The Galvanizing Standard

Performance & Durability in Guardrail Technology 2009

Gregory

Technical Information Regarding the Continuous Galvanizing Method vs. Batch Galvanizing for Coating Guardrail

Galvanized guardrail is commercially coated by either of two methods; (1) by chemically fluxing and batch dipping pre-formed steel parts into a bath of molten zinc, or (2) by first heating flat steel sheet in a reducing atmosphere and then passing it through a bath of molten zinc in a continuous moving web. While either method is capable of producing a product which meets guardrail technical specifications, the coating processes differ and produce significant metallurgical differences in the structure and characteristics of the galvanized coating. This presentation addresses those differences and their effect on the performance characteristics of the product.

The table on page three highlights many of the differences between the two galvanizing methods.

Front Cover: This installation, located on Deer Valley Road outside Newport, WA for the County of Pend Oreille, features Gregory's Continuous Galvanized W-beam directly attached to the post using The Gregory Mini Spacer. This reduced offset system requires no blocks, uses conventional posts and panel, is NCHRP-350 and MASH approved, and can be used at post spacing up to 12' 6". Designed to improve the performance of guardrail barriers with it's "predictable release", the Gregory Mini Spacer can help stretch your safety budget further than ever before. Contact us for more information!

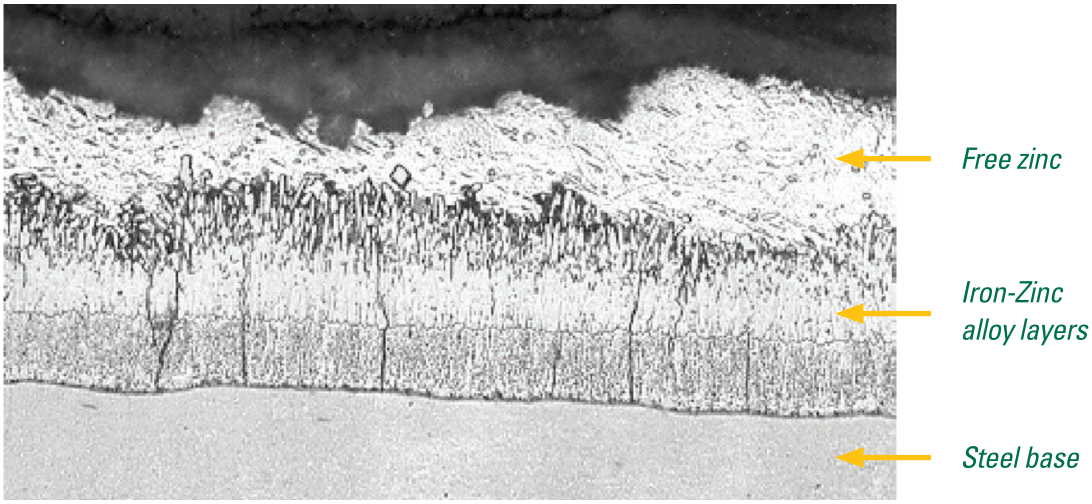
The Process

Batch Galvanizing	**Continuous Galvanizing**
Galvanizing done on pre-formed parts	Galvanized done on flat steel in coils: forming done later
Zinc immersion times of several minutes to allow significant iron-zinc alloys to form	Immersion times in zinc only a few seconds: alloy formation limited
Coating comprised of about 50% free zinc and remainder iron-zinc alloys	Coating is essentially all free zinc
Zinc thickness controlled primarily by immersion time and rate of withdrawal	Coating weight controlled by high technology air knives
Zinc coating weight typically about 4 oz. per sq. ft. of steel (but can also be affected by base metal composition)	Infinite coating control between 0.40 oz. and 4.0 oz. per sq. ft. of steel (not affected by base metal composition)
End-to-end coating uniformity on long sections affected by gravity induced draining of liquid zinc from high end	Coating done on a continuous flat web with ‘no ends’

