“A Technical Report on The Service Life of Ground Rod Electrodes”

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Forward

This report is intended to provide the electrical industry with technical information that will facilitate the proper application of ground rod electrodes. In addition to its electrical design and function, the grounding system must also be qualified based on the corrosion resistance of its component parts. Electrical elements buried underground are subject to much harsher conditions than their counterparts that reside above-grade or inside a structure. The ability of an electrical grounding component to resist corrosion determines its service life. Corrosion itself is a complicated phenomenon that has an entire engineering community dedicated to its study and prevention. Unfortunately, that knowledge and expertise has translated very little to the electrical community. As a result, there is a general lack of understanding as to what differentiates a copperbonded ground rod from a galvanized ground rod. The answer primarily lies in the ability of the two coating materials, namely copper and zinc, to resist all forms of corrosion: galvanic, electrolytic, and chemical. The following is a discussion that combines theory, independent technical studies, and practical field experience to allow engineers, contractors, inspectors, industry groups, and other interested parties to make educated decisions.

Functions of the Grounding System

A modern facility grounding system serves many purposes. Its most important task, and that which should be held paramount, is to protect people. The grounding system limits the voltage potential between non-current carrying conductive objects and between non-current carrying conductive objects and the earth effectively reducing the risk of electrical shock. The grounding system is also essential to the safe and effective dissipation of lightning current captured by lightning protection systems and effective operation of transient voltage surge suppressors (TVSS). TVSS devices are put under increased stress by a poor grounding system and their ability to protect valuable equipment is compromised. In a lightning protection design, failure of any of the grounding components significantly increases the risk of side flashing and structure fire during a lightning event. Modern electronic equipment relies on an effective grounding system to provide a signal reference for low voltage digital signals. Utilities rely on effective grounding to prevent the flashover of insulators on transmission lines and to protect expensive equipment, such as transformers, capacitors, reclosers, and lightning arrestors used on distribution systems. Most would agree that these are all very important functions. It is the importance of any system that should drive the quality of the components used to implement it.

Grounding System Components

The performance of the grounding system is dependent upon the effective operation of several installed components: the grounding conductor, the grounding connector, and the grounding electrode. Failure of any one of these components renders the entire system ineffective and increases the jeopardy to people and equipment. Most of the grounding system is concealed in the harsh underground environment, making inspection of the elements difficult or impossible. The initial selection of the components used in the grounding system is of critical importance to its long-term effectiveness. They should possess excellent electrical conductivity, be mechanically robust, be able to withstand repeated fault and surge currents, and be resistant to corrosion. Ideally, the grounding system components should have a service life equal to that of the facility.

Importance of the Ground Rod

The grounding electrode provides the physical connection to the earth and is the instrument used to dissipate current into it. The copper cold water pipe has historically performed this role. Although many facilities have primarily relied on the cold water pipe in the past, less copper water pipe is now being installed in favor of non-conductive plastics. To accommodate this, the NEC requires that the water pipe ground be supplemented with an additional electrode. There are many types of electrodes available to meet this safety requirement including structural steel, concrete-encased electrodes, plates, ground rings, and rod or pipe electrodes. However, the ground rod is the most commonly installed electrode of which copperbonded and galvanized steel rods dominate. The reports below will demonstrate the corrosion resistance of each type of rod.

"Underground Corrosion" –National Bureau of Standards Circular 579

From 1910 to 1955, the National Bureau of Standards conducted an extensive underground corrosion study in which 36,500 specimens, representing 333 varieties of ferrous, nonferrous, and protective coating materials were exposed in 128 test locations throughout the United States. It is widely regarded as one of the most comprehensive corrosion studies ever conducted. ERICO will use this study to show that rods coated with 10 mils of copper can reasonably be expected to perform well in excess of 40 years in most soil types. It will also be shown that galvanized rods coated with 3.9 mils of zinc should be expected to perform for only 10-15 years in most soil types. The intent is to highlight the importance of choosing the proper electrode for a given application by showing the difference in life expectancy.

Section 11 of the report covers the field tests on copper and copper alloys. Table 48 compiles average weight loss per year (in oz/ft^2) of copper pipe specimens buried in 43 different soils for periods of 8 to 13 years. Each ounce per square foot corresponds to an average penetration of 1.4 mils. An analysis of the 14 soil locations that were exposed for 13 years (table 1) shows that an average total penetration after that time was less than .0005 mils. An analysis of the remaining 29 locations that were exposed for 8 years shows an average total penetration of .0009 mils. In the table below, material "M" was assigned to the copper specimens with a 99.94% copper content. Material "P" had a 99.93% copper content chemistry. The average of the two materials is also shown.

