Grounding and Corrosion of Dissimilar Materials

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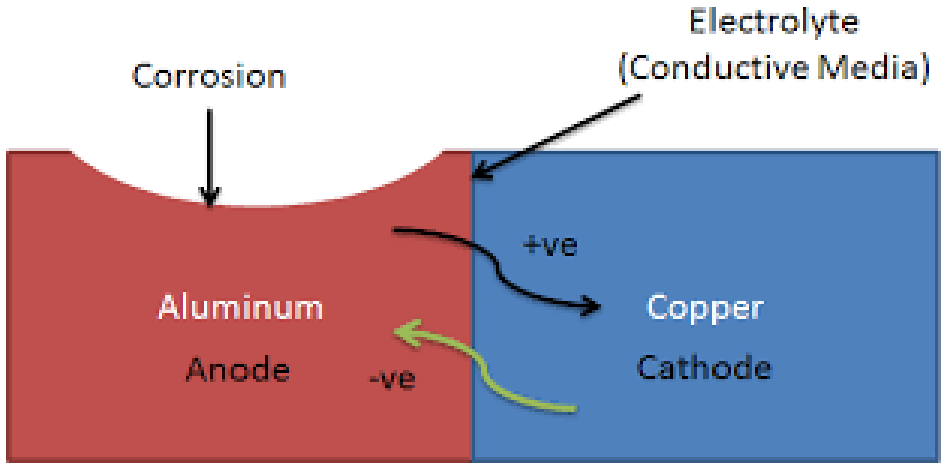
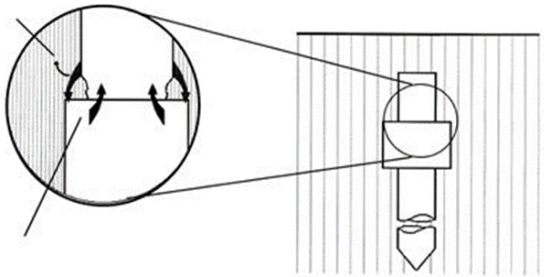
Corrosion

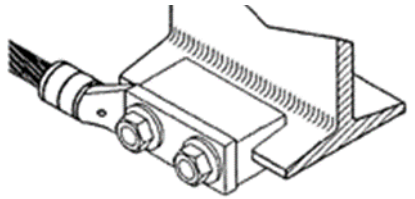
- Galvanic corrosion is an electrochemical process whereby one metal corrodes preferentially to another whenever both metals are put in electrical contact and immersed in an electrolyte.
- What is surprising to some is that soil or air can act as an electrolyte.



Grounding -Corrosion Overview

- Above grade corrosion takes place mainly through galvanic action when two metals are exposed to an electrolyte
- Below grade connections are subject to galvanic corrosion and acidic corrosion depends on soil pH.
- Fence posts, gates, mesh and barbed wire often require bonding to the ground system. Connecting to structural steel has similar requirements to those described for pipe including unique configuration, potential for corrosion, and structural dependence.





Underground

Copper and galvanized steel are more susceptible to corrosion where the pH of the soil exceeds 8. Soil analysis at this site (a dairy pasture) indicated a large concentration of organic acids. Stainless steel ground rods were recommended, along with tinned 250 kcmil copper conductors. They were connected with a bronze fitting listed for that purpose, and coated with zinc-rich protective paint.

Bare copper can be directly attached to rebar for concrete encasement. Note that exothermic welding was utilized for this purpose. The concrete that will surround the rebar will act as a buffer, helping to prevent galvanic action from the soil. (“Steel rebar embedded in concrete has approximately the same potential as copper, thus will not corrode” – IEEE Std. 142-1991)

