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100% SOLIDS RIGID POLYURETHANE COATING TECHNOLOGY FOR CORROSION PROTECTION OF STEEL UTILITY POLES

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Abstract: 100% solids, aromatic or aliphatic, rigid polyurethane coating technology has become one of the main technologies that provides long-term corrosion protection of steel utility poles in North America for underground or aboveground applications. This paper outlines the corrosion mechanisms of these applications and highlights the challenges of the use of these coatings on galvanized surfaces of both embedded portions and aboveground portions of today's steel utility poles. The paper reviews the basic chemistries and the development of the 100% solids, aromatic and aliphatic, rigid polyurethane coating technology for the steel utility pole industry as well as how these advanced coatings meet the application challenges in terms of design and fabrication, surface preparation, application, performance and quality inspection. Several new developments are also discussed.

INTRODUCTION

Wooden, concrete, composite, and steel poles are the most common types of utility poles used by today's utility industry for transmission and distribution of power or communication. Over 50% of the utility poles in North America, particularly distribution poles, have traditionally been constructed of wood. It's been that way since the early days of the utility industry, when wood was a cheap and readily available material. In the past 20 years, however, the utility market has made a dynamic and interesting shift to the strength and reliability of steel. There are several reasons for this shift: a) The use of wooden poles contributes to deforestation; b) Wooden poles must be protected with continuous re-treatment over their life span (usually 30 years if properly treated) to avoid deterioration due to insects, microorganisms, wood peckers, and fungi; c) Most wood treatments that are used contain toxins; the commonly-used penta treatment is classified by the EPA as a probable human carcinogen; composite poles such as fiberglass reinforced composite (FRC) poles also bring some health concerns such as possible skin irritation and inhalation of fiberglass dust; d) Steel poles can be fabricated to support larger and heavier loads with longer spans and greater height requirements; e) Steel poles can also be manufactured to a utility's specification and pre-drilled for ease of maintenance or in anticipation of future services; f) Being hollow in structure, steel poles are significantly lighter than wooden poles, composite poles and concrete poles, which saves on transportation costs and helps with installation; neither wood nor concrete really competes with steel over 90 feet in lengths; over 60 feet, they are expensive to transport; g) Steel is more resistant to lightening strikes; h) During replacement, the existing hardware being used with the wooden poles can easily be mounted into steel poles; i) Steel poles provide uniform diameter and strength that prevents any diameter shrinkage and eliminates the need to re-tighten fittings in the future. j) Steel poles are easier to install due to less weight and pre-drilled holes, especially in off road locations and areas with rough terrain; easier installation means less time and thus less installation costs; and finally k) When properly protected, steel poles provide a longer life span (60 to 80 years vs. 30 to 35 with wood).

Steel poles sound like a wonderful advancement for the utility industry except for one thing – "Corrosion". When steel poles are embedded in the ground, soil conditions, both chemical and abrasive tend to eat away at steel if it isn't properly protected. Steel poles are also subject to atmospheric corrosion in today's industrialized environment. In order to protect the steel from corrosion, galvanizing has become very popular with today's steel utility pole manufacturers and users. While various studies and surveys have proven the relatively long-term protection for steel poles by hot dip galvanizing in atmospheric environments, there is still a lack of performance data in the literature documenting the safe usage of embedded galvanized steel utility poles in soils. In general, the same soil conditions which destroy steel rapidly are also destructive to galvanized steel. Therefore, corrosion protection measures for the embedded portions of steel poles are needed in most soils to prolong the service life span of the poles. For the aboveground portion, while galvanizing can provide excellent atmospheric corrosion protection to the steel, the utilities are also increasingly demanding additional color and durability to delay the degradation of galvanizing in aggressive exposure.

Steel poles are also made from weathering steel, which must be protected from corrosion below grade and high strength non-galvanized steel which requires both below ground and above ground protection against corrosion. While the same coatings usually work on all these substrates, the focus in this paper is on galvanized structures.