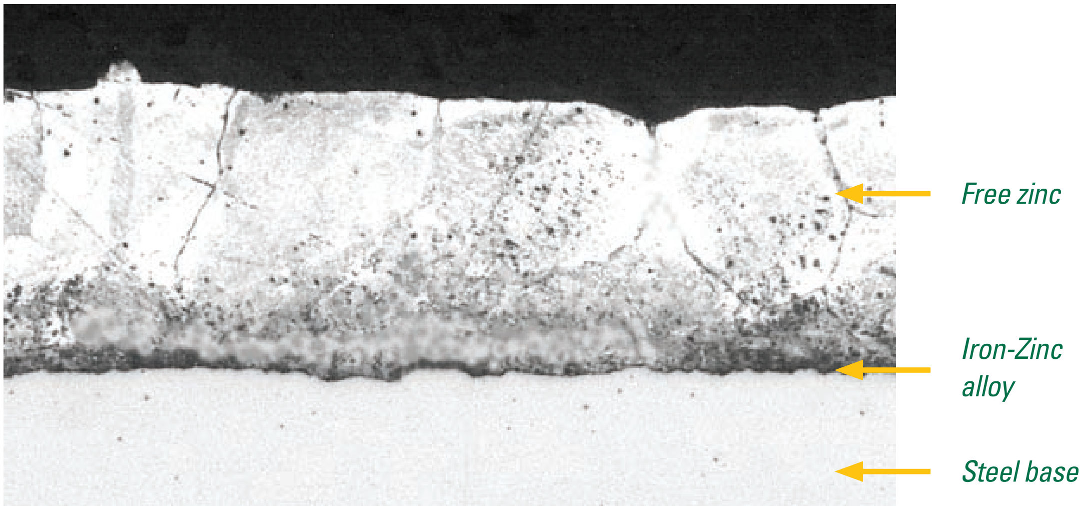
The effect of zinc immersion time combined with alloy inhibiting measures produces a very differing structure of the galvanized layers as shown in the following photomicrographs.

The Product

Micrograph Section of Batch Galvanized Coating



Micrograph Section of Continuous Galvanized Coating



The difference between the coating structures is readily seen whereby the batch galvanized product has about half of its coating in the form of iron-zinc alloy layers which have grown from the steel base. In contrast, the continuously galvanized coating consists of virtually 100% free zinc with only a 'sub-microscopic' alloy bonding layer.

In terms of corrosion performance, there is general agreement that the protective life offered by the coating is a straight-line function of the coating thickness (free zinc + alloy layers). The AASHTO federal specification body has designated two classes of zinc coating designated Type I and Type II. Type I requires a minimum average zinc coating weight of 2.0 ounces per square foot of rail and Type II requires a minimum average of 4.0 ounces per square foot of rail. Published corrosion studies[1] indicate the following:

Environment	Corrosion Loss/ yr. mils	Predicted Life: Type I	Predicted Life: Type II
Rural	0.04	42 years	85 years
Urban-Industrial	0.12	14 years	28 years
Marine	0.09	19 years	38 years

This data is taken from the standard technical literature and not yet verified by Gregory independent observations. However, zinc thickness measurements which were taken on Type II guardrail exposed for 14 years on the PA Turnpike and Type I guardrail exposed for 14 years in Charlottesville VA show lower zinc thickness attrition rates than the above and thus the numbers in the table are suspected to be conservatively low.[2] There is further evidence that the projected life shown in the above tables is significantly low as environmental awareness and regulations have reduced the levels of pollution and corrosion rates beginning in the 1980’s.[3]

The manner in which the two different galvanized products appear when corrosion has taken place is highly important. When the iron-zinc alloy layers begin to corrode, their iron content shows a rust-like appearance not readily distinguishable from base metal rusting.

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[1] X.G. Zhang, “Corrosion of Zinc & Zinc Alloys”, Table 4, ASM Metals Handbook, Volume 13B, 2005.

[2] Coating weight checks on the Charlottesville exposure (interstate highway) show minimal zinc loss after 14 years and residual coating weights are still within the Type I standards. The Type II residual coating weights from the PA Turnpike site would appear to be in excess of initial values but this is attributed to a roughening of the zinc surface by corrosion products formed in this more aggressive environment. However, it appears that the majority of the original zinc coating still is in place.

[3] X.G. Zhang, “Corrosion of Zinc & Zinc Alloys”, p. 404, ASM Metals Handbook, Volume 13B, 2005

The Product (cont.)

