

Duplex Zinc Corrosion Protection for Marine Structures

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ABSTRACT

Corrosion of marine infrastructure is relentless. The continual exposure to moisture in the presence of chlorides can rapidly degrade steel structures. The use of paint as a barrier coating for corrosion control requires near constant maintenance. Conversely, a duplex zinc coating, that is, a metallic zinc coating with a paint top-coat, offers both barrier and sacrificial corrosion protection mechanisms, with much longer lifetimes between maintenance compared to paint only coatings. A paint top-coat over a metallic zinc base layer protects the zinc from initial corrosion. The metallic zinc base layer similarly protects the paint from underfilm corrosion at scratches and holes. In this way, duplex zinc coatings provide more than twice the life of the corrosion protection provided by one coating system alone. The synergy between the zinc and the paint coatings provides protection far superior to either system used independently. Duplex zinc coating systems have decades of proven performance protecting marine structures from corrosion.

Key Words: Zinc Coatings, Hot-Dip Galvanizing, Thermal Sprayed Zinc, Duplex Coatings

INTRODUCTION

Metallic zinc coatings have a long history of providing corrosion protection for steel in marine environments, including port facilities, ships, offshore oil platforms and wind energy structures. Metallic zinc coatings provide not only the barrier protection usually associated with paint coatings but also galvanic protection in the event that there is any disruption in the protective coating, such

as mechanical damage, local removal of the coating for maintenance or structural modifications, including the installation of bolt holes and welding. The zinc will corrode preferentially to protect the steel.

Zinc coatings can be applied by hot-dip galvanizing or by thermal spraying. 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 thermal sprayed zinc coatings, there is no size limitation to the part to be coated, and the technology is fully portable, allowing easy field applications.² Thermal sprayed zinc is also classed as a 'cold' technology and will not change the mechanical properties or the geometry of the steel being coated.

Both processes are complementary, with thermal spray usually being specified for structures too large to fit in a galvanizing kettle, or for field applications where the structure remains in place. While the application process is very different, the corrosion protection provided by the metallic zinc coatings is the same.

The lifetime of the zinc coating, applied either by hot-dip galvanizing or zinc thermal spray, can be extended even further in marine or other environments by overcoating it with an engineering paint system. Paint over metallic zinc is called a duplex coating.³ The paint can be a single or multilayer paint system. Duplex or painted metallic zinc coatings provide improved corrosion protection performance.

HOT-DIP GALVANIZING

Hot-dip galvanizing, also known as general galvanizing, produces a zinc coating by completely immersing the steel in a bath of molten zinc.¹ Prior to immersion in the zinc bath, the steel is chemically cleaned to remove all oils, greases, soil, mill scale, and oxides. Surface preparation for galvanizing consists of degreasing, pickling, and fluxing.

After surface preparation, the clean and fluxed steel is galvanized by complete immersion into a bath of molten zinc. While in the galvanizing kettle, the molten zinc metallurgically reacts with the iron in the steel to form a distinct coating structure approximately 100um (4mils) thick, shown in 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 the steel (25Mpa (3,600 psi)) and also 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.

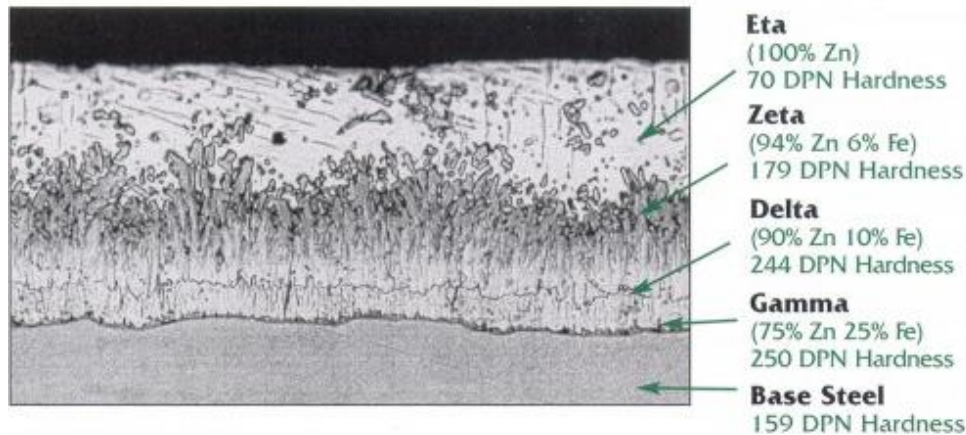


Figure 1. Hot-dip galvanized coating structure (courtesy of www.galvanizeit.org)

