In recent years the use of corrosion resistant reinforcing is becoming increasingly prevalent in concrete construction. In part this is due to the increased use of higher strength concrete which is more susceptible to cracking, but the increased importance architects and engineers are placing on life cycle costs and structure longevity play a part as well. The frequency with which projects requiring corrosion resistant reinforcing arrive in a precasters bid pile is increasing, and having the knowledge to accurately estimate the costs associated with whatever material is specified is critical to submitting a successful, profitable proposal. Hot dip galvanizing is only one of the many choices for protecting reinforcing steel from corrosion, and like every other system, it has its plusses and minuses. But our concern is not to discuss *why* someone might choose to specify hot dip galvanized reinforcing, but provide an overview of what does a contractor need to know in order to accurately bid, and ultimately profit from a job on which galvanizing has been specified.

Galvanizing to prevent rust has been around a long time. The earliest known example zinc of galvanizing being used to protect metal is some armor originally from 17th century India recently discovered stored in the Royal Armory museum collection in England. The earliest reference I can find for galvanized *reinforcing bar* being used in concrete is by the US military engineers in Bermuda around the end of World War II..

With the introduction of epoxy coatings in the 1970's galvanizing became a relatively minor segment of the corrosion resistant reinforcing market, and this in part is the reason there has not been the same volume of information available to contractors about using galvanized reinforcing as there has been available for some other products. Thankfully, the galvanizing industry has begun to address this and there are several excellent resources available to specifiers and engineers. The International Zinc Association has a website (www.galvanizedrebar.com) that is an excellent source for information on galvanized rebar. The American Galvanizers Association also has detailed information at their website www.galvanizeit.com. With input from the galvanizing industry the CRSI has recently updated their *Manual of Standard Practice* to include instructions on using galvanized reinforcing, and ACI committee 222 is updating their galvanizing references as well.

Much of the information below is in response to questions which repeatedly came up in working on these projects, or have been raised by DOT engineers at a series of Corrosion Resistant Reinforcing seminars being held by FHWA at various locations this past year.

Carl Maki
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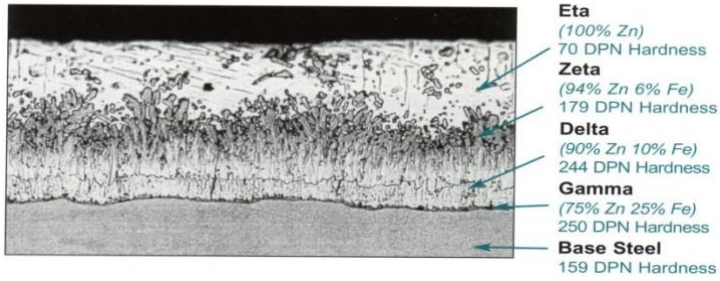
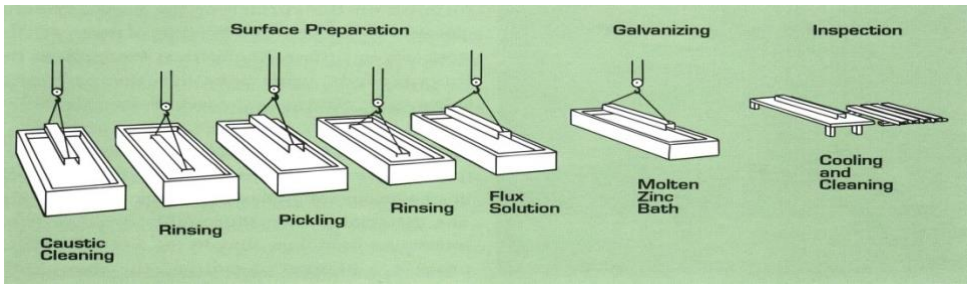
The Galvanizing Process

Most engineers know that galvanizing is accomplished by coating steel with zinc in order to protect the steel from rust but not everyone realizes that galvanizing can be a generic term, covering a variety of methods for depositing the zinc on the steel surface. Electroplaters, manufacturers of zinc rich paints and metalizing companies all use the term galvanized to describe their coating. While these coatings all contain zinc, their structure and performance is very different from a hot dip galvanized coating. A hot dip galvanized coating consists of layers of various zinc iron alloys which develop when (clean) steel is immersed in molten zinc. Usually performed in a temperature range of 825 to 850 degrees F , the zinc and steel react metallurgically to create a hard, stratified layer of these alloys which is tightly bonded and, when properly applied, is quite ductile.



