INVESTIGATION INTO THE CAUSES OF PREMATURE CORROSION OF PRE-FABRICATED STEEL FACTORY BUILDING

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***Abstract**: Premature corrosion of steel roof panels of a prefabricated factory building was reported just two months' after installation. In order to find out the causes of this corrosion, physical investigation of the affected roof was carried out and samples of the panels and relevant information were collected. Laboratory tests were carried out on the samples using light optical microscopy, scanning electron microscopy (SEM), energy dispersive X-ray micro analysis (EDX) and tensile tests. Test results show that the steel roof was constructed from painted as well as Al-Zn coated steel sheet, conforming to ASTM A 792M Grade 340 and ASTM A 792M-A150. Analysis of other results suggests that the rusts were superficial in nature and they did not start from the steel sheet of the roof panels. Based on the superficial nature of the rust spots, their morphology, chemical analysis etc., it is believed that rust spots were caused by the corrosion of steel swarfs that deposited on the roof panels. The swarfs originated from drilling, cutting and riveting operations during installation. Proper cleaning of the roof immediately after installation could have avoided the problem. Importance of awareness about the danger of improper cleaning and regular maintenance of roof panels after installation is discussed.*

***Keywords**: Premature corrosion, galvanized, steel debris, roof panel, superficial.*

INTRODUCTION

Prepainted metal coated steel sheet has been successfully used for decades in various climates for building cladding (roofs and walls). With proper selection of the paint system, careful design of the building and regular maintenance, long and trouble-free service can be achieved[1]. A metal roof lasts 2 to 3 times longer than a non-metal roof[2]. Metal buildings comprise almost half of low-rise, non residential construction and a high fraction of these buildings use prepainted metallic coated steel sheet for both the roof and wall panels. It is a cost-effective and long lasting product. Its appearance and longevity has been made even better. The two most common types of metallic coated steel sheet substrates used worldwide today are hot dip galvanized sheet and hot dip coated 55% Al-Zn alloy coated sheet. One important feature of the prepainting process is that it allows the application of thermally cured paint coatings, a process that provides superior paint properties (e.g. fade and chalking resistance) compared with most field applied or shop applied air-dry paints. Also, the superior bonding of the paint to the corrosion resistant, zinc containing layer creates a synergistic total coating system that is the reason for the long product life.

However, the in-service corrosion of structural steels can be the cause of considerable damage of machinery and plants, claiming economic costs due to replacement of components and maintenance, connected break-downs, decreased in-service life. In this field, galvanized steels encounter a considerable interest for their good resistance to corrosion both in humid atmospheres and aqueous media[3-9]. The protection obtained by zinc-base coatings is due to galvanic effect, as zinc is anodic to iron and, consequently, in humid or aqueous environments it behaves as sacrificial material at discontinuities in the coating[10].

Steel debris, when allowed to remain on a building roof following its construction, will quickly rust, causing an unsightly stain[11] that is difficult to remove. To the untrained eye, steel debris looks like premature corrosion. As a result of the appearance, the owner of the building may become understandably upset, believing the contractor used inferior materials that have little or no corrosion protection. Thus prevention staining of building panels from steel debris is essential. Steel debris includes iron fines left from cutting and/or drilling operations when using friction saws, abrasive discs, drills, etc. Additionally, weld splatter from welding operations may also contribute to steel debris. Steel debris may include other construction materials left on the roof, such as nails, screws, staples, nuts, rivet shanks etc.

Premature corrosion of steel roof panels of a prefabricated factory building was reported just two months' after installation. The aim of the present work is to investigate the causes of the premature corrosion of steel sheet roof panels in order to look for the remedies for its prevention.

EXPERIMENTAL

The methodology of this study consists of collection and analysis of information, physical inspection of the factory site, and characterization of roof panel materials by laboratory investigation.

The samples were tested for their compliance to the standard ASTM specifications. Coating was dissolved in 1:1 HCl solution. The exposed steel substrate was tested by optical emission spectrometer (OES) for its chemical analysis. The corroded samples were investigated to find out the causes of corrosion. The stain of the rust spots were treated with 10% H_2SO_4 solution at room temperature. The sample was kept dipped in H_2SO_4 solution for 5 minutes and the stain appearance was observed for investigation. The same sample was again dipped in H_2SO_4 solution for further 5 minutes and the appearance was observed. Thus, appearance of rust stains was observed after every successive 5 minutes dipping in 10% H_2SO_4 solution at room temperature and photograph of the appearances was taken using a digilal camera. For characterization of the samples, different techniques e.g., visual examination, light optical microscopy, stereo-microscopy, scanning electron microscopy (SEM), energy dispersive X-ray micro analysis (EDX), tensile tests were performed.

