Investigation of Staining of Newly Coated Steel Framing

Stephen W. Foster, *Wiss, Janney, Elstner Associates, Inc., Austin, Texas, USA*

Leonard L. Phelps, *Wiss, Janney, Elstner Associates, Inc., Northbrook, Illinois, USA*

This article is AMPP-copyrighted intellectual property. AMPP has provided view-only access of this article to Wiss, Janney, Elstner Associates, Inc. for posting on their website for review/reference purposes only.

No part of this publication may be downloaded, printed, shared, reproduced, republished, distributed, sublicensed, stored in a retrieval system, or transmitted, in any form or by any means (electronic, mechanical, photocopying, recording, or otherwise) without the prior written permission of AMPP.

Reddish-brown staining appeared on pre-primed steel framing members soon after the application of the topcoat. Despite the primer manufacturer's early hypothesis that surfactant leaching of the topcoat may have been the cause, field and laboratory investigations indicated that water-soluble corrosion products were being mobilized and deposited on the surface due to the presence of moisture. Pre-primed steel delivered to jobsites can begin to rust before receiving the topcoat. Areas of latent corrosion where the primer thickness was low, along with the framing that had been stored outdoors, likely led to corrosion staining after topcoat application.

Newly installed structural steel framing of the ceiling of a commercial construction project was exhibiting reddish-brown staining of the coating system soon after application of the topcoat, as shown in Figure 1.

The surfaces of structural steel members were to be prepared in accordance with SSPC-SP2[1] and SSPC-SP3[2] and the following coating system was to be applied:

1. Shop primer: One coat of a solvent-borne, modified phenolic alkyd resin metal primer, at 76 to 101 microns (3.0 to 4.0 mils) dry film thickness (DFT).
2. Field topcoat: One coat of water-based, flat, polyvinyl-acetate-acrylic-based latex at 56 microns (2.2 mils) DFT.

The primer manufacturer postulated that the staining was related to questionable ambient conditions during topcoat application—it occurred in a space that was not fully conditioned, which potentially led to cool, damp surfaces. Further, corresponding surfactant leaching came about because the topcoat was not able to dry and coalesce sufficiently.

Field Inspection

A field inspection was performed to identify the cause of the staining, which included visual observations, moisture testing, DFT measurements, and sampling for laboratory examination.

Visual Observations

Areas of reddish-brown staining and localized damage to the primer were common at uncoated bottom flanges and edges of the top flanges. This staining was observed at several topcoated areas, and approximately half of the framing appeared to have some degree of staining. When present, most staining was concentrated at the bottom flanges, near edges, or near crevices of member connections. Webs of beams typically did not include staining. However, the bottom of the bottom flanges of some members exhibited distinct, well-defined areas with a medium-dense population of stains, which can be observed in Figure 2.

Moisture Testing

A representative framing member was selected for experimental moisture exposure testing. No staining was observed along the west half of this member, and limited staining was present at the bottom flange of the east half of the member. The stains at this beam were faint compared to other areas with more pronounced staining. Moisture was introduced to the coating along the bottom flange at an area with and without staining. A paper towel wetted with distilled water was placed onto the bottom surface of the bottom flanges and covered with a plastic sheet taped to the flanges. After a 24-hour dwell-period, the wet paper towel was removed, and the surface of the coated flanges was observed. The area without prior staining exhibited minor brown stains near the edges of the bottom flange and one stain near the middle of the bottom flange. The stains at the area with prior staining became more pronounced, having turned noticeably darker, which is reflected in Figure 3. Moreover, the stains had leached onto the moist paper towel, which was collected for laboratory testing.

DFT Measurements

DFT was measured at select locations in general accordance with ASTM D4138[3] and ASTM D7091.[4] A paint inspection gauge was used to score a preselected angular cut into the coating system at four test locations, and coating DFTs were measured along the length of each cut at each test location.