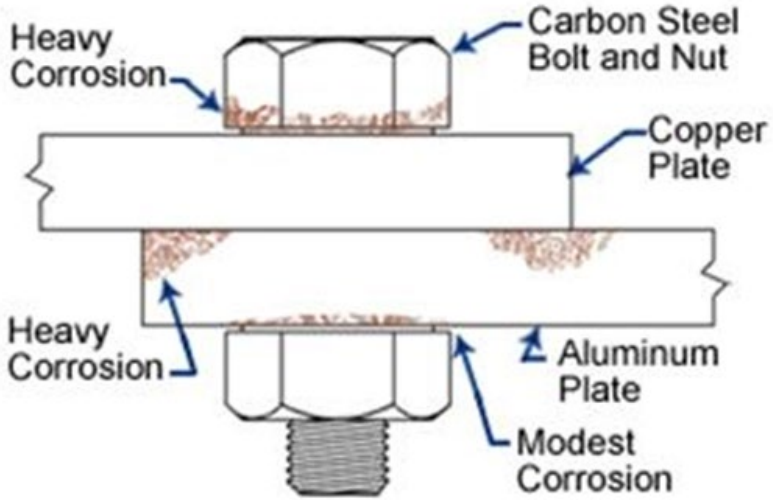
Above ground

Outdoor air can act as an electrolyte because it contains a variety of components which can cause corrosion of any metal. Varying moisture levels, salt and other contaminants are just a few. In overhead, outdoor construction, copper runoff can cause staining of pavement materials. It's one reason why older overhead telephone wiring (before plastic coverings) was usually tinned. In addition, copper runoff can be very corrosive to galvanized steel support structures, even when not in direct contact. In such cases, tinning of the conductors is recommended to prevent such conditions.

Tinned 4/0 copper conductor attached to a galvanized steel flange of a support column. Note the high pressure compression fitting and protective paint

Effect of Galvanic Corrosion

Example for which metal will corrode in contact with another dissimilar metallic material. Tin plating mitigates corrosion between galvanized steel and copper. Connecting bare copper to galvanized steel is not recommended for any environment.



Effects of Galvanic Corrosion

Galvanic compatibility

Metallurgy	Index (V)
Gold, solid and plated, Gold-platinum alloy	0.00
Rhodium plated on silver-plated copper	0.05
Silver, solid or plated; monel metal. High nickel-copper alloys	0.15
Nickel, solid or plated, titanium an s alloys, Monel	0.30
Copper, solid or plated; low brasses or bronzes; silver solder; German silvery high copper-nickel alloys; nickel-chromium alloys	0.35
Brass and bronzes	0.40
High brasses and bronzes	0.45
18% chromium type corrosion-resistant steels	0.50
Chromium plated; tin plated; 12% chromium type corrosion-resistant steels	0.60
Tin-plate; tin-lead solder	0.65
Lead, solid or plated; high lead alloys	0.70
Aluminum, wrought alloys of the 2000 Series	0.75
Iron, wrought, gray or malleable, plain carbon and low alloy steels	0.85
Aluminum, wrought alloys other than 2000 Series aluminum, cast alloys of the silicon type	0.90
Aluminum, cast alloys other than silicon type, cadmium, plated and chromate	0.95
Hot-dip-zinc plate; galvanized steel	1.20
Zinc, wrought; zinc-base die-casting alloys; zinc plated	1.25

For ***harsh environments***, such as outdoors, high humidity, and salt environments fall into this category. Typically there should be not more than 0.15 V difference in the "Anodic Index". For example; gold - silver would have a difference of 0.15V being acceptable.

For ***normal environments***, such as storage in warehouses or non-temperature and humidity controlled environments. Typically there should not be more than 0.25 V difference in the "Anodic Index".

For ***controlled environments***, such that are temperature and humidity controlled, 0.50 V can be tolerated. Caution should be maintained when deciding for this application as humidity and temperature do vary from regions.

This serves as a basic qualitative guide only.