Another unique characteristic of the hot-dip galvanized coating is the uniform and complete coverage of all surfaces. 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. Additionally, because hot-dip galvanizing is a total immersion process, all interior surfaces of hollow structures and difficult to access recesses of complex pieces are coated. This complete, uniform coverage of all surfaces ensures that critical points where corrosion commonly starts have the same protection as accessible, flat exterior surfaces. Galvanized steels are easily painted to produce duplex coatings.

ZINC THERMAL SPRAYING

Thermal sprayed zinc can be applied by either flame spraying or electric arc spraying.² For either process, the steel surface needs to be cleaned and prepared to receive the coating. Grit blasting of the steel surface, rather than shot blasting, is preferred to provide adequate mechanical adhesion of the spray coating to the steel.

Flame spraying 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. In arc spraying, two zinc wires are brought together at an angle between 30° and 60°, and an imposed voltage difference between them creates an electric arc which melts the wires. A gas flow, of either compressed air or a special gas, then atomizes and propels the molten metal droplets toward the steel substrate.

Although pure zinc was the first corrosion-resistant thermal spray coating to be applied to steel nearly 100 years ago, a zinc-15% aluminum alloy is now the coating of choice for marine applications.² A comparison of the melting rates for the zinc and zinc-15% aluminum alloy between the flame spray and arc spray techniques shows an increase in deposition efficiency and coating rate with the arc spray process.⁴

The thermal sprayed zinc coating is produced by impacting semi-solid droplets on a roughened steel surface. The coating thickness is dependent on the time of spray and produces a metallic layer with micro-pores as shown in Figure 2. Porosity typically makes up 5-7% of the coating volume, although the properties of the coating resemble that of solid zinc. The rough and porous surface of thermal sprayed zinc provides excellent paint adherence for duplex coatings.

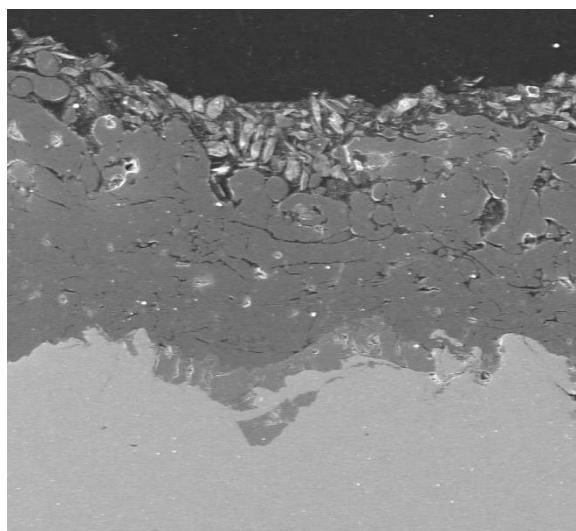


Figure 2. Thermal sprayed zinc coating structure

DUPLEX COATINGS

The service life of galvanized or thermal sprayed zinc coatings can be greatly extended if protected with a paint top-coat. The paint adds an extra layer of barrier protection, but more importantly, the zinc protects the paint from underfilm corrosion.³ The significant extension of the expected life of the combined thermal sprayed zinc-paint duplex coating compared to the sum of the expected lives of the zinc coating or the paint system used by themselves is known as a synergistic effect. The synergy effect is defined by a factor in the equation:

$$\text{Duplex service life} = \text{Synergy Factor} \times (\text{zinc life} + \text{paint life}). \quad (1)$$

For example, with a synergy factor of 1.5, a life to first maintenance of 12 years for the zinc coating, and a paint life to first maintenance of 5 years would give an expected protective coating system life of 25.5 years $[1.5 \times (12+5)]$. Synergy factors vary, depending upon the climate.³ Typical synergy factors found as a result of global corrosion testing are shown in Table 1. It can be seen that synergy factors increase with decreasing corrosivity, from 1.5 – 1.6 for sea water / immersion applications, up to 2.0-2.7 in mild onshore climates.