Over the past 20 years, the North American utility pole industry has shifted to 100% solids, plural component, rigid and structural polyurethane coatings as the main solution to the additional need for corrosion protection for steel poles of all the above types in underground applications. These 100% solids rigid and structural polyurethane coatings have been effective because of their outstanding life expectancy and performance, resistance to aggressively corrosive environments, high abrasion resistance, low temperature curing capability, strong adhesion, high film build, fast application, and compliance with the most rigorous regulations on volatile organic compound (VOC) emissions. More recently a shift to polyurethane has been evident on the aboveground portion of poles as well.

However, successfully applying the 100% solids, plural component, rigid and structural polyurethane coatings over galvanized steel poles has resulted in many challenges to coating manufacturers, steel pole OEM fabricators and coating applicators. Among these challenges are galvanizing layer structures, surface preparation, environmental conditions, coating application, quality inspection, trouble-shooting and repair, long-term performance, and cost.

This paper outlines the corrosion mechanisms of galvanized steel poles in both underground and aboveground applications. It reviews the basic chemistries and the development of the 100% solids, aromatic and aliphatic, rigid and structural polyurethane coating technology for the steel utility pole industry. It highlights the challenges of applying the 100% solids, aromatic or aliphatic, rigid and structural polyurethane coatings technology on galvanized surfaces of both embedded and aboveground portions of today's steel utility poles. Common defects and their causes are discussed. Finally the paper details some new technological developments.

CORROSION MECHANISMS OF GALVANIZED STEEL POLES

Galvanizing forms a metallurgical bond between the zinc and the underlying steel. During galvanizing, the molten zinc reacts with the surface of the steel to form a series of zinc/iron alloy layers, ranging from the pure zinc visible on the surface to a layer adjacent to the steel containing 75% zinc/ 25% iron. It is this layering process that protects the substrate. Figure 1 shows the microstructure of a typical galvanized steel pole.

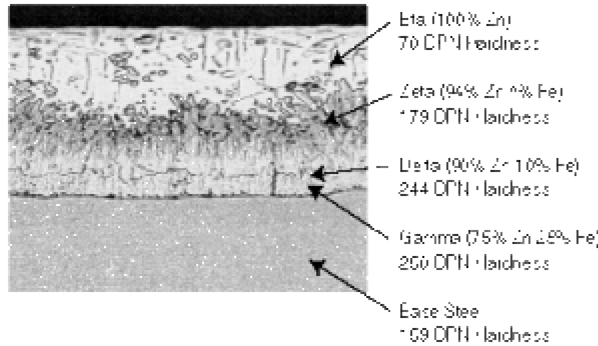

Figure 1. Microstructure of a typical galvanized steel pole

Although the pure zinc layer on the surface of newly hot dipped galvanized steel looks pure and shiny, it begins to oxidize immediately after exposure to air. Over time, this oxidation process transforms pure zinc into zinc oxide. Exposure to moisture leads to the formation of zinc hydroxide, or "white rust". Subsequent chemical reaction of the zinc hydroxide with carbon dioxide in air produces an adherent, relatively insoluble, dense layer of zinc carbonate. The zinc carbonate layer is primarily responsible for the corrosion protection provided by the galvanized coating on steel utility poles in most atmospheric environments.

The corrosion of zinc is influenced by many factors. This means that a generally applicable formula for corrosion rates can not be given. This also means that the surface conditions of galvanized steel poles are also significantly affected by environmental conditions. The atmosphere in cities and industrial areas contains various pollutants. These are able to attack the stable zinc carbonate film, producing more soluble products which can be washed away. In marine environments, the corrosion of zinc is influenced by the salt content of the air. However, marine air contains small quantities of magnesium salts, with good passivating influences. Corrosion is therefore not as great as may be expected. The colour of corrosion products varies according to the environment in which they are formed. Marine environments give somewhat whiter corrosion products compared with rural and urban environments. Corrosion products are usually darkest in urban environments.

