CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

DOUBLE PLUS THE LIFESPAN OF LARGE STEEL STRUCUTRES

Gagné, M.[1,3], Pole, S.[1], Duran, B.[2] and Goodwin, F.[2]
[1] International Zinc Association, Canada
[2] International Zinc Association, United States
[3] mgagne@zinc.org

Abstract: Large painted steel structures are almost always resulting in a near constant maintenance program. There are better ways to protect steel from corrosion. Enter duplex coating systems. Metallic zinc coatings with a paint top-coat, or 'Duplex Coatings', offer both barrier and sacrificial corrosion protection mechanisms providing more than twice the corrosion protection provided by one coating system alone. Empirical evidence shows that, duplex zinc coatings can provide 1.5 to 2.3 times the sum of the expected life of each system alone. A paint top-coat over a metallic zinc base layer protects the zinc from initial corrosion. The zinc base layer similarly protects the paint from under film corrosion at scratches and holes. The synergy between the two coatings provides protection far superior to either system used independently. This system also provides improved impact and abrasion resistance, resulting in longer lifetimes between maintenance compared to paint only coatings. Duplex zinc coating systems have decades of proven performance protecting steel infrastructure from corrosion.

1 INTRODUCTION

Paint is often specified as a primary corrosion protection system for steel structures, since it is relatively inexpensive and easy to apply. In fact, some 50M mt of paints are produced every year. The paint provides simple barrier protection by keeping corrosive elements away from the steel. Metallic zinc coatings provide more effective corrosion protection for steel by acting first as a barrier coating, keeping corrosive elements away from the steel, and secondly as a sacrificial anode (Porter 1994). Metallic zinc coatings can be applied by hot-dip galvanizing [HDG] or by thermal spraying [TSZ]. Hot-dip galvanizing involves the full immersion of the steel piece into a bath of molten zinc, which ensures complete coverage of all surfaces, inside and out. Zinc thermal spray involves projecting drops of molten zinc onto the surface of the steel using compressed air. With thermal sprayed zinc coatings, there is no size limitation to the part being coated, and the technology is fully portable, allowing easy field applications.

When metallic zinc coatings are painted, a 'duplex coating', the barrier protection of the paint extends the life of the metallic zinc coating, while the sacrificial nature of the zinc protects the paint from underfilm corrosion at discontinuities in the paint film such as at holidays, scratches or holes. In this way, the lifetime of the zinc coating, applied either by galvanizing or zinc thermal spray, can be greatly extended by overcoating it with a quality paint system. The enhanced corrosion protection mechanisms of paint over metallic zinc provide more than twice the corrosion protection provided by one coating system alone (van Eijnsbergen 1994). Duplex or painted metallic zinc coatings, provide double plus corrosion protection performance.

2 METALLIC ZINC COATINGS

2.1 Galvanized Steel

The hot-dip galvanizing process involves completely immersing the steel product in a bath (kettle) of molten zinc (Bablic 1950). While in the galvanizing kettle, the molten zinc metallurgically reacts with the iron in the steel to form a distinct coating structure approximately 100 microns thick (Figure 1). The hot-dip galvanized coating structure consists of a series of iron-zinc layers with a top surface layer of pure zinc. The intermetallic layers are tightly bonded to (9MPa), and harder than the base steel, offering excellent abrasion resistance. The zinc-iron alloy layers, metallurgically bonded to the steel, become an integral part of the steel rather than just a surface coating.

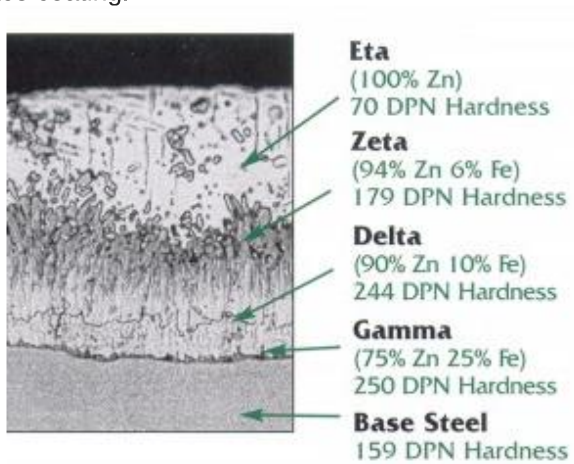

Figure 1- The hot-dip galvanized coating structure

A unique characteristic of the hot-dip galvanized coating is the uniform and complete coverage of all surfaces. As hot-dip galvanizing is a total immersion process, all accessible interior surfaces of hollow structures, including difficult to access recesses of complex pieces, are coated. Also, during the metallurgical reaction in the kettle, the zinc-iron alloy layers grow perpendicular to all surfaces, ensuring that both edges and corners have a coating thickness equal to or greater than flat surfaces. This complete, uniform coverage of all surfaces ensures that critical points where corrosion commonly starts have the same protection as accessible, flat exterior surfaces.