Nondestructive measurements were also performed using a magnetic thickness gauge. At each selected element, a total of four 25.8-square-centimeter (4-square-in) spots were selected on each surface, and five measurements were performed at each spot location for a total of 20 spot measurements. Table 1 summarizes the minimum, maximum, and average thicknesses. A representative paint inspection gage reading is illustrated in Figure 4.

FIGURE 1 Representative steel framing member exhibiting staining of the topcoat.

FIGURE 2 Representative area of medium-dense staining at bottom flange.

Laboratory Examination

Scanning electron microscopy with energy dispersive spectroscopy (SEM/EDS) was performed on stained and unstained paper towel samples to characterize the elemental makeup of the reddish-brown stains.

Samples

Six portions of paper towel samples were collected during the on-site moisture testing. Samples 1 through 3 represented portions of paper towels with spots of reddish-brown stain, and Samples C1 through C3 represented "control" samples from portions of the paper towel without an apparent stain. Samples 1, 3, and C2 were arbitrarily selected for the laboratory examination.

SEM/EDS Analysis

SEM and EDS studies were conducted to examine the elemental composition of the

FIGURE 3 Staining after moisture testing.

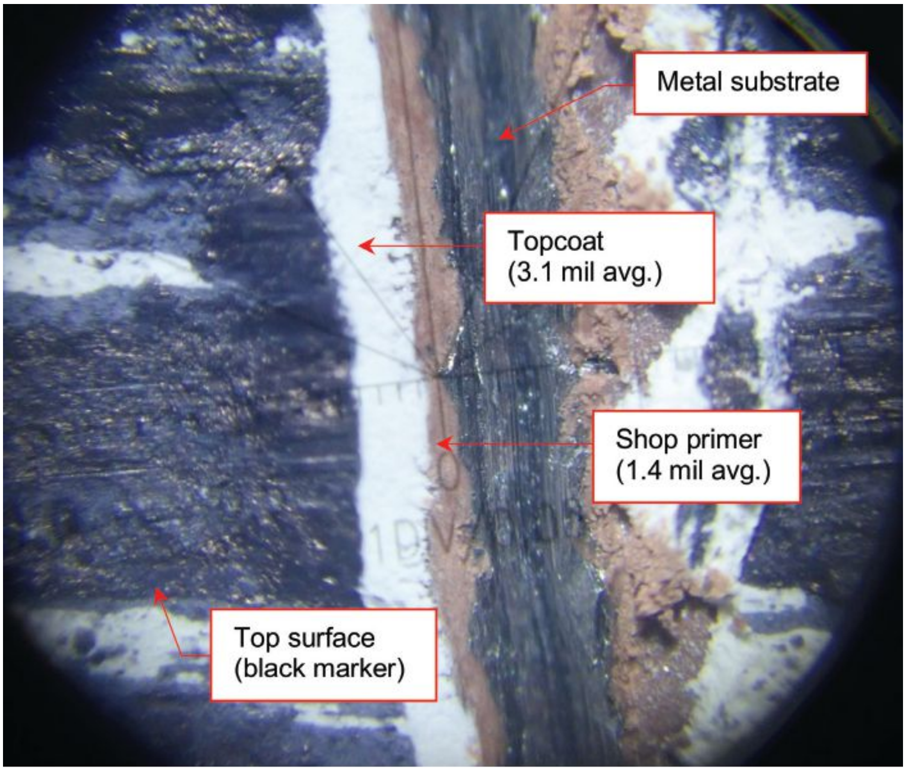

FIGURE 4 Representative measurement at stained area of bottom flange.

stained areas versus the unstained paper towel. To highlight any difference in the composition of the stained and unstained areas, backscatter mode imaging was used to examine the samples. Iron was detected in the areas of the staining of both Samples 1 and 3, as reflected in Figure 5. However, iron was not detected on the unstained areas of the paper towel of these samples. Additionally, SEM/EDS analysis of control sample C2, where no staining was present, did not indicate the presence of iron.