White rust formation has been linked to a problem area known as "white storage stain" or "wet storage stain", where surface exposure conditions are not conducive to the formation of the protective zinc carbonate patina. Continuous wet, humid conditions without the benefit of freely circulating air are associated with such problems. It is under the influence of carbon dioxide in the air, zinc ? zinc oxide ? zinc hydroxide is converted to basic zinc carbonates. If air access to the zinc surface is restricted, as in narrow crevices, then the area receives insufficient carbon dioxide to enable the normal layer of carbonates to form. The wet storage stain layer is voluminous and porous, and attached only loosely to the zinc surface. As a result, protection against continued attack does not exist. Corrosion can therefore continue as long as moisture remains on the surfaces. Coating over a galvanized steel pole with such wet storage stains is also often problematic. Wet storage stain is best avoided by preventing newly galvanized surfaces from coming into contact with rain or condensation during transportation. Materials stored outdoors should be stacked, allowing water to run off easily, so that all surfaces are well ventilated.

When a top coating is not applied, corrosion of galvanized steel poles does occur. Soils can contain weathered products, free or bound salts, acids and alkalis, mixtures of organic substances, oxidizing or reducing fungi, micro-organisms, etc. Depending on its structure, soil has different degrees of permeability to air and moisture. Normally, the oxygen content is less than in the air, while the carbon dioxide content is higher. The corrosion conditions in soil are therefore very complicated and variations can be great between different locations, even those in close proximity to each other. Thus the service life of galvanized but uncoated underground structures is difficult to estimate.

<u>100% SOLIDS RIGID POLYURETHANE COATINGS TECHNOLOGY</u>

Over the past 20 years, the North American steel utility pole industry has developed a process called "CorroCote" for coating galvanized steel poles for additional corrosion protection. Like the term of Kleenex for facial tissues, this "CorroCote" process originated from a product based on 100% solids rigid polyurethane coatings technology. The polyurethane coatings technology consists of two components: one isocyanate-rich solution and one polyol-rich solution. This has been defined as an ASTM D16 Type V polyurethane coating. Such a polyurethane coating film is formed when the two components are combined -- a rapid and exothermic chemical polymerization reaction takes place. By definition, the term "100% solids" means the coating system does not use any solvent to dissolve, carry or reduce any of the coating resins. Furthermore, the resins <u>normally still in a liquid state</u> will convert, 100%, to a solid film after application. Figure 2 illustrates the polyurethane coating reaction.

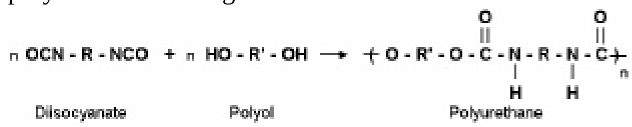

Figure 2. The polyurethane coating reaction

Also described as "structural polyurethane coatings", the 100% solids rigid polyurethane coatings technology used by the North American steel utility pole industry is a special member of the family of the 100% solids polyurethane coatings chemistry. The properties of 100% solids polyurethanes vary from very soft, rubbery elastomers (like running shoe soles) to hard, ceramic-like systems -- a good chemist can formulate 100% solids polyurethanes to do almost anything. The chemical bonds in the rigid polyurethane systems are highly cross-linked to each other to create hard, dense systems that have excellent chemical and moisture resistance (Figure 3). The rigid systems usually have excellent adhesion and are the best choice for the corrosion protection of metals or concrete pipes. On the other hand, the elastomers have a more linear structure with much less cross-linking that allows them to be very stretchy and elastic. These systems normally have great impact strength and flexibility, but relatively poor adhesion and chemical resistance. Elastomers are better suited to protecting substrates that tend to move and flex like concrete tanks or similar structures.

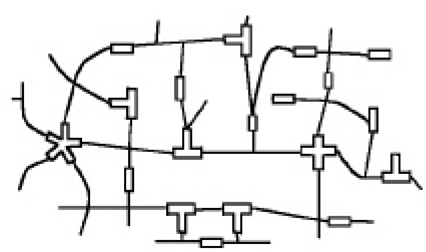

Figure 3. The 100% solids rigid polyurethane structure

The 100% solids rigid polyurethane coatings come with the choice of being aliphatic polyurethanes or aromatic polyurethanes. Aliphatic polyurethanes are polyurethanes based on aliphatic isocyanates (e.g. HDI) and mostly polyester and/or acrylic polyols. Aromatic polyurethanes are polyurethanes based on aromatic isocyanates (e.g. MDI) and mostly polyether polyols. Aliphatic polyurethanes are more expensive, but provide the best UV resistance and color stability among all types of industrial coatings. They are therefore suitable for exterior applications of many kinds, the aboveground portion of steel utility poles provides one example. Aromatic polyurethanes are cheaper and often used for interior lining or underground applications. Depending upon their formulation design, aromatic polyurethanes will exhibit a certain degree of color change ("yellowing") after a few days/months of UV exposure. However, their UV resistance is generally better than that of common epoxies. The aromatic polyurethanes are used for the underground and embedded portion of steel utility poles.

