Technical Note 3.07 Transit Abrasion on Galvanized Sheet Steel

Indian Sheet Steel Building Group: Technical Note 3.07

Transit Abrasion (Fretting Corrosion) on Galvanized Sheet Steel

Introduction

Galvanized sheet surfaces sometimes exhibit a surface imperfection that appears as permanent black spots, marks, lines, or patches. This condition has many names, including transit abrasion, friction oxidation, wear oxidation, and chafing; all being names for a form of erosion-corrosion known as fretting. It is a phenomenon that is more commonly seen on metal surfaces in mechanical assemblies (e.g., bolted, riveted, keyed, or pinned joints) and electrical contacts,[1] but can occur on galvanized sheet surfaces under certain conditions. Black fretting marks on galvanized sheet are almost impossible to remove, and are superficial, but are not the result of water damage – which can also cause black (along with white) stains in its most severe form. When fretting occurs on galvanized sheet surfaces, liquid water is not necessary for its creation, although fretting can occur in the same areas of sheets that are additionally damaged by storage stain from entrapped moisture.

Mechanism of Fretting Corrosion

Fretting corrosion refers to corrosion damage at the asperities of contact surfaces. This damage occurs under load and in the presence of repeated relative surface motion, as often induced by vibration.[2]

The requirements for fretting corrosion are: the interface must be under load, vibration or repeated relative motion must occur, and the load and relative motion must be sufficient to produce deformation on the surface.[3] Two mechanisms are proposed for fretting corrosion, wear-oxidation and oxidation-wear. The first theorizes that cold welding (fusion) occurs at contacting asperities under load and during subsequent relative motion these contact points rupture, with small fragments of metal being removed. These small fragments immediately oxidize. The process is repeated, resulting in the build-up of oxide residue. The oxidation-wear model proposes that the oxide layer is already present and when the contacting surfaces are subjected to relative motion under load, this layer is ruptured at the high points producing the oxide debris. The exposed metal is oxidized and the process repeats. Investigations have shown that both of these mechanisms operate to produce fretting corrosion.

[1] Bradford, S.A., Corrosion Control, 1993, Van Nostrand Reinhold, (Intl), p.110
[2] www.corrosion-doctors.org
[3] Fontana, M.G., Corrosion Engineering, 1986, McGraw Hill Companies, p.106

Displacements as little as 4x10^{-9} in [10^{-4} μm] can cause fretting.[4] It is seldom seen above amplitudes of 0.001 in [25 μm] and reaches a maximum at 0.0003 in [7.5 μm].[5]

The reason fretting damage can be a severe problem is that it so often happens at the interface of two highly loaded surfaces that are not designed to move against each other. In the case of machinery, it can unknowingly and prematurely wear out parts, and also induce cracks that can become fatigue failures. In electrical equipment it can increase resistance and cause intermittent connections or unexpected circuit failures.

Fretting Corrosion on Galvanized Sheet

For many years fretting problems have been observed on galvanized steel in both coil form and bundles of cut length sheets. The defect is never seen at the production line and when found is almost always at customer facilities. It tends to be more prevalent on coil form and on material thicker than 0.030 in [0.8 mm].[6] Without fail, it is also characterized by a lower intensity mirror image on the reverse side of the sheet.

Figures 1 and 2 illustrate the appearance of fretting on galvanized surfaces. In this case the marks are near the edge of the sheet and were reported to have mirror images on the opposite surface.[7] Figure 2 is a close-up of the mark on the right hand side of Figure 1. [8]

Figure 1. Fretting near coil edge

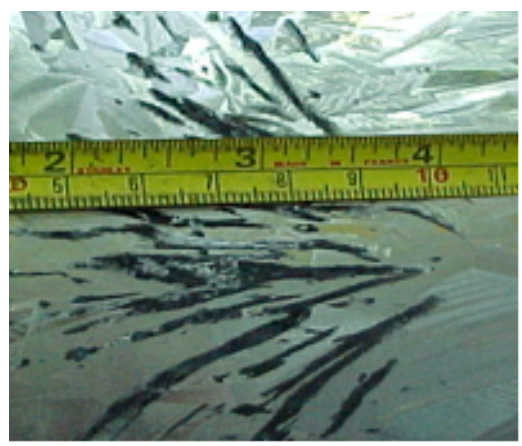

Figure 2 Close-up of right side of Figure 1

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[4] Ibid p.106
[5] Bradford, Op. Cit., p.111
[6] Chatterjee, Rajib, TATA STEEL, private communication with the GalvInfo Center
[7] Ibid
[8] Photos Courtesy of Shantau Chakraborty/Rajib Chatterjee – TATA STEEL - India

