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Corrosion Resistance of Electric Wire Terminals Used in Harsh Industrial Environments

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Abstract

Industry reports indicate that 50 to 60 percent of electrical downtime has been traced to open or intermittent connections.[1] Harsh industrial environments increase the risk of corrosion and chemical attack on metals used in wire terminal connections, potentially affecting electrical reliability. Engineers designing industrial control products must apply sound judgment in material selection and wire clamp design along with rigorous test methods to ensure reliable long term performance under harsh field conditions.

Accelerated corrosion testing is an important tool for use in product designs such as wire terminal systems. Test methods such as salt spray testing have traditionally been used to evaluate corrosion resistance but can seldom be correlated to actual field performance. Other methods using corrosive gas mixtures have been developed to better correlate with field conditions.

This paper studies corrosion resistance of wire terminal connections made from a variety of materials and protective platings and coatings. Accelerated test methods using both salt spray and corrosive gas mixtures were applied. The results show that each base metal and protective coating has it's strengths and weaknesses. Steel with zinc-trivalent chromate protective coatings performed well but vary significantly depending on the thickness of zinc, type of chromate, and use of sealers. Nickel-plated brass performed well except in environments with high concentrations of ammonia. Stainless steel provided the best and most universal corrosion resistance.

The information presented in this paper can be applied to make more knowledgeable product selection decisions that will help ensure long term reliability of electrical connections used in industrial control applications.

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Introduction

Intermittent wire connections are costly and time consuming problems that are unacceptable in today's highly automated industrial applications. Wet, dirty, and dusty industrial automation environments increase risk of corrosion or chemical attack on equipment. In food and beverage industries, cleaning agents and moisture threaten operations. Chemical processing facilities deal with reactive agents. Pulp and paper applications endure wet-end processing and bleaching. Metal and mining applications create airborne metal dust particles. Petrochemical manufacturers experience salt laden environments on off-shore oil rigs. Engineers designing industrial control equipment must apply sound judgment in material selection and clamp design along with rigorous test methods to ensure reliable long term performance under harsh field conditions.

Industrial control equipment typically has some form of wire terminals to provide power, control and communications within an automated system. It is not uncommon to have 250…500 individual wires connected to terminal blocks in a typical electrical panel. Wire terminals must be capable of carrying a range of current from a few milli-amps for low energy signaling to hundreds of amps for power generation. Electrical connections must have good mechanical properties and designs that securely maintain metal to metal contact to maintain low electrical resistance for current flow throughout the life of a product. Metals must be adequately protected against corrosive atmospheres and chemical attack to ensure both good mechanical and electrical performance.

There are many attributes that make up a reliable electrical connection. This article discusses corrosion resistance of metals commonly used in wire terminals for industrial control equipment. Corrosive atmospheres are identified for various industries. Basic wire terminal material properties are identified for metals and their protective coatings. Text book references are applied to compare conditions found in industrial environments with corrosion resistance of metals and protective coatings. A variety of accelerated corrosion test methods are identified and applied to study actual material performance. Considerations are provided to reduce the risks of corrosion and chemical attack in the application environment.

Corrosive Chemicals in Industrial Environments

Industrial electrical controls are present in nearly every manufacturing, process, and raw material environment. Destructive chemicals are also found in many of these same environments. Accelerating factors include moisture, temperature, and synergistic effects of chemical combinations. Chemical concentration levels often benign to humans can have detrimental corrosive effects on metals. Common cleaning chemicals such as ammonia can promote stress cracking in brass. Moisture is extremely corrosive to unprotected steel. Table 1 includes some of the more common chemicals and their sources in industrial environments.[2]

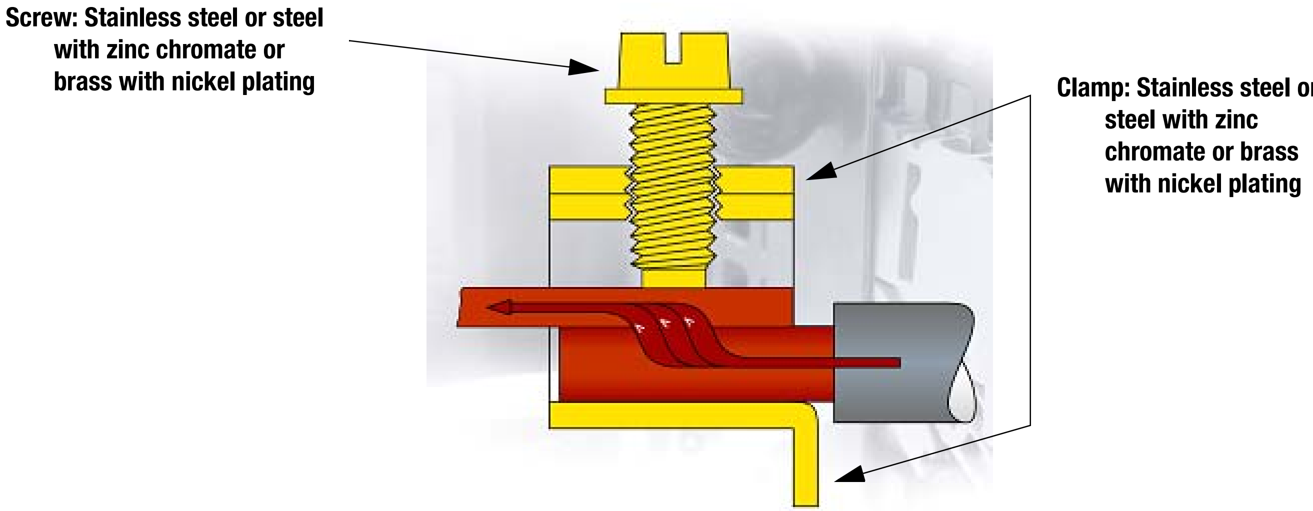
Table 1: Examples of Chemicals in Industrial Environments