The process for hot dip galvanizing is very simple as you can see from the diagram below - caustic cleaning, acid pickling and then fluxing before immersing in the molten zinc. No catalyst or current is required and so long as the steel is clean and the molten zinc is not blocked by trapped air or other mechanical means the formation of the coating is automatic. Any problems with galvanized coatings are usually really ether a cleaning or design problem.



It is important to note that the zinc coating on a galvanized piece of steel will add approximately 5%-7% to the original weight, although extremely heavy or light shapes may vary from this range. This 'after galvanizing' weight is what is multiplied by the quoted amount per pound to determine the amount the customer will be invoiced. (This is done because the configuration of the steel that is being galvanized and its metallurgic makeup can create significantly heavier coatings which are beyond the galvanizer's capacity to control). In job shop 'batch' galvanizing it is typical for each lift of material to be weighed as it leaves the production floor, with these weights then totaled for customer billing. However, for highly repetitive shapes and consistent material many galvanizers are willing quote a fixed, theoretical pickup rate to facilitate fixed per piece billing. The actual after galvanizing weight must also be considered when scheduling transportation of galvanized material to avoid over-weight loading of trucks.

Standards

In North America, precasters working with galvanized material will most likely encounter requirements either directly referencing, or based on one of five galvanizing standards. Most common for rebar is ASTM A767 *Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement,* which was issued in 1979 by the ASTM 1.05 committee on reinforcing standards and is generally viewed as the 'proper' domestic standard for galvanizing reinforcing bar in the US. As shown in the box below A767 lists two coating weights. While there is no guidance within ASTM767 as to when or where the heavier Class 1 coating might be preferable as opposed to Class 2, it is known that coatings above 100 microns in thickness are significantly less ductile, making Class 2 bar preferable for work intended to be bent after galvanizing. Where no type is specified, either may be used.

Domestic use embeds and similar concrete accessories are properly galvanized to ASTM 123 *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products.* You are also likely to see A123 as the specified coating for galvanized welded wire reinforcing mats, although there is a new ASTM standard *A1060/A1060M Standard Specification for Zinc-Coated (Galvanized) Steel Welded Wire Reinforcement, Plain and Deformed, for Concrete* that has been issued for that specific product. The 1060 standard is currently being revised for clarification.

A1060 lists two methods of manufacturing WWR, (1) welding of the sheets which are then galvanized, and (2) welding pre-galvanized wire into sheets. In method 1 the sheets are galvanized to conform to A123 and should have 600 gm2 or more of zinc coating. In method 2, the galvanized wire used to fabricate the mat may be purchased at any the six listed standard wire coating weights, starting at 135 gm2. When the pre-galvanized wire is welded together the coating damaged by the weld is not repaired. Mats manufactured by this method do not meet the requirements of A123 and should not be used if your contract specification calls for WWR galvanized that standard.

Standards based on European ISO 1461 are often encountered for export work headed to the Caribbean or South America. In Canada, rebar falls under specification CAN/CSA G164.

Comparison of Current Specified Coating Weights for Rebar					
	Nomenclature		UM	mils	oz/sq.ft.
ASTM767	Class 1		140	5.5	3.5
ASTM767	Class 2		85	3.35	2
ASTM123	Grade85		85	3.35	2
ASTM123	Grade100		100	3.94	2.3
CAN/CAS G164			87	3.42	2
ISO1461			85	3.35	2

Other than the welded after galvanizing mats, material galvanized to any of these standards might well be indistinguishable even to a trained observer, and the coatings could even be identical in metallurgical structure; but there are significant differences between the standards which should not be ignored. Most noteworthy, ASTM 767 requires post treatment of the galvanized bar with a chromate solution whereas ASTM 123, along with the Canadian and ISO based standards does not. Where ASTM 767 is specified, ASTM 123, CAN/CSA G164 or ISO 1461 certified material should not be substituted without prior, written approval from the specifying engineer.