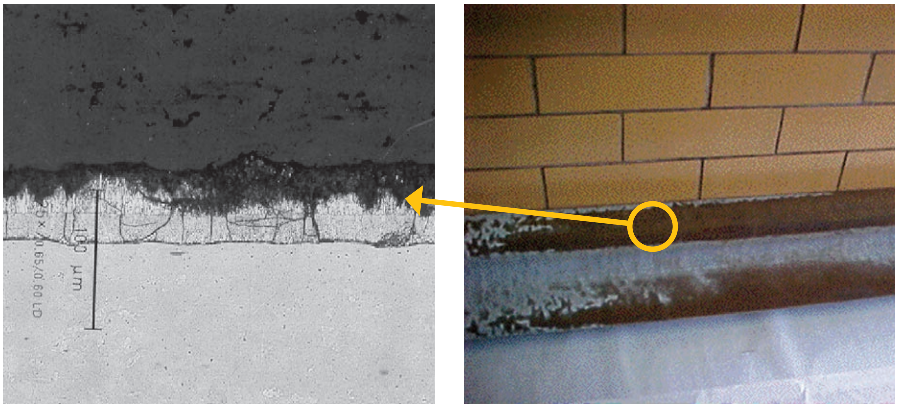
This effect is apparent when viewing guardrail which has been in service for sufficient time to allow exposure of its alloy layers to the environment. Since batch galvanized product consists of about 50% iron-zinc alloy layers, the visual lifetime prior to the appearance of rust is lowered by the presence of iron in the batch coated item.
The following photograph depicts red rust from alloy layers corrosion even though microscopic examination proves that there are residual galvanized alloy layers intact on the surface. In addition, a systematic end-to-end variation in coating thickness is frequently observed as shown below.

When a coated steel article such as guardrail is withdrawn from a liquid zinc bath, there occurs gravity-induced draining of the liquid from the high end of the article and also from high spots on the formed profile. Thus, rust-like appearance and systematic end-to-end variation are noted on batch coated rail.

In terms of zinc corrosion, it is first important to note that zinc is not an inert metal, but rather one which does react with the atmosphere but at a rate ten or more times more slowly than steel does. Thus, over years of exposure, the protective galvanized layer gradually thins away producing slightly soluble corrosion compounds which slowly wash into the environment. The free unalloyed zinc portion of the coating continues to appear as the light gray metal associated with galvanizing. However, the alloy layers contain significant amounts of iron within the coating and will thus resemble the corrosion often associated with base metal rusting. Indeed, it is difficult to distinguish between base steel corrosion and zinc alloy corrosion from a visual perspective alone.

Microscopic and other examination of a cross-section of the guardrail pictured below show iron-zinc alloy layers on the rusted areas.

As stated previously, the corrosion life expectancy of galvanized made by either process is a direct and linear function of the coating weight (free zinc + alloy layers). However, since batch galvanized product consists of about 50% iron-zinc alloy layers, the visual lifetime prior to the appearance of rust is lowered by the presence of iron in the batch coated item. Thus, from a visual perspective, the corrosion free lifetime is more closely related to free zinc thickness rather than total coating thickness. In that regard, the non-alloyed continuously galvanized product has a desirable very significantly thicker free zinc layer.



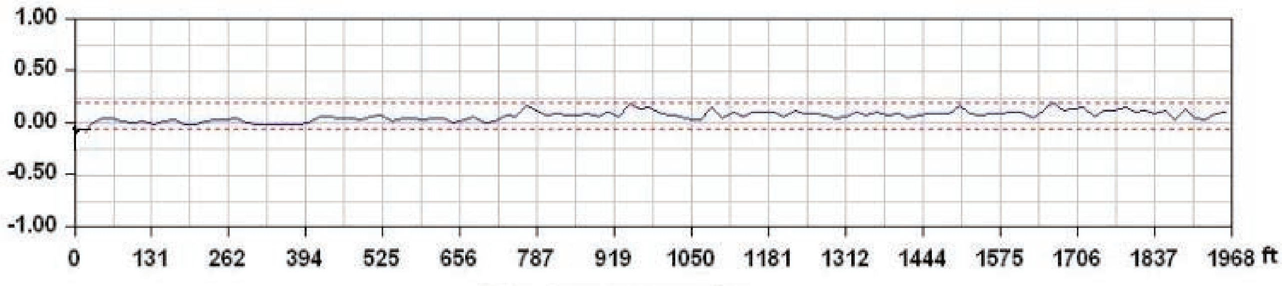
Microscopic cross-section of the coating shows an iron-zinc portion of batch galvanized coating still in place despite appearance

The above photographs also exhibit another characteristic which is associated with batch galvanizing. When a coated steel article such as guardrail is withdrawn from a liquid zinc bath, there occurs gravity-induced draining of the liquid from the high end of the article and also from high spots on the formed profile. This is the cause of the end-to-end thickness variations shown in the guardrail installation pictured above and in many others throughout the country. Such end-to-end variations have no meaning in a continuous coating process because the steel is coated as a continuous moving web and thus longitudinal uniformity is much improved. In March of 2009, Gregory Industries installed a state-of-art continuous zinc thickness of both Type I and Type II product during the coating process.

