U. S. Steel Košice, s.r.o.
A Subsidiary of United States Steel

R E C O M M E N D A T I O N S

related to transport and storage of galvanized sheets produced by U. S. Steel Košice, s.r.o.

In order to understand the practices and recommendations for successful handling of galvanized steel, some basic knowledge and theory must be explained.

Steel sheet is a very versatile product which is applied to many end uses including steel buildings, automotive panels, signs, and appliances. Unfortunately, it is prone to rusting, a phenomenon that causes the surface to become unsightly and, over time, may contribute to product failure. For this reason, steel is protected by a variety of methods ranging from internal alloying, e.g., stainless steel, to coating with metallic coatings and/or paints.

Corrosion is an electrochemical process that, in the case of steel sheet, oxidizes the iron in the steel. Oxidation, or rusting, occurs as a result of the chemical reaction between steel and oxygen. Oxygen is always present in the air, or can be dissolved in moisture on the surface of the steel sheet. During the rusting process the steel is consumed, converting iron to corrosion products. This aspect of steel sheet behavior is very undesirable, both aesthetically and from the aspect of service life. Eventually, often sooner than desired, steel sheet corrodes sufficiently to unduly shorten its service life, i.e., loss of structural strength, or perforation and intrusion of water.

Metallic coatings are a well-developed method of protecting steel as barrier and galvanic protection. Steel coated with metallic coating containing zinc or zinc alloys is protected from corrosion when freely exposed to the atmosphere due to the slow corrosion rate of zinc. When base steel is exposed, such as at a cut edge or scratch, the steel is cathodically protected by the sacrificial corrosion of the zinc coating. This occurs because zinc is more electronegative (more reactive) than steel. In practice, this means that a zinc coating will not be undercut by rusting steel because the steel adjacent to the zinc coating cannot corrode. Any exposure of the underlying steel, due to severe coating damage or a cut edge, will not result in corrosion of the steel until the adjacent zinc has been consumed. Unless relatively large areas of steel are exposed there is minimal effect on the overall service life of the coating.

The distance over which the galvanic protection of zinc is effective depends on the environment. There are situations, however, during shipping and/or storage of this product where damage can occur to the zinc surface due to two different types of accelerated corrosion. This paper provides guidance on the precautions that can be taken to avoid damage due to storage staining.

Storage Stain

Storage stain on galvanized sheet products is a corrosion product that is typically white, but which can also take the form of grey or black deposits on the surface. Since the most common form of discoloration is white in appearance, storage stain is often called *white rust.* It can occur when sheets of galvanized steel that are in close contact (in a coil or stacked in lifts/bundles) get wet, either by direct water intrusion, or condensation between the surfaces. The discoloration is due to the corrosion products that form after zinc reacts with moisture in the absence of free air circulation.

When zinc corrodes in the presence of air and moisture it undergoes a series of chemical reactions, changing from metallic zinc on the surface to other chemical compounds. In air, newly exposed zinc reacts with oxygen to form a very thin oxide layer. In the presence of moisture the zinc oxide reacts with the water, resulting in the formation of zinc hydroxide. Over time, and under the influence of cyclic weathering, the final corrosion product is zinc carbonate (formed by the reaction between zinc hydroxide and carbon dioxide in the air). Zinc carbonate is a thin, tenacious, compact, and stable (insoluble in water) film. When the surface is further exposed to rain or condensation, the protective film serves as a barrier between the moisture and the zinc underneath. This type of chemical layer is called a **passive film**. It is the presence of this passive film that slows down the reactivity of the zinc, thereby dramatically reducing the corrosion rate of the zinc coating.

As stated above, zinc is very reactive metal. It exhibits a low corrosion rate only because a continuous passive film forms on the surface. A key part of the corrosion mechanism is that the surface needs to dry in air in order to develop and maintain this passive layer. It is during the drying part of a rain cycle that the zinc carbonate passive film develops. Atmospheric wet-dry cycles are therefore necessary for zinc to develop passivity.