Many large agencies involved in large infrastructure and public works projects write their own standards which reference one of the above but often include additional requirements. These additional requirements should be discussed with the galvanizer as often they are not part of the normal galvanizing process and will not be performed without prior arrangement.

Chromating

A common question is why does ASTM767 specify chromate, and why is it needed? Galvanized reinforcing bar is post treated with a sodium dichromate solution to 'seal' the zinc surface so as to minimize the evolution of hydrogen gas when the zinc comes in contact with a high pH concrete 'pour'. The necessity and desirability of chromating and its effect on bond strength have been debated for several years. Proponents of chromating are concerned that such gassing might adversely affect the ultimate bond strength between the reinforcing and surrounding concrete. Advocates for removal of this requirement point to widespread successful use of galvanized reinforcing without chromate in other countries, recent laboratory tests which indicate it may actually *decrease* ultimate bond strength, and claim it adds unnecessary environmental impact and costs. This debate is far from resolved, but even though it is being questioned, chromate treatment is still ***mandatory*** under standard 767. Contractors, fabricators and galvanizers should not decide to skip it without written approval.

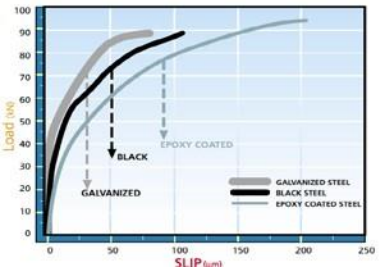
Over time, the chromate film over the zinc surface will be replaced by a film of zinc carbonate as the zinc proceeds in its normal reaction with the atmosphere. Because this reaction is a function of a variety of factors and the timing for it is imprecise, 'aging' is not generally considered a viable alternative where chromating is required.

Should a question arise the existence of chromates may be verified as there is a standard test for detection. ASTM B 201, *Practice for Testing Chromate Coatings on Zinc and Cadmium Surfaces* will detect chromate on recently processed surfaces. However, this test is unreliable on material which has been galvanized for some time as the chromate coating may have been fully replaced by zinc carbonate film. Since the carbonate film also protects this is usually not a problem.

It is also important to note that the use of chromate is not universal in the galvanizing industry. 'Job' galvanizers who focus mainly on structural steel elements have little need for this additional step and many have eliminated the use of chromates in their operation altogether. The precaster should verify that the galvanizer coating his material does include chromating if A767 is referenced.

Design

The maximum length of galvanized rebar available in any region is highly dependent on the capacity of local galvanizers and the size of their kettle and clearances in their plants. In most markets 40' or shorter bar is readily obtainable but local availability of longer lengths should be determined before design decisions are made. The largest kettles in the United States are all in the mid – sixty foot range. These operations can coat longer lengths by alternately dipping each end of a bar, but prior arrangement for this service and scheduling is strongly advised.



Despite any concerns about hydrogen evolution, testing has repeatedly shown that after fully curing, the bond between galvanized reinforcing and concrete exceeds that of black steel, eliminating the need for the extended lap splices required when using other coated bars. Design codes treat black steel and galvanized steel the same, a point worth review if your company does any of its own design work. I have encountered situations where engineers incorrectly used coated bar (epoxy) values for galvanized bar laps and development lengths, adding unnecessary cost.

The choice between using bar galvanized before cut and bend or material galvanized after fabrication may be dictated by your contract drawings or left up to you. Both methods are a part of ASTM767. If you are purchasing coated bar that is intended for fabrication after galvanizing this should be discussed with the galvanizer and it is best to specify ASTM 767 Class 2 bars to avoid problems with excessive cracking and flaking, as Class 1 bars are prone to do. Class 2 bars can be handled in the shop in the same manner as black bar with no special equipment or rollers necessary. Cut ends need only be touched up using zinc rich spray paint to meet the ASTM 767 requirements.

