# Comparison On the Study of Coating Effectiveness and Sacrificial Anode in A Corrosion Control in A Mild Steel; Pipe Borne Water

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**Abstract**

Corrosion, as an electrochemical reaction, results in the transfer of electrons between different chemical species. Most metals are susceptible to corrosion from water and the atmosphere. The impact of atmospheric gases on metal surfaces can be inconsistent, leading to roughness on the metal's surface, which in turn creates cavities and holes that deepen over time. (McGraw. Hull 2002) Significant losses due to corrosion are experienced globally. Furthermore, numerous failures of metal structures have been documented as a consequence of corrosion effects (corrosion podia). Therefore measures are taken to prevent and control corrosion. The use of coating and sacrificial anode are typical examples of such measures to protect/prevent the components (materials) from effect of corrosion. This paper research will provide a unique combination in the light of protection offered by the use of coating using paint and sacrificial anode using zinc on structural members' mild steel.

**Keywords:** *corrosion, electrochemical, zinc, anode, steel.*

**Introduction**

Hot dipping refers to a procedure where a metal substrate is immersed in a molten bath of a different metal. After the immersion, the second metal is deposited onto the first. It is crucial that the melting temperature of the first metal exceeds that of the second. Common substrate metals include steel and iron, while typical coating materials consist of zinc, aluminum, tin, and lead. **. (CellStar 2007)**

Preceding to coating, spring-cleaning of rust, scale, oil, paint and other surface contaminants is essential.

For coating process, immersion in the molten metal is done for phases ranging from a fraction of a minute for lesser objects like fasteners to some minutes for large scale structures. A temperature of approximately 450°C and 700°C must be maintained (bath temperature) for galvanizing (zinc coating) and aluminum coating respectively. A post coating treatment should follow depending on the requirement of the coated component. For example, slow cooling, quenching, conversion coating and painting (preceded by pre-painting treatments) might be done. (Granger and Blunt, 2002).

The aim of this paper is to present a comparative study between effectiveness of coating and sacrificial anode in corrosion control and prevention of mild steel pipe in tap water; the specific objectives include:

- To prepare various corrosion samples for tests.
- Prepare tap water as corrosion medium.
- Use weight loss method to determine corrosion rate.
- Compare the level of protection offered by various protection measure employed.

The present paper covers an investigation on the use of coating and sacrificial anode for corrosion prevention and control; however the research was limited to:

- The use of paint as a coating material.
- The use of zinc, aluminum and Magnesium, as sacrificial anode.
- The use of weight loss method for corrosion determination.
- The use of water as a corrosion medium at room temperature.

The present work was carried out through the following steps

1. Materials and equipment used during experiment will be sourced
2. Sample preparation
3. Selection of materials as sacrificial anode and type of coating
4. Making the corrosion cell to conduct the experiment

## LITERATURE REVIEW

### Metal Spraying Coating

Also referred to as spray metallizing, this process entails the impregnation of a base material with a metal or metal compound by applying the coating metal or compound onto the surface of the base metal through spraying. The metal utilized for deposition can be in the form of either wire or powder. Before the coating process, the surface of the substrate metal is meticulously cleaned to ensure proper adhesion of the sprayed metal and the formation of a uniform layer. The coating material in powder form is termed power metallizing, while the process is designated as wire metallizing when the coating is in wire form. In both scenarios, the coating metal is atomized prior to being sprayed under pressure onto the metal substrate (Mc Crown Hull, 2010).

Thermal spray processes are now widely used to spray coatings against, wear and corrosion but also against heat (thermal barrier coating) and for functional purposes. The choice of the deposition process depends strongly on the expected coating properties for the application and coating deposition cost. Coating properties are determined by the coating material, the form in which it is provided, and by the set of parameters used to operate the deposition process. Thermal spray coatings are generally characterized by a lamellar structure and the real contact between the splats and the substrate or the previously deposited layers determine to a large extent the coating properties, such as thermal conductivity, Young's modulus, etc. The real contact area ranges generally between 20 to 60 % of the coating surface parallel to the substrate. It increases with impact velocities of particles provided that the latter are not either too much superheated or below their melting temperature. That is why roughly the density of coatings increases from flame, wire arc, plasma, HVOF or HVAF and finally D-gun spraying and self-fluxing alloys flame sprayed and then re-fused. (Connolly and Hill, 2010)

