Ask Dr. Galv

Q **My customer has heard rave reviews about galvanized rebar's performance when embedded in concrete for marine applications . . . Why is HDG rebar out-performing black rebar in this particular application?**

A It's true that galvanized rebar outperforms black rebar in this application—the superior performance is a result of several factors stemming from zinc's unique corrosion behavior. The extended performance of galvanized rebar can be correlated to a higher threshold for corrosion initiation, reduced corrosion kinetics, and a lowering of stresses induced in the concrete as a result of the mobility of zinc corrosion products.

Chemical corrosion of steel results when a voltaic cell is formed contacting the steel surface. The cell contains four basic parts: anode, cathode, electrolyte, and return current path. For this discussion, let's focus on the electrolyte. In marine applications, the electrolyte is seawater—most importantly, the chloride content of that seawater. With respect to embedded rebar in marine environments, a degree of saturation of electrolyte must be reached in order for corrosion to begin. This is referred to as the "critical chloride threshold." Critical chloride thresholds are different for all metals, but the value most commonly used for black steel is 1.1 lbs/yd^3. Field evaluations for bridges in marine applications performed by CTL—a contractor for the International Lead Zinc Research Organization (ILZRO)—report HDG rebar performing corrosion-free for decades in chloride environments far exceeding the black steel threshold value (see chart, facing page).

From this research, it's reasonably deduced that the critical chloride threshold for galvanized steel is far higher than that of black steel, but that is only part of the reason for HDG rebar's noteworthy success. In high pH environments (namely saturated calcium hydroxide solutions . . . for this discussion, wet concrete mix), zinc surfaces passivate to form a calcium hydroxyl-zincate layer. A study by Andrade and Macias showed that this passive zincate layer can reduce corrosion currents, a scientific way of measuring corrosion potential, by an order of magnitude. This result was obtained in a chloride-free suspension and the effect of chlorides on the formation of this passive layer is not fully understood. Andrade and Macias showed that chloride concentrations of 0.3–0.9 molar do not have an affect on the formation of the passive zincate layer, but Sergi, Short, and Page suggest that higher concentrations do; however, they do not report a threshold value. Regardless, galvanized coatings after passivation show much lower corrosion currents in bench scale tests, equivocal to zinc losses of 1.5 µm/yr, and a service life of 100 years for an ASTM A 767 Class I coating.

(continued, facing page)

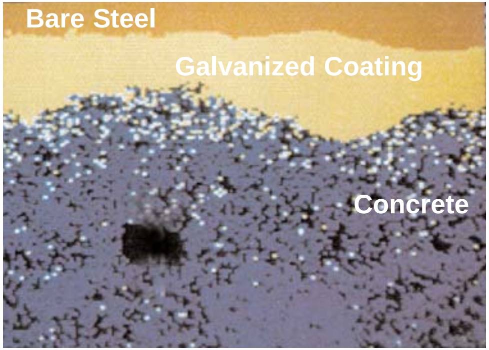
1995 Data Compiled from ILZRO Field Evaluations of Hot-Dip Galvanized Rebar

Bridge/ Structure Name	Location	Construction Year/ Project #	1975 ZE 206	1977 ZE 247	1982 ZE 320	1992 ZE 389	1994 ZC 1	Years-to Date Above Cl– Corrosion Threshold
			Years Since Construction					
PCA Slabs	IL	1963/1968	[6]					
Boca Chica	FL	1972	[3]			[19]		[21]
Seven Mile	FL	1972	[3]					[19]
Longbird	Bermuda	1952		[23]			[42]	[42]
Flatts	Bermuda	1966	8				[28]	[28]
Ames	IA	1967	7		14	[24]		[26]
Montpelier	VT	1971	3		[10]			[21]
Manicouagan	Quebec	1966	8					
Penno's Wharf	Bermuda	1964/1966/1969		[11*]			[28*]	[28*]
Hamilton Dock	Bermuda	1966		[11]			[28]	[28]
RBYC Pier	Bermuda	1968		[10]			[26]	[26]
Athens	PA	1973		[8]	[8]	[18]		[20]
Betsy Ross	PA	1973			8			
Corapolis	PA	1972			9	[19]		[21]
Hershey	PA	1975			[6]	[16]		
Orangeville	PA	1974			7			
Tioga	PA	1974			7	19		

[X] = At or above 1.1#Cl/cu. yd. Black Steel Corrosion Threshold
* = typical

The final and, perhaps, most remarkable phenomena contributing to the superior performance of galvanized rebar deals with the actual corrosion products of the zinc coating itself. Cracking—or, in its most severe form, spalling—occurs as a result of a local increase of internal pressure due to volume increase when metal transforms into corrosion products. As steel corrodes, the voluminous products formed as part of the corrosion reaction need some place to go and pressure builds until a crack in the concrete matrix results. Continued corrosion results in the production of more corrosion products, further cracking the concrete and spalling until the article is no longer fit for service.

Elemental map of galvanized rebar.
The corrosion products of galvanized rebar are less dense and do not build up pressure to cause concrete spalling (unlike the dense corrosion products of bare steel). The zinc corrosion products (depicted below, in white), migrate away from the galvanized coating and disperse into the concrete matrix.



The corrosion of zinc coated rebar occurs in a slightly different fashion. Zinc corrosion products are very small and migrate away from the surface of the rebar and into the bulk media of the concrete matrix. This can be seen in the picture above.

This phenomenon results in a small increase in internal pressure at a much slower rate. Ultimately, this translates into a longer service life for galvanized rebar.