Again, bars with heavier coatings Class 1 may also be bent under the specification, but touch up may be required in the bend area if flaking does occur. Successful galvanizing of ductile Class 1 coatings generally requires significant experience with the product. Test runs of material processed by the intended galvanizer are recommended before committing large amounts of material to a Class 1 bending program.

ASTM 767 requires the use of larger pin diameters when bending black bars before galvanizing. Table 2 in that specification lists a 6d pin for grade 60 bars #3 through #6 and a 8d pin for #7 through #12 bars. These larger pin diameters are intended to minimize cold working stresses which may be exacerbated by the galvanizing process.

When black and galvanized reinforcement are used together in concrete a bimetallic couple is created between the zinc coating and the black. Just as zinc corrodes preferentially to protect steel at breaks in the zinc coating, so will the zinc coating where it contacts the back rebar. Because the black rebar mat is such a large surface area the quantity of Zn consumed at the contact point could be significant. However, it should be noted that zinc consumption would only occur if the black rebar is exposed to conditions (chloride and moisture levels) that cause the black steel to corrode. Some designers choose to isolate the galvanized mat against this occurrence by using dielectric tape or another other isolator at points of contact. Even with isolators, care should be taken to insure adequate concrete cover of the black bar to prevent damage from corrosion of this material

Purchasing

There are several avenues via which a contractor can acquire galvanized bar for his shop. Historically the most common has been to contract with a rebar fabrication shop to cut and bend the needed material, arrange to have it galvanized and then deliver it to the contractor in a finished package. Larger precasters may buy black rebar from the mill, cut and bend it themselves and arrange for their own

galvanizing. The third option is to purchase pre-galvanized bar that is then cut and bent as needed on the shop floor.

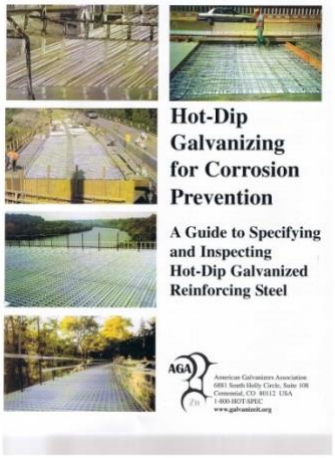
The purchasing documents should clearly state the standards to which conformance is required, including bar grade and any mill restrictions if any. Any extra contract provisions from your contract requirements that are beyond what is in the standard should be noted in writing. I recommend that any testing or inspection not included in the Standard Specification that you expect the galvanizer to perform be called out as a separate line item on your purchase order, even if there is no charge. You will want have a record of it being requested.

When purchasing bar which has been fabricated and then sent to galvanizing by a rebar shop, it is strongly recommended that you ask to meet with both the fabricator and the galvanizer to review your purchase order requirement s and your expectations before releasing the purchase order.

Galvanizers universally charge by the finished, galvanized weight and your purchasing documents should reflect that. A 45,000 pound truckload of black material sent to galvanizing will be invoiced back to you at approximately 47,700 pounds times the quoted galvanizing rate per pound.

Inspection

The norm for the galvanizing industry is that material should be accepted on their yard, or conversely, upon your receipt of the material. If approval by another agencies representative is required you should seek to have this done upon arrival of the material if possible. Many agency inspectors are unfamiliar with hot dip galvanized coatings and may have questions or be unsure about certain aspects of galvanizing. The American Galvanizers Association publishes an excellent inspection manual specific to galvanized reinforcing that is well worth the nominal cost to purchase a copy.



Most agencies list their acceptance criteria for galvanizing as a signed copy of a Certification of Compliance letter from the galvanizer referencing a particular shipment. This letter should accompany the shipment to your plant.