Discussion

Exposure and Storage Conditions

The storage conditions on this project were unknown; however, approximately half of the installed steel framing appeared to have some degree of damage and staining, indicating corrosion of the underlying primed steel and breach of the primer before topcoating had occurred. Shop-primed steel delivered to jobsites are often stored without protection from the weather. Often, even following erection, the primed steel remains unprotected and is allowed to weather for a period longer than recommended. As a result, primed steel often begins to rust before it receives a topcoat. Experience shows storage conditions of primed steel at the shop, during transportation, and at the construction site can be contrary to good practice.

Storage requirements are often ignored, poorly executed, or absent from specifications altogether. Proper storage should not allow water to become trapped or ponded, or dwell on primed steel, as it promotes coating deterioration and corrosion. Instead, primed steel should be stored so that it is kept off the ground and positioned to minimize collection of water, salts, dust, dirt, mud, or other contaminants, and it should have good air circulation for drying. For these project circumstances, storing the shop-primed steel outdoors represents a change from the intended interior/normally dry environmental conditions to conditions where the shop-primed steel experiences more severe exterior exposure ranging from exterior/normally dry to fresh-water immersion, possibly for extended periods of time, constituting a higher level of exposure to water through condensation, ponding, and trapping of water. The shop primer used is not suited for these more severe conditions for longer periods.

Additionally, coatings will generally have a more limited service life when applied over SSPC SP2- or SSPC SP3-prepared surfaces, which removes some, but not all, of the rust, mill scale, and other contaminants from the surface. These surface conditions diminish the long-term performance of the applied coating system, and corrosion develops more quickly relative to significantly cleaner surfaces

TABLE 1 SUMMARY OF COATING THICKNESS MEASUREMENTS

Coating Type	Test ID	Surface	Near/At Stains?	Coating Thickness (microns)					
				Destructive (ASTM D4138)			Non-Destructive (ASTM D7091)		
				High	Low	Avg.	High	Low	Avg.
Primer and Topcoat	1	Bottom flange	No	88.9 (primer)	50.8 (primer)	76.2 (primer)	216	165	193
				178 (topcoat)	127 (topcoat)	152 (topcoat)			
		Web	No	-	-	-	211	292	226
	1 (Moisture test beam)	North web	No	165 (primer)	114 (primer)	135 (primer)	297	178	234
				165 (topcoat)	127 (topcoat)	150 (topcoat)			
		South web	No	-	-	-	305	183	236
		East bottom flange	Yes	41 (primer)	25 (primer)	***35 (primer)***	130	97	***112***
				64 (topcoat)	89 (topcoat)	79 (topcoat)			
		West bottom flange	No	76 (primer)	102 (primer)	89 (primer)	185	135	157
				76 (topcoat)	114 (topcoat)	97 (topcoat)			
	4	Bottom flange	Yes	51 (primer)	5 (primer)	***25 (primer)***	168	122	142
				152 (topcoat)	102 (topcoat)	114 (topcoat)			
		Bottom flange	No	-	-	-	277	203	234
		Web	No	-	-	-	485	224	292
Primer Only	2	Bottom flange	N/A	89	64	***71***	97	51	***69***
		Web		-	-	-	107	76	91
		Top flange (underside)		-	-	-	89	58	***69***
	3	Web		102	76	97	89	53	76

****Bold, italic font*** *indicates average measurements that do not meet project requirements*

prepared in accordance with SSPC SP6 or SP10. In general, no coating will provide superior service life over a contaminated surface than the same coating applied over a clean surface in the same service environment.

Coating Thickness

The shop primer application did not meet the specified minimum thickness of 76 microns (3.0 mils) in several areas. Average thickness measurements for the shop-applied primer were consistently below the required minimum in regions where staining was present at the coating. The primer thickness at the underside of the bottom flanges was consistently less than the primer thickness at the webs, which is reflected in Table 1. At the moisture testing location, results clearly indicated lower primer thickness at the area with staining (approximately 35 microns or 1.4 mils) compared to areas without staining (approximately 89 microns or 3.5 mils). The field-applied topcoat typically met the minimum specified thickness. In many cases, the topcoat thickness was more than double the amount required.