Experimental data: ASTM B117 -Salt Spray (Fog) exposure Samples after 1008 hours

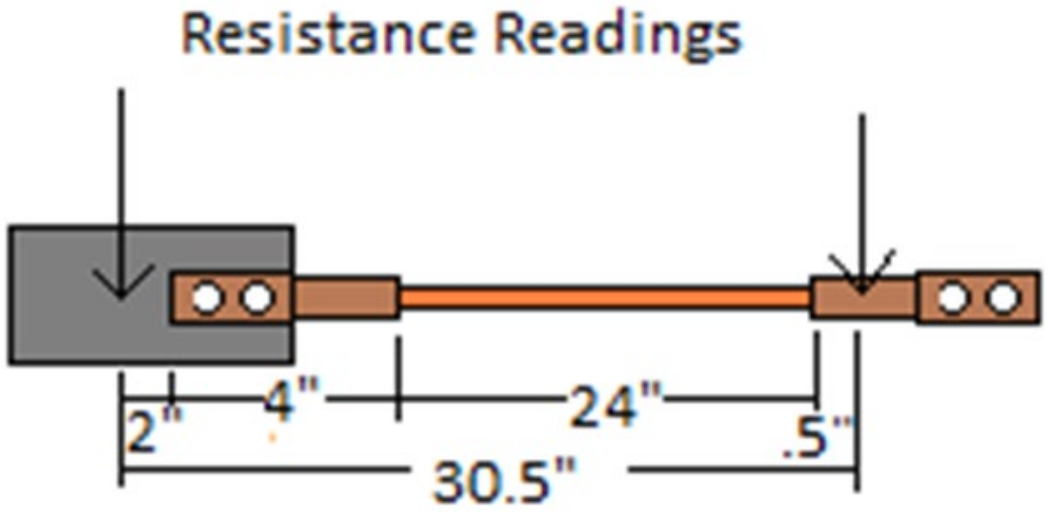
Sample #	Catalog #	Plating	Type	Material to Test	Installation
1	YGHA26-2NTN	Tin	Compression	Steel	No Penetrox
2	YGHA26-2NTN	Tin	Compression	Copper	No Penetrox
3	YGHA26-2N	Non-Plated	Compression	Steel	No Penetrox
4	YGHA26-2N	Non-Plated	Compression	Copper	No Penetrox
5	BCS-3	Non-Plated	Exothermic	Copper to Steel plate	No Penetrox
6	BCS-3	Non-Plated	Exothermic	Copper Clad to Steel plate	No Penetrox
7	GAR6426	Non-Plated	Mechanical	Steel	No Penetrox
8	GAR6426TN	Tin	Mechanical	Steel	No Penetrox
11	GAR6426TN	Tin	Mechanical	Copper Ground rod	No Penetrox
12	GAR6426	Non-Plated	Mechanical	Copper Ground rod	No Penetrox
13	GAR6426	Non-Plated	Mechanical	Steel rod	With Penetrox
14	GAR6426	Non-Plated	Mechanical	Copper rod	With Penetrox
15	YGHA26-2NTN	Tin Plated	Use w/WEEB-2N	Powder coated Steel Plate	No Penetrox
16	YGHA26-2NTN	Tin Plated	Use w/WEEB-2N	Powder coated Steel Plate	With Penetrox
17	YGHA26-2NTN	Tin Plated	Compression	Steel Plate	With Penetrox
18	YGHA26-2NTN	Tin Plated	Compression	Copper Plate	With Penetrox

Yellow- Highest resistance increase
Green – lowest resistance increase
Blue – Resistance fluctuating at 168 hours and 336 hours

