BLUNDERING TOWARDS SUCCESS WITH METAL SPRAY

John Michael Brodar, PE, Principal Engineer
Salt River Project
Phoenix, Arizona
Abridged and arranged by Ducare NZ Ltd.

Abstract:
A collection of situations, experiences and case histories discussing failures and successes utilizing thermal metal spray. Materials drawn from over 70 years of metal spray usage at an electric and irrigation class water utility. The focus is on learning from past mistakes and application of basic corrosion control knowledge.

HISTORY
The salt river project has been in existence longer than Arizona has been a state. It was formed in 1903 as the first reclamation project established by the Federal Reclamation Act of 1902. Its purpose was to 'tame the Wild Salt' and provide a reliable source of water for Phoenix and the Valley of the Sun. Reliable water would enable the building of farms and ranches:” the blooming of the desert”.

To provide a reliable source of water it would be necessary to build a storage dam, a diversion dam, a canal system and various laterals and ditches to deliver the water. In order to build the dam it was necessary to build a road through 30 miles of Desert Mountains. All of this would be a mighty and expensive undertaking.

The Salt River Valley Water Users Association was formed by a few hundred residents. Its boundaries were determined and all land within its boundaries pledged as security for construction loans from the Federal Government. In order to help defray the cost of these loans it was decided to spend a little more and install a dynamo at the dam and to sell this new thing: electricity.

The roads were built. The dams were designed and construction begun. The canals were carefully laid out to allow gravity flow. They were excavated using horse and mule and oxen drawn sledges, frequently following the prehistoric canal system left by a largely unknown Indian civilization. Plans were begun for a transmission line to bring the electric power to be generated at Theodore Roosevelt Dam to the shareholders of the Water Users Association.

The planning of the electric transmission line was not to be undertaken lightly. Seventy-six miles of desert and rugged mountains separated the generator from the farmhouses waiting for electric lights. The Apache Trail, that rock and dirt road blasted into the sides of Mountains, was only slightly wider than a single wagon. It had so many twists and turns and sharp bends that transporting 40ft wooden poles would be almost impossible. Moving these poles from the roadway to the mountain crests without machinery would require super human effort. How would the system be maintained? What would happen when fire destroyed the wooden poles? Other means would have to be found.

The Salt River Project was not founded by bankers, industrialists or engineers. It was founded by ranchers and farmers and other men of vision who wanted to improve their lives by direct action. Their solution to the problem of the electric transmission line reflected their occupations. Some unidentified individual knew of a company back east that manufactured galvanised windmill towers. These galvanised steel windmill towers would be the perfect thing. Shipped in boxes small enough to transport, with pieces small enough for a man to carry to a mountaintop. It was known how well galvanised steel lasted & towers built of steel would be immune to brush fires.

The windmill manufacturers back in Kansas or Iowa could not imagine why anyone would want hundreds of windmill towers but no windmills. After confirming the order decided to sell them what they wanted.

The windmill crates arrived and were transported to the site by wagon trains. Then crates were opened and pieces loaded onto horses, mules and burros. For the steepest assents they were loaded onto the backs of men. At the most inaccessible locations even the water, sand and cement for tower foundations were manually carried eighty pounds at a time. When the job was done, all knew that these galvanised towers would stand for a long time impervious to wind rain and fire. The first all galvanised steel transmission line in the world had been installed.

The farmers and sons of farmers managing the day to day operation of the water irrigation business had two real advantages over the Hohokam Indians who had preceded them by 500 years. They had steel and concrete. Of the two, steel was much more significant. Concrete is only an improvement over stone and mud, while steel permitted new possibilities.

The problem with steel and water is rust. Rust could be restrained but not conquered. Red lead paint could be applied to offer some protection. It could be re-applied again and again.
The answer was there but not understood. The galvanised steel roofs of the ranch and farm structures were almost indestructible. The galvanised buckets and horse troughs held the same water they were attempting to control. These mundane objects withstood the waters corrosive attack for years, even decades with no special effort.

The use of galvanised bolts and hardware for water immersion service was attempted. The results were usually dismal failures with a few occasional successes. The use of corrugated galvanised sheet was surprisingly successful except for at drilled holes and cut edges where rusting began and spread like a cancer over the entire surface. It became apparent that galvanised materials could be used successfully in water service, if the entire finished structures were galvanised.

This new knowledge was of limited value. Phoenix is in the middle of a desert, even today the nearest major population center is hundreds of miles away. A major industrial center with galvanising facilities was many more hundreds of miles distant. It was simply too expensive to import iron and steel, field fit and fabricate components only to disassemble them for round trip shipment to a distant galvaniser.

Some time in the mid 1920s an alternative to galvanising was introduced to the workshops of the Salt River Water Users Association. "Thermal metal spray." This process offered an alternate method of depositing zinc metal to a steel substrate without the capital expense of a galvanising line and it was field portable, consequently for over seventy years zinc thermal spray has been used to greater and lesser degrees by various groups and departments. Its use spread from the water distribution and transmission system to the various dams. Its use crossed the internal boundary from water to the electric side of the business. Zinc metallizing has been used to protect 'A' frames and other substation components, transmission and distribution poles and towers. It has been used extensively for hand rails, stairs and ladders. Zinc metal spray is protecting microwave towers on mountaintops and various components hundreds of feet below the surface of lakes. It has been used in numerous applications where the objective was to “do it once, do it right ” and “forget the need for maintenance”.

For atmospheric exposures in rural Arizona zinc metal spray has a useful life estimated in hundreds of years. In water immersion and splash zone service its actual life has varied greatly. In some applications its appearance after 20 years is little different from the day it was installed while at other locations it has failed in less than one year. The following examples and case histories are presented with the hope that others may learn from our past mistakes, successes and novel applications of zinc metal spray.

