United States Steel Corporation

Technical Bulletin
Construction

Rollforming Prepainted Galvanized & Prepainted GALVALUME® Steel Sheet Products

Introduction

By far, the most common type of forming associated with Prepainted Galvanized Sheet and Prepainted GALVALUME® Sheet products is contour rollforming to convert flat, coiled sheet product into shaped profiles for use in the construction industry. During rollforming, steel Sheet is fed from a coil through a series of roll stands to progressively change the shape of the flat steel Sheet into a shaped panel. The rollformed panel has a distinct shape that provides a desirable appearance plus stiffness to the steel sheet.

During rollforming, the thickness of the steel sheet is generally not changed. The change in profile is most often accomplished by simple bending of material with unconstrained edges. At times, some profiles are formed by a combined bending and stretching deformation. In these cases, a slight amount of thinning of the sheet does occur, and as a result, the strain associated with these particular types of bends is often higher than for simple tension bends. The profiles that involve bending and stretching are associated with the introduction of profile bends that are formed while the sheet is constrained between two sets of forming rolls.

Prepainted Galvanized Sheet and Prepainted GALVALUME® Sheet have been used successfully for many years by a number of metal-building manufacturers. The excellent performance of both products, when properly rollformed and installed, has contributed to the ongoing growth of the metal-building industry.

The intention of this document is to discuss what happens to the steel and coating during rollforming, and how to optimize the rollforming operation so that any adverse effects of forming on the product's performance in the field are minimized.

Rollforming, Tension-Bend Cracking, and Corrosion Behavior of (Unpainted) Hot-Dip Metallic-Coated Steel Sheet

In order to understand what happens to Prepainted Hot-Dip Metallic-Coated Steel Sheet products when they are exposed in the environment, it is important to understand first what occurs when these products are rollformed in the unpainted or bare condition.

Often, the amount of strain (metal deformation) that occurs in the area of tension bends during the rollforming of metallic-coated steel Sheet causes cracking of the metallic coating. The cracks that form are restricted to the coating metal; the steel is not cracked. Thus, the integrity of the product with respect to its load-bearing and weatherproofing (leak tightness) capabilities is not affected.

From a metallurgical perspective, the primary reason that small cracks form in the coating (often referred to as "crazing," "microcracking" or "tension-bend cracking") is that the coating is essentially in an "as-cast" condition. That is, the coating grain structure that forms when the coating solidifies on the steel sheet surface has not been refined by mechanical working and annealing. Ordinarily, as-cast metals exhibit limited ductility.

Because tension-bend cracking (TBC) of the coating is a common phenomenon on hot-dip-coated steel sheet when it is rollformed, it is important to consider how this phenomenon impacts the corrosion-resistance performance in the field.

For bare (unpainted) galvanized and GALVALUME® Steel sheet, it is generally felt that TBC does not have a significant effect on the corrosion performance or life of the product even though moisture and the contaminants in the moisture come in direct contact with the steel in the cracked areas. Both galvanized and GALVALUME® coatings offer sufficient sacrificial, galvanic protection so that the steel exposed at the base of the crack is protected from corroding. Thus, the performance and product life and in the environment are usually not noticeably affected.

The excellent galvanic protection provided by the metallic coating for unpainted products is in part associated with the large anode area (the entire sheet surface) compared with the relatively small cathode area (the steel surface exposed at the base of the cracks). Galvanic protection, by its very name, implies that the coating is sacrificed (dissolved) to protect the steel. Since the coating is boldly exposed, there is a large amount of zinc available to take part in the chemical (corrosion) reaction that protects the small amount of steel exposed at the cracked locations. Thus, the coating can provide protection to the exposed steel for a long time. The performance in the vicinity of a crack is similar to that experienced at a sheared edge.

Rollforming, Tension-Bend Cracking, and Corrosion Behavior Of Prepainted, Hot-Dip Metallic-Coated Steel Sheet

When prepainted, metallic-coated steel sheet is rollformed, cracks develop in the metallic coating somewhat similar to the behavior of unpainted sheet. Concomitantly, there is a tendency for the paint to crack in the same locations as the cracks in the metallic coating. This occurs because most 1-mil thick paint systems (primer + topcoat) are not flexible enough to bridge over the cracks in the metallic coating. Often, when a crack develops in the metallic coating, further bending causes the crack to become wider. This increasing amount of crack-opening displacement puts an especially heavy burden on a paint to bridge over the crack without eventually cracking itself.