Salt spray corrosion stages

Video

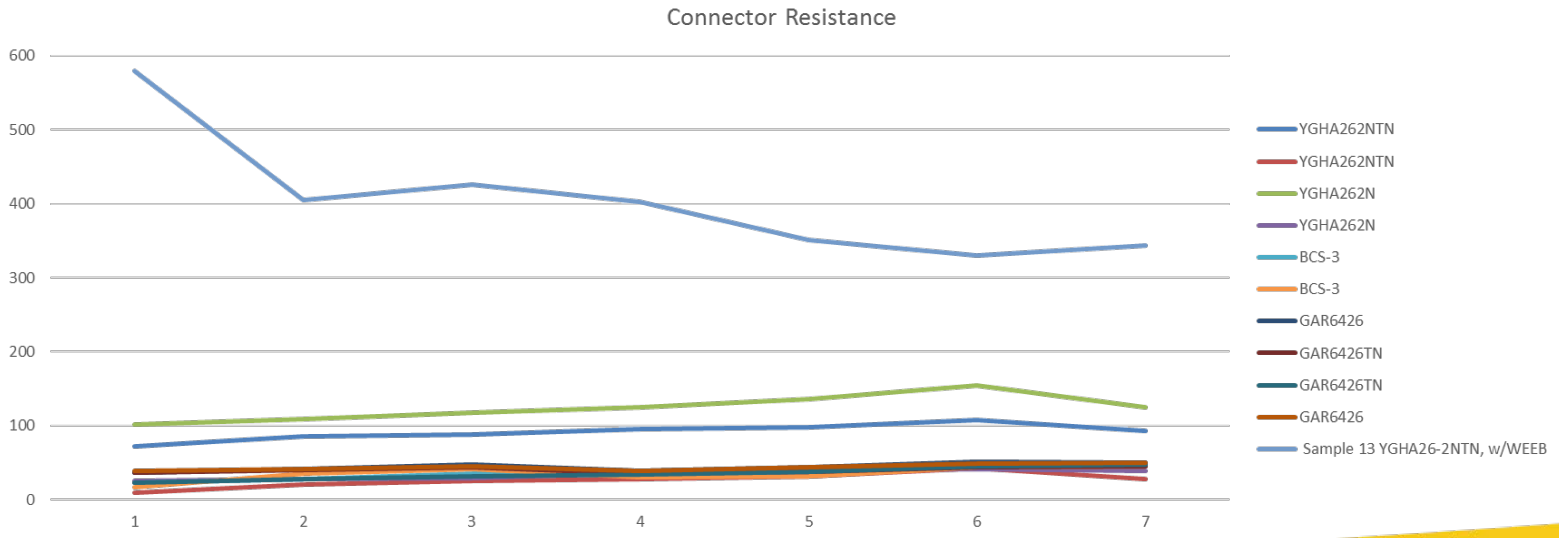
Resistance Measurements and Equipment



MANUFACTURER	MODEL	DESCRIPTION	SERIAL #	RANGE	CAL DATE	DUE DATE
AGILENT	U1252B	DMM	MY54130243	AUTO	11/28/18	11/28/19
ASCOTT	1000L1P	Salt Fog Chamber	2021	20°C to 40°C	05/03/18	05/03/19
SORENSEN	DCS8-125	POWER SUPPLY	9308124	0-125 DC AMPS	05/04/18	05/04/19

Resistance data for connections without Penetrox™

			Initial Reading Before Test (21°C)		Reading 1 168 Hours (21°C)			Reading 2 336 Hours (22°C)			Reading 3 504 Hours (20°C)			Reading 4 672 Hours (23°C)			Reading 5 840 Hours (22°C)			Reading 6 1008 Hours (22°C)		
Sample	Connector	Conductor	Actual	Cor to 21°C	Actual	Cor to 21°C	% RR	Actual	Cor to 20°C	% RR	Actual	Cor to 20°C	% RR	Actual	Cor to 20°C	% RR	Actual	Cor to 20°C	% RR	Actual	Cor to 20°C	% RR
1	YGHA262NTN	Steel Plate	72.9	72.6	85.8	85.5	117.7%	89.2	88.5	121.9%	95.8	95.8	131.9%	99.6	98.4	135.5%	108.7	107.8	148.5%	94.1	93.3	128.6%
2	YGHA262NTN	Copper Plate	10.1	10.1	20.5	20.4	203.0%	25.8	25.6	254.4%	27.5	27.5	273.4%	31.5	31.1	309.4%	42.6	42.3	420.1%	28.3	28.1	279.1%
3	YGHA262N	Steel Plate	101.9	101.5	109.5	109.1	107.5%	117.9	117.0	115.2%	125.2	125.2	123.4%	137.4	135.8	133.8%	155.4	154.2	151.9%	126.4	125.4	123.5%
4	YGHA262N	Copper Plate	25.9	25.8	28.5	28.4	110.0%	28.9	28.7	111.1%	36.6	36.6	141.9%	39.1	38.6	149.8%	42.1	41.8	161.9%	38.7	38.4	148.8%
5	BCS-3	2/0 AWG	22.8	22.7	27.7	27.6	121.5%	35.9	35.6	156.8%	38.9	38.9	171.3%	41.6	41.1	181.0%	48.8	48.4	213.2%	45.2	44.8	197.4%
6	BCS-3	7 NO. 7	17.1	17.0	35.5	35.4	207.6%	42.1	41.8	245.2%	30.2	30.2	177.3%	31.8	31.4	184.5%	44.3	43.9	258.0%	45.8	45.4	266.8%
7	GAR6426	Steel Pipe	37.2	37.1	42.0	41.8	112.9%	48.3	47.9	129.3%	38.5	38.5	103.9%	44.7	44.2	119.2%	51.5	51.1	137.9%	50.8	50.4	136.0%
8	GAR6426TN	Steel Pipe	36.8	36.7	40	39.8	108.7%	44.6	44.2	120.7%	34.9	34.9	95.2%	38.3	37.8	103.2%	44.6	44.2	120.7%	45.7	45.3	123.7%
9	KC26	Galv. Steel	49.2	49.0	43.8	43.6	89.0%	73.2	72.6	148.2%	124.6	124.6	254.3%	155.2	153.3	312.9%	161.7	160.4	327.3%	165.2	163.9	334.4%
10	KC26	Steel	62.1	61.9	54.4	54.2	87.6%	102.9	102.1	165.0%	78.4	78.4	126.8%	88.7	87.6	141.7%	92.7	92.0	148.7%	92.4	91.7	148.2%
11	GAR6426TN	Ground Rod	23.4	23.3	27.4	27.3	117.1%	32.1	31.8	136.6%	34.1	34.1	146.3%	38.5	38.0	163.2%	45.1	44.7	192.0%	48.5	48.1	206.4%
12	GAR6426	Ground Rod	38.8	38.6	41.4	41.2	106.7%	45.4	45.0	116.5%	38.6	38.6	99.9%	44.9	44.4	114.8%	48.7	48.3	125.0%	49.9	49.5	128.1%
13	Sample 13 YGHA26-2NTN, w/WEEB	Powder coated steel plate	533.1	579.5	451.7	404.5	69.8%	466.7	426.4	73.6%	486.8	402.2	69.4%	498.4	351.4	60.6%	506.8	330.5	57.0%	536.7	343.7	59.3%