Another observation made about the nature of these marks, in the case of coil-form material shown in Figures 3 and 4, is that they are located exclusively in the area of contact of the saddle support that cradled the coil(s). The coils had been shipped with their eyes horizontal and aligned perpendicular to the direction of movement.

Figure 5 is fretting on corrugated galvanized sheet that was observed after transport to a jobsite from a roll-forming mill.[9]

Figure 5. Transit Abrasion (fretting) on corrugated galvanized sheet

Given that relative motion between surfaces is a requirement for fretting to occur, where do these marks on galvanize come from, and why are they black and impossible to remove short of abrading them off?

The relative motion comes from vibrations that occur during shipment of the product. While this type of damage can occur on truck shipments, it is rare, probably because truck transport tends to involve shorter distances (fewer vibration cycles), and perhaps vibration amplitudes above the maximum known to cause fretting (25 μm). How material is supported on trucks (bearing points), and road conditions can have an effect, however, on the propensity for transit abrasion. Transport by train and ship/barge is typically of a longer duration, therefore any vibrations causing low amplitude relative surface motion have much more time to do damage to the surface, and the nature of the movement over steel rails and through water may play more of a part in generating low amplitude vibration. Also, the high power diesel engines used to propel trains and ships may be a factor in contributing to the generation of these vibrations.

[9] Photo Courtesy of Shantanu Chakraborty/Rajib Chatterjee – TATA STEEL - India

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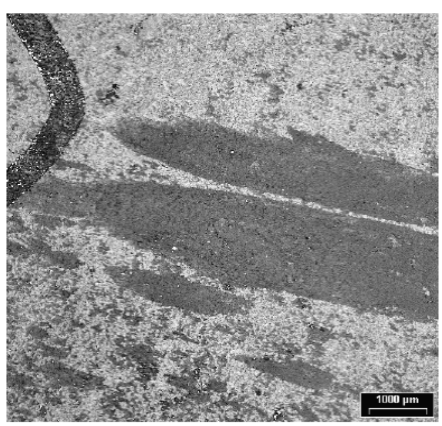
The second factor that contributes to transit abrasion is load on the surfaces. The black marks are rarely over the entire surface area of a sheet, but are concentrated in specific regions, that have been noted in some cases, e.g., Figs 3 & 4, to be the point(s) that bear the weight of the entire coil or bundle, and perhaps the additional load of product stacked on top. These bearing points are where the most pressure would result on any surface asperities, and is where fretting would begin if relative motion between surfaces does occur.

As for the observation that fretting is less common on sheets thinner than 0.8 mm, it is quite possibly related to the number of laps per unit weight of coil, or number of sheets per unit weight of cut-to-length bundles. The thinner the sheet, the more contacting surface area per unit volume to resist relative movement induced by vibration. Also, in the case of coil-form, thin sheet is recoiled using higher tension than for thick sheet, thus allowing less chance for surfaces to slide against each other. In other words, everything else being equal, thicker sheets will slide easier against each other than the same weight of thinner sheets because there is less total frictional force (per unit volume) to resist sliding.

The reason the marks on galvanize are black is believed to come from the nature of the extremely small zinc oxide particles (wear debris) that are the likely result of small amplitude vibration. Zinc oxide that is formed from corrosion of zinc in the atmosphere, or manufactured intentionally for industrial use, is a white powder. Black transit abrasion marks on galvanized surfaces have been shown to be zinc combined with a higher percentage of oxygen than is the case with the metallic zinc on the rest of the surface (see Figure 6),[10] indicating a different form of zinc oxide. It is theorized that this oxide is black, either because of different optical properties than zinc oxide that appears white, or the manner in which the very fine oxide particles are bonded to the surface of the underlying zinc.



