Hot-Dip Galvanized Rebar vs. Epoxy-Coated Rebar

Hot-Dip Galvanized Rebar	Performance & Condition	Epoxy-Coated Rebar
No	**Special Handling**	Extensive
No	**Subject to UV Damage**	Yes
Yes	**Touch-up after Placement**	Yes
Equivalent to Black Bar	**Overlap Length**	Additional Steel Required
No	**Holidays/Pinholes**	Yes
Yes	**Fabricate after Coating**	Yes
Excellent	**Bond to Concrete**	Poor
No	**Underfilm Corrosion**	Yes
Yes	**Cathodic Protection**	No
Excellent	**Abrasion Resistance**	Poor
All	**Installation Conditions**	Temperature > 50 F

Hot-Dip Galvanized Rebar: A Concrete Investment

The integrity of concrete structures is largely based on the durability of the reinforcing steel. Corrosive elements penetrate the permeable concrete subjecting the rebar to corrosion. The corrosion products that form on steel have a greater volume than the metal consumed in the corrosion reaction, which causes internal concrete pressure to build. As corrosion continues, the pressure will eventually exceed the tensile strength of the concrete causing the concrete to crack and spall as shown in figures 1 and 2. The corrosion products of galvanized rebar are less dense and do not build up pressure to cause concrete spalling. The zinc corrosion products migrate away from the galvanized coating and disperse into the concrete matrix, as seen in figure 3.

Figure 1
Spalling concrete under bridges signifies a deteriorating strcuture and presents a safety hazard for traffic below.

Figure 2
Black reinforcing bars are exposed by spalling concrete on the underside of these stairs. This unsightly deterioration is unsafe for people to use.

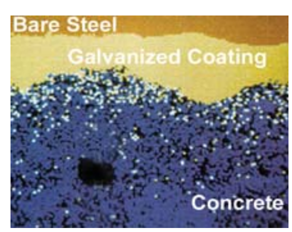


Figure 3
The white dots indicate the presence of zinc-oxide, a corrosion product of galvanized rebar, migrating away from the surface of the rebar without cracking the concrete.

Performance & Condition Notes

Special Handling

- The zinc coating of HDG rebar is harder than the steel itself. Bundling, dragging, and rough treatment prior to and during placement have no detrimental affect.
- ECR requires delicate handling to prevent damage to the epoxy coating. Any damage to the coating prior to placement will compromise the corrosion protection.

UV Damage

- HDG rebar is unaffected by UV ray exposure during field storage and installation period.
- ECR coatings break down under UV ray exposure.

Touch-up

- HDG rebar coatings are tenacious and resistant to scratching and chipping during shipping and placement. Only cut ends need touch-up in the field because of zinc's cathodic protection ability.

Overlap Lengths

- Laboratory tests show no significant difference in the slip for HDG and black rebar in loaded bars.
- American Concrete Institute (ACI 318) recommends 20% more overlap when using ECR.

Holidays/Pinholes (Coating Inconsistencies)

- HDG specifications allow for zero uncoated surface area. The HDG process ensures 100% of the bar is coated with zinc.
- ECR specifications allow for a percentage of the bar to have holidays and pinholes, comprimising its protection mechanisms before it reaches the job site.

Bond to Concrete

- There is no significant difference at ultimate load between the bond strength of ribbed galvanized and black rebar.
- ACI Code requires the basic development length for ribbed epoxy-coated bars to be increased due to the loss of bond strength as a result of the epoxy coating.

Fabricate After Coating

- HDG can and is often fabricated/bent after coating.
- ECR is not practically fabricated after coating as the epoxy will crack/flake.

Underfilm Corrosion

- The zinc of HDG rebar is self-healing and impermeable. If HDG rebar is damaged, there is only small, localized corrosion.
- ECR coatings are permeable and once corrosion begins, it spreads throughout the bar underneath the epoxy film.

Cathodic Protection

- HDG offers sacrificial protection to the substrate steel. HDG prevents corrosion in chloride ion concentrations 2 to 5 times greater than what causes corrosion of black rebar. HDG also provides barrier protection.
- ECR offers only barrier protection that is compromised by allowing a percentage of pinholes and holidays in the coating.

Abrasion Resistance

- HDG rebar coatings (alloy layers) are harder than the substrate steel with a hardness ranging from 179 to 250 DPN (Diamond Pyramid Number).
- ECR must be handled with extreme care to avoid all contact and scraping against other ECR bars in order to avoid coating damage.