Also thermal spray coatings contain some defects as pores, often globular, formed during their generation, un-molten or partially melted particles that create the worst defects, exploded particles, and cracks formed during residual stress relaxation. The cracks appear as micro-cracks within splats and macro-cracks running through layered splats especially at their interfaces and tending to initiate inter-connected porosities. Moreover, when the spraying process is operated in air, oxidation of hot or fully melted particles can occur in flight as well as that of splats and successive passes during coating formation. Thus, depending on the spray conditions and materials sprayed, the coatings are more or less porous and for certain applications must be sealed by appropriate means. (Maruyama*et al.*, 1967 and Paul, 2011, Sun*et al.*, 2006)

**Types of Metallic Spray**

**Wire Spraying** With this process, a specially designed gun is used, having a nozzle (similar to a welder's heating torch) which burns Oxygen and Acetylene achieving temperatures up to 5500°F. A wire is fed through the center of the nozzle into the flame where it is melted. Compressed air is concentrated around the flame atomizing the molten material into fine spherical particles and propelling these particles at high velocity onto a specially prepared substrate. By controlling the rate of feed of the wire through the flame, we can control the melt and atomization of metals with various melting points. With this gun, any wire may be sprayed which has a melting point below 5500°F.

**Powder Spraying** In this process, the basic principle of the heat source is the same as for wire spray except that powders are fed through the flame and propelled by high velocity Oxygen or air onto a Substrate. As with metallizing, any powdered metal or ceramic having a melting point below 5500°F. can be sprayed. This gun is mainly used for Hard Surfacing.

**Electric Arc Spraying** This equipment is comprised of DC Power Supply combined with a specially designed Spray Gun. Two wires are fed simultaneously through the gun at an angle so as to meet as they exit from the gun. The wires are insulated from each other but at the point where the wires exit from the gun, one wire is charged positive and the other negative, causing them to throw a molten arc between each other. Just behind this point we inject high velocity air or inert gas which atomizes the molten arc and propels the atomized particles onto the substrate. The temperature of the arc is controllable to a maximum of approximately 10,000°F. With this equipment, we can spray any type of metals which have melting points below 10,000°F.

**HVOF** The High Velocity Oxygen Fuel (HVOF) process was developed to produce high quality metal, carbide and various specialty coatings. A complete line of powders are available, which are specifically engineered for application with the HVOF System. The commercialization of this coating technology now affords industry the ability to get unique coating properties and extend the range of applications which previously could only be performed by proprietary coating processes.

**Plasma Spray** When Plasma spraying, the plasma is created by an electric arc burning within the nozzle of a plasma gun. The arc gas is formed into a plasma jet as it emerges from the gun nozzle. Powder particles are injected into this jet where they melt and then strike the surface at high velocity to produce a strongly adherent coating. Almost any material can be sprayed including metals, ceramics and plastics. The work piece remains cool because the plasma is localized at the gun. Applications for plasma sprayed coatings can be found in all industries - ranging from scuff resistant coatings on piston rings to thermal barriers on turbines and abrasion resistant coatings in the textile and paper industries

Flame Spray Arc Spray

Figure 1 a & b: flame spray and Arc Spray

**Cladding Metal Coating**

The metals most commonly used in cladding systems are aluminium alloy and steel. However, stainless steel, copper, lead and bronze can be and have been used to create a more distinctive appearance and/or to improve the durability of the facade. Table 1 compares the typical physical properties of metals suitable for cladding. This Technical Note describes the properties and uses of ferrous metals including plain carbon steel, zinc coated steel and stainless steel. Non-ferrous metals are described in Technical Note 23. Plain carbon steel Properties Plain carbon steels are iron-carbon alloys that may contain small amounts of other alloying elements such as manganese, phosphorous, sulphur, copper and silicon. Mild steel refers to steel with a carbon content up to 0.25% to which no other alloying elements have been deliberately added. It is strong, ductile and readily weld able. Steel will quickly corrode when exposed to normal moist atmospheres; consequently, when used externally, it is common for mild steel to be galvanized, and then painted for architectural reasons. Failure to galvanized steel prior to application of paint coatings is a common cause of corrosion – certain architectural paint coatings (e.g. polyester powder coatings) do not fully protect against corrosion. The corrosion resistance of mild steel can be increased by adding up to 0.1% copper. Plain untreated mild steel generally has a yield strength of approximately 250 N/mm2 and an ultimate tensile strength of about 420 N/mm2.