APPLYING 100% SOLIDS RIGID POLYURETHANE COATINGS

Successfully applying the 100% solids, plural component, rigid and structural polyurethane coatings over galvanized steel poles has resulted in many challenges to coating manufacturers, steel pole OEM fabricators, and coating applicators. Among these challenges are galvanizing layer structures, surface preparation, environmental conditions, coating application, quality inspection, repairing and trouble-shooting, long-term performance, and costs. The key to success is a proper understanding of the entire zinc application and aging processes and how these processes affect the coating application and properties. Without that understanding, even the most experienced coating shop can be hit with costly delays and a frustrated shop foreman due to coating delamination, pinholing and other problems. This can actually occur with virtually any brand or generic type of coating.

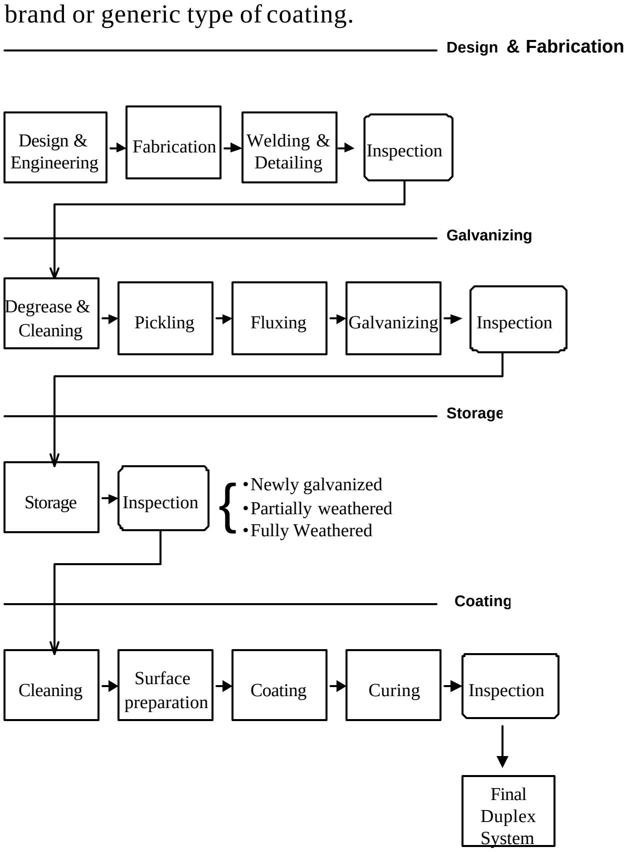

Figure 4. The production of coated steel utility poles

When attempting to achieve the successful application of a 100% solids rigid polyurethane coating over a galvanized steel pole, it is always essential to start with the end in mind. The purpose of coating over galvanized steel poles, also known as a duplex system, is to ensure a longer, more predictable service life. The service life is related to three important variables. The first one is adhesion or, more precisely, the long-term adhesion property of the duplex coating systems within themselves and the substrate. The second one is the thickness of the protective polyurethane coating system and the galvanizing zinc coating. The third is the physical properties of the polyurethane coating. With these ends in mind, we are able to resolve any challenges that one would face in each step of the process during the production of coated steel utility poles as shown in Figure 4.

Design & Fabrication: The structure fabrication should be directed to help obtain a galvanizing zinc coating free of defects and to help control the zinc film thickness. Some welding materials are not compatible with galvanizing or produce different coating thickness. Proper drainage design of the pieces helps the galvanizer to deliver a more consistent product and reduce waste. Proper design and fabrication can also help to avoid design and fabrication defects for the polyurethane coating application such as corners, edges, crevices, etc, which are often the problematic areas due to difficulties with proper surface preparation and coating application.