The Product (cont.)

This coating weight gage is unique in the industry and has the ability to chart three dimensional zinc profiles of the total surface of guardrail panels. The following chart exhibits a typical longitudinal profile of a Type II galvanized coil destined to be formed into guardrail panels.

Bottom Side Zinc Deviation from Aim Thickness



The ability to continuously monitor zinc coating weight during the galvanizing process affords a means to control uniformity and reliability which is unmatched in the guardrail production industry.

Galvanic Protection

Zinc coating protects steel in two ways: first by acting as a corrosion resistant barrier separating the steel from the environment; zinc corrodes but at a rate about 10 or more times more slowly than steel. Second, zinc electrochemically protects steel sacrificially where the coating is scratched or cut as at a sheared edge by the well known principle of galvanic protection. Guardrail which has been continuously galvanized and formed last has small areas of exposed steel which result from hole punching operations or transverse shearing of lengths. Speculation that exposed steel would produce rust stains has been proven unfounded because of the galvanic protection provided by zinc. The most authoritative work on galvanic protection has been done by Dr. Gregory Zhang of Cominco Ltd. His work[4,5,6] indicates that the principle of sacrificial protection in guardrail cut edges is sufficient to protect these sheared edges in this context.
In communication with Gregory Industries, Dr. Zhang has stated that, “Based on experimental results, the cut edge of galvanized steel sheets with a thickness of at least 3mm (0.120 in.) is in general galvanically protected in normal atmospheric environments”. (3 mm converts to 0.120 inch).

This photograph was taken in April, 2009, fifteen years after erection and service of Gregory rail (on the right) on the Pennsylvania Turnpike between Pittsburgh and Youngstown. This section does not show any corrosion problem at this transverse sheared edge or at bolt holes. The section on the left of the photograph is not of Gregory origin.

Theoretical indications regarding the effectiveness of sacrificial edge protection have been confirmed by actual observations under conditions of real exposure. In that regard, Gregory has a large body of experience in a wide area of the United States. A typical installation of guardrail on the Pennsylvania Turnpike (in an area where road de-icing salts are used in the winter and between the industrial cities of Pittsburgh and Youngstown) shows no significant corrosion of sheared edges after 15 years' exposure as the following photograph shows.

A longer view of the same installation (left) showing all the product in excellent condition after 15 years exposure

Gregory Industries, Inc. has conducted accelerated corrosion tests which confirm the efficacy of edge protection. These tests were verified by an independent study done by the Michigan DOT which concludes that "There was no difference in guardrail corrosion performance in the salt fog test for the two methods of manufacturing (pre and post galvanized) based on visual inspection and nut loosening torque values."[7] The above facts are consistent with the AASHTO M180 specification which states *"The beams may be galvanized before or after fabrication" and "Uncoated edges resulting from transverse shearing or punching of holes will not be considered objectionable".*

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[4] X.G. Zhang, Galvanic Protection Distance of Zinc Coated Steel under Various Environmental Conditions @, Corrosion, Vol.56, p139-143, 2000.

[5] X.G. Zhang, Galvanic Corrosion @, book chapter in the Uhlig Corrosion Handbook, Second Edition, 2000

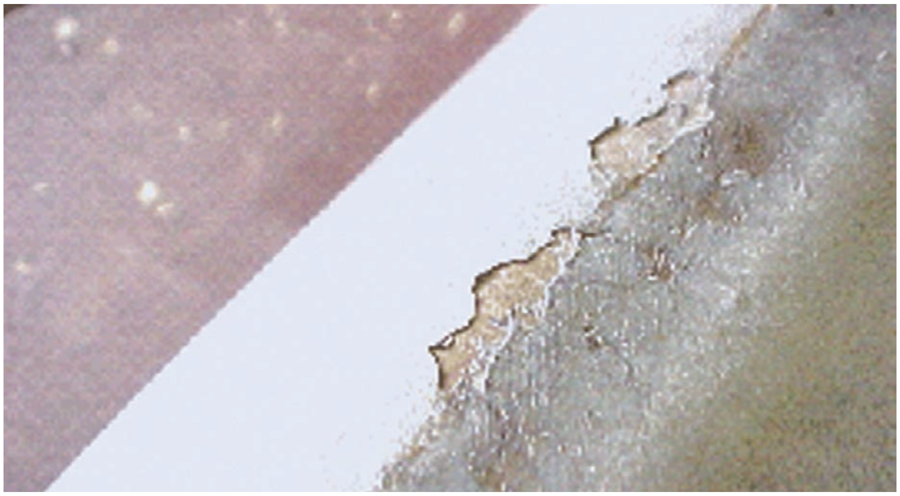
[6] X.G. Zhang, "Corrosion of Zinc and Zinc Alloys" ASM Metals Handbook, Volume 13B, 2005.