“Those who ignore history are bound to repeat it.”

WHY ZINC METAL SPRAY?

In many respects zinc metal spray is an ideal shop coating. It offers these advantages over paint type coatings.

- There is no cure time, parts can be handled immediately after coating.
- Materials are of consistent quality and purity. No mixing is required before application.
- Parts are immediately serviceable.
- A single coating method is applicable for immersion, alternating wet and dry, or atmospheric exposure.
- Zinc metal spray is not affected by long term exposure to the intense sunlight, manufactured parts can be stored outdoors for long periods without damage or degradation.
- Zinc metal spray is extremely durable, thus simplifying transportation & erection of the metallized components to the job site. Touch up is almost never needed, usually occurring only when the part is so physically damaged that it requires repairs.
- Adhesion to steelwork is better than most paints. Sprayed zinc or aluminum are often specified as base layers for paint systems for this reason. Experience has shown that properly applied metal coatings are adequate if sealed and that the paint overlay offers no further advantage.
- There are no volatile organic compounds, solvents or hazardous wastes involved with zinc metallizing.

Zinc Metallizing is not the same as Galvanising
Hot Dip galvanising produces a metallurgical reaction called diffusion that produces a coating consisting of a series of zinc iron alloys. At the interface the alloy is mostly iron. Moving outward the zinc content increases and at the surface it is nearly pure zinc. ASTM specifications A 123 and A153 require a minimum thickness of slightly less than 75um for light construction and hardware to slightly less than 100um for the heaviest steel sections. The finish may be very smooth making painting somewhat difficult.

Zinc metal spray does not have a high enough heat input to form a metallurgical bond. Therefore eliminating the risk of thermal metallurgical degradation. The deposited metal is almost pure zinc through out (minor impurities include zinc oxides). Thickness of the applied coating generally varies from 50um to a maximum of 250um. Generally little is gained by increasing the film thickness above this range and adhesion and cohesion problems have been reported when coatings over 250um. Zinc metal spray is 1 to 2% porous, with a textured surface which provides an excellent base for zinc compatible paints. (it does not require degreasing, etch priming or sweep blasting for paint to stick)

The Role of Electrolytes
We are all familiar with the concept of The Fire Triangle. Oxygen, fuel and a heat source are required to produce a fire.

Corrosion has a similar concept The Corrosion Rectangle. For corrosion to take place it is necessary to have an anode, a cathode, an electrolyte and a metallic connection (metallic path). Zinc metal on a steel substrate is the anode, the steel the cathode and the application method is the metallic connection. The electrolyte is the big variable.

When zinc metal spray is used in atmospheric exposure it generally has the corrosion resistance of pure zinc. If the zinc coating is intact there is no strong cathode and corrosion is minimal. Air is not a good electrolyte. Any air gap is enough to prevent a corrosion cell between the zinc metal-sprayed surface and an adjacent surface of bare mild steel. If the surfaces are close enough together that rain water or dew can bridge the gap a different condition exists. The water film forms a very effective electrolyte and consumption of the zinc will proceed.

Water and soil are good electrolytes. Distance is not a factor in the corrosion rectangle. This implies that when you have a good electrolyte the anode and cathode can be far apart and still cause a corrosion problem. This distance can be millimetre's, metres and in extreme cases it can be measured in kilometres.

It is necessary to identify your electrolyte so you can know where to look for possible anodes and cathodes.

Area Ratios

What are area ratios? Why should you care about area ratios?

It is the most common cause of zinc metal spray failure
More applications of zinc metal spray for fresh water immersion or under ground service have failed due to blissful ignorance than any other reason. The neglected topic is the area ratio of anodes to cathodes. For zinc metal applied to mild steel this is the ratio of the area of exposed zinc to exposed mild steel.

By applying metal spray to one half of a plate of any size an area ratio of 1:1 will result. If 3/4 of the surface is covered the ratio increase to 3:1. If only 1/8 of the surface is left bare the ratio becomes 7:1. These area ratios are much too small to insure a long service life in immersion conditions. To achieve a successful long-term fresh water immersion service life the area of the zinc must be five or more orders of magnitude (100,000 times) greater than the total surface area of the bare steel. This is an area ratio of zinc to steel of 100,000:1 or more.

As an example of a suitable area ratio consider that a zinc metal sprayed area measuring 10 square metres with a total surface area of exposed steel of 31 square millimetre's has an area ratio calculated as: 10 sqm / 31 sqmm = 104,000 : 1

The area of the zinc anode is very easy to identify. This is not always true in regard to the cathode. It is very important to realize that the area of the mild steel cathode may be much greater than first believed. The trick is to fall back onto the corrosion rectangle. A metallic connection or metallic path is necessary for corrosion to take place. Follow any and all metallic paths to locate all possible cathodes.

Assume that two identical components have been fabricated of mild steel and completely zinc metal sprayed, Both will be placed in immersion service.

1. One is attached to the sides of a concrete box using galvanised bolts.
2. The other is attached to the sides of a bare steel box using galvanized bolts.

1.
In the concrete box the metallic path ends with the galvanized bolts. The anticipated cathode (bare steel) is very small, where a small amount of galvanizing was damaged when the bolts were tightened. The anticipated service life of this installation will be years or decades. It is a successful application of zinc metal spray for long term corrosion control.

2.
The metallic path for the other component includes the bolts and through the bolts the entire wetted area of the steel box. The anode to cathode ratio [the surface area of the zinc to the surface area of the steel] is small and consumption of the zinc will proceed rapidly. This system will fail rapidly. How long it lasts is a function of the electrolyte, the thickness of the zinc and the extent of the unfavorable area ratios. The significant factor is that this second example will begin to fail the moment it is placed in service.