Chemical	Source	
H_2S Hydrogen Sulfide	• Forest Products Processing • Waste Water Processing	• Rubber Processing • Geothermal Regions
NH_3 Ammonia	• Fertilizer Manufacturing • Wastewater Processing	• Food and Beverage Cleaning Agents • Agricultural Regions
SO_2 Sulfur Dioxide	• Oil and Gas Processing • Metal Processing • Power Generation	• Cement Processing • Tire Manufacturing
Cl_2, Chlorine Cl Chloride Ions"	• Water Processing • Food and Beverage Cleaning Agents	• Pulp and Paper Processing
NaCl Sodium Chloride	• Marine • Rubber Processing	• Sea Coast Regions • Food Processing
NaOH Sodium Hydroxide	• Textile Processing • Pulp and Paper Processing	• Soaps and Detergent Processing • Food and Beverage Cleaning Agents
$NaCO_3$ Sodium Carbonante	• Pulp and Paper Processing • Soaps and Detergent Processing	• Glass Processing
NaClO Sodium Hypochlorite	• Food and Beverage Cleaning Agents (Bleach)	
NO_x Nitrates	• Food Processing	• Fertilizer Manufacturing

Wiring Terminal Construction

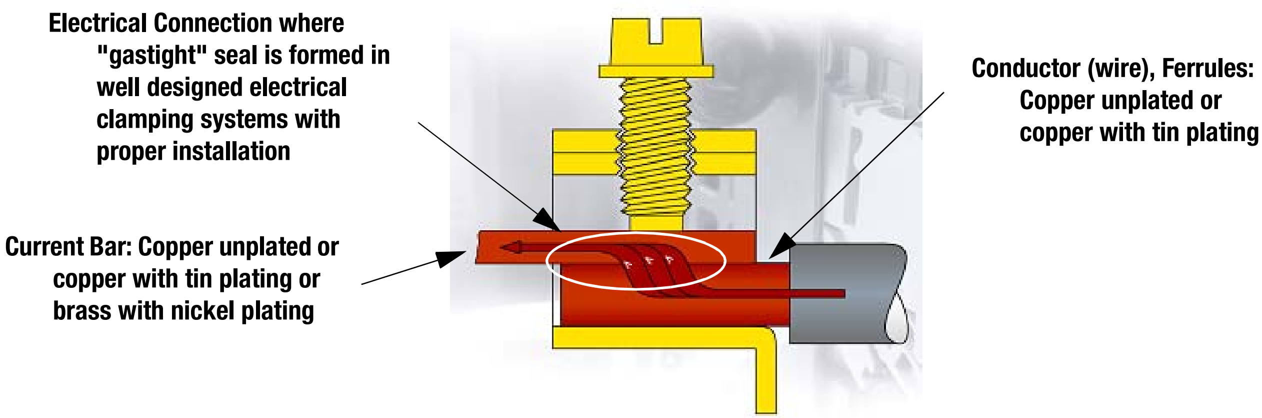
Wiring terminals are available in several different styles including screw terminal, spring clamp, and insulation displacement connection. Terminals are designed to perform both mechanical and electrical functions. Figure 1 describes the metals commonly used in the mechanical system.

Figure 1 Common Metals Used in Clamping System



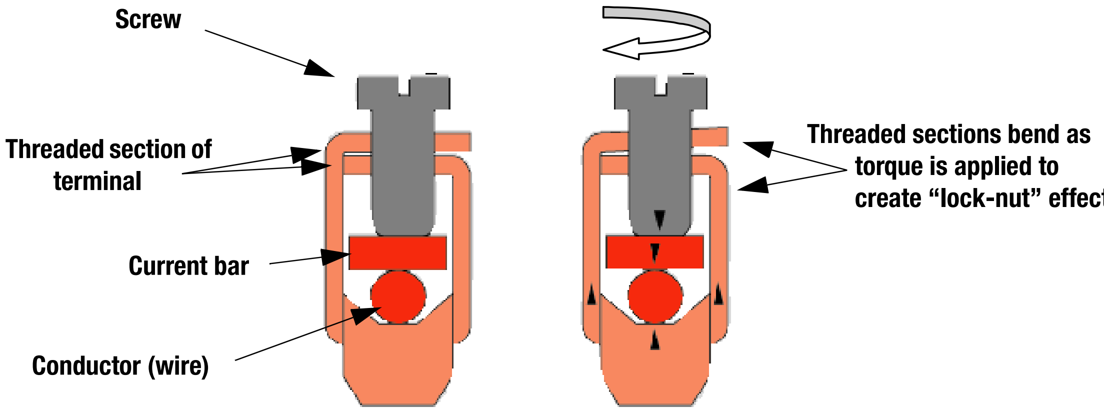
The clamping system is designed to securely hold the wire conductor against a current bar. Electrical current flows through the connection between the wire and current bar. The clamping force of the terminal is intended to create a "gastight" electrical connection. This means the wire and current bar are clamped together tightly to form a seal and prevent exposure of the electrical connection to the environment and potential corrosion of the metals.

Figure 2 Common Metals Used in electrical System



Industrial applications typically include operating conditions such as mechanical shock and vibration, thermal cycles, and corrosive atmospheres. A reliable connection must be capable of maintaining the clamping force and thus the gastight connection over the installed life. Well designed screw terminals will have a feature to maintain the clamping force by incorporating a lock nut effect that guards against loosening of the screw. This feature is often referred to as "anti-vibration," "prevailing torque," or "self locking," and can be accomplished in several different ways. In a screw clamping system, for example, the screw thread is formed in two separate pieces of metal. The two threaded sections are designed to be slightly out of alignment resulting in a "lock-nut" effect on the screw.