[7] Copy of the MI DOT report available upon request

Coating Ductility & Adhesion

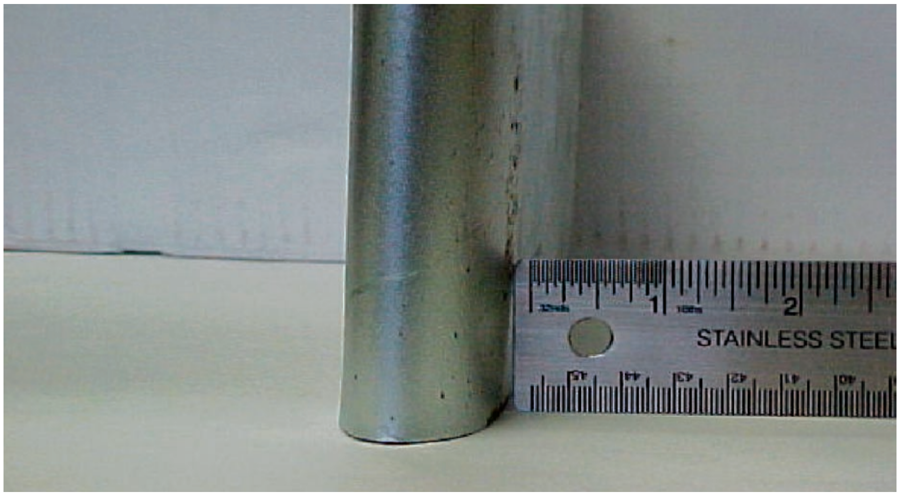
We had previously noted that a batch galvanized article has about half of its coating in the form of iron zinc alloy compounds. These are notoriously brittle and thus tend to crack when the article is deformed or impacted. In contrast, a continuous galvanized coating is virtually 100% ductile free zinc. It is not uncommon to see coating damage on batch galvanized areas where there has been accidental deformation or impact damage as below:

Example of coating fracture and spalling due to impact damage on batch galvanized guardrail



In contrast, a continuous alloy-free coating can readily be bent nearly 180 degrees without cracking or peeling as shown below.

The steel sample was a flat section coated to Type II guardrail standards and then formed in a 180º bend to show the coating ductility



Environmentally Friendly

The continous method of galvanizing guardrail is environmentally friendly in terms of both content and energy. The lead content of the coating applied by Gregory is virtually zero and falls within the RoHS standards (less than 0.10%). This is in contrast to most batch galvanizing processes which use, for technical reasons, a zinc bath which produces a residual lead content of about 0.5% in the coating. As the guardrail weathers, and the coating is gradually consumed, the lead is released to the surrounding environment. In addition, the surface passivation treatment of Gregory galvanized product uniquely meets the RoHS standards for hexavalent chromium.

In terms of energy use, the continuous galvanizing method used by Gregory Industries, Inc. is highly efficient using primarily electrical energy instead of natural gas. Our experience and studies have shown that the total energy need to galvanize in our facilities is at least three times lower than comparable galvanizing by the batch hot dip method.

Specification	Min. Avg. oz/ft^2 per side	Min. Spot oz/ft^2 per side	Min. Avg. mils per side	Min. Avg. spot mils per side
AASHTO M 180 Type I	1.00	0.90	1.70	1.53
AASHTO M 180 Type II	2.00	1.80	3.40	3.06
CAN/CSA-G164-M92	1.31	1.18	2.22	2.00

