Inspecting for Galvanization-related Cracking in Steel Structures

Visual inspection is not always capable of discovering cracks in galvanized metal

BY RICHARD M. BELDYK

The most important method of inspection for galvanized articles is visual. A variety of simple physical and laboratory tests can be performed for
- ◆ *Thickness*
- ◆ *Adherence of the coating*
- ◆ *Uniformity of the coating*
- ◆ *Appearance.*

The above statement paraphrases a common opinion from a great number of sources, but I disagree with it. Over the past several years, I have investigated weld and base metal cracking of galvanized steel. While such cracking is not a new problem, as a literature search will show, it is one not easily recognized or identified. When a crack is reported to the galvanizer, the standard statement heard is "bad steel." Cracks are quickly repaired and forgotten; performing a failure analysis is a secondary consideration, at best. The purpose of this article is to provide some insight into the problem and suggest methods for locating invisible cracks in galvanized steel.

There are many references for the inspection of galvanized coated steel for thickness, adherence, uniformity, and appearance of galvanized coatings. Thickness is generally measured nondestructively, utilizing these gauges. If you are unfamiliar with magnetic coating thickness gauges, information is available at *www.defelsko.com/applications/galvanizing/app-galvanizing.htm*. If you do not have a guide with photographs, Section 30 of the Material Inspection Guide from the Texas Department of Transportation can be downloaded from *http://manuals.dot.state.tx.us/dynaweb/colmates/mig/@Generic__BookTextView/6058;cs=default;ts=default*. (Note that there are two underscores before "*BookTextView*.")

Types of Cracks in Galvanized Steel

Visual testing (VT) of steel structures is the most widely used inspection method of all time. Certified Welding Inspectors use it. Engineers rely on it. Even the untrained general population can readily spot some problems. However, with newly galvanized structures, the crack is generally covered by a layer of galvanizing, so the crack component will pass visual inspection even when examined by highly trained inspectors. With galvanized structures that are in service, the cracks may propagate into new steel exposing the surface, leading to the formation of a stain on the surface.

Beam cope cracking occurs in the galvanizing kettle. If the cracks open wide enough in the kettle, the crack is visible when removed from the bath; however, the galvanizing will completely cover a tight crack making it invisible. Galvanized-induced cracking (GIC) is generally considered a form of liquid metal embrittlement (LME) or liquid metal assisted cracking (LMAC).

Cases of galvanized-induced cracking have been reported in every continent with a variety of different galvanizing alloy mixes. While some alloy mixes seem more prone to inducing cracking, the problem is more complex than that. Following are just some of the factors that can play a role in galvanized-induced cracking in addition to the galvanizing alloy mixture:
- ◆ Residual steel
- ◆ Excess silicon in the weld metal
- ◆ Rate that the steel is dipped into the galvanizing kettle
- ◆ Dwell time in the kettle
- ◆ Carbon equivalent of the base and weld metals
- ◆ Tensile and yield strengths of the materials
- ◆ Relative thickness of the pieces
- ◆ Prior thermal processing of the base materials
- ◆ Tramp elements in the base metals.

A significant change to one or more of these factors can cause galvanized-induced cracking.

Thickness measurements and visual inspection may be all that is required for handrails and similar items, but highly restrained structures such as roof trusses, bridges, sign structures, or any structure where a failure could result in the loss of life or property damage should be inspected for cracking. From a fabricator's point of view, it is not economical to perform a root cause failure analysis for every crack; however, the cracks need to be detected, repaired, and product shipped out the door.

How to Detect Galvanized-Covered Cracks

The first line of defense is utilizing a trained visual inspector to examine the coated surface. The inspector will look for abnormalities such as surface-breaking cracks or abrupt changes in the spangle morphology on the surface. To inspect questionable areas, the inspector should either remove some of the galvanizing to obtain a better view of what is there or, preferably, utilize nondestructive testing methods.