The single most common cause of **failure of zinc metal-sprayed** components in **fresh water** **immersion or underground service** is lack of understanding of **area ratios.** The ratio of exposed zinc to exposed steel. When this ratio is very high the overall surface has the natural corrosion resistance of zinc, when this ratio is low, much of the zinc surface behaves as a sacrificial anode and has a correspondingly high corrosion rate.

Area Ratio Examples

Demossing Structure

Irrigation water is diverted from the Salt River at the Granite Reef Dam. At this point all river water normally flows into either the Arizona Canal or the South Canal. Each canal is equipped with an automatic demossing structure to collect vegetation and other debris that may have been picked up by the water while flowing in the open river. The demossing structure for the South Canal is approximately 30m wide and consists of two sets of trashracks with automated mechanical cleaning equipment and a set of three radial gates that can serve as a bypass.

The trashracks made up of 3x10mm bars 5m long on 35mm centers. A total of 476 bars are used to make up the four sections. The cleaning mechanisms consist of chain driven scraper bars and conveyors. Metal fingers project from the scraper bars into the space between the trashrack bars. As the chain pulls the scrapper bar upward across the face of the trashrack bars the projecting fingers force any collected debris upwards towards the conveyor, a result even those portions nominally in atmospheric exposure are frequently wetted and as this complex mechanism has a lot of steel in immersion. The sliding contact between the moving parts limits the usefulness of conventional paints. The trashrack bars were left uncoated during original construction. When it became obvious that the bars would require replacement two decisions were made

1. The new bars would be zinc metal sprayed for long service.
2. Due to the short outage schedule, only one section of the trashrack bars would be replaced each year.

The bars were cut to length, welded into subassemblies and zinc metal sprayed in the shop. During the outage the bar assemblies were welded into place. It was a quick and efficient replacement.

The following year the next sections of trashrack bars were prefabricated and ready for assembly when the annual outage occurred. The canal was drained and work started on the second bar replacement program. While inspecting the work completed the previous year, the work crew noted that no zinc metal spray was obvious on the lower half of the bars. The significance of this missing zinc was not recognized. The third sets of replacement bars were prepared and installed the following year before engineering staff investigated the problem.

When the first bar replacement was complete the zinc to steel ratio of the entire structure including the gates and cleaning mechanism was about 1:8 There was little zinc and a lot of steel. The zinc that was in the circuit acted as a cathodic protection anode from the moment that the canal was refilled with water. All of the zinc metal spray applied to the underwater portion of the bars during the first replacement was consumed before the second replacement occurred. this scenario was repeated for two more cycles.

The problem of an adverse anode/cathode area relationship was identified. It was explained by the engineering staff. The cost of zinc metal spraying 3/4 of the trashrack had been wasted. The entire effort to utilize zinc metal spray below the waterline on this job was a complete failure.

Dam Gates

A set of nine 8m x 7m radial gates was scheduled to be repainted. All gates were blasted clean to white metal. Three gates were zinc metal sprayed at 200-250um. Three gates were painted with inorganic zinc. The last three gates were primed with red lead (vinyl) All gates were top coated with UAVEVR3 material (three coat vinyl resin paint) After four or five years service all gates regardless of primer used had the same general appearance. Most of the surface was in excellent condition. Numerous rivet heads showed a rust ring around the rivet. At the waterline where the topcoat had been damaged the steel was pitted.

At another dam in the same river water two 15m x 15m gates were coated with 175-250um of zinc metal spray. When the lake level was lowered enough to inspect portions of the gate that were normally in continuous immersion no rusting or pitting was noted after more than 20 years of service without any maintenance.

The most significant difference between these two sets of dam gates is the zinc to steel area ratio. Top coated zinc is as a sacrificial anode when the topcoat is damaged. On the “zinc metal spray only” gates, the area of exposed zinc is virtually total and no steel is exposed and therefore the zinc does not behave as an anode. The zinc corrosion rate approaches the natural corrosion rate of zinc in fresh water not the accelerated consumption rate of zinc anode.

Radial Canal Gates

Numerous radial gates are utilized through the gravity flow canal system. Gates are used to control the direction of water flow. They are also used to accommodate the occasional rapid change in elevation of the grade. When used in this fashion the downstream water level may be as much as four feet lower than the stream level. The gates are operated remotely by a combination of microwave and landline communications. Raised to increase water flow, increasing the pressure at the base of the gate. The upstream face of the gate sees continuous full immersion. The downstream side may be dry (no flow condition) or in full immersion on the open portion with a splash zone.

There have been several generations of standard radial gate designs for the canal system. For many years the standard was to use galvanized corrugated sheet for the plate with the structural members including the radial arms painted. The next standard was a change to zinc metal spray for all structural members, bolts and cut edges on the galvanised skin plate. In the late 50s or early 60s the utility started its own fiberglass shop where they fabricated large diameter elbows and special transition fittings for the canals and distribution system. Specially fabricated fiberglass skin plates were designed, tested and approved for replacement of the corrugated galvanised skin plate.

The fiberglass skin plates with zinc metal spray on radial arms and other structural shapes remained the standard for the Canal Radial Gates for over 25 years. With retirement of key personnel, aging shop facilities and the increased availability of custom fiberglass work in the Phoenix area it was decided to abandon the “in house” fiberglass construction. At this point the economics of using stainless steel for the skin plates was revisited. Over 25 years many things had changed, the real cost of stainless steel sheet had dropped, the real cost of fiberglass skinplate had increased and material costs were no longer the major cost - labour played a greatly increased factor in evaluating lifetime costs. The decision was made to use 6mm stainless steel plate for the skin on the radial gates.