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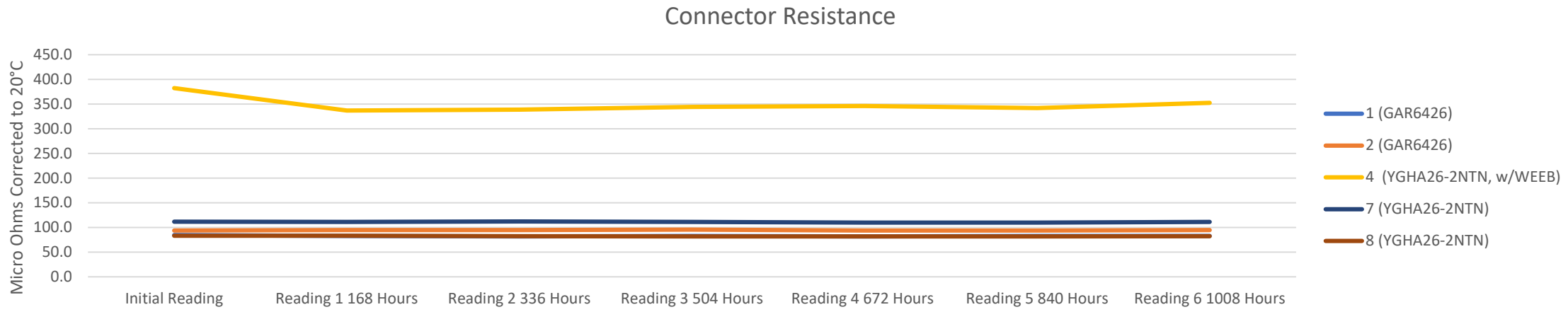
Resistance data for connections with Penetrox™

	All Readings are in Micro-Ohms and Corrected to 20°C																			
	Initial Reading		Reading 1 168 Hours			Reading 2 336 Hours			Reading 3 504 Hours			Reading 4 672 Hours			Reading 5 840 Hours			Reading 6 1008 Hours		
	Temp (°C)	22	Temp (°C)	20		Temp (°C)	20		Temp (°C)	20		Temp (°C)	19		Temp (°C)	21		Temp (°C)	21	
Sample	Measured	Corrected	Measured	Corrected	% RR	Measured	Corrected		Measured	Corrected		Measured	Corrected		Measured	Corrected		Measured	Corrected	
1 (GAR6426)	85.5	84.8	83.2	83.2	98.1%	82.2	82.2	96.9%	83.1	83.1	98.0%	81.9	82.2	96.9%	83.2	82.9	97.7%	83.2	82.9	97.7%
2 (GAR6426)	94.8	94.0	94.7	94.7	100.7%	95.1	95.1	101.1%	95.6	95.6	101.7%	93.6	94.0	99.9%	94.5	94.1	100.1%	95.2	94.8	100.8%
3 (YGHA26-2NTN, w/WEEB)	533.1	528.9	451.7	451.7	85.4%	466.7	466.7	88.2%	486.8	486.8	92.0%	498.4	500.4	94.6%	506.8	504.8	95.4%	536.7	534.6	101.1%
4 (YGHA26-2NTN, w/WEEB	385.4	382.3	337.2	337.2	88.2%	338.9	338.9	88.6%	344.3	344.3	90.1%	344.7	346.1	90.5%	343.3	341.9	89.4%	354.1	352.7	92.2%
7 (YGHA26-2NTN)	112.9	112.0	111.5	111.5	99.6%	112.4	112.4	100.4%	111.3	111.3	99.4%	109.6	110.0	98.2%	110.7	110.3	98.4%	111.8	111.4	99.4%
8 (YGHA26-2NTN)	84.1	83.4	83.3	83.3	99.8%	82.5	82.5	98.9%	82.1	82.1	98.4%	81.7	82.0	98.3%	82.5	82.2	98.5%	82.9	82.6	99.0%