Galvanizing: The thickness of the zinc coating will depend partly on the dipping time, but mainly on the silicon content of the steel. The “Sandelin” range is the interval of silicon content in steel, which gives a rough zinc layer due to irregular growth of the intermetallic layers. A good design aimed to control the zinc coat thickness will call for steel grade with a silicon concentration of less than 0.03% and phosphate content of less than 0.04%. The galvanizer should be advised of the grade of the steel selected in order to adjust the process and determine the galvanizing technique. Poor galvanizing would also result in high porosity of the zinc coating layer, increasing the chance of pinholing and off-gassing when a polyurethane coating is applied over it.

Storage and zinc weather conditions: Coating over galvanizing can be adversely affected by the fact that zinc oxide and zinc hydroxide are highly reactive and will cause a coating to delaminate. A pure, freshly applied zinc surface is the best surface for coating. If this is not available (i.e., if the galvanized surface is more than one day old), we have found that it takes at least 2 to 3 weeks for the zinc to reach the less-reactive zinc carbonate stage – and even then, chemical changes slowly continue to occur. The galvanized zinc coating can take up to two years to weather completely. During the 2-3 week interval mentioned above, the surface is unstable and poor adhesion will occur unless the oxides and hydroxides are removed by blasting the surface. On older structures, there is an added complication; the surface chemistry is more stable but the risk of dirt and other contaminants is high. To add to the confusion, there may be another contamination source right back at the beginning, namely the galvanizing dip tank itself. Further research in that area is ongoing.

In order to determine the degree of weathering of the galvanized steel surfaces, they are divided into three categories (Table 1):

Table 1. Zinc weathering conditions and resolutions

Zinc conditions	Resolutions
Newly galvanized steel	Zinc oxide and corrosion products formed 24 to 48 hours after galvanizing are powdery and lightly adhere to the surface. Abrasive grit blast is recommended to profile and clean the surface. Solvent cleaning or warm-jet wash might be needed before blasting to remove contamination if any.
Partially weathered galvanized	Zinc oxide and zinc hydroxide must be removed prior to coating. Grit blasting the surface eliminates the corrosion products and produces profiling. Solvent cleaning or warm-jet washing might be needed before blasting to remove any contamination.
Fully weathered galvanized	Solvent cleaning or warm-jet washing is needed to remove zinc oxide and zinc hydroxide from the surface and contamination if any, followed by a sweep grit blast to profile the surface.

Surface preparation: A "commercial blast" using angular abrasives such as steel grit, aluminum oxides grit or silica sand, regardless of the age and condition of the surface is required for long term result. This blasting technique removes contaminants and by-products and provides an anchor pattern in the remaining pure zinc, all without removing a significant amount of the zinc itself. To some extent, alternation blast media such as steel shot are used. Our experience is that these alternative media do not provide an adequate anchor pattern and long term performance including adhesion will be poor. The use of acid etching, commonly used for atmospheric exposure, has shown some promise under laboratory conditions but requires further research and is not currently used for buried or immersion service.

Table 2 compares the performance testing properties between galvanized steel panels coated with a 100% solids rigid polyurethane coating under three different surface preparation methods: grit blasting, shot blasting, and acid etching. It is interesting to note that, while the three different surface preparation methods might produce similar initial adhesion pull-off values, it is long-term performance testing such as cathodic disbondment testing that tells the real long term story. Grit blasting is the benchmark against which the alternatives must be measured.

Table 2 Performance properties of duplex 100% solids polyurethane/galvanized steel systems under different surface preparations.