The actual construction costs were even less than estimated - major savings were achieved from reduced layout due to all welded construction compared to having to drill matched holes for bolted construction. Several of the new gates were installed and all was well.

After several years it was noted that the zinc metal spray was gone and the steel was rusting on the radial arms. This was a problem that had not been experienced in over 25 years. Further inspection revealed that the zinc was only missing on the lowest radial arms and the supporting structural steel below the water line on the downstream side of the gates. Several of these gates had been in service for a considerable period of time, first with fiberglass skin plate and then with no other modification, stainless steel skinplate. It was unclear why these members should suddenly fail.

The recommended engineering fix was to apply zinc metal spray on the down stream side of the stainless steel skin plate. It was a job to explain to the maintenance crew that the corrosion on the zinc metal sprayed radial arms was due to galvanic attack caused by the introduction of a large area of stainless steel (new skinplate) The area of stainless steel on the downstream side of the gate in immersion, was very large compared to the surface area of the zinc. As soon as the zinc was consumed below this water line the galvanic couple accelerated the corrosion on the mild steel.

This story is not does not end at this point. In under 10 years, various people have recommended the elimination of the zinc metal spray on the stainless steel skin plates as a cost cutting measure on at least three separate occasions. These well meaning suggestions were made by people who had no understanding of the significance of the anode to cathode area ratio.

Appearance Tiger Stripes

After a brief period of experimentation and a feasibility study it was decided to develop a standard design for direct embedded steel transmission line poles. A standard design would allow for economy in design and fabrication or purchase. These poles would be set in a hole drilled in the ground and backfilled with a lean concrete. The major cost savings resulted from the elimination of the reinforcing cage set in concrete in the traditional manner.

These poles have an octagon cross-section and are tapered over their length. The standard design is for three different diameter sections. The use of 1,2 or 3 sections for a particular pole is determined by the required height of the cross arms. The finished height can be adjusted downward by simply drilling the hole deeper and embedding more of the base. This arrangement allows for an extremely wide range of finished heights from only three components.

After the concrete for the base is set the next section is simply lifted into position with a crane. The octagon shape allows selection of the pole arm orientation, the tapered male and female connection plus the weight of the section secure the piece in place with no additional labour.

The concept proved to be an immediate success. A specification was prepared to order a number of each of the three sections for warehouse stock. The original specification required that the poles are galvanized or zinc metal sprayed. As can be imagined more of the top sections were used than bottom sections. Bottom sections were used so infrequently that a section might be in warehouse stock for two or more years. The higher usage of the top two sections required replenishments of stock. Since these were now standard components with a list of qualified suppliers it was only a matter of delivery time.

The day came when the only available top section was zinc sprayed, the only available middle section was galvanized and the only available bottom section was zinc metal sprayed. While this visual contrast between metal spray and galvanize was readily apparent it was not the biggest problem. While the zinc metal sprayed bottom section was lying on its side for several years in the outdoor pole yard, unexpected things happened. Phoenix is in the desert and the pole storage yard is in a rural desert environment. The corrosion rate for zinc in Phoenix is less than 0.25um/ year. Zinc metal-

sprayed components had been used in atmospheric exposure for decades with no apparent detrimental effects and no outdoor storage related problems were anticipated.
There is a lot of blown dust in Phoenix and not much rain, apparently not enough to wash off the dust. There was enough dust on the upper surfaces of the horizontal poles to form a more aggressive electrolyte than pure rainwater. The electrolyte ponded on the upper horizontal surface dripped over the edges and left stains in various shades of gray.

When these water stained bottom sections were set in place the formerly vertical stain patterns were now horizontal, they stood out like a sore thumb and gave the poles a distinct Tiger Stripe appearance. It is estimated that this staining would naturally blend out in 25 to 35 years and will have no detrimental effect on service life.

Rust Stains - Switchyard
Engineering staff were called out to inspect a substantial failure at a switchyard. It was reported that the galvanizing on the A frames and other structures was failing and rust was bleeding through the galvanize. This problem seemed serious since the switchyard was still under construction and galvanising failures in such short periods of time were quite unexpected.

A visual inspection at the switchyard quickly revealed the apparent problem. Galvanised structures throughout the facility did in fact appear to be rusting. Inspection under power magnification revealed apparent numerous pinpoint rust patterns.

Walking from structure to structure it became apparent that most of the rusting was occurring from ground level to about 3m high. Galvanised structures from different manufacturers frequently appear different and size of grain may differ as well as spangle or brightness. It was obvious that these components had come from more than one source. Even the few pieces of zinc metal-sprayed steel had the same rust pattern. It is extremely unlikely that the same manufacturing defect would occur at two different galvanizing plants. It is almost impossible to imagine how the same problem would also occur while zinc metallizing.

A typical area was again examined under magnification. Using the most versatile inspection tool, the pocketknife, a pin point rust spot was examined under magnification. The rust disappeared. Another was selected and probed with the knife and it too disappeared. Some 400-grit sandpaper was used to clean a small area. The rust was readily removed and there was no evidence of a surface defect.

After talking with the construction personnel it was confirmed that there was several suppliers involved and that deliveries from these suppliers were direct to the staging area of the switchyard. This eliminated the probability of a surface contaminant during transportation. Looking at the erected structures more closely it was noted that those nearest the various roadways showed more rust than those located away from the roads.

Engineering staff were thoroughly perplexed, then a dust suppression water truck came by. It was noted that the height of the water spray closely matched the visible rust patterns. Internal examination of the truck water tank revealed that it was heavily rusted. Rust particles were being dispersed with the dust suppression water drying on the zinc coated surfaces and becoming visible.