Table 1 compares a variety of nondestructive examination methods according to their ability to detect cracking beneath galvanizing. While the best method is to prevent cracks from occurring in the first place, it is readily apparent from the table that there is a great need for new technology and techniques for determining cracking beneath galvanizing. Alternating curent

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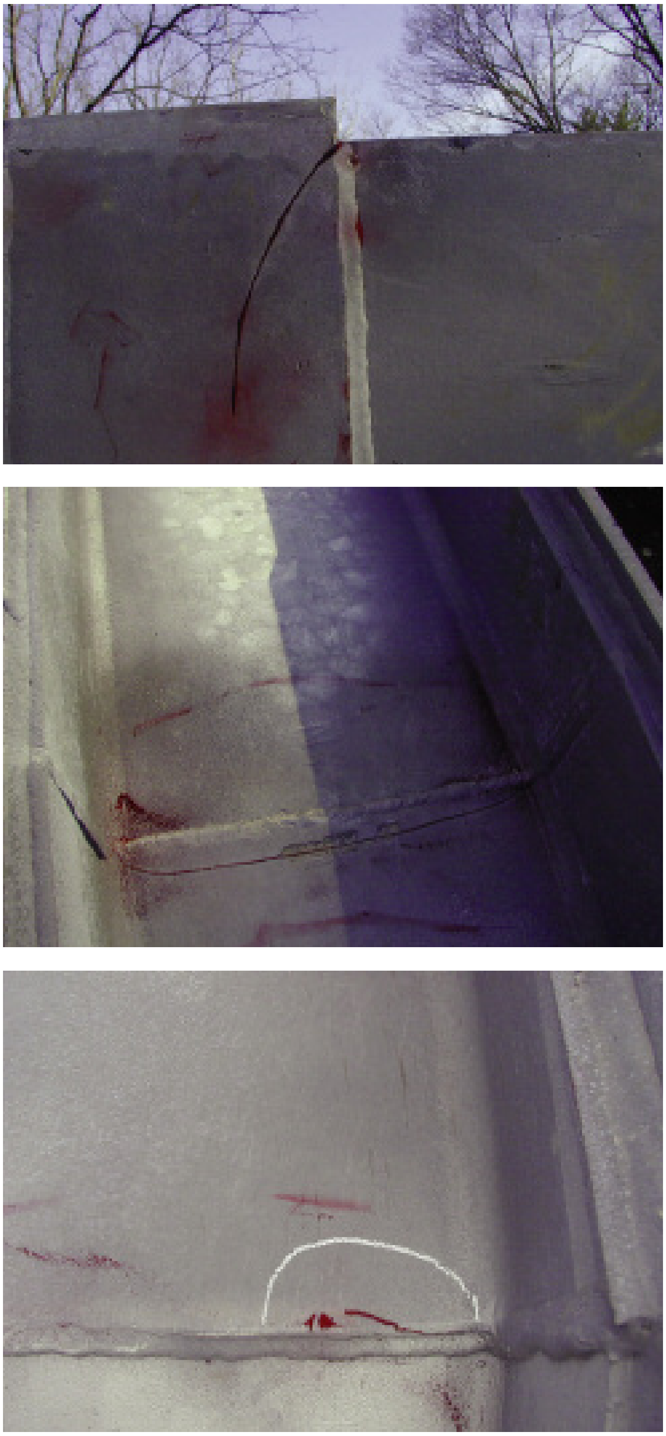

Fig. 1 — Three examples of cracks that weren't visible originally, but which showed up through use of magnetic particle testing.