Systems/testing methods	Performance results
Grit blasted galvanized steel coated with polyurethane	
Adhesion (ASTM D4541)	1900-2000 psi glue failure
Adhesion (ASTM D6677)	Rating 7
Cathodic disbondment (ASTM G95, 28 days)	8.0-11.0 mm disbondment
Shot blasted galvanized steel coated with polyurethane	
Adhesion (ASTM D4541)	500-2800 psi adhesive-glue failure
Adhesion (ASTM D6677)	Rating 6
Cathodic disbondment (ASTM G95, 28 days)	24.9 mm to complete disbondment
Acid etched galvanized steel coated with polyurethane	
Adhesion (ASTM D4541)	1900-2000 psi glue failure
Adhesion (ASTM D6677)	Rating 6
Cathodic disbondment (ASTM G95, 28 days)	17.8-22.0 mm with occasional complete disbondment

The surface preparation procedure for plural component polyurethane is not different from other coatings. However to obtain the extraordinary benefits that this coating can provide in a duplex system, a close compliance with the specification is required. The galvanized surface must be free of protrusions and slag. Oil, grease and corrosion products need to be removed along with dirt and any other contaminants. The galvanized surface needs to be free of residual salts, chromates and any other products produced or introduced during galvanizing. After abrasive grit blasting, the surface angular profile should be close to 2.5 mils with the entire surface abraded to an appearance and feel similar to sand paper.

Polyurethane coating application: The most desirable characteristic of a duplex system is to obtain and maintain good adhesion to the galvanized steel surface during its service life. The 100% solids, plural component, rigid or structural polyurethane coatings have proven excellent performance in duplex systems and have been used on galvanized steel utility poles for more than 20 years with excellent results. Besides the outstanding adhesion, they are resistant to moisture diffusion through the paint film.

100% solids rigid polyurethane systems are applied with a plural component pump and gun. The material is pumped at high pressure and temperature and mixed at the tip of the gun where it is atomized and sprayed. There are several different brands of plural component equipment available, all have the same basic equipment configuration: pump, heater, filters, heated hoses and spray gun. The fast curing feature of this system offers important logistic and operational advantages. The material can usually be dry to handle in 5 to 10 minutes.

Plural component airless spray application is more complex than regular airless application. The coating should be sprayed in one multi-pass coat to a minimum thickness of 16 mils for underground service or 8 to 10 mils for aboveground. To avoid costly overbuild, the sprayer should aim for a film thickness in a range of 16 to 20 mils for underground corrosion protection of the embedded and belowground portion, and 8 to 12 mils for atmospheric protection of the aboveground portion of the steel utility poles.

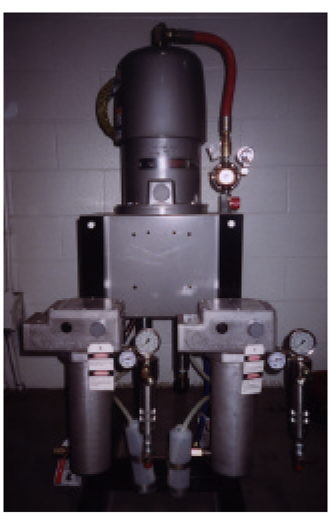

Figure 5. Plural component spray equipment

Quality inspection: Like applying any other coating, quality inspection is very critical to the successful application of 100% solids rigid polyurethane coatings technology. Quality control programs should be adjusted to the particular needs of the process. Table 3 lists some of the tests that are commonly applied.

Table 3 Common quality inspection tests

Fabrication:	**Galvanizing**	**Polyurethane Coating**
• Steel grade and composition • Welding procedures • Mechanical properties • Embrittlement (ASTM A 143)	• Surface condition • Film thickness • Zinc coating Adherence • Zinc weathering • Mechanical Properties	• Contaminants from galvanizing process • Environmental conditions • Surface profile • Film Thickness • Holiday detection • Coating adhesion • Mechanical properties • Appearance

COMMON COATINGS DEFECTS AND CAUSES:

Common application problems and resolutions associated with the application of 100% solids rigid polyurethane coatings on steel utility poles are as follows:

- Uneven coloring and uncured resins. Uneven coloring is mainly due to phase separation and pigment settling when the materials have not been recirculated or agitated before spray. Uncured resin can be the result of unequal metering or incomplete mixing of the ingredients. Root causes include clogged filters, low pressure or unheated or insufficiently heated product.