Summary & Conclusions

1. All Gregory guardrail product is produced in conformance with the following standards. (All below in terms of 'per side' of product)
2. Gregory Industries, Inc. offers Type I and Type II coated rail to the guardrail market at the choice of the buyer. In severe applications, such as industrial or tropical marine environments, a more economical Type I rail is projected to have a use life approaching 20 or more years and, in rural environments, a use life exceeding 40 years and could thus be the product of choice.
3. Continuous galvanized rail has a coating of 100% zinc instead of the typical iron-zinc alloy comprising half of the coating. The alloy portion of the coating is less desirable due to the red rust when it is exposed. This raises serious questions as to whether the base steel beam has been thinned. A continuous galvanized coating will continue to appear gray as it weathers throughout its entire service life.
4. The principle of galvanic protection which is offered by zinc is effective in preventing unwanted rust staining or corrosion at sheared edges for both Type I & Type II coatings.
5. Since the continuous galvanized product is roll formed after galvanizing, the shape and dimensional conformity are superior to product which has been formed prior to galvanizing.
6. The coated edges of the rail are clean and free from zinc 'icicles'; thus more feet of this rail can be erected per time unit; and installation is minimized saving time and money.
7. Continuously galvanized rail has a more superior formability and resistance to impact damage.
8. The continuous galvanizing process is more energy efficient.
9. The continuous galvanized coating is more environmentally friendly as it is virtually and uniquely lead free and meets RoHS environmental standards. In contrast, the batch dip galvanizing process typically uses a zinc spelter containing about one percent lead, much of which remains in the coating. Such lead will gradually leach into the environment as the product weathers. Also, Gregory uses a surface passivation system which meets the environmental standards for hexavalent chrome. In addition, Gregory Industries, Inc. requires three or more times lower total energy units per ton of product galvanized compared with the batch hot dip method.

Type I or Type II

Gregory Indusries produces both Type I and Type II guardrail specifications. The products are identical with the single exception of zinc coating thickness requirements[8]. The AASHTO committee has designated both types in their specifications, ostensibly because corrosion conditions and corrosion rates vary so widely in the various geographical areas of the United States. For example, a study of the corrosivity of 45 world-wide locations which was done under the auspices of the ASTM[9] shows an average annual zinc weight loss in 12 northeastern and midwest U.S. cities of 0.10 oz/ft^2 compared with only .013 oz./ft^2 in Phoenix, Arizona. These data predict a coating lifetime in the Phoenix area which is more than seven times that of the comparative eastern/midwest cities. Thus, a Type I coating in the Phoenix area (and presumably in a large part of the west and southwest) can be expected to have a service life more than 3.5 times longer than Type II in its comparison cities even though the initial zinc weight is only half as much. Consequently, a more economical Type I coating may be the specification of choice in many applications.

The factors which affect the corrosion rate of galvanized steel have been studied and qualified in a 1968 study authored by Guttman and Sereda[10]. They found positive correlations between corrosion rates and the following three factors; time of wetness, temperature and SO_2 concentrations. In the case of guardrail, the close proximity to highways adds another highly important factor which is snow and ice precipitation which results in the use of road salt and exposure from splashing. Gregory's observations of guardrail exposed for 15 years are relevantly consitent with these published studies except that it presently appears that pollution abatement efforts in the U.S. have reduced corrosion rates overall. Our evaluations of Type II rail exposed on the Pennsylvania turnpike near Pittsburgh show a coating thickness which appears to be close to or in excess of its initial unexposed values. However, closer examination shows that a surface roughness has developed because of the development of dense and adherent corrosion products on the surface (thus making accurate residual zinc thickness values indeterminate).

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[8] AASHTO specifies a zinc wt. of 2.0 oz/ft^2 of product on Type I guardrail and 4.0 oz/ft^2 on Type II rail

[9] "Metal Corrosion in the Atmosphere", ASTM STP 435, Table 15

[10] ibid

This is typical of atmosphere corrosion of galvanized products and is discussed more thoroughly by X. Gregory Zhang[11].

In contrast to the above, Type I guardrail exposed near Charlottesville, VA for the same time period shows little or none of the rough corrosion products on the surface and appears to have changed little during its nearly 15 years of exposure along an interstate highway (photo below).

This photograph of a Gregory guardrail product installed in Charlottesville, VA in 1994 was taken in April of 2009. The sheared transverse edge and bolt hole edges are corrosion protected by galvanic action.

The obviously more mild corrosion conditions for Charlottesville are mainly attributed to lower snowfall, almost half as much as Pittsburgh and more rapid melting, both effects leading to lesser road salt exposure on the guardrail. The total precipitation in Charlottesville as (rain or melted snow) is slightly higher than it is in Pittsburgh (42.6 inches/yr. vs. 37). The previously referenced Phoenix area has an annual precipitation of fewer than 10 inches and virtually no snowfall. These comments and observations should facilitate decisions on choosing Type I or Type II for a given geographic area.

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[11] ASM Handbook 13B, “Corrosion”, pp. 406, 407

Gregory Industries, Inc. • 4100 13th Street, SW • Canton, Ohio 44710
Phone 330-477-4800 • Fax 330-477-0626 • www.gregorycorp.com