Figure 3 Example of Anti-Vibration Feature



Other requirements necessary to ensure reliable connections include installing a conductor size that is within the specified range for the terminal, and applying the correct tightening torque as recommended by the manufacturer. Consideration should also be given to corrosive elements that could be present in the application and the corrosion resistance of metals and plating systems used for wire terminals.

Metals and Protective Coatings Used In Wiring Terminals

Metals used in wiring terminals generally have platings/coatings for protection against corrosion and chemical attack. Exceptions would be stainless steel which has a high level of corrosion resistance to many chemicals. Protective coatings can be classified as "sacrificial coatings" or "barrier layer coatings".

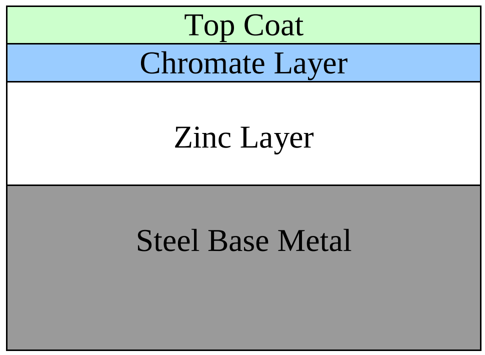
Sacrificial coatings are intended to be consumed during the corrosion process while providing a protective layer that prevents or substantially delays corrosion of the base metal. If the sacrificial coating is consumed then the base metal will no longer have a protective layer and be at risk for corrosion. Steel is often protected by a sacrificial plating of zinc.

Barrier layer coatings are intended to provide a protective seal to prevent corrosive and chemical attack. They are not consumed as part of the corrosion process. The coatings are effective unless they are porous or mechanically damaged. Examples of barrier layer coatings include the following:

- Chromate (technically referred to as a passivation) applied over zinc
- Top coat or sealer applied over chromate
- Nickel applied over brass
- Tin applied over copper

Steel Clamps and Screws

Carbon steel is the most widely used material for screw terminal construction. Steel is often protected by zinc-chromate plating systems. An example of a quality zinc-chromate plating system including barrier and sacrificial coatings is shown below.



Zinc Protective Coating

A layer of zinc is applied on top of the steel. Zinc corrosion due to moisture can be seen as a white powdery substance forming on the component surface, and termed "white rust". If the zinc layer has been consumed then "red rust" corrosion of the base steel material will appear, eventually structurally weakening the component. Zinc is a metal which is less noble than steel, and corrodes at a much slower rate than steel. The corrosion protection provided by zinc is nearly proportional to the thickness of zinc. The rate of zinc corrosion is increased in environments with high moisture from humidity or condensation. Because industrial products must endure many years of service life, a generous layer of zinc is further protected by coatings such as chromate and top coat sealers.

Zinc-Alloy Protective Coating

Zinc alloy coatings have been used in Japan and Europe since about 1980 to improve performance in the automotive and avionics industries.[3] They are designed to perform the sacrificial function of pure zinc but are consumed a much slower rate, resulting in improved corrosion protection of the base metal. Common alloys include zinc-aluminum, zinc-iron, zinc-cobalt, zinc-nickel and tin-zinc. Zinc-Nickel produces the highest corrosion resistance of the zinc-alloy compositions.[4] Corrosion resistance of zinc-nickel alloys in wet salt environments (typically simulated by salt spray tests) performs approximately three times better than pure zinc.[5] Improvements in corrosion protection resulting from zinc alloy systems are highly desirable especially when replacing hexavalent with trivalent chromates.

Replacing Hexavalent Chromate with Trivalent Chromate

Zinc and zinc-alloys are typically protected by a thin barrier coating of chromate that is also referred to as a passivation (chemical treatment to form a protective passive film).[6] Chromate coatings traditionally used have been hexavalent (CrVI or Cr^{6+}). Legislation in Europe and elsewhere has identified hexavalent chromium as a substance of concern in particular applications.[7] This has fostered efforts to find replacements that are environmentally acceptable and provide suitable corrosion resistance. Trivalent chromate (CrIII or Cr^{3+}) is the most widely commercially accepted alternative to hexavalent chromate.[8] Several considerations need to be made when hexavalent is replaced by trivalent: color is not identical; corrosion resistance is reduced; and there are no "self healing" properties.

Hexavalent chromate is available in various colors. Terminals & terminal screws which had this protective coating typically were a drab yellow or drab green color. Trivalent chromate is available in various colors also, but terminals typically use a "clear chromate" that is generally metallic in color with a slight bluish tint, sometimes referred to as iridescent. In most cases it is easy to distinguish what type of chromate is applied based on the color, however a more thorough analyses may be required to confirm the chromate composition if color dyes have been used.

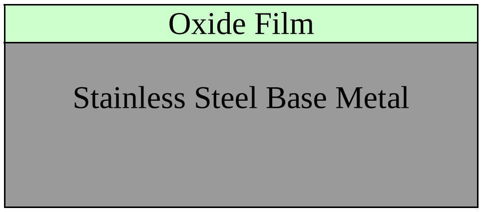
Trivalent chromate corrosion resistance varies depending on its chemical composition and on how well it was applied to the terminal or screw. Trivalent chromate can be more susceptible to corrosive attack than hexavalent chromate.[9] Equivalent corrosion resistance can be achieved by specific chemistries or by applying a sealer or top coat to protect the trivalent chromate. Other improvements in corrosion resistance can be achieved by using a zinc-nickel alloy, which can far outperform corrosion resistance of zinc-hexavalent systems.[10]

Hexavalent chromate had a self-healing function, when scratched for example it would flow back together to re-form its protective barrier.[11] Trivalent chromate does not have self-healing properties. A part that is scratched will likely corrode quicker because the sub-layers of zinc or the base metal are no longer protected from the environment. Sealers are used to improve the performance of trivalent chromate by providing an extra barrier layer. Some sealers are formulated with the self-healing effects. Plating formulations using nano-composite technologies are available for use as top coats or as alternative replacements for chromates. These formulations blend several materials to inhibit corrosion and claim to have self-healing properties traditionally found in hexavalent chromates.[12]

Sealer coatings are typically silicate-based and form a clear film with excellent resistance to chemicals and water.[13] Trivalent chromate typically requires an additional top coat to achieve equivalent corrosion resistance of hexavalent chromates. Care must be taken when using top coats as many are non-conductive and thus could potentially affect electrical performance. In a typical terminal the conductor wire is clamped directly to a current bar and therefore a sealer on the clamp or screw would not affect the electrical connection. See Figure 2.