2.2 Thermal Sprayed Zinc

The thermal spraying of zinc involves melting a zinc source, such as a wire, and propelling the drops onto the surface of the steel with compressed air or another specialty gas. Both flame spraying or arc spraying may be used for zinc coatings (Prenger 2014). Flame spraying uses an acetylene-oxygen flame to melt a zinc wire that is continuously fed into this flame, while a stream of gas then propels the molten metal droplets in the direction of the steel surface. Arc spraying employs two zinc wires, which are brought together at an angle between 30 and 60°. An imposed voltage difference between them creates an electric arc, which melts the zinc wires. As with flame spray, a gas flow then atomizes and propels the molten metal droplets toward the steel substrate. Pure zinc and Zn-15%Al alloy are commonly used for thermal spraying (Prenger 2012).

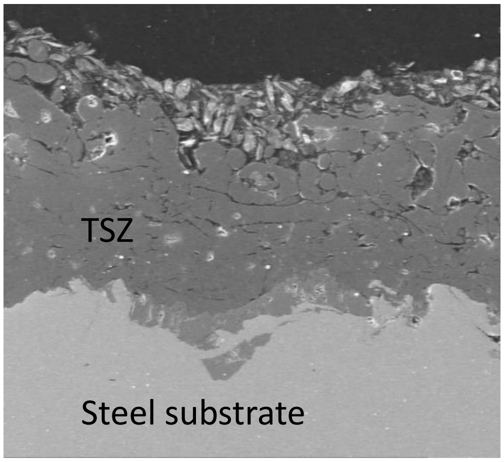

Figure 2 - The thermal sprayed zinc coating structure

As the liquid zinc droplets impact on the steel surface, the coating builds up to the desired thickness. The overlapping of pancaked particles produces a metallic layer with micro-pores and oxide coatings on the individually solidified particles. Coating thickness is dependent on the time of spray. Porosity typically makes up 5-7% of the coating volume. The overall coating has characteristics similar to solid metallic zinc, including a Vickers hardness of around 70.

3 DUPLEX COATINGS

Duplex coatings are produced by painting over a metallic zinc coating. A duplex coating structure is shown in Figure 3. In this case there is a 100 microns thick thermal sprayed zinc layer on top of the base steel. The thermal sprayed zinc is sealed and then overcoated with a typical paint system for aggressive environments consisting of an epoxy mastic barrier coat with a polyurethane top coat. The total coating thickness is approximately 350 microns.

The corrosion protection provided by a duplex system will be significantly longer than that of the metallic zinc or paint coating alone. The improved corrosion protection provided by the duplex coating compared to the expected lives of the zinc coating or the paint system used by themselves is known as a synergistic effect.

Figure 3 - The Duplex coating structure

The reason for this improvement in service life is that zinc corrosion products have much lower volume than iron corrosion products and therefore exert less lifting force on the paint in compromised areas. Also, zinc corrosion products have a barrier effect and may seal pores in the top paint coating.

The synergy effect is defined by a factor in the equation:

[1] Duplex service life = synergy factor x (zinc life + paint life)

For example, with a synergy factor of 1.5, and an expected life to first maintenance of 12 years for metallic zinc and a life to first maintenance of 5 years for paint would give an expected protective coating system life of 25 years [1.5 x (12+5)]. Synergy factors vary, depending upon the climate. Typical synergy factors found as a result of global corrosion testing have been compiled (Table 1).

Table 1 - Synergy Factors for determining life of duplex coatings

Environment	**Synergy Factor**
Industrial / Marine	1.8 – 2.0
Sea Water / Immersion	1.5 – 1.6
Mild Climate	2.0 – 2.7

It can be seen that synergy effects in severe industrial and marine environments range from 1.8-2.0, whereas in non-aggressive climates, for example, in mild onshore climates they can range from 2.0-2.7. The basic reason for this synergy is that zinc supports the paint when it begins to fail and prevents corrosion creep and other mechanisms of paint failure from proceeding anywhere near as rapidly as they would occur with a steel substrate that does not have the protection of the intermediate metallic zinc coating (van Eijnsbergen 1994).

4 DUPLEX COATING APPLICATIONS

Whether applied by galvanizing or thermal spray, duplex zinc coatings have been used for decades to successfully mitigate steel corrosion in many applications, especially for public infrastructure.