Rust Stains Mountain Top Microwave Relay Tower
Unknown to many of the people living in Arizona there are mountains rising from the desert floor that are tall enough to go through several ecological zones. As you work your way to the top you go from

low desert to mid and high desert. On the taller mountains snow routinely falls during winters, deer abound and tall pine trees grow. It is very similar to the Flagstaff area.

The microwave relay tower on one mountaintop was reported to be rusting. This structure was over 20 years old and had required no maintenance.
The lush vegetation at the site made it very clear that the area received much more precipitation than the Phoenix area. A visual inspection of the tower from the ground revealed the zinc metal spray to be in good condition, and typically 100-180um thick. It became apparent that the rusting problem was only noticeable on the upper 1/3 of the tower. When general corrosion occurs in atmospheric exposure, failures are not typically limited to arbitrary portions of the structure such as the upper 1/3!

The rust pattern made it clear that it would be necessary to climb the tower for a closer inspection. Film thickness was tested during the assent it was also noted that the galvanised bolts for the tower structure were in excellent condition with no traces of rust.

As unlikely as it sounded it was beginning to look as though proximity to the microwave equipment was resulting in accelerated corrosion of the zinc. Finally the true situation resolved itself. The four bolts securing the micro wave dish to the four tower legs were not galvanised and never had been, the rust was simply a stain that originated at the bolts. The zinc immediately above the bolts was in excellent condition. The entire repair and only maintenance for this zinc metal spayed tower in over 20 years consisted of replacing four bolts with similarly sized galvanised bolts. Estimated service life for the tower with no additional maintenance exceeds 100 years.

<u>Other Problems</u>

Zinc Steel Potential Reversal

During the 1960s the residential hot water tank industry was severely impacted by changing life styles and an unexpected phenomenon. For several decades galvanised water tanks provided economical long-term service. The large zinc to steel surface area ratio insured cathodic protection to any exposed steel. The life style change involved the increasing popularity of automatic dishwashers.

The dishwasher manufacturers recommended water temperatures typically in the range of

65 degC to 80 degC Without an automatic dishwasher most home owners maintained their hot water temperatures at only 46 degC to 52 degC. Hot enough to be useful but not so hot as to be wasteful. The galvanized water tanks equipped with either natural gas or electric heaters could easily reach these higher temperatures but there had been no prior need for such hot water.

The unexpected phenomenon is the potential reversal of zinc and steel that occurs when water temperature is increased some where above 57 degC. Zinc is anodic to steel in fresh water immersion. It will protect steel from corrosion in water immersion, at normal atmospheric temperatures. When water temperatures increase the potential difference between zinc and steel decreases until at some point the potential of the zinc is the same as the steel. Any further change in the potential difference now makes the steel the anode and the zinc the cathode. The large surface area of the zinc promotes the very rapid pitting of the small area of exposed steel. The hot water tank is soon perforated.

It is suspected that 19th century galvanisers observed this phenomenon as antique galvanised buckets and cold process kitchen implements abound but there seems to be a conspicuous absence of galvanized pots and pans. Pots or pans would be subject to boiling water therefore zinc potential reversal and accelerated corrosion.

This is another example of knowledge lost in history.

A review of this phenomenon in readily available. Literature implies that the temperature at which this potential reversal occurs is somewhat dependent upon the composition of the water. This same potential reversal will occur with zinc metal spray and steel. It is recommended that a corrosion study or coupon test be performed whenever zinc metal spray is to be used in fresh water immersion or underground service if the temperature will exceed 51 degC.

It is desirable to perform a screening test at the operating temperature in the process water unitizing the anode/cathode area ratio to advantage for quick results. Using any convenient size zinc metal-sprayed coupon, machine an X into the base metal. Machining is necessary to ensure that all zinc is removed from the surface. Either prepare multiple coupons or first expose the coupon in room temperature water. No corrosion should occur at the machined cut. This test will confirm that zinc provides cathodic protection to the steel in the process water. Next expose the coupon to the process water at the anticipated operating temperature. If rusting occurs at this stage the zinc potential reversal has occurred and zinc metal spray is not suitable for this particular application. Since the zinc steel ratio is high and this test to determines if the zinc is the cathode in this particular electrolyte at this particular temperature, rapid rusting of the steel is expected to occur. The screening test ends with the first indication of active rusting of the steel which may be readily apparent in as little as an hour.

Plasma Arc vs Zinc Metal Spray

For more than 40 years adhesion of the zinc metal spray to a steel substrate simply had not been a problem at the Salt River Project. The management and crews of the mechanical construction and maintenance department were familiar with the requirements and had the tools to perform the work.
1. Since the 1960s a centrifugal blast facility has been available supplemented in turn by an open air sandblast facility,
2. A change in abrasives to copper slag,
3. Enclosed steel grit manual blast facility with automatic reclaiming.
These blast cleaning facilities enabled the crews to obtain a white metal blast with 75-125um surface profile.

A failure was noted on a series of transmission poles that had been recently fabricated. The zinc metal spray was reported to be coming off in sheets. When inspected it was apparent that the problem was limited to the base of the poles. All edges of the bases recently fabricated showed adhesion problems. A destructive test with a pocketknife revealed that it was possible to remove the zinc from these edges.. While the base metal under the removed zinc was white metal*, the surface appeared smooth to touch*. With only a casual visual inspection the surface looked as though it had profile but under a five power glass with a surface profile comparator it was obvious that any profile was less than 25 um.

These bases were heavy steel plate, 38 to 50mm thick. It was obvious that the plate used for the base was different than the plate used for the remainder of the pole. The plate material was checked and found to conform to specification. The same material had been used for years with no previous problem. When tested with a pocketknife adhesion was excellent on the base at all locations except the cut edge.