In areas where the primer thickness is low and steel has been stored outside and stacked on top of each other, low thicknesses and interfaces form temporary crevices where water could potentially become trapped, promoting areas of patterned latent corrosion that would be more prone to staining upon topcoating. Moreover, the primer thickness at the bottom flanges was consistently less than the primer thickness at the webs, and the primer thicknesses was less at areas with staining compared to areas without staining.

Staining

Based on the results of SEM/EDS testing, the staining was most likely attributable to water-soluble corrosion products. The moisture testing results indicate that the observed reddish-brown stains are initiated and exacerbated by the introduction of moisture to the coating system, indicating that a water-soluble substance such as underlying water-soluble rust is being extracted and deposited onto the surface of the coating system as reddish-brown stains. The source of moisture can be from the liquid phase of the topcoat itself during application or later from sources such as condensation as simulated by the wet paper towel used during testing. This staining mechanism would tend to manifest itself in areas where the primer is relatively thin and a less-effective barrier to moisture and migration of rust-solutes, more prone to development of pinholes or sim-

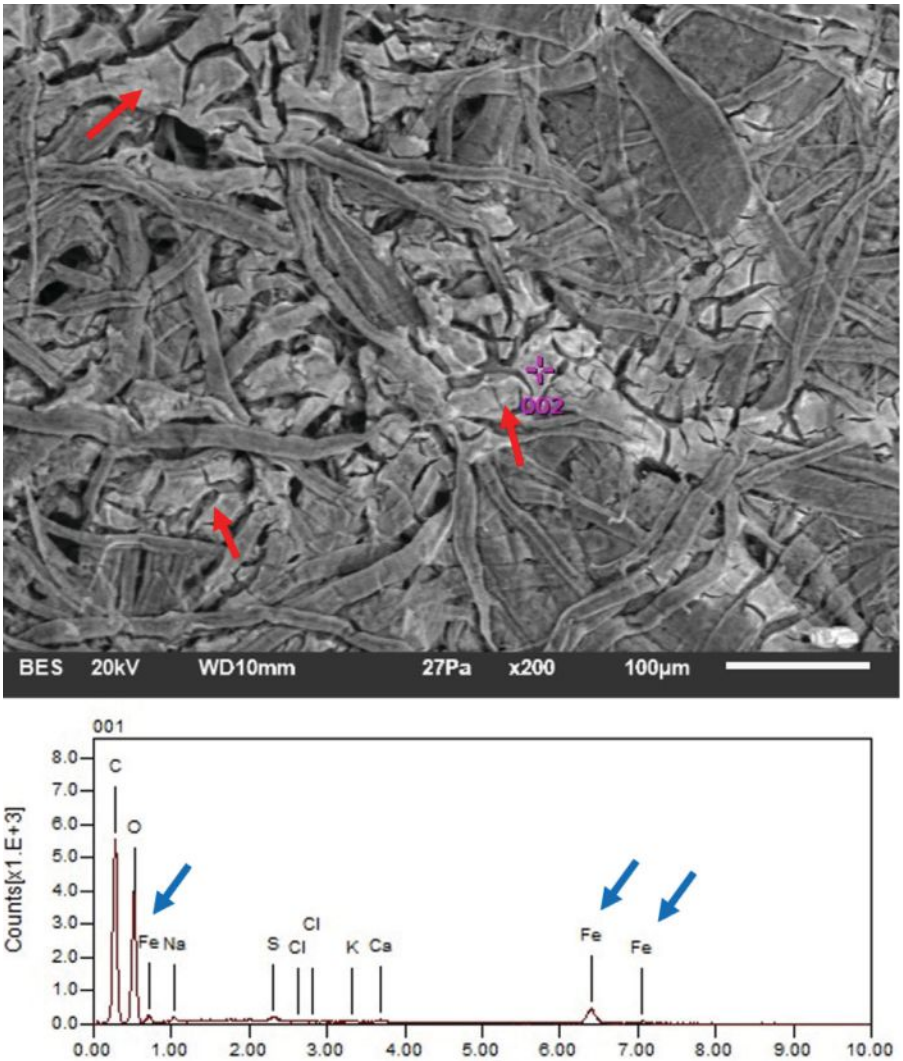

FIGURE 5 SEM image of Sample 1 taken in area of staining. Red arrows point to some of the stained areas on the paper towel. The spectrum shown in the lower portion of the illustration is an area analysis of the entire image, showing the presence of iron (Fe) peaks at 0.705, 6.398, and 7.057 keV (blue arrows).

ilar defects, and less resistant to damages that expose the underlying steel.

The surfactant leaching proposed by others as the cause of the reddish-brown stains would likely result in more uniform, widespread distribution of stains, as well as evidence of surface streaking from leached surfactant. Instead, the staining manifested in a more irregular pattern similar to where corrosion is more common in early stages such as at edges, planar areas with low coating thickness, or at crevices where moisture has potential to become trapped. For instance, a distinct area with concentrated staining, as shown in Figure 2, seems unlikely to occur as a result of surfactant leaching. Instead, given the surfactant is present all throughout the topcoat application and curing, and ambient conditions were likely very similar across the painted beams, staining due to surfactant leaching should be widespread throughout the painted steel, which it is not.

Conclusion

