-Cheb, Ceske Budejovice-Dolni Dvoriste, Krimov-Vejprty, Decin-Oldrichov, Usti nad Labem, etc.) without any failure of protective system.

ACKNOWLEDGEMENTS

This paper was elaborated with financial support of project MPO IP 9/2017.

REFERENCES

[1] ZHANG, X.G., *Corrosion and electrochemistry of zinc*, New York, Plenum Press, 1996

[2] NEVISON D.C.H., *ASM handbook*, *Vol. 13 Corrosion*, *9th ed*. New York: ASM International, 1987, 755 p.

[3] XIAO, Y., JIANG, X., XIAO, Y., MA, L., Research on Zn-Al15 thermal spray metal coating and its organic painting composite system protection performance, *Procedia Engineering*, 2012, Vol. 27, pp. 1644-1653