

Protecting Steel Structures from Corrosion with Thermal Sprayed Zinc Duplex Coatings

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ABSTRACT

In order for steel structures to meet a 100 year design life, protective coatings with very long durability are needed to reduce maintenance costs. Thermal spray zinc (TSZ) duplex coatings have proven to be very durable. The Norwegian Public Roads Administration (NPRA) have used TSZ duplex coatings for protection of steel bridges since 1965. Many steel bridges in Norway cross rivers or fjords along the sea coast and are exposed to a corrosive marine environment. In addition, many of the inland bridges are exposed seasonally to road de-icing salts. The results of coating performance evaluation on coastal and inland bridges show that very long lifetimes can be achieved with TSZ duplex coatings. There are examples of 50 year-old bridges with the zinc duplex coatings in good condition. There is no corrosion evident, and the bridges may realize their full design life without maintenance. Even in very corrosive environments, bridges with more than 40 year-old coatings are still in good condition. While the coating evaluation found a few bridges where the coating has failed after only about 20 years, the typical coating failure mechanisms are application errors, low paint film thickness and saponification of the paint.

Key words: Thermal sprayed zinc, duplex coatings, corrosion

INTRODUCTION

Duplex zinc coatings for steel structures consist of a metallic zinc coating, typically hot dip galvanized (HDG) or thermal sprayed zinc (TSZ), painted with a protective organic coating. Zinc coatings applied by hot-dip galvanizing involve the full immersion of the steel piece into a bath of molten zinc, which ensures complete coverage of all surfaces, inside and out.¹ Zinc thermal spray involves projecting drops of liquid zinc onto the surface of the steel using compressed air. With TSZ coatings, there is no size limitation to the part to be coated. TSZ coatings can be applied in the factory, although the technology is fully portable, allowing easy field applications.²

In a comprehensive study it was found that the durability of a duplex coating is longer than the sum of the durability of the individual metallic zinc and paint coatings.³ The reason for the extended life is that the paint top-coat provides extra barrier protection and protects the zinc from initial corrosion. The metallic zinc base layer similarly protects the paint from underfilm corrosion at scratches and holes, which normally occurs for plain painted steel.

The Norwegian Public Roads Administration (NPRA) tested TSZ duplex coatings on a number of coastal steel bridges from 1965, and following the success in these locations, mandated duplex coatings for all coastal steel bridges from 1969 and all inland steel bridges in 1977.⁴ Including the mainland and islands, Norway has over 100,000 km of coastline, so that most of the steel bridges cross rivers or fjords along the sea coast in a corrosive marine environment. The coastline also extends well above the arctic circle so that many bridges are also exposed to road de-icing salts during winter.

The NPRA expects a coating life of 35 years before first maintenance, and then preferably only the paint topcoat shall be renewed. That is, no blast cleaning to base metal, but only power washing of the paint layer. By taking preventative action to repair only the paint, the TSZ base layer will not corrode, and is applied only one time. During the 100 year design lifetime of a bridge, ideally there will be only two maintenance operations after 35 and 70 years where the paint topcoat is renewed.⁵

The International Standards Organization (ISO) has established categories for the classification of corrosive environments.⁶ Atmospheric exposure categories range from C1 – Indoors to C5 - Marine as shown in Table 1. Bridge inspections in Norway showed that very long coating lifetimes can be expected with TSZ duplex coatings in atmospheric exposures even in very corrosive C5 marine environments.

TABLE 1.
Corrosivity category as per ISO9223

Classification	Environment
C1	Indoor
C2	Rural
C3	Urban
C4	Industrial
C5	Marine

A coating performance indicator (CPI)⁷ shows that many bridges may realize their full design life without maintenance. The most important factor in determining coating life is the quality of the coating. Application errors like spitting, pinholes, and low paint film thickness were responsible for the observed coating failures. These errors decrease the protective properties of the paint film and hence, the overall life of the coating.

THERMAL SPRAYED ZINC

Thermal sprayed zinc can be applied by either electric arc spraying or flame spraying.² For each process, the steel surface needs to be prepared for thermal spraying. Grit blasting of the steel surface is required to provide adequate mechanical adhesion of the sprayed zinc coating to the steel.

The flame spray technique uses an acetylene-oxygen flame to melt a zinc wire or powder that is continuously fed into this flame. A stream of gas, generally compressed air, then propels the molten metal droplets in the direction of the steel surface. For the arc spraying technique, two zinc wires are brought

together at an angle between 30 and 60°, and an imposed voltage difference between them creates an electric arc. A gas flow, of either compressed air or a special gas, then atomizes and propels the molten metal droplets toward the steel substrate.

The deposition of semi-solid droplets on a roughened steel surface produces a metallic zinc layer with micro-pores that typically make up 5-7% of the coating volume. The thickness of the thermal spray coating is dependent on the time of spray. For duplex coatings, the metallic zinc base layer is usually 100µm thick. If the thermal sprayed zinc coating will not be painted, the zinc is generally applied to a thickness of at least 200µm. The TSZ coating has a rough surface which is excellent for paint adhesion and characteristics similar to solid metallic zinc, including a Vickers hardness of around 70.⁸

Pure zinc coatings for corrosion protection of steel were first applied by thermal spray over 100 years ago. Now the zinc-15% aluminum alloy coating, developed in the 1970s, is the alloy coating of choice for the most severe environments. A comparison of the melting rates for pure zinc and the zinc-15% aluminum alloy between the flame spray and arc spray techniques also shows an increase in deposition efficiency and coating rate with the arc spray process.⁹

It should be noted that thermal sprayed aluminum (TSA) should not be used as a base layer for paint coatings.⁴ In the presence of chlorides, the aluminum corrosion products convert to hydrochloric acid which quickly consumes the aluminum layer causing rapid coating failure.¹⁰ Exposure tests on scribed panels between painted thermal sprayed pure zinc (100µm thick) and pure aluminum (200µm thick) showed the presence of underfilm corrosion creep after 5 years of marine exposure on the aluminum coatings but not on the zinc coatings. The results of the tests with various paint coating systems are summarized in Table 2. The duplex zinc coatings have excellent performance, while the aluminum based coatings are showing corrosion creep.

TABLE 2.
Corrosion creep from scribe after 5 years marine exposure

Thermal Spray Metal	Paint top coats	Total DFT (um)	Corrosion Creep (mm)
Zinc 1	Epoxy + Polysiloxane	255	0
Zinc 2	Epoxy + Epoxy + Acrylic	300	0
Zinc 3	Epoxy + Epoxy + Polysiloxane	325	0
Aluminum 1	Epoxy + Polysiloxane	360	17
Aluminum 2	Epoxy + Epoxy + Acrylic	435	12
Aluminum 3	Epoxy + Epoxy + Polysiloxane	450	15