In contrast with the corrosion behavior for unpainted product which as stated previously is relatively insignificant, the corrosion behavior and product performance for prepainted sheets are affected significantly by the occurrence of cracking at the tension bends in a rollformed panel. This is true for galvanized sheet as well as GALVALUME® sheet.

Because cracks in the paint are often coincident with the cracks in the metallic coating, the environment has direct access to the steel. The intrusion of water during periods of rain, which often is contaminated by atmospheric pollutants, can have a noticeable influence the corrosion performance and life of the product.

The difference in the corrosion behavior between unpainted and painted products is that the paint serves as an insulator so that the anodic area (the area where the coating dissolves to protect the steel during a corrosion reaction) is restricted to the metallic coating exposed only in the immediate vicinity of the crack. When the anode area is reduced in this manner, important changes in the corrosion behavior occur.

Prepainted Hot-Dipped Galvanized Sheet

For Prepainted Hot-Dip Galvanized Sheet, coincident cracks in the zinc coating and paint film trigger accelerated corrosion and loss of zinc in the small area immediately adjacent to the cracks. This is a significant contrast compared with unpainted galvanized sheet. The amount of zinc available to galvanically protect and inhibit corrosion of the steel is very small.

As the zinc immediately adjacent to the crack is dissolved away by corrosion, the paint that was bonded to the zinc coating peels back slightly. It loses adhesion simply because the zinc underneath the paint is gone. The peeling paint exposes more zinc, and the corrosion reaction that causes very localized zinc dissolution continues. This behavior occurs slowly, but nevertheless, the product life is affected. Eventually, perhaps as short as 10 years or even less in industrial and acid rain environments, the steel begins to corrode and exhibit red rust at the tension-bend locations. This occurs because so much zinc has been dissolved away in the area of the original crack that it can no longer protect the steel completely. Away from the cracked region, the zinc beneath the paint is essentially unaffected.

Fortunately, the tension bends are at the elevated locations on the formed panels. The water runoff occurs in the valleys; thus, there is essentially no concern about perforation at the tension bends. The steel exposed at these locations corrodes very slowly. The issue is cosmetic appearance.

Prepainted GALVALUME® Sheet

Prepainted GALVALUME® sheet, which also is prone to develop coincident cracks in the GALVALUME® coating and the paint during rollforming if the amount of strain is not controlled, behaves differently than prepainted galvanized sheet. It behaves differently in two ways.

First, the GALVALUME® coating is composed of a duplex microstructure. At a microscopic level, the coating is composed of zinc-rich regions and aluminum-rich regions. The volume percent of the aluminum-rich areas is very high, about 80 percent. As the coating corrodes to protect the steel in the immediate vicinity of a crack, the zinc-rich areas dissolve similarly to the zinc in a galvanized coating. However, the aluminum-rich zones do not dissolve along with the zinc-rich areas. As a result, the paint is able to stay partially bonded to the aluminum-rich areas in the GALVALUME® coating. The tendency for loss of paint adhesion immediately adjacent to the original crack, as occurs when the metallic coating is all zinc, is reduced.

Second, the coating is not as galvanically reactive as a galvanized coating. Therefore, corrosion of the zinc-rich regions in the GALVALUME® coating in the immediate vicinity of a crack does not occur as quickly as for the pure zinc in a galvanized coating.

On the basis of these two differences, it might seem that Prepainted GALVALUME® Steel Sheet would clearly outperform Prepainted Galvanized Steel Sheet in the environment. Unfortunately, the reduced galvanic reactivity of the Prepainted GALVALUME® coating has a negative aspect. That is, since the coating is less galvanically protective, the exposed steel at the base of the crack in the paint and metallic coating often begins to corrode fairly soon after exposure, within months in some environments. When this occurs, a slight amount of rust staining (reddish in color) is often visible on the surface of the paint in the vicinity of the tension bends in the rollformed panel. The staining is caused by a "bleeding" of the steel corrosion products that formed at the base of the cracks. This staining is referred to as "tension-bend staining" (TBS).