Table 1 — Comparison of NDE Methods for Detecting Cracks in Galvanized Steel

Visual Testing	Oldest NDE method. Most defects found with VT.
Machine Vision Testing	Potentially great technology; thus far undeveloped.
Thermal Vision Testing (IR)	Flash or thermal wave thermography shows good potential; thus far undeveloped.
X-Ray Testing	Not applicable except where film may be placed perpendicular to radiation source.
Dye Penetrant Testing	Generally not applicable. However, long-term bleed-through techniques (72 hours) have been successfully utilized.
Helium Leak Detection	Could be used in some cases, but is expensive and requires special equipment and custom fixtures.
Ultrasonic Testing	Multiple layers of zinc-iron phases hinder the reliability and usefulness of UT. Manual shear wave testing is not very accurate for vertical cracks. Manual surface wave testing is not currently developed. Phased array testing has potential and is being used in some locations. Detection reliability is a severe problem on zinc bridging cracks. Currently fillet welds cannot be inspected.
Magnetic Particle Testing	The recommended 0.004 in. of typical galvanization borders the maximum coating MT thickness limit. Dissolved iron at the bottom of the galvanization layer may hinder/obscure particle pattern formation. Nickel and iron in the galvanizing alloy hinder the usefulness of this method.
Eddy Current Testing	Magnetic problems from iron in the galvanization layer hinder crack detection.
Alternating Current Field Measurement	Sensitivity and probability of detection affected by zinc and iron at zinc boundaries. There is a possibility signal processing could overcome this problem.

field measurement (ACFM) shows significant promise for this application; however, the most economical and commonly used nondestructive examination method is magnetic particle inspection (AC yoke with dry powder).

Using Magnetic Particle Testing

The goal is to ensure that discontinuities that could possibly cause cracking are at a minimum. It has been suggested that microscopic cracks and other surface discontinuities (those requiring a 25× magnification to observe) act as stress concentrators and crack initiators. Very careful attention to indications is required. What is acceptable for a nongalvanized structure may initiate a crack in a galvanized structure. Therefore, prior to galvanizing, 100% of each weld and 4 inches of the base metal on each side of the weld should be inspected with magnetic particle testing (MT) methods.

After galvanizing, the procedure should be repeated.

Because many indications are "weak" and "fuzzy," a trained inspector is required to identify them. In addition, multiple yoke placements should be utilized to inspect the area. Typically, the yoke's legs are placed 45 deg from the previous position. As with all MT inspections, questionable indications should be ground or the upper surface removed for further inspection.

Figure 1 shows cracks that were not visible to the eye because they were completely bridged by galvanizing. As you can see, they became very visible through the use of magnetic particle methods.

Conditions that Lead to Cracking

Three conditions affect the occurrence of galvanized-induced cracks:

1) Stress
2) Zinc wetting and thermal characteristics
3) Steel characteristics

In order to occur, galvanized-induced cracks do not require a preexisting visible crack caused by fabrication. The higher the weldment stress level, the higher the probability and severity of GIC.

Stress is an important factor, and thermal stresses may be very high where extremely large parts are partially dipped (meaning they must be double-dipped) into the molten bath. This creates an almost 1000°F gradient with an extreme rate of thermal gradient rise at the point of immersion in the zinc. Weldments of various sizes may be capable of yielding stress levels when dipped, with small thinner sections producing vectoring cracks between welds. A rule of thumb is to keep the ratio of the thick-to-thin member less than 3 to 1.

The principles of cracking may be understood, but the specifics of each material and molten zinc bath are not. However, residual stress can be somewhat controlled. Properly designed welding sequences may be capable of reducing the tendency for GIC.

Delayed postgalvanization welding cracks have been observed. It has been hypothesized that excessive amounts of silicon may affect the tendency for weld cracking by inducing excess and delayed transport of weld filler alloying elements; i.e., these elements are in the diffusion process long after the weld has cooled to ambient temperature. During the dipping process, the heat of the molten zinc may cause a redistribution of the alloying elements, weakening the weld after galvanization. Note that large amounts of silicon in the weld filler metal will produce a large and undesirable buildup of zinc on the welds. This zinc will form several postgalvanization compounds of Fe + Zn on the surface of the weld, changing the transverse stress component of the weld.

On a normal weld surface, the transverse stress is in compression, but a postgalvanization weld longitudinal crack indicates that these stresses were in tension at the time of crack formation. Since many of these cracks appeared to be delayed, but with many found prior to entering service, a mechanism producing transverse tensile stress must be present. Welds of unequal profile may enhance this mechanism.

The defense to use against GIC is to use proper welding techniques, preheat, and dry electrodes and flux. A 100% magnetic particle inspection should be performed prior to galvanizing. The following should be done after galvanizing:

1) Visually inspect
2) Measure the thickness
3) Perform a 100% magnetic particle inspection using the AC dry yoke method.❖