Proper application of the shop primer to achieve the minimum specified thickness, as well as inclusion in specifications for proper execution of storage of shop-primed steel, could have potentially prevented its premature corrosion prior to topcoating, which would have helped mitigate or prevent the occurrence of the staining. Depending on the degree of staining of a given member, either localized coating repairs—including proper surface preparation and cleaning, or complete coating removal and recoating of the affected members—were performed to remove the stains. Additionally, the application of a stain-blocking topcoat could also limit susceptibility to future staining should members be exposed to future moisture conditions such as condensation.

Had the steel been abrasive blasted in accordance with SSPC SP6 or SSPC SP10 and then pre-primed, we anticipate staining of the primer would be delayed, but not necessarily avoided given the circumstances of handling, storage, and exposure. Abrasive-blasted, pre-primed steel, if left unprotected outdoors for a long enough period, can also rust and potentially migrate and stain the coating surface.

References

1 SSPC Standard SP2 (latest revision), Hand Tool Cleaning (Pittsburgh, PA: SSPC).

2 SSPC Standard SP3 (latest revision), Power Tool Cleaning (Pittsburgh, PA: SSPC).

3 ASTM Standard D4138-07a, "Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means" (West Conshohocken, PA, 2022).

4 ASTM Standard D7091-22, "Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals" (West Conshohocken, PA, 2022).

STEPHEN W. FOSTER is associate principal and unit manager for Wiss, Janney, Elstner Associates, Inc., in Austin, Texas, USA, email: sfoster@wje.com. He has been involved in the evaluation, design, and rehabilitation of numerous engineering projects, including concrete, steel, wood, and masonry structures. He is experienced with assessment and repairs related to corrosion, coatings, and cathodic protection systems. He Is an AMPP certified coatings inspector, AMPP corrosion technologist, and AMPP CP2 - cathodic protection technician, He has been a member of AMPP for 12 years.

LEONARD L. PHELPS is associate principal for Wiss, Janney, Elstner Associates, email: lphelps@wje.com. He often serves as a lead chemist on project teams that resolve construction-related materials problems. His experience includes various coating projects, including failure analysis, condition assessment, laboratory and field testing, corrosion protection, specification development, remedial coating recommendations, coating characterization, performance evaluation, and long-term durability assessment. He is an AMPP protective coating specialist. MP