RESULTS AND DISCUSSION

Visual inspection

Although nothing much can be seen in the general view, close examinations reveal the presence of red-brown rust spots, most are about equal/less than one millimeter in diameter on the panels. The spots occur fairly wide over the whole roof. But the density of rust spots varies greatly: at most places the rust spot density is sparse, while at others the spots are more densely distributed. Figure 1 shows a view of rust spots as black spots on one of the affected areas.

Figure 1: Red-brown rust spots (appeared as black spots) occurring on a panel.

In addition to the rust spots, a number of elongated yellow rust stains were also found (Fig. 2). These are supposed to have been caused by loose steel bolts lying idle on the roof which were seen nearby during the physical investigation.

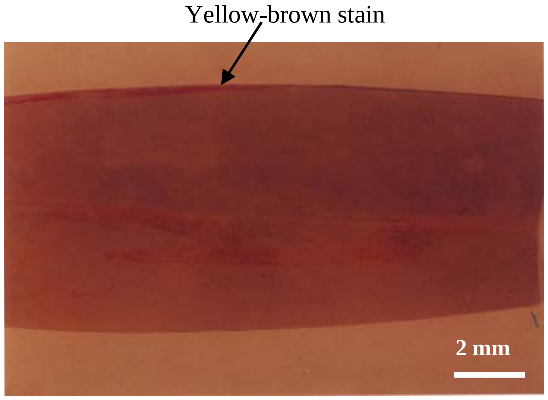


Figure 2: Elongated yellow-brown stains (appeared as dark area) on a panel caused by corrosion of loose bolts lying idle on the roof.

Material characteristics of the roof panel

Results of the chemical analysis and mechanical tests carried out on steel sheet of the roof panels are summarized in Table 1a and 1b respectively.

The above results show that the steel sheet used in the roof panel conforms to the specification ASTM A 792M Grade 340. A cross-sectional scanning electron micrograph of the roof panel material is shown in Fig. 3. The thickness of the aluminium-zinc coating is found to conform to ASTM A 792M-A150. The chemical composition of the galvanized coating obtained by EDX analysis also conforms to this specification. The EDX spectrum as well as chemical analysis of the aluminium-zinc coating is shown in Fig. 4. Both primer and top coat were also present on top of the aluminium-zinc coating.

Corrosion characteristics of roof panels

Stereo-microscopic investigation revealed that the rust spots on the panel generally consist of a central dark deposit surrounded by a lightly stained area (Fig. 5). Chemical analysis of the rust spots by EDX shows the presence of mainly iron and oxygen (Fig. 6). Some carbon, aluminium, silicon etc. were also present as contaminants; peaks of the latter two elements could also come from underlying aluminium-zinc coating. The central deposit of the rust spot was found to be brittle and could be easily removed mechanically with fingernail, which left only a thin dark patch.

When treated with acid (10% dilute H_2SO_4) at room temperature, the deposit and the stain of the rust spots gradually disappeared (Fig. 7). After about 15 minutes dipping, the rust spots totally disappeared leaving no traces of rust on the paint. This suggests that the rust is superficial. It is thought to have been caused by outside agent and not by corrosion product of the steel sheet of the roof panel itself. No sign of paint degradation was seen under the rust spots. This implies that the corrosion that started from outside has not yet penetrated the paint. Cross-sectional scanning electron microscopic investigations across different rust spots also corroborated this finding. The nature of the rust spots viz., their morphology, chemical analysis, superficial nature etc. suggests that these have been caused by corrosion of steel swarf. Steel swarfs, which are fine steel debris particles, usually originate from drilling, cutting, riveting operations during construction of the building itself and/or as contamination from nearby steel buildings under construction. It is known from the literature[11] that fresh steel debris stains are small red-brown colored spots with a central dark spot. On bare panels, galvanic action protects the debris, possibly depleting the metallic coating in the immediate vicinity. An old steel debris stain appears as a smoother surface with a localized red-brown stain in the area where the steel particle corroded away. Iron fines from drilling cause groups of stain spots around the hole. Cutting often causes a line of stain spots along the cut. Tracked particles cause randomly dispersed spots on the roof.

Stereo-microscopic investigations on the

Table 1a Chemical analysis result of steel roof panel

Chemical composition (wt.%)					
C	Mn	S	P	Cu	Cr
0.13	0.38	0.006	0.011	0.01	0.03

Table 1b Physical and mechanical characteristics of steel sheet

Sheet thickness (with coatings on)	: 0.55 mm
Yield strength	: 351 N/mm^2
Percent elongation (in 100 mm)	: 28%
Metallographic structure	: Cold worked

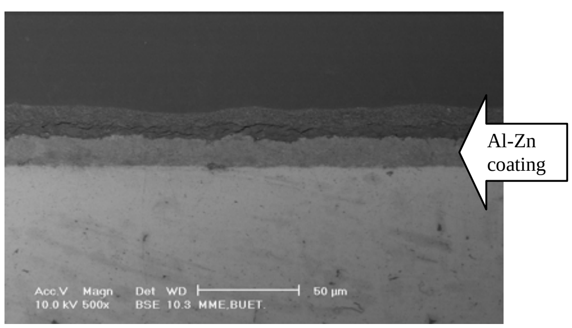


Figure 3: Cross-sectional scanning electron micrograph of roof panel samples.