Stainless Steel Clamps and Screws

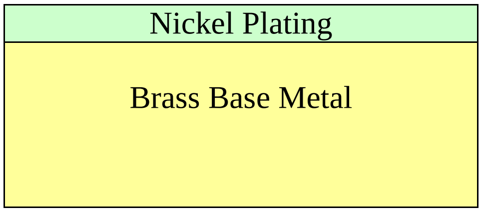
Stainless steel is most widely used in spring clamp terminals and insulation displacement terminals for its high mechanical strength properties. Stainless steels perform well in many corrosive environments because of a "passive" oxide film that is maintained by the chromium content of the steel. The film is considered continuous, nonporous, and is self healing.[14] Austenitic stainless steels (grades 304 or 316 for example) may be susceptible to stress corrosion cracking where there is a combination of chlorides, elevated temperatures 65-71°C (150-160°F), and mechanical stress.[15]



Stainless steel parts typically undergo a passivation process after they have been fabricated. Passivation is essentially a cleaning process to remove iron contamination left behind on the surface of the part as a result of coming into contact with iron material during machining. These iron contaminants are potential corrosion sites if not removed.

Brass Terminals and Current Bars

Brass is a copper alloy typically containing about 30% zinc by weight. It is easy to produce and often a cost effective material with a reasonable combination of strength and electrical conductivity. A downside to brass is that it can be susceptible to stress cracking when exposed to certain chemicals and in combination with mechanical stress. Chemicals such as ammonia, chlorides, and nitrogen compounds can react with brass. Mechanical stress is the result of the clamping force generated by the terminal screw or spring holding the conductor. Stress cracking can occur in the brass terminal, and the clamping force can be lost resulting in an unreliable electrical connection.



Nickel Plating

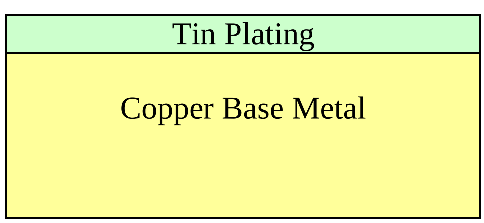
Brass is often protected by nickel, which is a barrier type plating. Good plating processes are needed to ensure the coating is free of porosity, voids, cracks, and other defects which would otherwise expose the brass to environment. Nickel coatings can have micro pores or pinholes which allow the corrosive environment to contact the base metal. Generally the pores are not a concern unless the product is used in an atmosphere with high concentrations of chemicals that are likely to attack the base metal.

Nickel plating processes have been identified as posing risks to human health according to the U.S. Environmental Protection Agency. Plating companies are required to implement medical surveillance procedures for personnel exposed to nickel compounds.[16] Legislation in Europe has identified nickel as a substance of concern when used in applications such as wrist watches or jewelry where there is prolonged contact with the skin.[17] Brief contact with nickel is not a concern because there is insufficient time to react with sweat to form a by-product that can irritate the skin.[18]

Copper Current Bars, Wires and Ferrules

Copper is desirable for the current bar because of its low electrical resistance and capability to carry electrical current without generating excess heat. Oxide that forms on copper is typically copper oxide (Cu_2O), other oxides may form as a result of environmental contaminants such as sulfides and chlorides.[19] Oxide(s) are typically poor electrical conductors and therefore increase the resistance of the electrical connection. Increased resistance can result in undesirable temperature rise for larger loads and open circuits for smaller loads.

Copper oxides can be seen by a darkening in color. Copper oxide is not a very stable compound and therefore undergoes other reactions quite easily. A reaction with acid results in copper hydroxide that is a green color and visible on the surface. Acids are present in the air due to emissions from automobiles for example and can result in the greenish color of copper building roofs and gutters.



Tin Plating

Copper used in current bars or wire terminals is often protected against oxides with tin, which is a barrier type plating. Tin offers corrosion protection, especially from the oxidation due to air and sulfur compounds.

Industrial Environments and Wiring Terminal Corrosion Resistance

Corrosion can be difficult to characterize as it occurs under a wide variety of conditions and is dependent on the environment, metals and their protective coatings. Environmental effects include air-borne or liquid chemicals, temperature, and moisture. Corrosion can occur rapidly or slowly over many years depending on chemical concentration levels and combinations present in the environment. Essential requirements of protective coatings include high corrosion resistance and good adhesion to the base metal. Although some materials have better overall performance, circumstances exist where nearly every material is susceptible to corrosion or other forms of chemical attack. A well designed terminal will include an assessment of material corrosion resistance based on field experience and accelerated test methods.

Corrosion Test Methods

Accelerated tests have been used for many years to gain a better understanding of the corrosion process and protection methods for industrial control equipment. Laboratory tests are designed to produce results in a very short period of time. Results may not be representative of corrosion seen throughout the service life of a product especially considering that real world conditions vary greatly and often times have unique attributes based on specific applications. Salt spray testing has historically been used to study corrosion resistance but may not be representative of atmospheres found in many industrial environments. Applications with salt laden atmospheres are typically limited to specific processes or sea coast atmospheres. Evaluating performance in other application environments necessitates consideration of a broader spectrum of test methods.