**Table 1:** Typical values of some physical properties of metals suitable for cladding

| Metal | Density ($kg/m^3$) | Thermal conductivity (W/m°C) | Coefficient of thermal expansion ($\times 10^{-6}$/°C) | Modulus of elasticity ($kN/mm^2$) | Tensile strength ($N/mm^2$) | Melting point (°C) |
|---|---|---|---|---|---|---|
| Aluminium | 2800 | 200 | 24 | 70 | 70 to 140 | 680 |
| Mild-steel | 7850 | 55 | 12 | 207 | 420 to 510 | 1900 |
| Stainless steel | 7800 | 15 | 17 | 207 | 500 | 1440 |
| Copper | 8930 | 400 | 17 | 100 to 130 | 210 to 360 | 1083 |
| Lead | 11340 | 35 | 30 | 1.4 | 15 | 327 |
| Brass (40% zinc) | 8400 | 129 | 21 | 103 | 370 to 540 | 905 |
| Aluminium Bronze | 8800 | 70 | 18 | 120 | 420 to 690 | 1050 |

Cold working and heat treatment can raise both values to about 460 and 600 N/mm2, respectively. The elastic modulus is not significantly impacted by the steel's strength. Strength can be increased by changing the alloy's composition, specifically by adding more carbon. However, this will result in less ductility because strength gradually decreases at temperatures above 300 °C, necessitating fire protection for structural components.

European Standards, which employ distinct categorization schemes, are replacing British Standards in the classification of steels. Steel designation schemes are outlined in BS EN 10027. The name system is covered in Part 1, while the numbering system is covered in Part 2. Two further naming schemes are provided, one based on composition and the other on the material's mechanical or physical characteristics and intended purpose. The most relevant parts of the system based on use and mechanical /physical properties are as follows:

- a letter (S for structural, B for reinforcing, E for engineering), followed by the yield strength in N/mm2, or
- Y (for prestressing) followed by the tensile strength in N/mm2, or
- H denoting cold rolled flat products of high strength steel for cold forming followed by the yield stress or T and the tensile strength, or
- D for other flat products followed by C for cold rolled, D for hot rolled or X where rolling condition not specified.

There are three systems based on composition, which relate to non-alloy steel, non-alloy steel with high manganese content and alloy steel For non-alloy steels the letter C is used followed by the carbon content multiplied by 100. For alloy steels, the letter X is followed by the carbon content multiplied by 100 followed by the chemical symbols of the alloying elements in order of decreasing concentration followed by the percentage compositions of the alloying elements to the nearest integer separated by hyphens. The numbering system consists of five digits. The first digit is 1 for steel. The next two digits indicate the material group number as defined in the standard, for example 01 and 91 are for general structural steel with a tensile strength less than 500N/mm2. The final two digits are sequential numbers allocated by the European Registration Office.

Applications

Steel is used in building facades in many forms including:

- Hot rolled structural sections for the main building frame,
- Cold forming of sheet or plate can be used for the production of lighter structural sections for curtain wall frames, cladding rails and purlins and for making brackets.
- Steel strip is also used for profiled metal sheeting, cladding panels, vapor barriers, flashings, copings, etc.
- Black bolts and nuts are produced by machining forged steel. While high strength friction grip bolts are made by forging and are heat treated after manufacture.
- Hot rolled steel bars are used for reinforcement of concrete.
- Brackets, screw fixings, etc.

Standards covering products relevant to cladding are as follows:

**BS 1449** Steel plate sheet and strip has been substituted by a large number of European standards. The following are relevant to materials used for cladding:

**EN 10051** Specification for continuously hot rolled uncoated plate sheet and strip of non-alloy steels. Tolerances on dimensions and shape.

**BS EN 10131** Cold rolled uncoated low carbon and high yield strength steel flat products for cold forming. Tolerances on dimensions and shape.

**BS EN 10149** Specification for hot rolled flat products made of high yield strength steels for cold forming.

**BS 4360** Specification for wieldable structural steels has also been replaced by a number of European Standards. The most relevant is BS

**EN 10025**:**1993**, Hot rolled products of non-alloy structural steels and their technical delivery conditions.

In the **BS 4360** classification, grades were based on the tensile strength whereas European grades are based on the yield strength.

Thus grades 40A, 43A and 50A in BS 4360 are equivalent to S235, S275 and S355 in the current European Standard. Additional confusion arises from the fact that a previous version of BS EN 10025 issued in 1990 was based on the tensile strength and used the prefix Fe. The letters following the strength in these grade designations indicate impact performance and a C in the current European system indicates suitability for cold forming.

Guidance on the structural use of steel is given in BS 5950 and guidance on the use of profiled steel cladding is given in CP 143: Part 10 and BS 5427.

**Zinc coated steel**

Zinc coating is the most common way of protecting steel against corrosion, although it is often pre-treated and then over-painted to enhance corrosion resistance and appearance.