Mag x 12

[10] Chatterjee, Rajib, TATA STEEL, private communication with the GalvInfo Center

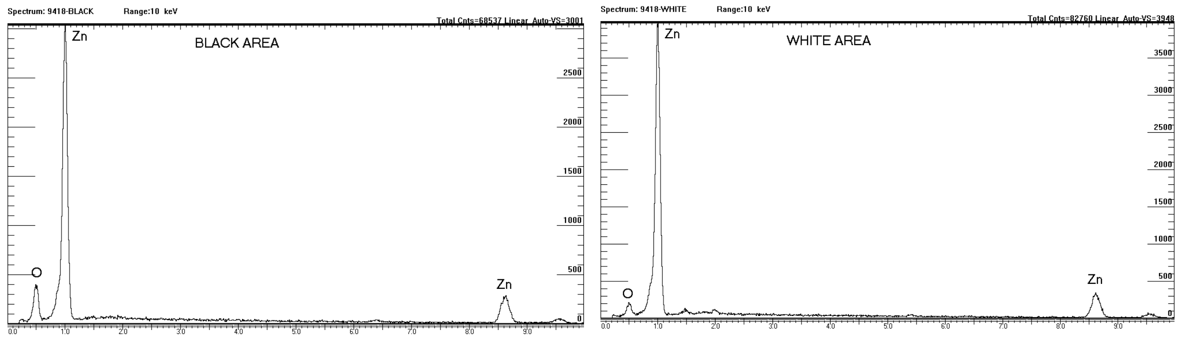


Figure 6. Analysis indicating black area has at least twice the oxygen content of the normal white zinc. (Courtesy of Shantanu Chakraborty/Rajib Chatterjee – TATA Steel India)

	O	Al	Si	Fe	Zn
Black	14.74	1.17	0.63	1.55	81.92
White	6.97	2.25	0.68	0.88	89.22

Minimizing Fretting Corrosion on Galvanized Sheet

There are a host of preventive measures,[11,12] that can be taken to minimize fretting corrosion in mechanical assemblies. These include: lubricating with low viscosity oils or greases, optimizing the surface roughness to alter friction coefficients, isolating from vibration, increasing the recoiling tension or load to reduce slip, and decreasing the load at bearing surfaces.

All of the above measures are not practical in the case of galvanized sheet, but investigations at one steel supplier have indicated that some are effective to varying degrees.[13] An action that is very effective is redesigning support saddles to reduce concentrated point loading on the bottom of coils. By distributing the weight of the coil over the entire area of the saddle(s), there is less pressure at any one point, resulting in less transit damage given that vibration will always be present. A slightly less effective way of accomplishing the same result is to reduce the coil size, but this is perhaps not a desirable option for all situations. With either of these actions, care should be taken to avoid stacking coils during transit, as material on the bottom could become overloaded, even with well-designed saddles under them.

Another option to reduce fretting is to oil the sheet, thereby reducing friction. Oiling has been found not to be effective in all circumstances and has other

[11] Bradford: Op. Cit., p.111
[12] Fontana, Op. Cit. p.108
[13] Chatterjee, Op. Cit.

drawbacks, such as telescoping of coil walls; oil oozing from the walls; and being unacceptable to the customer.

An obvious cure would be to eliminate the small amplitude vibration of coiled or stacked galvanize sheet. Accomplishing this is very unlikely given the nature of long distance shipping methods.

Sheet with Fretting Marks – Suitability for Use

Fretting marks on galvanized sheet are surface oxide phenomena that can be a major aesthetic issue, but there is no evidence they have a negative affect on corrosion resistance. Bright galvanize has a covering layer of zinc oxide that is not visible, whereas any fretted spots have an oxide layer that is black. This being the case, the product can generally be used in situations where appearance is not a factor, e.g., hidden structural members. In fact, specification EN 10326 Continuously hot-dip coated strip and sheet of structural steels, technical delivery conditions; states in clause 11.2 that darks spots resulting from friction during shipping generally only impair the appearance.

Summary

The unsightly black marks sometimes seen on galvanized sheets have been shown to be the result of fretting corrosion that occurs during transit of the product, either from the producer to the fabricator/service center, or from the fabricator/service center to a jobsite. The most effective methods of minimizing fretting damage (transit abrasion) are to reduce bearing point loads on coils or bundles, and to oil the surface. Product with fretting marks is generally suitable for use if appearance is not a factor, such as in the case of hidden structural members