Corrosion Test Methods Correlated To Field Conditions

In the 1980's efforts were made to research and classify atmospheres that may affect electronic devices.[20] The intent was to develop a correlation between application environments and accelerated test methods. Thousands of test sites have been analyzed by placing copper coupons in industrial application environments for a period of time. The coupons were then studied in a laboratory to identify corrosive deposits and concentration levels. In the 1990's standards organizations developed accelerated test methods and guidelines corresponding to the atmospheres found in industry. These test methods involve applying a combination of corrosive elements, temperature and humidity for a specified period of time. Standards include the following;

- American Society for Testing and Materials, ASTM B845-97 Standard Guide for Mixed Flowing Gas Tests for Electrical Contacts
- International Electro technical Commission, IEC 60068-2-60 Environmental Testing Part 2: Tests - Test Key: Flowing Mixed Gas Corrosion Test

These tests are most useful in simulating application environments because they are based on extensive field studies and include synergistic affects of multiple corrosive elements being present at the same time.[21] For example

ASTM B845 test method H conditions correspond to many industrial and related locations (including storage areas) where moderate amounts of pollution are present in poorly controlled environments.[22] A test duration of 20 days is generally accepted to simulate a 10 year service life. Corrosive atmospheric testing is widely used as a method of assessing electrical connectors for reliable use in office and industrial environments.[23]

Salt Spray (Fog) Test

Salt spray testing was originally intended as an accelerated laboratory test to assess corrosion resistance of metals and surface coatings for seacoast environments. Standardized test methods include the following:[24]

- American Society for Testing and Materials, ASTM B117 Standard Practice for Operating Salt Spray (Fog) Apparatus
- International Electro technical Commission, IEC 60068-2-11 Basic Environmental Testing Procedures Part 2 Test Ka: Salt Mist

The salt spray test is most useful in providing a relative comparison of corrosion resistance between various metals or protective coatings, for example to compare corrosion resistance of different chromate systems on the same base metal. Favorable salt spray test results are often misrepresented as assurance that a product will be suitably protected from corrosion in any environment. Performance prediction of a component in its application environment has seldom been correlated with salt spray results.[25]

Visual and Electrical Test Criteria

Metals and protective coatings used in terminals and terminal screws have strengths and weakness when exposed to corrosive conditions. Zinc plated steel materials are most susceptible to corrosion resulting from salt spray tests. Corrosion first appears visually as white rust is formed from zinc. Although visually unappealing the electrical performance is typically unaffected due to the gastight connection between the conductor (wire) and terminal. Nickel plated brass and stainless steel withstand salt spray testing with virtually no signs of visual corrosion but are susceptible to mechanical failures from other corrosive atmospheres. Mechanical failures such as stress cracking can result in an unreliable electrical connection. Consideration should be given to judging corrosion resistance of wire terminals by applying both visual and electrical criteria.

Salt spray testing has traditionally been based on visual criteria only. A typical performance criteria for industrial control products is to have no visible white or red rust after a minimum 96 hour duration in salt spray. It is also wise to consider electrical performance since this is of greater importance for connector reliability.

In many cases electrical performance will continue to function normally even after severe corrosion can be seen on the terminal. The gastight connection prevents the electrical contact area from being exposed to the corrosive atmosphere. Conversely in the case of stress cracking, the material may look unaffected but be damaged to the point were the electrical connection is no longer functional. Electrical performance can be verified by a voltage drop test as defined by industry standards. In preparation for corrosion testing, conductors are installed in the terminals and the voltage drop is measured and recorded. Conductors remain clamped in the terminals during the corrosion test. Following the corrosion test the voltage drop is measured again and shall not exceed 150% of the value measured before the test to be considered an acceptable performing product.[26]

Corrosion Test Results and Discussion

It is not realistic to draw conclusions about corrosion resistance from one accelerated test. Rather, consideration should be given to a combination of tests preferably correlated to actual field conditions. Several different test methods were applied to study corrosion performance of a variety of wire terminal materials. Test methods included mixed flowing gas, single component ammonia, and salt spray. Base metals included steel, stainless steel, brass and copper. Protective coatings included zinc, chromate, nickel and tin.

Mixed Flowing Gas (MFG) Test Results

A variety of terminal materials were exposed to a MFG test.[27] Testing was performed with corrosive gas mixture to simulate 10-year equivalent exposure to a harsh corrosive environment, severity level G3.[28] The test was 20-days in duration with the following conditions;

100 ppb H2S Hydrogen Sulfide	75% relative humidity
200 ppb NO2 Nitrogen Dioxide	28-29 degrees Celsius
200 ppb SO2 Sulfur Dioxide	ppb = Part per Billion
20 ppb CL2 Chlorine	

Following the test corrosion deposits were identified using energy dispersive spectrometry and X-ray diffraction.[29] Corrosion was found on all of the metallic parts except the austenitic stainless steel surfaces and steel plated with zinc-nickel alloy.

Steel parts plated with zinc and hexavalent or trivalent chromate tended to show a breakdown of the chromate and some corrosion of the zinc. The corrosion deposits appeared as hydrated forms of zinc oxide (white), zinc chlorate (white), and/or zinc sulfide (colorless). This corrosion was not heavy.

Nickel plated parts tended to show two forms of heavy corrosion. The plating tended to show hydrated forms of nickel sulfate (blue-green). The nickel plating on these parts is relatively thin and tends to be porous. Base metal corrosion was also found on most of the parts. The brass parts had various forms of hydrated copper sulfide (black), copper chloride (blue green), and/or copper hydroxide (blue) present. Nickel plated steel parts showed various forms of hydrated iron oxides (reddish brown).