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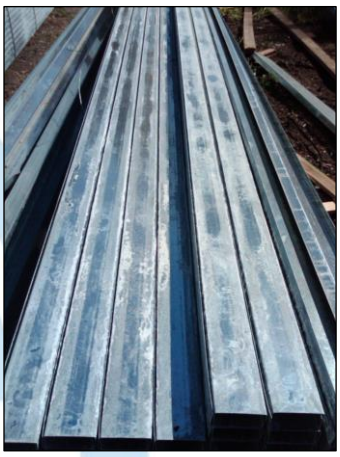
When galvanized sheet gets wet while still in coil form, or stacked into bundles at a roll-forming plant or jobsite, without proper air circulation and possibility to dry, the storage stain can result. Storage stain (white rust) is simply the chemical compound, *zinc hydroxide (ZnOH)*, which forms when zinc is in contact with moisture. It does not convert to a zinc carbonate passive film because the tightly packed sheets **are not** freely exposed to oxygen/carbon dioxide-containing air. A protective zinc carbonate film never gets a chance to form. Since the corrosion reaction continues to proceed as long as the surfaces are wet and starved for oxygen and carbon dioxide, a large accumulation of zinc hydroxide can form. Zinc is a very reactive metal in the presence of moisture when conditions do not allow the passive film to form.

When white rust does occur, there is an actual loss of zinc coating, and some of the zinc that is intended to protect the coated steel product while in service is consumed by oxidation. The extent of the damage is primarily dependent on the exposure time to moisture, the temperature that is experienced during storage, and the presence of accelerating corrosive agents, such as chloride-containing salts.



The surface of the zinc coating in the area that experienced white rust is "etched" and no longer has the bright, reflective appearance of as-produced galvanized sheet. Removing the white rust will not eliminate the etched appearance. This is why, for applications where appearance is critical, galvanized sheet with white rust may not be acceptable.

To prevent rejection of material, every precaution should be taken to avoid storage stain on galvanized sheet. Also, specific practices have been developed that allow the shipment and storage of galvanized sheets without the formation of storage stain.

Steel sheet manufacturers apply to the galvanized surface various types of "surface treatment" – passivation/chemical treatment, oiling or application of thin organic coatings. *When an order is placed, it is necessary to specify whether surface treatment or any kind of temporary corrosion protection "is" or "is not" required.* It is important to remember that mill-applied surface treatments are temporary, not permanent and serve just for the time of transport and storage until final utilization of material. Mill-applied surface treatments *minimize* the tendency for storage stain; however they *do not eliminate* its occurrence if the product is subjected to very adverse conditions. An example would be having a coil get wet during transit to a customer, and then allowing the coil to sit in a warehouse for a long period without any attempt to dry it. Even if the product is treated with passivation or thin organic coatings, it is still important to keep moisture from between the wraps while in coil form, or stacks of sheets/blanks. For a number of reasons, some end uses for galvanized sheet require the use of galvanized product without any surface treatment. In such cases, protection against wetness during shipment/storage is paramount, and the best practice is to ensure that is it consumed by the user at the earliest opportunity.

Best Practices

1. The steel manufacturer needs to apply the surface treatment in the specified manner to cover uniformly the entire surface area of the sheet.
2. When possible or required, wrap the coils with packaging materials that are specially made for this application.
3. The shipper needs to protect the steel during shipment to the customer's plant. Even if the coils/bundles are wrapped, ship only in covered watertight conveyances. If it is necessary to use an uncovered conveyance, wrap the load completely with a tarp to assure no water intrusion if it rains during shipment. Avoid tearing the paper.

4. The best practice is to store coils in a climate-controlled warehouse. When receiving material in the warehouse, keep it packed until the temperature of material and warehouse temperature are equal. Use the material promptly. Whenever possible, do not allow the product to remain in storage for extended periods of time (in excess of two months). Storing galvanized coils in unheated warehouses over the winter carries the risk of condensation forming between the laps due to sudden temperature drops after a warm period. This can occur even when the coils are paper wrapped and encased inside metal shipping shrouds. In this circumstance, white rust can form after a few weeks, even on well-passivated or other way treated sheet.
5. For shipping from the manufacturing plant to the final location, the product again needs to be protected, especially if sheets/parts are in intimate contact with each other. When this is the case, the product is very susceptible to storage stain, as the zinc surfaces will not dry properly if they get wet.
6. Paper wrapping is one way to protect the sheets while in transit or during storage at a jobsite. Be careful to not wrap the bundle if the sheets are wet. This traps moisture in the bundle and prevents drying.
7. If bundles of galvanized sheets or blanks get wet, the only way of preventing or minimizing storage stain is to immediately separate all the pieces so they can individually dry.
8. Do not wrap the sheets tightly in plastic. Allow the product to “breathe” by providing air circulation.
9. If outdoor storage is unavoidable, place bundles above ground by at least 30cm to allow air circulation underneath. If bundles are stacked, ensure free circulation of air between bundles using cured lumber spacers.
10. Inspect material frequently to assure that the panels have not become wet.
11. Elevate one end of a bundle of sheets to allow water to drain if moisture gets between the sheets. Make sure there are no low spots along the length so as to allow water to flow freely if necessary. If bundles have been found to be wet, separate all the sheets immediately.
12. When shipping manufactured parts or storing them outdoors, they must be dry and free of roll or press forming lubricants and protected from the weather. If not protected from the weather, then each part should be ‘free standing’ (not touching other parts), with any concave parts being placed so the concave side is down and not able to collect water.