- Blistering. This is one of the most common failures in the application of 100% solids plural component polyurethanes. The size of the blister usually depends on the degree of adhesion of the coating to the surface and the pressure of the gas or liquid within the blister. The usual causes of blistering are a contaminated substrate surface (e.g., moisture, oil, grease, sweat, dust) or an improper mismetering (off-ratio mixing) of the 2 components. Blistering can also be caused by gun 'spits'. For galvanized steel surfaces, blisters can be formed if reactive zinc oxide or zinc hydroxide has not been removed prior to the application of 100% solids polyurethane as discussed earlier in this paper. The above problems can be avoided by making sure the surface is clean; by only triggering the spray gun off target before applying the coating to the substrate; by keeping the product supply warm; by regularly cleaning filters, mixers, and spray guns to avoid cavitation and off-ratio spray; and by applying the polyurethane to newly fresh or cleaned galvanized steel surfaces.

- Overspray. Overspray is also common with 100% solids polyurethanes. It is caused by improper gun adjustment or configuration, or by coating at too great a distance from the substrate. Failure occurs when pinpoint rusting forms at an oversprayed area. Planning spray patterns along with proper gun control will eliminate this problem. Under normal conditions, the gun should be held perpendicular to the substrate with the tip 18 to 24 in. (0.5 to 0.6 m) away.

- Holidays. Holidays often occur when the applicator has missed coating the surface, or where thin spots exist in difficult-to-coat areas such as outside corners, along welds, around bolts and rivets, or wherever there are angles in the substrate surface. Attention to detail and spraying with a 50 percent overlap will help avoid holidays. Application technique and experience are important in this area.

- Delamination. Delamination occurs when the coating fails to adhere to the surface. A closely related phenomenon is intercoat delamination, the loss of adhesion between coats. It occurs most often where surface preparation is poor, the substrate is contaminated, or repair or maintenance coatings are being applied over existing coatings. Insufficient rinsing after degreasing and phosphating inevitably results in poor paint adhesion. Test the surface for residuals on the zinc surface. If the same type of coating is being applied over a prior coat, the failure is usually caused by missing the recoat window, or by the poor surface condition of the existing coating. (The original coating may be chalky or have embedded dirt.) Delamination may also be caused by an off-ratio spray. Around the off-ratio area, intercoat adhesion will be very poor. Delamination could be due to the poor surface conditions prior to the coating. If the hygroscopic zinc corrosion products are not properly removed, the coating's adhesion will be seriously affected. The inclusion of dross and ashes from the galvanizing process need to be removed prior blasting and coating.

- Fisheyes. Fisheyes or cratering can be an application problem, a material problem, or both. When they are a material problem, fisheyes occur when the material has a very high or very low surface tension. For the most part, however, fisheyes are an application problem caused by contaminants such as dirt or oil on the surface or the wet coating. Regular maintenance of the compressor and the use of airline dryers will ensure clean, dry air when removing dust prior to coating.

- Pinholing. Pinholing occurs more frequently on galvanized metal than on non-galvanized. This occurs for complex reasons beyond the scope of this paper and reported in greater detail elsewhere. The hygroscopic and semi-porous nature of galvanizing surface and its tendency to oxidize rapidly are some of the contributing factors. The recent introduction of a penetrating sealer (see Recent Developments below) solves this problem in almost all cases, regardless of the specific cause.

- Cracking. Cracking could be an issue if aromatic rather than aliphatic polyurethane coatings are used for long term aboveground exposure. In order for cracking to occur, several factors must be occurring at the same time: a) Temperature extremes - temperature variations cycling over a prolonged period (either from cool to very hot or freeze/thaw or both; b) Lack of adhesion -- Adhesion does not change significantly over time and a well-adhered coating is quite resistant to undercutting; c) A stress point – examples include edges, corners and welds which can be doubly vulnerable because of erratic coating thickness in these areas. Where the initial bond is marginal, this can set up horizontal stresses at the interface between the substrate and the coating or it can make the coating vulnerable to perpendicular stresses near the external stress source. The latter is observed as a crack in the coating. There are ancillary factors to be considered as well. For example, darker colors will be affected by temperature extremes to a greater extent than lighter ones.

- Orange peel and superficial defects. Poor mixing, inadequate spray pressure and high humidity will affect the finish of the coating.