Zinc protects the underlying steel in two ways:

- The zinc performances the role of physical barrier between a potentially corrosive environment and the steel substrate. Under most conditions zinc corrodes more slowly than steel; under normal atmospheric exposure zinc corrodes at a rate of between about 1/10 and 1/50 of that of steel.
- The zinc provide galvanic or sacrificial protection at exposed cut edges and at scratches.

For minor defects in the zinc coating it will continue to protect the underlying steel by galvanic action, giving very good performance in clean, neutral conditions, performing well in mildly alkaline conditions, but subject to chemical attack in acidic (industrial) environments. Larger areas of damage (maximum 40mm2) should be repaired using either zinc-rich paint or low melting point zinc alloy repair rods or powders, which should be at least equal to the thickness of the original zinc coating.

The degree of protection also depends on the area of zinc exposed adjacent to the defect. Where the zinc is painted the area of zinc exposed adjacent to a defect will be reduced and consequently the degree of protection will also be reduced.

There are many methods of zinc coating steel:

- Continuous hot-dip galvanizing
- Hot-dip galvanized coating of articles
- Thick hot-dip galvanized coating
- Centrifugal galvanizing (BS 729)
- Zinc spray (BS EN 22063)
- Zinc plating
- Sherardizing
- Coatings incorporating zinc dust

The most commonly used methods are continuous hot-dip galvanizing of coil, hot-dip galvanized

**3-Vacuum Coating**

Vacuum coatings processes use a vacuum (sub – atmospheric pressure) environmental and an atomic or molecular condensable vapor source to deposit thin films coatings. The vacuums environment is used not only to reduce gas particle density but also to limit gaseous contamination, establish partial pressures of inert and reactive gases, and control gas flow.

**Basic Coating**

For routine gold sputtering of SEM samples, the manual sputter coater (B7340) provides an alternative and cost effective solution. For high sample throughputs, or occasions where alternative target materials, such as gold/palladium, are required to accomplish finer grained coatings, the automatic coating unit (B7341) should be selected. For micro analytical applications where gold coating may not be appropriate, the carbon coater (B7367A) is ideal. The dual carbon rod source, with unique current feedback control, gives highly reproducible carbon coatings for SEM samples. The pumping system (B7366) is designed for use with the coating units. It includes an anti-vibration platform, stainless steel bellows connection and vacuum fittings.

In a situation where both carbon and gold sputtering are required, the dual pumping system (B7736) with changeover valve can be used to pump two coating units.

Where an accurate determination of coating thickness is required, the manual film thickness monitor (B7348) can be used with all the units. It can also be shared amongst two coaters, by adding the hardware kit (B7735). Additional automation of the coating process can be attained by fitting the film thickness monitor with terminator (B7349) to the automatic sputter coater. With this fitted, sputtering.is automatically terminated when the desired pre-set thickness has been reached.

**High Resolution Coating**

Preparing samples for examination in an FEG SEM requires fine grained coatings in order to make the most of the greater resolution available. The high resolution coater (B7234) includes chromium and platinum/palladium targets as standard. The turbo molecular drag pump offers the high vacuum and high volume gas handling essential for sputtering these materials. The rotary planetary stage and film thickness monitor are also included as standard, to ensure that coating thickness can be kept to a minimum to prevent charging.

**High Vacuum Carbon Coating and Metal Evaporation**

For carbon coating of mounted, polished samples for microprobe analysis and back scatter applications, the SEM turbo coater (B7230) should be used. The higher vacuum gives a fine unceasing carbon layer and the optional rotary planetary stage guarantees a uniform coating over a number of samples. The SEM turbo coater should similarly be used for carbon coating of highly contoured or porous samples; tilting the rotary planetary phases ensures that all facets of the specimen are consistently coated and specimen charging can be eliminated with the minimum thickness of coating.

The TEM turbo coater (B7232) has been designed to provide all the facilities essential for TEM and in the basic form can be used to make thin carbon support films or for coating grids. The auxiliary power supply allows a variety of other accessories to be easily fitted. These comprise a metal evaporation source, aperture cleaning and glow discharge for the hydro philisation of grids. A rotary shadowing table is also accessible as an accessory.

## SOME DEVICES USED FOR VACUUM COATING

**Manual sputter coater**

As shown if Fig.2, it is a simple-to-use basic instrument for gold coating of SEM specimens. It has completely variable current control, a digital process timer with pause option, a variable height specimen table, a hinged top plate and an O-ring sealed vacuum chamber.