Further conversations with the machine shop personnel revealed a fabrication change. These were the poles fabricated with bases cut on the new Plasma automatic cutting machine. An invitation to look at the new piece of equipment was offered, along with an explanation of the process. One of the major advantages while cutting the bases with the plasma arc was that the edge needed no additional machining steps. During the demonstration it was observed that a discoloration appeared away from the cut edge. This discoloration approximately matched the pattern of poor adhesion on the base plate.

Many structural steel grades are classified as non-heat treatable, because their acceptable composition while remaining within specification, varies so greatly that the effects of heat treatment are not predictable. This does not mean that the mechanical properties are unaffected by heat treatment temperatures, only that the results may not be predictably repeatable for different mill runs.

This particular batch of heavy plates was hardened by the heat treatment caused by the intense heat of the plasma arc-cutting machine. The components were sent to the manual steel grit blast facility where the edges were blasted, no apparent improvement was noted. Attempts to manually reblast these cut edges with much harder copper slag offered only marginal improvement, in the blast profile. When viewed with the comparator the profile was estimated to be between 12 to 25um. It was decided to apply some zinc metal spray to a test area with the slightly improved blast profile. Attempts to remove the zinc with a pocketknife and by beating on it with a hammer indicated that adhesion had been improved. The remaining components were similarly treated and the job completed. Other possible treatments include detempering using conventional gas welding equipment or grinding to scarify the area to provide an anchor pattern or to remove the heat effected metal.

Sulfuric Acid - Irrigation Structures

All water transmission and distribution within the Salt River Project Irrigation District is by gravity flow. Large open canals are used to transport the water and distribution is through open laterals and ditches. A diversion box is a typical lateral structure. This rectangular concrete structure will typically have water flowing in on one side from the canal, the other three sides are used to direct the outflow in any of three directions. A slide gate is used to control inflow and outflow. The gates are manually operated. The gates typically 6mm steel plate that has been zinc sprayed for corrosion protection.

Many of these gates have been in service for one or more decades with no maintenance. However gates at several locations were being replaced on an annual basis. The really strange thing was that not all gates at a particular location were being attacked. Engineering was requested to investigate to determine why some of these gates were failing so rapidly.

Many soils in Arizona are highly alkaline. One of the by-products of the copper mines and refining operations is the production of sulfuric acid. Farmers utilize this relatively inexpensive source of sulfuric acid to improve the PH of their soils. Flood irrigation is used almost exclusively in the Phoenix area and farmers are dispersing the sulfuric acid by adding it to the irrigation water.

The problem of the failing zinc was solved when it was observed that the farmer at one location was utilizing the diversion box as a mixing chamber for his sulfuric acid. Depending upon where the farmer actually located the sulfuric acid drip hose within the rectangular concrete structure, the zinc on one, two or three gates would be rapidly consumed. The inlet gate was seldom attacked because the water current kept the acid from contacting that gate.

Sulfuric Acid - Cooling Water

Power plants located in the desert use cooling towers to provide a source of cooling water. When the water is passed over the cooling tower some of it evaporates. This evaporation process cools the remaining water. This water is then pumped through circulating water lines to the condenser and other heat exchanges.

When this water evaporates it leaves any dissolved salts behind which increases the level of salt concentration, the PH tends to rise and the corrosive nature of the water increases due to increased conductivity, and as the water falls through the cooling tower fill it picks up oxygen. The change in conductivity and increased oxygenation results in very aggressive water. When looking at a water analysis it would seem that zinc metal spray would be an ideal coating for mild steel exposed to this water. The pH is typically in the 7.5 to 8.5 range. The PH adjustments are made with acid additions.

At one site a new steel bulkhead was fabricated and zinc metal sprayed. This particular site has the option of using cooling towers or canal water in a “once through mode”. The new bulkhead is used to close off the canal water. Shortly after it was installed for the first time the sulfuric acid addition valve was left open. The steam generating unit had been shut down and there was no circulating water flow. The PH in the circulating water system dropped to less than 1 and the zinc metal spray was completely stripped before the error was detected.

In an effort to develop a standard repair procedure for circulating water line coatings metal spray was considered. The problems of PH excursions were explained and plant personnel indicated that with proper operating procedures it would not be a problem. It was suggested that aluminium metal spray might be more resistant to sulfuric acid than zinc. Several zinc and aluminium coupons were prepared and placed in the circulating water pump pit for exposure and future evaluation.

Three months later the coupons were extracted for evaluation. The aluminium looked OK but the zinc was gone and the coupons severely corroded. The coupons had been placed three feet downstream from the sulfuric acid addition point. It was decided that it would be okay to use zinc metal spray since all repair work was down stream of the circulating water pumps and that the up stream sulfuric acid additions would be thoroughly mixed prior to contacting the zinc.

Upon inspecting the repairs two years later it was reported that all zinc near the circulating water pumps had been consumed. As zinc repairs nearer the unit were inspected more and more zinc was found to be remaining. The zinc metal spray in the return line appeared in excellent condition.

With hindsight it is apparent that the sulfuric acid may well be thoroughly mixed during its progress through the circulating water pumps but the acid is not fully reacted with the alkaline constituents of the water at that point. It is assumed that free sulfuric acid remains for a considerable period of time and distance in the circulating water lines after passing through the pumps. This dwell time may exceed several minutes, during which time the acid will react preferentially with the zinc metal spray.

Sulfuric Acid - Copper Mines
When most people see copper mine tailings for the first time they find it hard to believe that this mountain is "man made". These tailing piles are the waste product of over 100 years of copper mining and refining. One of the quirks of this industry in Arizona is that the waste product from the earlier times has a higher copper content than most ore that is processed today.