Since the 1960’s, the Norwegian Public Roads Administration has been specifying duplex zinc coatings, applied by thermal spraying, to successfully mitigate corrosion of steel bridges (Knudsen 2012). About 4,500 steel bridges of various types from floating to suspension are protected by duplex thermal sprayed zinc coatings.

The Rombak Fjord bridge, in the Norwegian Arctic, is a suspension bridge with a strengthening steel truss structure, approximately 750m long, with about 40m vertical clearance for marine navigation. The bridge was built in 1964, and due to insolvency of the contractor was not painted. In 1970, after six years of service, it was decided to protect the corroding bridge with a duplex coating. The bridge was blasted to white metal and then thermal sprayed with 100 microns of pure zinc, followed by a four-coat alkyd paint system of 200-300 microns. The bridge truss structure is riveted with a significant number of overlapping joints that are prime locations for corrosion initiation, yet as shown in Figure 4, the bridge still shows no sign of corrosion after 40 years of service and has required no maintenance related to remediation of steel components protected with this duplex system (Knudsen 2012).

Figure 4 - The Rombak bridge in 2009 (Knudsen, 2012)

In comparison, the Brevik bridge, located south of the arctic circle, is a very similar suspension bridge with a strengthening truss structure, approximately 750m long, with about 40m vertical clearance for marine navigation. However, the Brevik bridge was only painted for corrosion protection. Since construction in 1962, the Brevik bridge paint coating has been maintained each decade, and the bridge was fully repainted in 1992. An inspection in 2001, nine years after the repainting, revealed significant corrosion, especially in the overlapping joints. The bridge required paint maintenance again in 2013.

The life cycle costs for the Rombak and Brevk bridges are compared after more than 50 years of service in Table 2. The initial cost of the duplex coating on the Rombak bridge is approximately 30% more expensive than the paint only system used on the Brevik bridge. However the repeated paint maintenance required on the Brevik makes the total cost of ownership for paint coatings more than two times as expensive as the duplex coating. Not included in the cost comparison are the scaffolding and containment costs for repainting, which could double the values listed, further enlarging the cost difference.

Table 2 - Life cycle cost comparison of the Rombak and Brevik bridges

Rombak Bridge	Cost (US$/m^2)	**Brevik Bridge**	Cost (US$/m^2)
Duplex coating - 1970	85	Paint coating – 1962	55
Paint maintenance - 2012	35	Paint maintenance - 1970’s	45
		Paint maintenance - 1980’s	45
		Total repainting - 1992	70
		Paint maintenance - 2013	45
Total	120	Total	260

The Staten Island ferry terminal, in New York City, New York, was rehabilitated in 1995 with a duplex coating consisting of a pure zinc thermal spray coating with a paint topcoat. The rehabilitation work used 200-250 microns of thermal sprayed zinc, together with one layer of paint. This coating was applied to vehicle ramps, pedestrian railings, ramp barriers and handrails. Ferry terminals must support protection from the environment, and also the constant daily wear from passengers and vehicle traffic. An inspection by the New York City Transit Authority revealed some damage to the paint coating, but no corrosion was observed on any of the metallized and coated surfaces after 10 years of service (Metalize).

The Valley Metro Light Rail System in Phoenix AZ is one of the largest infrastructure projects ever undertaken in the region. A valuable investment in the Valley's future, the light rail was needed to meet the growing transportation needs and relieve traffic congestion in the greater Phoenix area. The selected fully loaded light rail car can take as many as 180 cars off the road, while a three-car train could take the equivalent of 540 cars off the road. As the population densities of major cities continue to grow, cost effective, low-maintenance facilities, such as the light rail are critical. The hot-dip galvanized steel combined with a paint top coat will ensure the light rail will remain a beautiful and functional mass transit system for decades, reducing paint maintenance and lowering overall life cycle costs (AGA).

5 SUMMARY

Duplex zinc coatings have been used successfully for decades to mitigate simple steel corrosion issues in a variety of applications across a broad range of environments. Zinc provides the most effective corrosion protection for steel by acting first as a barrier coating, keeping corrosive elements away from the steel, and secondly as a sacrificial anode. Zinc will corrode preferentially to protect the steel.

Duplex or painted zinc coatings provide improved corrosion protection performance. The reason for this is that zinc supports the paint when it begins to fail and prevents corrosion creep and other mechanisms of paint failure from proceeding anywhere near as rapidly as they would occur with a steel substrate that does not have the protection of the intermediate metallic zinc coating.

Zinc coatings can be applied by galvanizing or zinc thermal spray, although the thermal spray process allows for the protection of much larger structures and is fully portable, making it ideal for retroactive field application as well as for protecting new larger structures.

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