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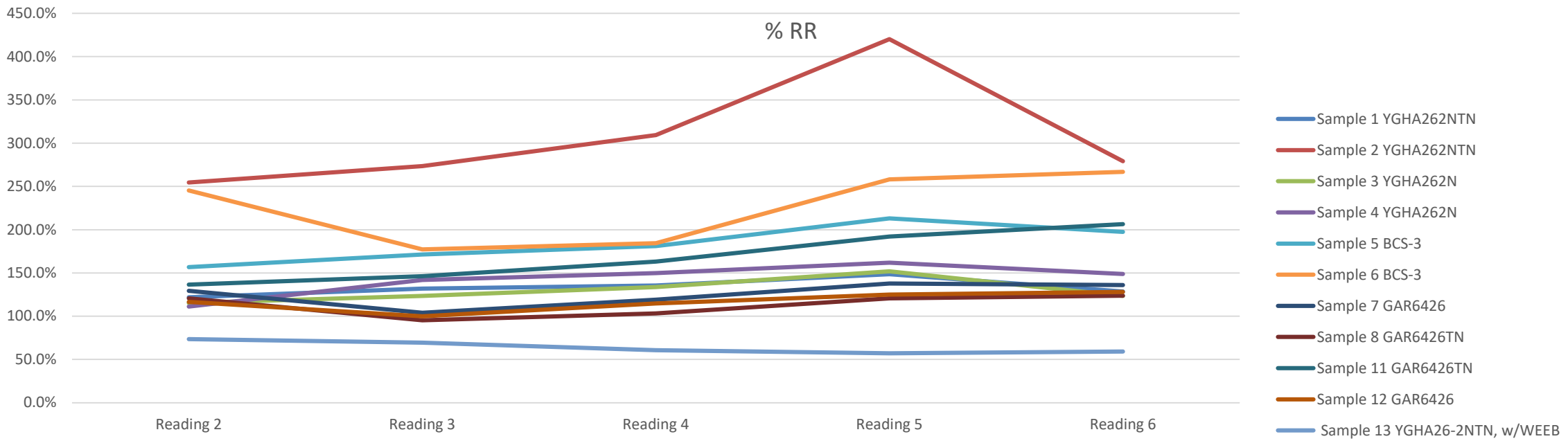
RR data for connections without Penetrox™



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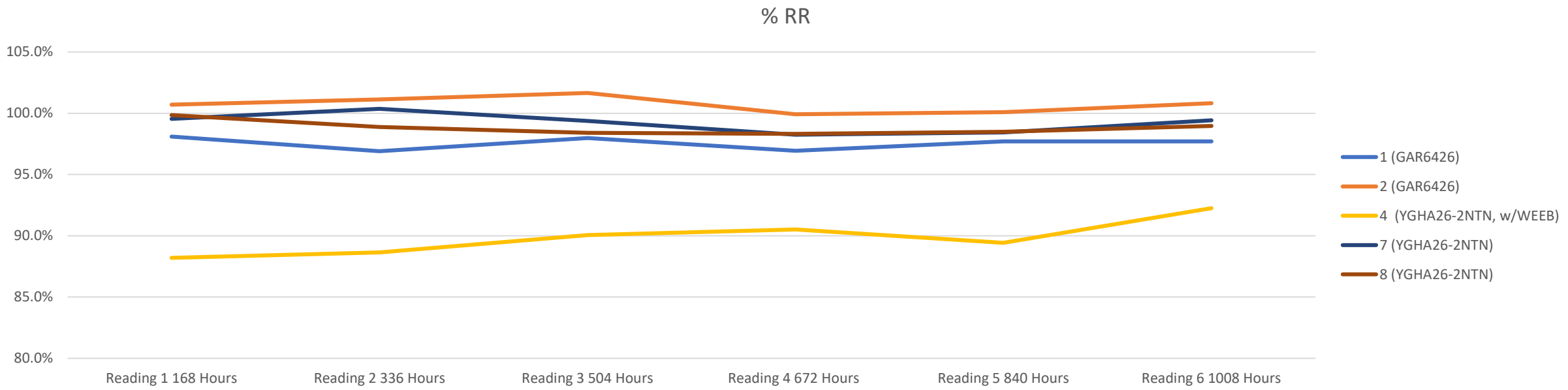
RR data for connections with Penetrox™