The most common problems with galvanizing can be identified through a simple visual inspection. Material with sharp drip spikes which may be dangerous to handle may be rejected as may material which is fused together. Isolated black spots which appear to be from under the coating are repairable if small in size, but excessive frequency or spots which in their aggregate exceed 2% of the bar surface should be rejected. Stains which appear to wholly rest on top of the coating surface are usually cosmetic in nature and not cause for rejection.

Embrittlement Testing

While A767 does not require embrittlement testing, some State or other agency specifications do call for certain tests to be performed. When mandated, the specification will usually reference procedures in

either ASTM 615 (for pre-galvanized bar) or ASTM143 (post galvanized bar). Since these tests are not part of A767 and outside the scope of usual and customary practices at most galvanizing plants, care should be taken to insure that any such tests are discussed with the galvanizer before work commences and that these tests will be performed correctly and will satisfy specification requirements. Costs for such performing such testing may be charged by the galvanizer as an separate service item or rolled into the overall galvanizing cost. Since this testing is destructive, sufficient additional material must be provided to the galvanizer to conduct it. Unless other arrangements are made, embrittlement testing (when required) should be performed by the galvanizer before shipping.

Placing

Galvanized rebar can be installed in the same manner as uncoated reinforcing. Because it is UV stable and highly damage resistant there are no real limits as to how far in advance of a pour it can be put in place nor is there a need for elaborate placing schemes to minimize damage to already installed bars. Any touch up is minimal and usually caught before a bar is installed. ASTM A780 outlines several methods to repair galvanized coatings, of which the most widely used is zinc rich paint, sold in either brush on or spray form. Paints should have dry-film zinc content greater than 92%, and paints meeting this criterion are widely available at industrial supply and paint centers nationwide.

Galvanized tie wire or plastic clips should be used when assembling or installing galvanized bar, and bar supports should also be galvanized steel, plastic or some other inert material such as masonry. If mechanical couplers are being used, they should be galvanized as well.

Galvanized bars may be welded in the field with the Architects / Engineers authorization. In most cases they will want the base steel to meet ASTM 706. Welding of galvanized reinforcing steel should conform to both American Welding Society *AWC D1.9*, and with *AWS ZWC*, which calls for welds to be made on steel that is free of zinc adjacent to the weld to prevent strength reduction through zinc inclusion in the weld itself. The zinc coating shall be removed at least one inch from either side of the intended weld zone and on all sides of the steel part by grinding or equivalent means. Once the weld is completed, the coating in the area of the weld can be repaired using procedures described in ASTM A780 to complete the corrosion protection on all surfaces.

Fumes from welding galvanized steel can contain zinc, iron and other noxious substances, and proper ventilation that minimizes worker exposure to fume is essential. The specific precautions are found in *ANZI/ASC Z-49.1 Safety in Welding, Cutting and Allied Processes*.

Handling and Storage of Material

Galvanized bar may be handled in the same manner as uncoated ‘black’ bar. There is no requirement for special slings or fork lift blades covers to unload or move it. Galvanized material is 100% UV stable and can be

stored outside with no damage from exposure to the sun or weather. It does not need to be covered. It is suggested that bar be stored off the ground on wood dunnage, and that normal precautions be taken against handling damage to avoid snagging and bending individual bars. Galvanized material should be stored away from uncoated steel racks chains etc as these uncoated items have a tendency to bleed rust stains onto the galvanized surface, often mistakenly diagnosed by inspectors as "rust bleeding through".

Resources

The following organizations have excellent resources available to answer questions, with staff engineers available to assist with galvanizing questions at no charge, provide copies of research data, design guides and inspection manuals for free or at nominal cost:

International Zinc Association	www.galvanizedrebar.com	
Mr. Doug Rourke (PE)	galvrebar@iza.com	
American Galvanizers Association	www.galvanizit.com	
Dr. Tom Langill	tlangill@galvanizeit.org	1 800 hot-spec
South Atlantic Galvanizing	www.southatlanticreinforcing.com	
Mr. Carl Maki	cmaki@southatlanticllc.com	803 261 3314

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