No one wanted to haul these tailings for a second time if another method could be developed to extract the copper "in-situ". Leach mining was developed to accomplish this task. Sulfuric acid is high pressure sprayed over the surface of the tailing pile and allowed to percolate through the mound. During the acids descent it dissolves copper and carries it in solution. This copper rich solution is collected and processed to recover the copper and recycle the sulfuric acid.

Fog in the desert is not a normal condition though it does happen under the right conditions several times a year. The sulfuric acid spray process is a 24 hour 365 day process and when there is a fog the acid quickly becomes dissolved in it. This acid fog can travel significant distances and is responsible for the acid attack of the galvanised or zinc metal-sprayed towers and the aluminium conductor on nearby high voltage transmission lines. It is known to have caused power outages.

OTHER SUCCESSES

Field Metal Spray At the Dams

- While performing a safety of dam inspection in the late 1970s it was noted that when steel was blast cleaned and zinc metal sprayed in the field a significant amount of overspray stuck on adjacent concrete. Further more this inadvertent metal spray had remained in place even though water releases had occurred. Fast moving water is a very powerful force. This implied that it was possible to apply zinc metal spray to concrete.

From unrelated cathodic protection work it was known that most concrete had an electrical resistively very similar to soil typically in the 6,000 to 10,000 ohm cm range. Subsequent tests confirmed that zinc metal spray on concrete provided a low resistance contact to the concrete.

One of the very hot corrosion topics of the day was how to economically apply cathodic protection to bridge decks to prevent corrosion of the rebar and subsequent spalling of the concrete . With all of the concrete dams and other water structures at the Salt River Project an economical fix for this chloride ion induced problem was of interest.

The zinc metal spray on the concrete the corroding reinforcing bar problem and prior cathodic protection experience all came together in one solution. It would be possible to apply zinc metal spray to concrete dams or bridges to form a huge distributed anode that could be very easily and economically applied. By providing the bulk of the protective current with a rectifier the actual consumption of the zinc would be greatly reduced and a long service would be possible. It would be possible to apply the zinc metal spray to the underside of bridges and the expense of roadway replacement could be avoided.

- At other locations it was noted that zinc metal spray also had been inadvertently applied on top of coal tar epoxy The concept of using zinc metal spray as a instant repair for paint films was developed. By applying a light first coat it is possible to apply zinc metal spray on almost any coating or surface The key is to keep the heat input low to avoid burning or igniting the surface during the initial application.

After the initial layer of zinc is applied, it acts as a heat sink for subsequent layers. When used as a "instant cure coating" for repairs it is recommended to extend the zinc on to sound coating for a considerable distance. This extra zinc will help improve the zinc to steel area ratio and extend the life of the repair. The extra zinc is in metallic contact with the underlying steel at the repair site and will continue to provide it with cathodic protection if the zinc at the repair becomes consumed.

- At a recent dam repair site several huge 15m x 15m vertical gates were scheduled to be zinc metal sprayed. In the past these gates had been scaffold for coating work. With improved weather prediction and space imaging it was possible to know that no major inflows would occur unexpectedly. This time all work blast cleaning and zinc metal spray was done at the top of the dam. The gate was incrementally raised to the existing platform. This method provided one dimensional automation to the metal spray effort and greatly reduced costs.

This concept can be extended to other work. Can the work be mounted in a lathe or other moving equipment? Does the part move in its normal operation? look for any possible advantage to reduce scaffolding and the need to repeatedly move equipment.

Improved Grounding - Rock and Concrete

Zinc metal spray has been used to reduce step/touch potential on rock and concrete. By applying zinc metal spray to the rock or concrete surface and bonding this coating to a good ground (electrical earth). The step/touch potential was eliminated by having the effective step potential of a metal surface. The bond was achieved by bolting a steel plate to the rock or concrete. Zinc metal spray had been applied to the rock/concrete surface under the bond and to the underside of the steel plate. After being bolted in place the plate was further secured by building up the metal spray at the edges until all gaps had been filled.

Improved Grounding - Wood

A series of wooden transmission poles were to be installed near a radio tower. It was known that if a continuous overhead ground wire was used near this radio tower that much of the radiated power would be diverted to ground. An isolated overhead ground wire (for lightning protection) was installed on several poles near the radio tower. This ground would have low impedance to earth for a lightening strike but high impedance for the radio frequency.

After several years of operation it was noted that where the ground wire mounting hardware was attached to the pole that the wood was charred. One bolt was even smoking when inspected. The resistance to earth through the wood pole was low enough that there was some leakage current. The limited contact area from the bolts caused a sufficiently high current density that the wood was getting hot enough to char.

The solution was to increase the contact area of the metal hardware to the wood pole. This was accomplished by applying zinc metal spray to the wooden pole in a band about two feet wide all around the pole. This zinc metal spray had almost no effect on the impedance to earth, because there was still over 12m of bare wood between the zinc band and ground. The repair included drilling new boltholes and remounting the hardware. Service life is now over 15 years.

Staging Area

One of the most persistent problems with performing maintenance coating work for immersion service is the limited access. Manholes, ladders, and the floor space immediately surrounding them are needed for access during the majority of the coating work. With all the foot and tool traffic these areas are sure to be damaged. All too often these areas are left uncoated until the last moment. Frequently they are not fully cured when the equipment must be returned to service.

Blast cleaning these areas and applying a zinc metal spray coating at the start of the job provides an almost indestructible staging area. If the zinc is fully resistant to the water and acid additions are not a problem, this staging area can be left bare. With a properly maintained barrier coating on the rest of the surface the zinc to steel area ratio will still be very high.