Installation Conditions

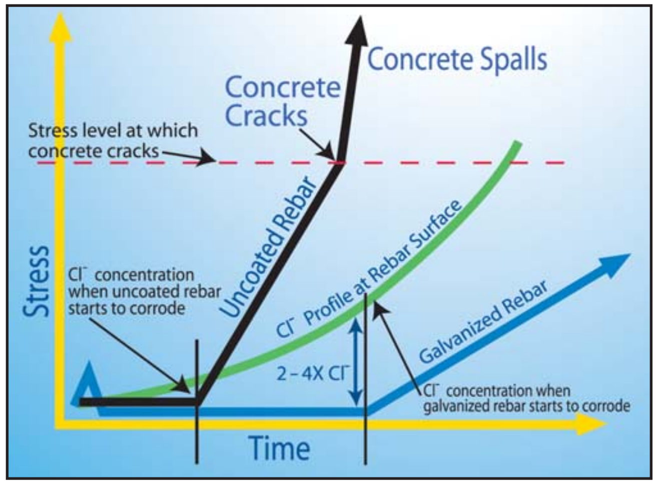
- HDG can be handled in all temperatures.
- ECR coatings may crack when handled in temperatures less than 50 F.

Accelerated Performance Tests

- Real-world performance (>30 years) shows HDG passivates after curing of concrete, producing zinc corrosion products that migrate away from the concrete matrix (no cracking/spalling pressure is created) and has a higher threshold for chloride corrosion.
- Estimates of epoxy-coated rebar (ECR) performance is largely based on accelerated salt spray test data. The artificial conditions of salt spray tests accelerate only one parameter and monitor corrosion current, which does not mimic real world conditions.

The deterioration of reinforced concrete structures is a major problem. The cost of repairing or replacing deteriorated structures, estimated to be more than $20 billion and to be increasing $500 million a year, has become a major liability for highway agencies.[1]

Service Life Model of Uncoated vs. Galvanized Rebar



This model illustrates how the service life of concrete is affected by chloride concentration and corrosion of the embedded rebar. Corrosion of rebar can be described in three stages: initiation, protection, propagation.

Initiation
Initiation is the time it takes for chlorides to permeate the concrete and accumulate at the rebar surface to a concentration that will cause corrosion. A certain critical chloride threshold exists for different rebar materials to begin active corrosion. The galvanized rebar threshold is 2 to 4 times higher than black steel[2].

Protection
Once the chloride threshold has been reached, black rebar enters into the stage of active corrosion, or in the case of galvanized rebar, the zinc coating begins to provide protection for the underlying steel.

Propagation
Pressure builds up in the concrete as steel corrosion products develop on black rebar. Once this pressure exceeds the tensile strength of the concrete, the concrete will crack and allow additional corrosive chlorides to penetrate the concrete. The corrosion products of galvanized steel cause harmless pressure that migrates from the surface of the bar into the concrete, filling any voids, cracks, or crevices that may already preexist. The less dense zinc corrosion products allow the galvanized coating to provide corrosion protection while extending the integrity of the concrete itself.

Reinforing Bridge Case Studies

A true test to determine the performance of corrosion resistant rebar is to monitor a reinforced structure over time. Accelerated tests can often be misleading as they do not accurately mimic real world conditions. Real world studies have been conducted on both galvanized and epoxy-coated reinforced bridge decks. The results below summarize inspection data that was taken from multiple studies. For comparison purposes they are grouped in similar environments that are assumed to be relatively equivalent in corrosivity.

Bridge	System	Install Date	Survey Date	Avg. Corrosion	Avg. Disbondment	Estminated Time to First Corrosion(Yrs)
Boca Chica Bridge Florida[3]	Hot-Dip Galvanized	1972	1975 1991 1999 2004	0%	0%	72
4 Bridges California[4]	Epoxy	1983	1992	12%	24%	11

"California reported coating disbondment at both corroded and non-corroded areas."[4]

Bridge	System	Install Date	Survey Date	Avg. Corrosion	Avg. Disbondment	Estminated Time to First Corrosion(Yrs)
Athens Bridge Pennsylvania[5]	Hot-Dip Galvanized	1973	1981 1991 2001	0%	0%	71
Tioga Bridge Pennsylvania[5]	Hot-Dip Galvanized	1974	1981 1991 2001	0%	0%	70
14 Bridges New York[4]	Epoxy	1980	1990	35%	--	10

"The number of defects in the epoxy coating and the amount of disbondment influence the performance of epoxy-coated rebar."[4]

Bridge	System	Install Date	Survey Date	Avg. Corrosion	Avg. Disbondment	Estminated Time to First Corrosion(Yrs)
Curtis Road Bridge Michigan[6]	Hot-Dip Galvanized	1976	2002	0%	0%	69
12 Bridges Michigan[4]	Epoxy	1975	1988 1989 1992	20%	--	13-17