The corrosion of the steel is not detrimental to the life of Prepainted GALVALUME® Sheet in that the initially formed products of corrosion plug the cracks, and further corrosion of the steel is negligible. However, TBS may be aesthetically objectionable if it is readily visible. Since TBS is usually visible only at distances of less that 5 to 10 feet, it is generally only a problem for sidewall applications, not roofing. Also, it is only visible when the paint is white or light-colored. The tendency for TBS is most prevalent in acid rain and industrial environments.

What to Do? Ways to Minimize Tension-Bend Cracking

The above discussion on corrosion at tension bends of rollformed, prepainted-steel sheet shows that, no matter whether the product is Prepainted Galvanized Steel Sheet or Prepainted GALVALUME® Steel Sheet, it is important to minimize the amount of cracking in both the metallic coating and the paint. How is this accomplished? A number of factors influence the cracking tendency. These include:

- The thickness of the steel sheet
- The strength of the steel
- The thickness of the metallic coating
- The thickness and flexibility of the paint (primer + topcoat)
- The panel design especially the bend radii
- The rollformer design
- The operation of the rollformer.

The next sections in this technical bulletin are intended to provide insights into the influence of each of these variables.

Important Factors to Minimize Tension-Bend Cracking

Steel Thickness

- Thinner steels generally experience less strain at the outer fibers of the tension bends for a given bend radius, and therefore, less microcracking.

Steel Strength & Formability

- High strength steels, especially Grade 80, often exhibit more microcracking than lower strength steels because the actual bend radius for a given profile is often more severe than designed. The reason is that high strength steels like Grade 80 have limited ductility and may not conform to the bend radii ideally imposed by the rollformer rolls. Instead, the bends may exhibit kinks rather than a smooth, uniform radius.

- Higher strength steels typically have to be rollformed to tighter bend radii during rollforming because they exhibit more springback after deformation. This may contribute to excessive amounts of cracking in that it's not the final radius that influences cracking, but the radius imparted instantaneously during the forming operation that has the greatest impact on microcracking.

- Lower strength steels typically exhibit less oilcanning. This, in turn, reduces the need for deep minor ribs, the ribs that are used to minimize oilcanning. Minimizing the depth of these minor ribs is especially important because they often involve bending plus stretching deformation, a deformation mode that not only contributes to a high density of cracks, but also to a wide crack-opening displacement. This behavior seems to accelerate tension-bend corrosion.

Thickness of the Metallic Coating

- Thinner coatings are generally less prone to tension-bend cracking than thicker coatings. For example, AZ50 is preferred over AZ55. Similarly, G60 is less prone to cracking than G90 and thicker coatings. However, for galvanized steel, one needs to exercise caution about selecting thinner coatings because the life of prepainted galvanized sheet is influenced by the zinc coating thickness. Thicker galvanized coatings, i.e., G90 instead of G60, offer better resistance to paint-undercutting corrosion when cracks do occur at tension-bend locations as well as at sheared edges.

Type of Primer/Paint and Thickness

- The inherent flexibility of paints and primers differs from one resin type to another. Usually, polyester and urethane primers are more flexible than epoxy primers. Concerning topcoats, PVDF topcoats are generally more flexible than SMP topcoats.

- Concerning paint-film thickness, there are several thick-film primers available commercially today that offer good flexibility and have demonstrated good resistance to cracking during rollforming. For topcoats, thick-film plastisols which are often specified to be 4-mils thick are known to be very flexible. In recent times, several 2-mils thick systems have been commercialized.

- Remember, the other performance characteristics of paints, especially chalk and fade resistance, need to be considered when selecting a paint. Plastisols, although they offer good corrosion protection in most applications, are very susceptible to chalking and fading versus PVDF and SMP paints.

Panel Design

- Obviously, the design of the panel itself, especially the radii of the bends, is an important variable that needs to be studied carefully. It has perhaps the greatest influence on the cracking tendency. It is possible to design architecturally desirable profiles while, at the same time, maintain fairly large bend radii.

- Typically, when the bend diameter at a tension bend formed during rollforming is less than about 6T*, some amount of cracking of the paint and metallic coating is evident when observed under a low power magnifying lens. This is true for both galvanized and GALVALUME® coatings. In some cases, this minimum bend diameter for no cracking is as high as 8T, while depending on how well the product is handled and the type of paint used, the minimum bend diameter for no cracking may be as low as 4T or even lower for some thick paints.