When using zinc metal spray in a confined area care must be taken to confirm that there are no explosive vapors. and the ventilation is adequate to keep zinc fume concentrations low. If flame spray is used there is also the problem of carbon monoxide and depleted oxygen levels.

<u>Painting Over Zinc Metal Spray</u>

Any paint suitable to go over galvanise or inorganic zinc rich paint can be used on zinc metal spray. Many epoxies can be used to topcoat zinc metal spray. Zinc metal spray is 1- 2 % porous, so a light mist coat technique may be necessary.

<u>Zinc Metal Spray as a repair for galvanize</u>

Zinc metal spray is an excellent repair for galvanized steel. For best results the repair area should be blast cleaned to white metal with a suitable profile. Power grinding or sanding with coarse grit may be adequate for small areas. Equipment that will produce an SSPC SP11, power tool cleaning to bare metal might be considered for repair work.

The porous and rough texture of zinc metal spray can be reduced by direct application of heat with an oxy-acetylene torch if using flame spray. With skill this procedure can minimise the appearance different between the repair and the galvanize.

Very dilute hydrochloric acid can sometimes be used to blend in colour differences due to age or repair.

<u>Blind Side Coating for Weld Repairs and New Construction</u>

Zinc metal spray applied to the blind side of a lap welded joint can produce a coating that will not be damaged by subsequent welding. A weld such as this is not contaminated by the zinc and loses no strength. (see liquid metal embrittlement caution). A set of 100mm plates were lap welded (6mm fillet) with a single pass using a MIG welder with no effect on the zinc. When a 5mm stick electrode was used the zinc was clearly melted and discolored. No effort was made to repeat the test at lower welding currents but it was apparent that a reduced current would minimize damage done to the zinc.

A practical application of this technique is to apply zinc metal spray to one side (earth side) of tank bottom plates. After laying out the plates, welding proceeds normally. This zinc metal spray will serve as both a protective coating and as a source of cathodic protection for tank bottoms, even with secondary containment. Care must be used in regard to the anode, cathode area ratio.

Another possible use is as a repair patch to the side of a coated tank or pipe line that is inaccessible from the inside. The hole must be enlarged and made to be oval or rectangular in shape such that the scab plate can be inserted through the hole. With the zinc metal-sprayed side towards the water the repair can be fillet welded into place. Damage to the existing coating will be limited to the crevice area created by the overlap of the scab plate. The actual weld can be protected by using stainless steel welded metal. Exposure to the water at the heat damaged coating can be minimized by applying a caulk to the tank/scab plate interface outside of the heat effected zone.

Steel Construction Slip Critical Joints

The Ninth Edition of the manual of steel construction allowable stress design includes in appendix A Testing Method to Determine the Slip coefficient for Coatings Used in Bolted Joints. The roughness of zinc metal spray and its instant serviceability make this an ideal application. There can be significant economic impact as improved friction coefficients allow smaller bolts or reduced numbers of bolts to be used on properly designed joints.

The advantage of zinc metal spray over paint type coatings is especially significant for this type of work. Metal spray can be utilized as a shop primer for field repair or as a field applied coating to last minute modifications.

Independent steel company report dated November 1968

Bare mill scale	*.27*
Hot Dip Galvanising	*.16*
Zinc, metallized	*.64*
Steel sand blasted	*.47*
Steel rusted and wire brushed	*.51*
Steel aluminum painted	*.17*
Steel red lead primed	*.07*

Other Metals For Specialized Applications

- When evaluating a new condensate storage tank (distilled water) aluminium was considered. An aluminium tank would not require any coating or other maintenance. The evaluated cost was too great and the aluminium alternative was dropped. As an alternate aluminium metal spray for the tank internal surfaces was recommended. The evaluated cost for ten years was less than for a mild steel tank with a conventional coating. The option was later dropped because there was no available case history.

- Copper has been applied to steel and concrete to prevent marine growth for many years. In the past this has typically been copper pigmented paint. Copper metal spray can provide this same function. Care must be utilized to keep the anode/cathode area relationship in mind. Suggested application would be to lightly splatter the copper on top of a non-conductive barrier type paint. Copper should be applied lightly enough to prevent metallic contact between copper deposits but heavy enough to prevent marine growth*. Remembering that steel is an anode to copper and if the outer coating was damaged back to bare steel then area ratios would come into play.*

- Stainless steel has been suggested over mild steel in immersion service. While it is possible to apply stainless steel metal spray to the mild steel it is not recommended for immersion service without extensive testing. All metal spray applications are porous and stainless steel is cathode to mild steel. In service the mild steel may corrode underneath the stainless steel coating. Failure may be either penetration or disbandment of the stainless steel.

- Lead metal spray was considered for use in high acid areas in pollution removal equipment. Lead has excellent resistance to sulfuric acid. Lead metal spray was considered as an alternate to terne plate or lead lining

  For this corrosion resistance usage the lead should be heat fused to eliminate porosity after application. The recent regulations regarding lead in the work place will probably prevent this method from being used.

- Extreme caution should be used when zinc metal spray is being considered near high nickel or chromium alloys. Liquid metal embrittlement is known to occur due to surface contamination of these types of alloys in high heat environments. The minimum temperature for this phenomenon to occur does not appear to be well documented.

Conclusion

Zinc metal spray as well as metal spray with other materials is a proven technology with substantial advantages over paint type coatings. When used in atmospheric service it is similar to hot dip galvanise in performance. When used in water immersion or underground the entire application must be reviewed by a knowledgeable individual to confirm that the zinc to steel the anode to cathode area ratio is proper.

There are many novel uses for zinc metal spray remaining to be found. With the application of existing knowledge many future problems can be avoided.