Design for Uniform Corrosion

One definition of product failure is “not meeting the service expectations of its design life.” If a building clad with galvanized sheet is designed to last for 20 years with no major maintenance, then it should show no signs of red rust before this time. The atmospheric corrosion rates of zinc coatings are well known (see EN), so it’s a relatively simple matter to select the appropriate coating weight for the application. In designing a structure, it is important to ensure that a particular exposed surface (roof elevation, side wall, etc.) is exposed to the same weather as uniformly as possible across the entire surface area. The design of a building, or any other structure that is subject to weather, should not have configurations where water drains incompletely and/or pools. The longevity of galvanized sheet exposed to weather depends on wet/dry cycles to form the protective zinc oxycarbonate patina. When it is subjected to long periods of wetness, this protective layer breaks down, increasing the zinc corrosion rate. Well-designed structures clad with galvanized sheet will dry uniformly and quickly after a rain event. This minimizes the chance of localized severe corrosion hotspots. Keep in mind that “protected exposure” surfaces, e.g., north-facing walls, do not dry as quickly as other orientations.

- **Building Design Considerations**

Corrosion is greatly influenced by the time of wetness. One of the most important design rules, therefore, is to ensure that all rain and melting snow can run off a building. Water should not be allowed to collect and sit in contact with a building.

- **Galvanic/Bimetallic Corrosion and Dissimilar Metals**

When zinc and steel are in contact in the presence of an electrolyte, current will flow from the steel to the zinc, so that the zinc becomes an anodic electron-producing region while the steel is cathodic and consumes electrons, preventing it from combining with oxygen and forming rust. This property of zinc is used in many applications as a galvanic protector of steel. Galvanized sheet on buildings should not be allowed to come in electrical contact with other more noble (less electrochemically active) metals such as copper, lead and tin. Nor should rainwater be allowed to drain from these metals onto zinc surfaces. Rapid corrosion of zinc will

occur in either situation. While zinc and aluminum are galvanically compatible, it is not recommended that water be allowed to drain from aluminum surfaces to zinc surfaces.

- **Contact with Soil**

Zinc corrosion in soil involves different chemical reactions than is the case in air. It is a very complex topic, due mostly to the myriad soil types and conditions that exist. Some soils are very corrosive to zinc. To avoid mutual contact, design so that galvanized sheet on buildings is kept away from the ground. If it is necessary to bring it close to ground level, there should be a non-soil cover such as gravel, stones, pavement, etc.

- **Condensation Issues**

Galvanized sheet used to clad some commercial and industrial buildings, and many farm buildings, is sometimes the only separation between the inside and outside "climate", i.e., there is no inner wall or ceiling structures separated from the outer wall by insulation, etc. This is the case in many animal confinement buildings. If it becomes warm and humid inside such a building when it is cold outside, condensation can form on the inside of the wall and roof panels. Condensate can be present for long periods and will then accelerate corrosion of any zinc coating. If animal waste products become dissolved in the condensate, then corrosion can be dramatically accelerated.

- **Design for Maintenance**

Good design can prevent many, but not all, corrosion problems from arising. Regular inspection and maintenance is necessary to identify and deal with issues as they arise. To ensure that it is easy to inspect and maintain all parts of a building clad with galvanized sheet, it has to be considered during the design stage. Simple designs that allow easy inspection are important. Walkways may be needed on roofs or near other areas of a building that cannot be seen from the ground. Avoid areas of galvanized sheet that could be subject to corrosion but cannot be seen at all. Do not design configurations where there is no access or not enough room to perform maintenance.

Always keep in mind – if galvanize is kept dry, white rust will never be an issue.

Summary

Unsightly white/grey/black storage stains and black marks due to fretting corrosion can result in rejection of galvanized sheet and products made from it. With proper attention paid to shipping, storage practices and well-designed structures, these rejections can be minimized or even eliminated.