The control allows the sputter current to be set independently of the gas pressure, which is adjusted distinctly by a manual leak valve. Coverage and grain size are optimized for any specimen. The cool magnetron type head with 57 mm diameter target gives efficient sputtering with minimal heating. Coating time is set by a timer with a digital readout and kept in the memory. The vacuum status and sputter current are displayed on the panel meter.

A modular desktop design combine's sputter control unit, pumping system and thickness monitor into an area of only 400 x 600 mm. It is fully integrated using a quick release all-metal coupling system. The adjustable height specimen table will accept up to 12 pin type stubs or can be used as a platform for other types of stubs and specimens. A vacuum feed through is provided for the optional film thickness monitor.

*Chamber size: 120 x 120 mm.*
*B7340 Agar manual sputter coater*
*B7366 Pumping system*
*B7348 Film thickness monitor*


Figure 2: Manual sputter coater

**Automatic sputter coater**

A more cutting-edge sputter coater where the complete sequence of flush, leak, coat and vent is habitually controlled. The solenoid functioned leak valve permits the gas pressure to return spontaneously to pre-set conditions. The coater can also be activated in the manual mode if required. A digital programmer that works with the gas pressure controls the sputter current. The magnetron head can effectively sputter a variety of target materials at sputtering currents up to 40 mA. The digital timer can be used to set, store, and display coating time.
The ending film thickness monitor can be added to further automate the process. This allows you to set the desired thickness and, once it is attained, the sputtering operation will immediately stop. Figure 3 shows the Automatic sputter coater.

Chamber size: 120 x 120 mm.
B7341 Agar automatic sputter coater
B7366 Pumping system
B7348 Film thickness monitor
B7349 Terminating film thickness monitor


Figure 3: Automatic sputter coater

**SEM automatic carbon coater**

When a conductive low atomic number coating is needed for routine coating of SEM and microprobe samples, the Agar automated SEM carbon coater is a specialized device. Highly reproducible carbon coatings are produced by the twin carbon rod source with a special current feedback control. The digital programmer can be used to enter and show the necessary voltage setting and evaporation time in automatic mode. Additionally, there are two modes for coating heat-sensitive samples: manual and pulsed. The working distance can be altered thanks to the specimen table's height adjustment feature. This coating machine can be utilized with the manual film thickness monitor (B7348) if a precise coating thickness measurement is needed. A vacuum feed through is also incorporated for this purpose.

Figure 4: SEM automatic carbon coater

Chamber size: 120 x 120 mm.
B7367A Agar automatic SEM carbon coater
B7366 Pumping system
B7348 Film thickness monitor

**High resolution sputter coater**

The Agar high-resolution sputter coater presents a genuine solution to the challenges faced when coating complex samples for FEG SEM imaging.

To reduce the impact of grain size, the coater allows complete control over thickness and deposition parameters.

The turbo molecular drag pump delivers the high vacuum essential for sputtering non-noble metals, while exhibiting excellent gas handling properties.

The magnetron sputtering head possesses the high current capability necessary for sputtering chromium, and a source shutter for target conditioning is included as standard.

Chromium and platinum/palladium targets are provided to produce fine grain coatings of varying densities.

Additional target materials are available and can be easily swapped.

The rotary planetary stage with tilt guarantees that highly contoured samples receive an even coating.

This ensures that the minimum coating thickness can be applied to achieve conductivity without sacrificing fine specimen detail.

The dual height 150 mm diameter work chamber allows for easy adjustment of the working distance .The integrated terminating film thickness monitor allows the coating thickness to be closely controlled and reproduced for repeat samples.

Figure 5: B7234 Agar high resolution coater

**CONCLUSION:**

Metal coating or metallizing is defined as the application of very thin metallic coatings for either active corrosion protection (zinc or aluminium anodes) or as a protective layer (stainless steels and alloys). Application can be by flame spraying or electroplating.

Hot dipping is form of galvanization. It's the process of coating iron and steel with zinc, which alloys with the surface of the base when immersing the metal in a bath of molten zinc at a temperature 840 degree Fahrenheit

Metal spraying is a technology, which protects and greatly extends the life of a wide variety of products in the most hostile environments and in situations where coatings are vital for longevity.

Cladding refers to bonding dissimilar metals. It is different from fusion welding or gluing as a method to fasten the metals together. Cladding is often achieved by extruding two metals through a die as well as pressing or rolling sheets together under high pressure.

Vacuum metal coating also known as vacuum metallizing is a coating process where extremely thin layers of metal are applied to an object in a high vacuum environment. This process allows the metal to exactly copy shape and contour of the applied object.

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