- The limiting bend radii, discussed above, reflect the tendency for microcracking on simple tension bends with unrestrained edges. If the rollforming of a particular profile involves both bending and stretching, such as when a formation is introduced at a location where the panel is constrained laterally by already-formed profiles that are tightly bound in the dies, the limiting radii for no cracking is usually larger. Examples of this are minor ribs and beads that are introduced into the flat sections of a profiled sheet to remove oilcanning. These so-called minor bends can be more prone to TBC than the large major profile bends which are often rollformed while the sheet ends (side of the sheet) are unconstrained.

Rollformer Design

- Rollforming equipment that incorporates many rollforming stands to input a given profile is preferred over equipment that has only a few stands. This provides a smoother transitioning and a lower tendency for microcracking.

- Good alignment of the rollforming equipment is important to attain smooth bends without imparting excessive complex strains during the forming operation.

- Rollformers that involve forming from the center of the panel out to the edges of the sheet are preferred. Any bends that are made while the sheet is constrained in any manner from lateral inward flow tend to exhibit more cracking, especially larger crack-opening displacements.

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*6T is defined as the bend diameter obtained by bending over 6 thicknesses of the steel sheet.

Operation of the Rollformer

- Maintaining good alignment of the rollformer stands and the uncoiler is vitally important. For example, if the uncoiler is not properly aligned with the forming stands, excessive amounts of reforming can be encountered in the vicinity of the bends. This causes localized work hardening of the metallic coating and the steel sheet, which can increase the tendency for microcracking.

- Flatteners at the entry end of some rollforming lines, used to remove coil set, should be set carefully to remove all the coil set, while at the same time, be monitored to assure that the paint film is not abraded or scored.

- The forming rolls should be properly set to avoid kinking of the panel as it is fed into the line. If the panel kinks instead of following the roll contour, the bend radius is more severe and additional microcracking can occur. As stated previously, Grade 80 is more prone to develop kinks in the profiled bends.

- The peripheral speed of the rolls should closely match the speed at which the sheet is being fed through the line. A speed mismatch can cause scoring of the sheet, and thereby, contribute to an increased cracking tendency.

- The mating top and bottom spindle rolls should have adequate clearance to allow forming without abrading the coating. If abrasion occurs, the paint film integrity is often degraded and the metallic coating can become work-hardened at the outer surface. This may lead to more microcracking in the succeeding rolls.
- Warm forming, a technique that involves preheating the prepainted sheet just ahead of the forming rolls, has been shown to be beneficial to decrease tension-bend cracking. Clearly, the flexibility of the paint is improved by warm forming. Also, the cracking tendency of the metallic coating may be reduced.

Other Types of Forming

- For construction applications that involve prepainted products, there will undoubtedly be some need to employ press-brake forming for trim parts. It is important that these parts be formed using techniques and equipment that provide large bend radii so that microcracking is held to a minimum.
- Avoid overbending when press-brake forming as this again increases the tendency for microcracking.
- Equally important is the need to protect the painted surface from scratches and abrasions while using a press-brake or any other freeforming tools.

A special type of forming that is applied to prepainted sheet products is roll embossing. Care should be taken to assure that the paint and metallic coating do not exhibit cracking. As long as the pattern (depth and sharpness of the embossment edges) of the embossment is sufficiently gentle to assure that cracking and/or marring of the paint does not occur, the life of the product should not be negatively impacted.

Summary

The purpose of this technical bulletin is to assist the metal building industry with maximizing the performance of Prepainted Galvanized Steel Sheet and Prepainted GALVALUME® Steel Sheet products. In order to satisfy building owners for a long time and improve the performance and image of prepainted steel sheet products, the following issues should be addressed:

- Careful selection of the prepainted steel products that are available,
- Intelligent design of the panel and its bend radii, and
- Proper selection of the rollforming equipment and its installation and use.

The correct answers to these issues are not always the same. The location within the country (acid rain region, close to the ocean, rural setting, etc.), the closeness to other industrial sites, the use of the building as well as other issues need to be addressed before the best prepainted building panel can be selected. Perhaps, most importantly, it requires an upfront understanding of the building owner's expectations.

For additional discussion on any of these topics, please contact your local U. S. Steel Sales and/or Customer Technical Service representative.