"In Michigan, coatings on epoxy-coated rebar segments extracted from the decks with moist concrete could easily be removed."[4]

1950s-60s ➜ Bermuda Experience

Hot-dip galvanized rebar has been used extensively since the early 1950s. One of the first known installations is the Longbird Bridge in Bermuda by the US Navy in 1953. Galvanized rebar was used to reinforce the bridge deck in the construction of a single approach span concrete bridge. The Bermuda marine environment is highly corrosive as exhibited by inspections of the Longbird Bridge in 1978, and again in 1995. Chloride levels in excess of 7.3 lb/yd^3 (4.3 kg/m^3) were found in concrete samples taken from areas surrounding the galvanized rebar. Despite these high levels of chlorides (about six times the amount necessary to initiate corrosion of black steel) the thickness of the galvanized coating was sufficient enough to qualify as newly galvanized rebar, 42 years after placement.

1970s ➜ United States

By the early 1970s the United States Federal Highway Administration (FHWA) and state Departments of Transportation recognized the need for a viable form of corrosion protection for rebar. Hot-dip galvanizing was used to construct bridges in Florida, Pennsylvania, Michigan, Vermont, and Wyoming. Years later, the bridges were inspected to determine the performance of the galvanized rebar and the expected service life of the bridges. The table shows data from the bridge inspections and indicates sufficient coating thicknesses to provide an additional 50+ years of service life.

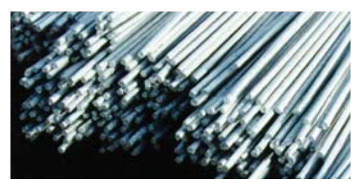
Bridge	Installed	Inspection Date	Chlorides (lb/yd^3)	Coating Thickness (mils)
Boca Chica Bridge, FL	1972	1999	3.21	6.7
Tioga Bridge, PA	1974	2001	2.23	7.8
Curtis Road Bridge, MI	1976	2002	6.88	6.1
Spring Street Bridge, VT	1971	2002	4.17	7.5
Evanston Interchange, WY	1975	2002	2.55	9.3

1980s ➜ New York State Thruway Authority

Based on a Federal Highway Association (FHWA) endorsement and research conducted by numerous states, the New York State Thruway Authority (NYSTA) had seemingly solved its corrosion problem by implementing the use of epoxy-coated rebar in bridge decks during the early 1980s. In as little as 10 years, doubts surfaced regarding the protection provided by these epoxy-coated systems. Within another four years, cracks began to appear in these bridge decks, at which time the NYSTA decided to utilize hot-dip galvanized rebar as its corrosion protection method of choice. Other concerns noted in a NYSTA report indicate inferior epoxy-concrete bond, as well as damage to the epoxy coating prior to placement from rough field handling, which compromised the corrosion protection prior to bar placement.

1990s ➜ Bridge Decks and Beyond

Hot-dip galvanized rebar continues to be specified in bridge decks due to its superior corrosion resistance characteristics and extensive performance history. Galvanized rebars have been used in numerous other industries, including the general construction of buildings, piers, marinas, industrial foundations, highway barriers, coastal sea walls, and numerous other corrosive and structurally critical areas where concrete is used.



[1] E.J. Gannon and P.D. Cady. *Condition Evaluation of Concrete Bridges Relative to Reinforcement Corrosion*, Volume 1: *State of the Art of Existing Methods*, Publication No. SHRP-S/FR-92-103, Strategic Highway Research Program, Washington D.C.

[2] Yeomans, Stephen R. *Galvanized Steel Reinforcement in Concrete.* 2004.

[3] Construction Technology Laboratories, Inc. C.A. Olson and M.A. Nagi, P.E. *Evaluation of the Performance of Galvanized Steel Reinforcement in Concrete Bridge Decks: Boca Chica Bridge, FL.* 2002.

[4] Concrete Reinforcing Steel Institute. Research Series 5. J.L. Smith and Y.P. Virmani. *Performance of Epoxy-Coated Rebar Bridge Decks*. 1999.

[5] Construction Technology Laboratories, Inc. C.A. Olson and M.A. Nagi, P.E. *Evaluation of the Performance of Galvanized Steel Reinforcement in Concrete Bridge Decks: Athens and Tioga Bridges, PA.* 2002.

[6] Construction Technology Laboratories, Inc. C.A. Olson and M.A. Nagi, P.E. *Evaluation of the Performance of Galvanized Steel Reinforcement in Concrete Bridge Decks: Michigan, Wyoming, Vermont.* 2003.

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