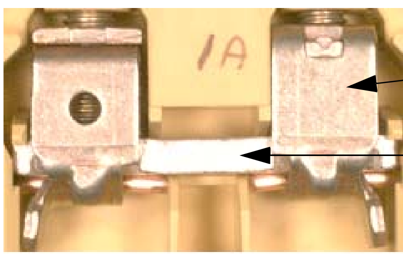
Tin plating showed some porosity in thin layers combined with surface irregularity, typically along a sheared edge where no plating was applied due to the fabrication process. Tin plated parts tended to show base metal corrosion in these areas, which was mostly copper sulfide (black), as all of the tin plated parts were over copper alloys. The corrosion on these parts tended to be light.

Exposed copper conductors became heavily corroded with copper sulfide (black).

Electrical performance was measured once before the corrosion test and once after the test. The test was intended to determine if corrosion would have a detrimental effect on electrical performance. Voltage drop measurements were within the specified values according to standard IEC 60947-7-1, Terminal Blocks for Copper Conductors, therefore all cases had satisfactory electrical performance.

Steel with Zinc and Hexavalent Chromate

Before MFG Test

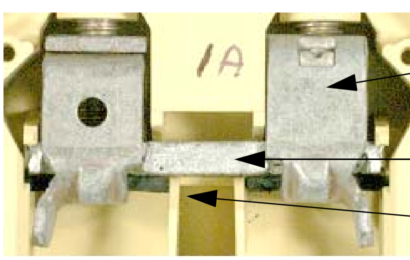


Materials

Terminal: Steel with zinc plating and hexavalent chromate

Current Bar: Tin-plated copper

After MFG Test



Corrosion Deposits

Terminal: General chromate breakdown, slight zinc corrosion, no steel corrosion

Current Bar: Some sulfur corrosion of the copper, mainly on the part edges where the tin is thinner.

Conductor (wre): Copper sulfide (black

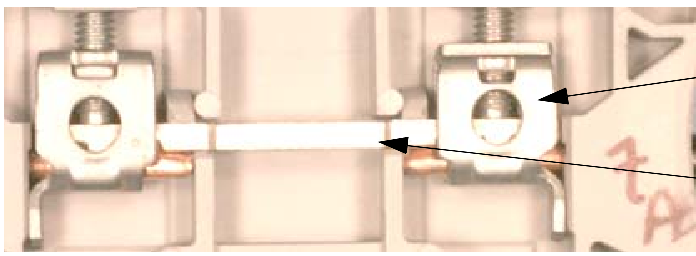
Clamped Portion of Copper Conductor (wire) After MFG Test

Electrical Performance
Voltage drop before MFG: 0.26 mv
Permissible voltage drop after MFG: 0.39 mv
Actual voltage drop after MFG: 0.26 mv
Results: Pass

No visual corrosion in gastight connection.

Steel with Zinc and Trivalent Chromate

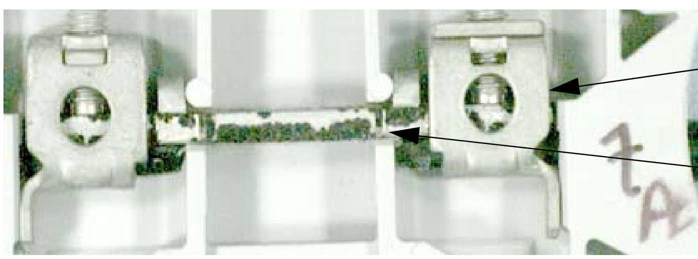
Before MFG Test



Materials
Terminal: Steel with zinc plating and trivalent chromate.

Current Bar: Tin-plated copper

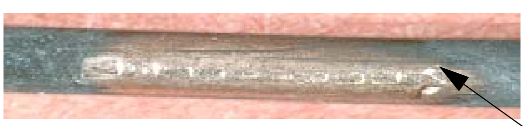
After MFG Test



Corrosion Deposits
Terminal: General chromate breakdown, slight zinc corrosion, no steel corrosion

Current Bar: Corrosion of the copper concentrated along edges and surface discontinuities.

Clamped Portion of Copper Conductor (wire) After MFG Test

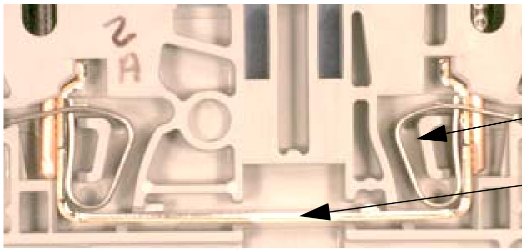


Electrical Performance
Voltage drop before MFGL 0.86 mV
Permissible voltage drop after MFG: 1.29 mV
Actual voltage drop after MFG: 0.88 mV
Results: Pass

No visual corrosion in gastight connection

Stainless Steel

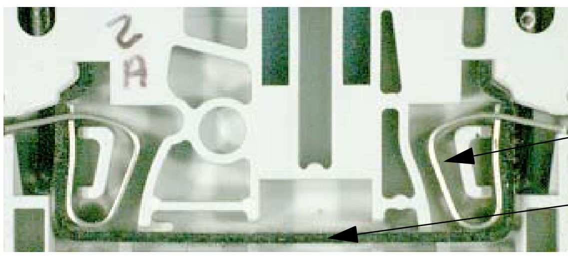
Before MFG Test



Materials
Terminal: Austenitic stainless steel

Current Bar: Tin-plated copper, edge is bare copper.

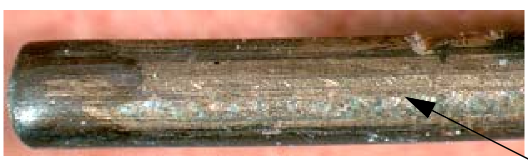
After MFG Test



Corrosion Deposits
Terminal: No apparent corrosion.