Soil	Duration	Material "M"	Material "P"	M-P Average weight loss (oz/ft2) per year	Mils/yr Penetration
31	13.7	0.0083	0.0086	0.00845	0.00001183
27	13.6	0.012	0.012	0.012	0.0000168
36	13.6	0.019	0.019	0.019	0.0000266
2	13.5	0.023	0.016	0.0195	0.0000273
5	13.4	0.03	0.032	0.031	0.0000434
7	13.4	0.036	0.026	0.031	0.0000434
9	13.4	0.03	0.036	0.033	0.0000462
26	13.4	0.013	0.012	0.0125	0.0000175
30	13.4	0.0078	0.0097	0.00875	0.00001225

41	13.4	0.027	0.03	0.0285	0.0000399
47	13.4	0.032	0.035	0.0335	0.0000469
6	13.3	0.011	0.0093	0.01015	0.00001421
10	13.2	0.076	0.095	0.0855	0.0001197
24	13.2	0.019	0.018	0.0185	0.0000259
Avg. of years	**13.42**			**Average Penetration in Mils/yr**	**0.000035135**
				Total Penetration after 13.42 yrs. (mils)	**0.000471562**

Table 1. Analysis of specimens exposed for over 13 years.

Soil	Duration	Material "M"	Material "P"	M-P Average weight loss (oz/ft2) per year	Mils/yr Penetration
1	8.1	0.06	0.063	0.0615	0.0000861
20	8.1	0.042	0.039	0.0405	0.0000567
3	8	0.027	0.029	0.028	0.0000392
8	8	0.024	0.019	0.0215	0.0000301
12	8	0.312	0.278	0.295	0.000413
13	8	0.023	0.031	0.027	0.0000378
14	8	0.04	0.025	0.0325	0.0000455
15	8	0.013	0.016	0.0145	0.0000203
16	8	0.057	0.058	0.0575	0.0000805
17	8	0.037	0.04	0.0385	0.0000539
18	8	0.0076	0.0077	0.00765	0.00001071
19	8	0.039	0.04	0.0395	0.0000553
22	8	0.068	0.07	0.069	0.0000966
23	8	0.118	0.135	0.1265	0.0001771
25	8	0.012	0.011	0.0115	0.0000161
28	8	0.084	0.079	0.0815	0.0001141
29	8	0.123	0.116	0.1195	0.0001673
33	8	0.137	0.117	0.127	0.0001778
34	8	0.016	0.022	0.019	0.0000266
35	8	0.017	0.016	0.0165	0.0000231
37	8	0.169	0.162	0.1655	0.0002317
38	8	0.025	0.043	0.034	0.0000476
40	8	0.125	0.168	0.1465	0.0002051
42	8	0.047	0.049	0.048	0.0000672
43	8	0.635	0.555	0.595	0.000833
44	8	0.079	0.061	0.07	0.000098
45	8	0.033	0.03	0.0315	0.0000441
4	7.9	0.019	0.019	0.019	0.0000266
32	7.9	0.049	0.018	0.0335	0.0000469
Avg. of years	**8**			**Average Penetration in Mils/yr**	**0.000114759**
				Total Penetration after 8 yrs. (mils)	**0.000918072**

Table 2. **Analysis of specimens exposed for 8 years.**

The time required to remove 10 mils of copper can be used to establish a ground rod's nominal service life. Although different soils were used, the data from 8 to 13 years shows that the rate of corrosion seems to lessen with time. This is probably due to the protective copper oxide film that develops on the rod. Although extrapolated corrosion data often does not follow real life exposure, it can be conservatively assumed that in the vast majority of soils tested, a service life of far in excess of 40 years can be expected.

In 1924, an underground exposure test was initiated on a series of five different base metals to which a series of zinc coatings were applied by the hot-dip process. The test was terminated after 10 years. 208 galvanized pipe specimens were tested with an average zinc coating thickness of 2.82 ounces per square foot. Each ounce per square foot equals .00172" of coating thickness for a total of roughly 4.9 mils of zinc. Additionally, a number of galvanized steel plates were buried with a coating thickness range of 2.8 – 8.8 mils. The results are summarized in Table 65 of the study. The report states, "An analysis of these data showed that in most of the soils, zinc coatings of 2 oz (3.5 mils) or less were destroyed during the 10 year exposure period, and pitting of the underlying steel occurred." Regarding the protection afforded by zinc coatings to steel pipe, the report concludes, "…a nominal 2-oz coating would be adequate in inorganic oxidizing soils for at least 10 years. It was also shown that a 3-oz (5.2 mils) coating provided adequate protection for 10 to 13 years in all the inorganic reducing soils except in soils containing high concentrations of soluble salts." Keep in mind; a galvanized ground rod has a nominal 3.9 mil coating.

Additionally, an analysis of the galvanized pipe shown in Table 65 shows an average penetration of roughly 2.5 mils after 10 years. Keep in mind, after 13 years; the average penetration of copper was .00047 mils. This study definitively shows the difference in corrosion resistance between copper and zinc. Copper provides protection that is several orders of magnitude greater than zinc.