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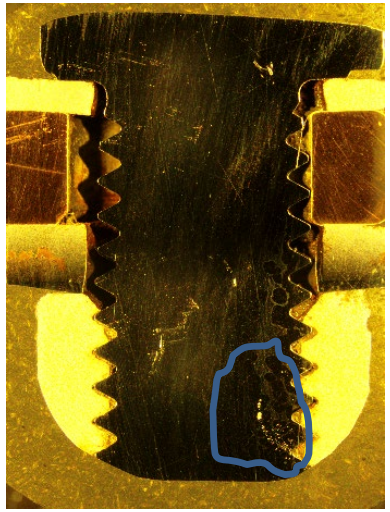
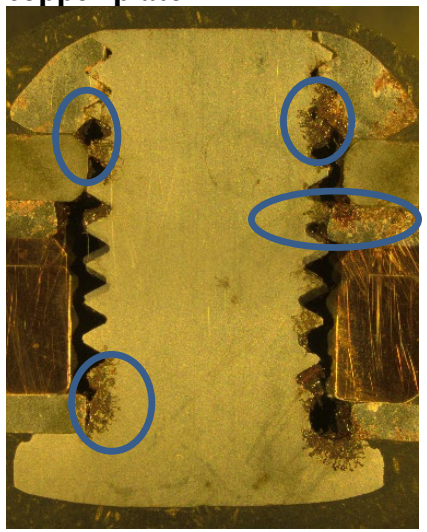
Connection cross sections without Penetrox™

Cross sections of assembled connections after 1008 hours of salt spray with corroded area in different locations.

Sample1. (Image_216)
YGHA262NTN with **steel plate** and **SS hardware**

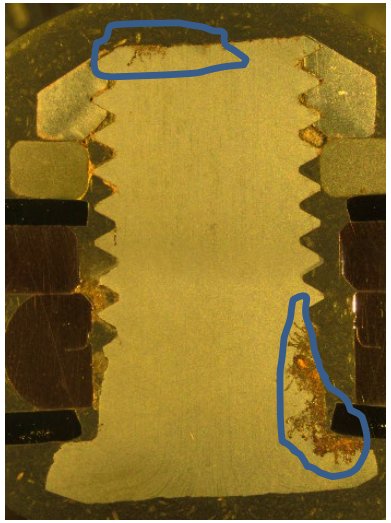


Sample 2. (Image_219)
YGHA262NTN with **copper plate** and SS hardware



Sample 3. (Image_214)
YGHA262N with steel plate and SS hardware

Sample 4. (Image_220)
YGHA262N with copper plate and SS hardware



Fragments of corrosion area from samples 1-4 shown above.