Current Bar: Sulfur corrosion of the copper concentrated along edge.

Clamped Portion of Copper Conductor (wire) After MFG Test

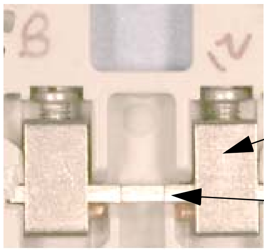


Electrical Performance
Voltage drop before MFG: 1.6 mv
Permissible voltage drop after MFG: 2.4 mv
Actual voltage drop after MFG: 1.6 mv
Results: Pass

No visual corrosion in gastight connection.

Brass with Nickel Plating

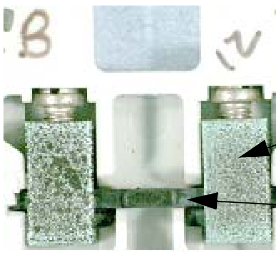
Before MFG Test



Materials
Terminal: Brass with nickel plating

Current Bar: Brass with nickel plating

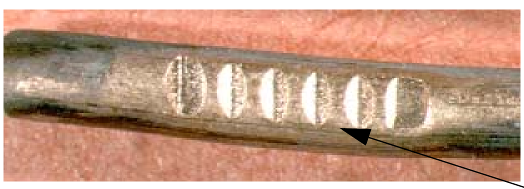
After MFG Test



Corrosion Deposits
Terminal: Heavy corrosion of the nickel.

Current Bar: Some corrosion of the nickel and copper.

Clamped Portion of Copper Conductor (wire) After MFG Test



Electrical Performance
Voltage drop before MFG: 1.1 mv
Permissible voltage drop after MFG: 1.6 mv
Actual voltage drop after MFG: 1.1 mv
Results: Pass

No visual corrosion in gastight connection.

Single Component Ammonia (NH_3) Test Results

Brass and steel were evaluated in a 10,000 ppm Ammonia (NH_3) atmosphere for 168 hours. Nickel plated brass exhibits no visible corrosion when attacked by ammonia but is susceptible to stress cracking. Stress cracking occurs when brass is exposed to certain chemicals in combination with mechanical stress. Chemicals such as ammonia, chlorides, and nitrogen compounds can react with brass. Mechanical stress is created from the terminal screw clamping force. When stress cracking occurs the brass material is cracked and the electrical connection is lost or becomes unreliable. Steel is resistant to stress cracking in ammonia atmospheres.

Brass with Nickel Plating

Stress crack

Electrical Performance
Unreliable

Steel with Zinc Plating and Trivalent Chromate

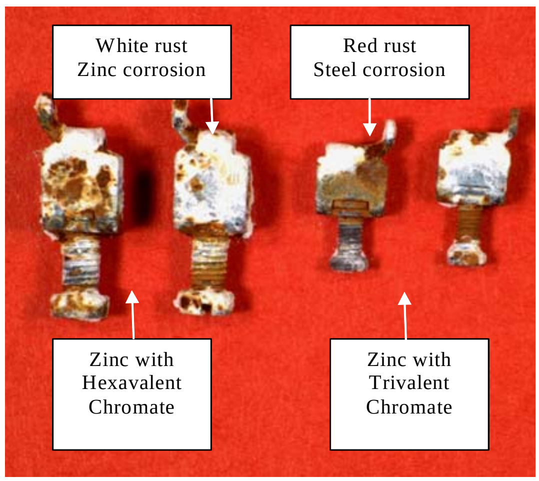
Electrical Performance
Voltage drop before ammonia test: 0.7 mv
Permissible voltage drop after ammonia test:
1.05 mv
Actual voltage drop after ammonia test: 0.7 mv
Results: Pass

Single Component Salt Spray Test Results

Steel with Zinc or Zinc-Nickel and Chromate

The corrosion process for a steel component with coatings of zinc, chromate, and possibly a top coat typically occurs in several steps. First the top coat and/or chromate layer breaks down and exposes the zinc. Zinc corrodes by exhibiting a white powdery substance referred to as "white rust". Eventually the zinc layer is consumed, exposing the base steel metal to the salt spray. Steel corrodes by exhibiting "red rust". Salt spray testing for industrial environments is typically applied for a minimum duration of 96 hours with the criteria of no visible corrosion (white or red rust).

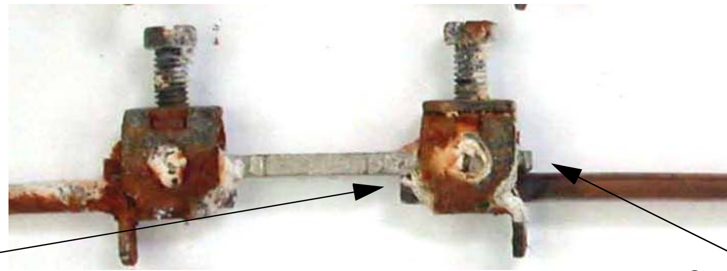
Steel terminals were tested in salt spray for extended durations (several hundred hours) to study variations of zinc chromate systems. Results indicate that a zinc-nickel alloy has superior performance compared to systems using plain zinc. White rust corrosion of zinc and red rust corrosion of steel can be seen in the photos.



Electrical Performance of Severely Corroded Steel Terminals

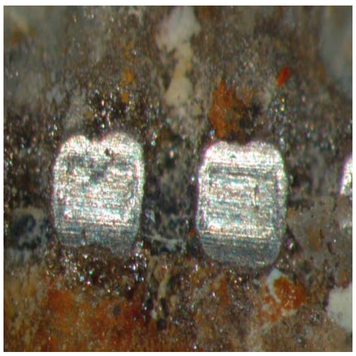
ATTENTION

Severely corroded terminals after extended durations in salt spray environments are capable of maintaining good electrical performance because of the gastight electrical connection. Steel components provide the mechanical clamping force and copper components provide the electrical connection. Current carrying materials such as copper and copper alloys are more resistant to corrosion from salt spray.