"Field Testing of Electrical Grounding Rods" – Naval Civil Engineering Laboratory (NCEL)

In cooperation with the National Association of Corrosion Engineers, the NCEL conducted a 7-year program of testing metal rods for electrical grounding. Copperbonded, stainless clad, and galvanized steel rods were included among other materials. Samples were buried individually and connected in pairs to determine the galvanic corrosion effect each rod had on other metals. Although this study is not nearly as rigorous as the one undertaken by the NBS, it does provide an independent source of information specifically relating to ground rods. The study set out to establish the best type of electrode as determined by the following:

1. It should be easy to drive
2. It should be resistant to corrosion
3. It should not cause galvanic corrosion to nearby metal.

Regarding single rods, these observations were made after samples were removed following 7 years of exposure:

Galvanized steel rod: "Most of the galvanizing had been lost. Rusting of the steel was greatest near the surface of the ground. Pitting was worst here and near the tip."

Stainless-clad steel rod: "The cladding was free of corrosion, but at the tip the steel core had corroded to a point about 1 inch inside the cladding."

Copper-clad steel rod: "The copper cladding was virtually free of corrosion, but the steel core had corroded at the tip to a point 2 inches inside the cladding."

The study concluded, "Magnesium, aluminum, zinc, mild steel, and galvanized steel rods did not have the desired corrosion resistance." There was a concern about the copper clad rod causing galvanic corrosion to coupled mild steel. The amount of galvanic corrosion caused by coupling copper and steel will vary depending on their ratio. Since the ratio of steel to copper in most grounding systems is usually large, the amount of steel corrosion is negligible. Additionally, there are often other sources of copper in the ground, which can add to galvanic corrosion concerns. Two studies have now been examined that clearly show the corrosion difference, and therefore expected life, between galvanized and copperbonded rods.

National Electrical Grounding Research Project – Pawnee Site Exhumation

The NEGRP was started in 1992 to compare the long-term performance of different types of grounding electrodes. Originally organized by the Southern Nevada Chapter of the IAEI, the study is now governed by the Fire Protection Research Foundation. In 2003, one of the original sites (Pawnee) was excavated and the rod electrodes removed. 5/8" copperbonded and ¾" galvanized rod samples were exhumed. The results were definitive. The 5/8" copperbonded rod was virtually free of corrosion while the ¾" galvanized rod showed significant deterioration (see pictures on next page).

Figure 1. ¾" x 10' galvanized rod removed after 10 years (Pawnee Site).


Figure 2. 5/8" x 8' copperbonded ground rod removed after 10 years (Pawnee Site).

Figure 3. Close-up of 5/8” x 8’ copperbonded rod after 10 years. Electrode type H.

Figure 4. Close-up of ¾” x 10’ galvanized rod after 10 years. Electrode type I.

Recommendation

As a worldwide leader in manufacturing a complete range of grounding products, ERICO is uniquely qualified to comment on this subject. In 2003, ERICO sold millions of galvanized and copperbonded ground rods. ERICO's position is that galvanized ground rods are better suited for short-term, non-critical installations. For the majority of installations, copperbonded and stainless steel rods provide better protection for people and equipment due to their longer service life. Detecting failed ground rods is not easy. Their location below grade makes access difficult even if one remembers that they are there to check. Installing rods that don't need to be checked provides the greatest level of safety.

It has been shown through the independent studies above that 3.9 mils of zinc can only be expected to provide protection for 10-15 years in most soil types mimicking real-life field experience. This is substantially less than the life provided by a copperbonded rod. Although the data gathered by the NBS is over 50 years old, it is still absolutely relevant. Metals still corrode at the same rate today as they did back then. Many of the accepted practices used by the electrical industry today are based on work that pre-dates the NBS study. Let us not forget the work done by Georg Simon Ohm in the 1800s. Simply stated, the 3.9 mils of zinc on a galvanized rod is not equivalent to the 10 mils of copper on a copperbonded rod. That difference needs to be accounted for. ERICO recommends the following guidelines be used for selecting ground rods:

3.9 mil zinc coating: Acceptable for facilities having a service life of up to 10 years. Not recommended for deep driving applications.
10 mil copper coating: Acceptable for facilities having a service life up to 40 years. Acceptable for deep driving applications.
13 mil copper coating: Acceptable for facilities having a service life up to 50 years. Recommended for deep driving application.

It is important to remember that the ground rod is only one component of the grounding installation. A superior grounding design will address every aspect of the system and seek to include high quality products that maximize value to the facility owner.

REFERENCES

1. "Underground Corrosion," Melvin Romanoff, United States Department of Commerce, National Bureau of Standards, Circular 579 (April 1957).

2. "Field Testing of Electrical Grounding Rods," Naval Civil Engineering Laboratory, Naval Facilities Engineering Command, Technical Report R660 (February 1970).