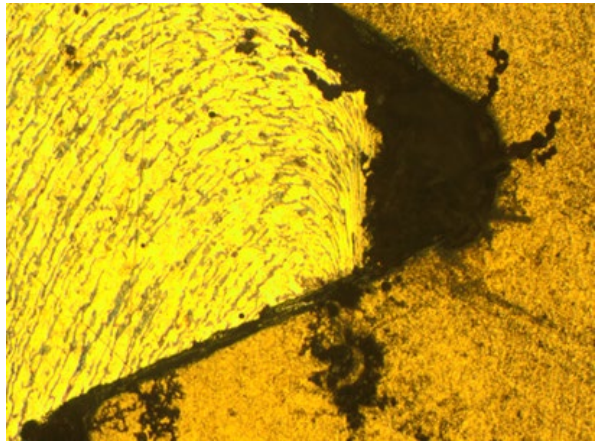


Photo 1. Copper to steel. Pitting Corrosion

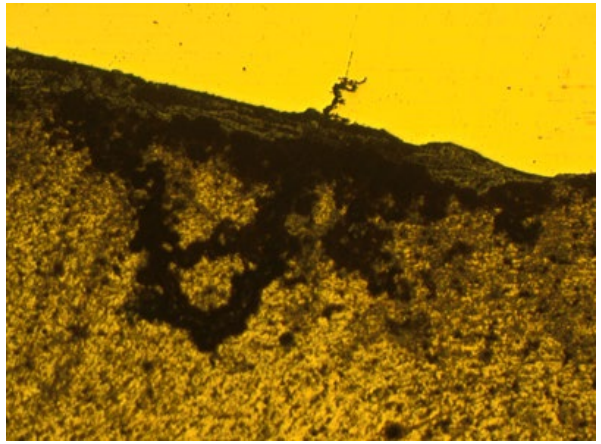


Photo 2. Copper to steel. Pitting Corrosion

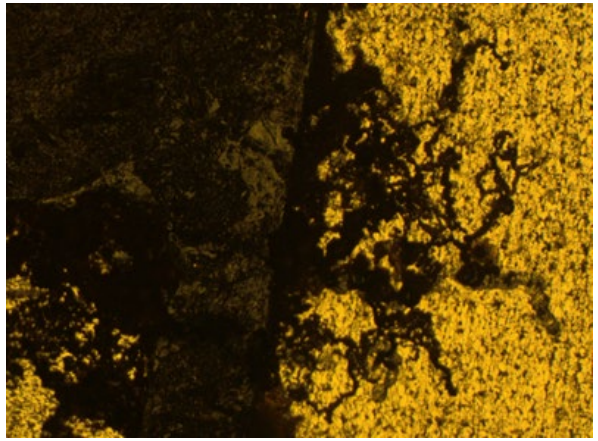
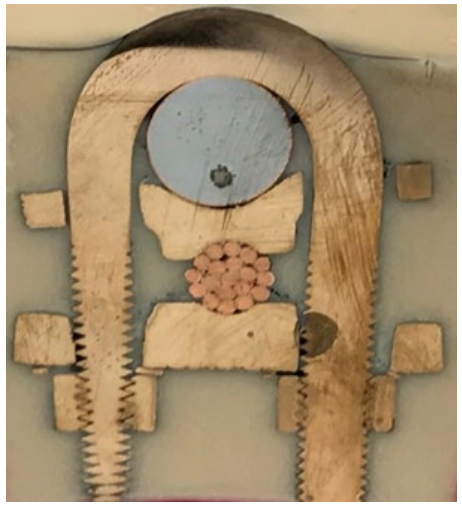


Photo 3. Steel Corrosion

Connections Cross-sections without Penetrox™

BCS-3 with 7 No. 7
Copper clad to Steel Plate

GAR6426TN
Copper ground rod



GAR6426
to Copper ground rod

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Observations

- The amount of deep pitting in the steel during this testing on all samples is a good indication of the severity of the test procedure.
- All but two of the connections exhibited relative stability and even those two were stabilizing by the end of test. This would indicate a long-life expectancy even in very harsh corrosive conditions.
- Applying Penetrox™ to all connections noticeably improved resistance stability

Summary

- Copper to Steel and Tinned Copper to Powder coated steel (Samples 1, 3, and 15) showed the highest increase of resistance after 1008 cycles of salt spray and most severe corrosion area in the copper – steel contact. Observed galvanic corrosion
- Copper to Copper connections (Samples 2, 4 and 11, 12) and Exothermic connections (Samples 5 and 6) showed lowest increase of resistance after 1008 hours of Salt Spray and no visible corrosion in contact area. Observed no galvanic corrosion.
- Connections of Copper GAR ‘s plated and not plated to Steel Pipe showed some fluctuations of the resistance between 168 hours and 336 hours of salt spray and then some increase of the resistance until 1008 hours of Salt spray. Non conclusive

Conclusions

- Experimental data proved that galvanized steel and steel are not a good choice for grounding applications with copper because of galvanic corrosion and increasing resistance with increasing time of the exposure to salt spray. In real life the corrosive environment can be more complex and severe than lab conditions.
- Best results were achieved with Copper to Copper connections and copper clad to steel plate at Exothermic connection.
- The use of a proper oxide inhibitor can mitigate the majority of the corrosion effects at the connection interface.

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