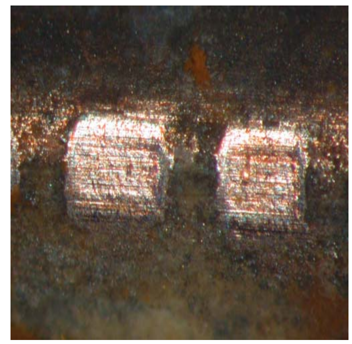


Tin-plated copper current bar

Copper conductor (wire)



Electrical Performance
Voltage drop before salt spray test: 0.95 mv
Permissible voltage drop after salt spray test: 1.42 mv
Actual voltage drop after salt spray test: 0.98 mv
Results: Pass



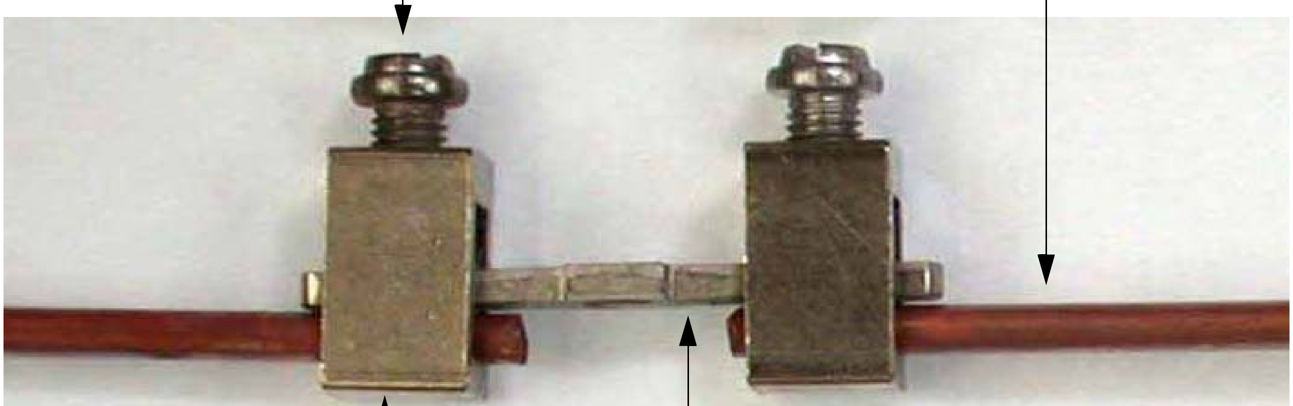
No visible corrosion in contact area of gastight connection zone inside of clamp.

Stainless Steel, Brass and Copper

Materials such as stainless steel, brass, copper and tin can withstand hundreds of hours of salt spray with negligible signs of corrosion.

Stainless steel screw

Copper wire



Nickel-plated brass terminal

Tin-plated copper current bar

Electrical Performance
Voltage drop before salt spray test: 1.3 mv
Permissible voltage drop after salt spray test: 2.0 mv
Actual voltage drop after salt spray test:1.3 mv
Results: Pass

Prevention Strategies

Industrial controls typically need to be located near equipment that resides in hostile corrosive environments. Consideration should be given to identifying corrosive elements in the environment and choosing materials accordingly. Placing controls in the appropriate enclosure is an effective method for reducing risks of corrosion. To maximize protection there must be no openings of the enclosure walls and doors must be maintained closed. Reducing humidity or condensation inside an enclosure is also an important consideration because moisture tends to accelerate the corrosion process. Heating and air condition systems are effective in controlling moisture. In harsh environments consideration should be given to more elaborate measures such as air filtration systems, air purge systems or locating electrical equipment in a control room.

Corrosion inhibitors are chemicals in the form of strips or canisters that can be placed inside an enclosure. Inhibitors are designed to vaporize and condense on all surfaces inside the enclosure providing short term protection against corrosion. Before using inhibitors precautions should be taken to investigate chemical compatibility with other materials inside the enclosure and surrounding environment.

Precautions during installation and start up can be helpful. Consideration should be given to installing electrical equipment after enclosures are complete with fully sealed with doors, electrical fittings, etc. The following standards are available to help select a suitable enclosure construction based on the environment;

- National Association of Manufacturers Association (NEMA) Publication 250, Enclosures for Electrical Equipment
- International Electro technical Commission (IEC) Publication 60529, Classification of Degrees of Protection Provided by Enclosures

Conclusion

Price is often a factor when purchasing automation equipment. While the initial purchase price may be attractive the costs of flimsy construction and low quality materials resulting in unreliable performance adds up quickly. Industry reports indicate that 50 to 60 percent of electrical downtime has been traced to open or intermittent connections. Reliable electrical connections at a fair price can be achieved with sound engineering judgment, a thorough understanding of application environments and rigorous testing.

Material performance is best understood by applying a combination of tests, preferably correlated to actual field conditions. Each base metal and protective coating has its strengths and weaknesses. Steel with zinc-trivalent chromate protective coatings performs well but vary significantly depending on the thickness of zinc, type of chromate and use of sealers. Nickel plated brass performs well except in environments with high concentrations of ammonia. Stainless steel provided the best and most universal corrosion resistance.

Judging corrosion resistance of metal components has traditionally relied on visual appearance only. A well designed terminal clamp will have a gastight seal protecting the electrical connection from corrosion. The electrical performance will continue to function normally even after severe corrosion can be seen on the terminal.

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