NEW DEVELOPMENTS

As the North American and European steel utility pole industry more widely select 100% solids rigid polyurethane coatings as one of their main answers to additional corrosion protection for steel poles, innovations continue to appear, four are worth noting.

The first innovation involves the modification of 100% solids polyurethane coatings by using fine ceramic microspheres. Ceramic modified polyurethanes exhibit double the impact resistance and triple the abrasion resistance in a branch of coatings technology that already leads the industry in this regard. This extra toughness extends the potential design life dramatically.

The second innovation involves the development of edge retention technology for 100% solids rigid polyurethane coatings. This breakthrough results from the joint development between a coating manufacturer with the U.S. Navy for ballast tank application. Since many edges exist in most steel utility poles, edge retentive capability of a coating is desired. Figure 5 illustrates a typical cross-section result of this edge retention coatings technology for a sharp corner.

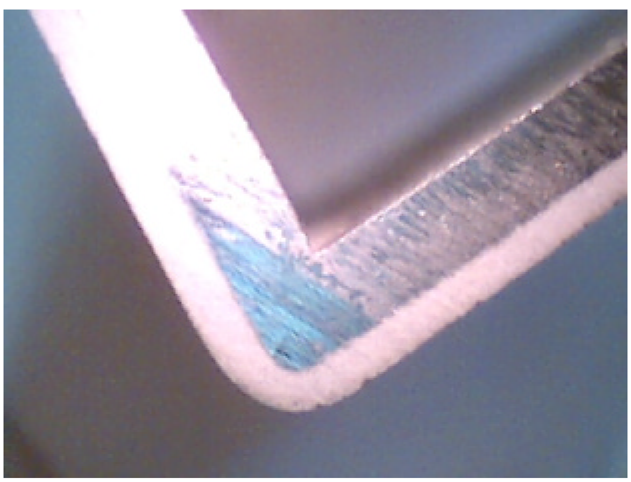

Figure 5 100% solids, edge retentive, rigid polyurethane coatings technology

The third innovation involves the development of a penetrating sealer capable of eliminating pinholing, a common problem on galvanized metal. This solvent-free epoxy/polyurethane hybrid can be applied like a varnish and preserves all the performance advantages discussed earlier. See Table 4.

Table 4. Performance properties of a duplex 100% solids polyurethane/galvanized steel system with a solvent free penetrating sealer.

Systems/testing methods	Performance results
Grit blasted galvanized steel, sealed with the penetrating sealer, and then coated with 100% solids polyurethane	
Adhesion (ASTM D4541)	1900 psi glue failure
Adhesion (ASTM D6677)	Rating 7
Cathodic disbondment (ASTM G95, 28 days)	8.0-11.0 mm disbondment

The fourth development is the commercial acceptance of the 100% solids, rigid, aliphatic polyurethane coating technology. This technology offers the distinct benefits of: UV resistance, high gloss retention, the ability to withstand extreme temperatures, outstanding longevity, and environmental compliance with no VOC's. Based on the use of aromatic polyurethanes for embedded service since the 1980's, the acceptance of aliphatic polyurethane for above ground service promises to dramatically improve the productivity and quality. This tough polyurethane coating is a high-density layer of thermoset plastic that bonds directly onto steel. It's virtually impervious to nature's wrath so it will keep steel utility poles looking great for decades to come. It can be produced in a wide array of colors, so steel poles can blend into any environment. This technology provides excellent adhesion over a non-primed steel or galvanized surface (> 1,500 psi), fast initial film property development, and superior corrosion and chemical resistance. Figure 6 shows the application of the 100% solids rigid aliphatic polyurethane on a galvanized steel communication tower.

Figure 6. A 100% solids, rigid, aliphatic polyurethane coating used for protection of a communication tower.

CLOSING REMARKS

The steel utility pole industry is a good example of how advanced coatings technologies can help to provide add-on corrosion protection and thus change the dynamics of an industry. 100% solids, aromatic or aliphatic, rigid polyurethane coating technology has become one of the main technologies that provides long-term corrosion protection of steel utility poles in North America for belowground or aboveground applications. These advanced coatings have met the application challenges in terms of design and fabrication, surface preparation, application, performance and quality inspection for galvanized steel substrates.

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