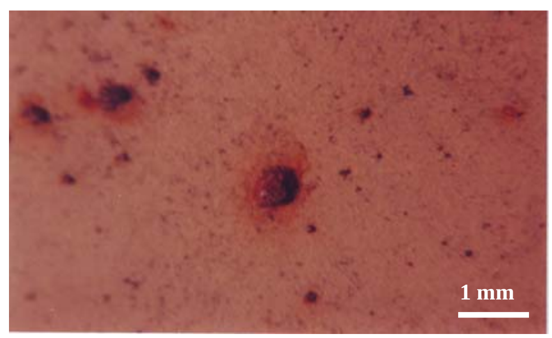


Figure 5: Stereo-microscopic view of rust spot showing a central dark deposit surrounded by stain.

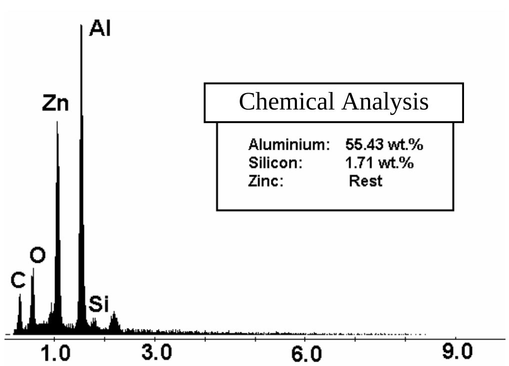


Figure 4: EDX spectrum and chemical analysis of aluminium-zinc coating [Carbon and oxygen are supposed to cause by contamination].

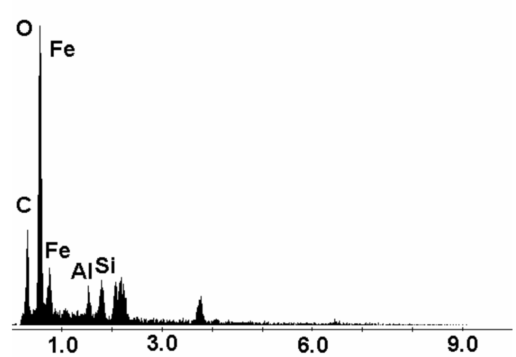
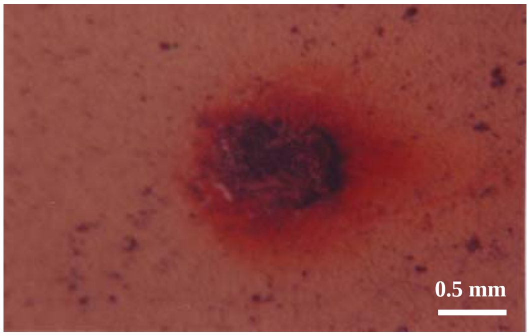
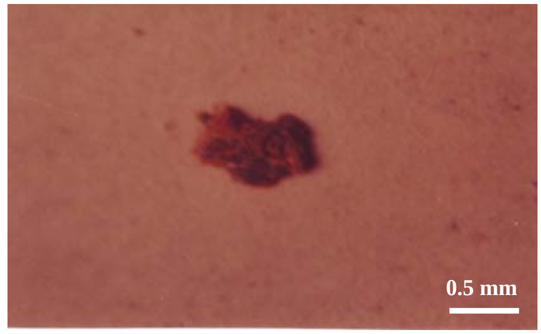


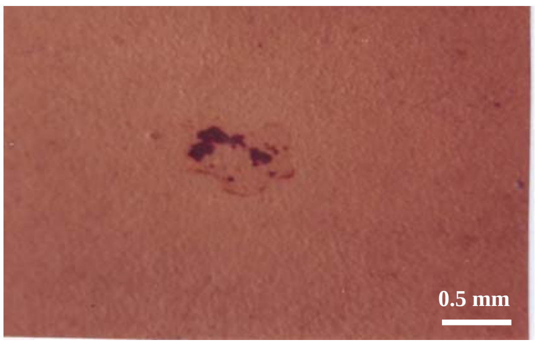
Figure 6: EDX spectrum showing iron and oxygen as the main constituent elements of rust spots.



(a) As-received



(b) Acid dipping: 5 min.



(c) Acid dipping: 10 min.

(d) Acid dipping: 15 min.

Figure 7: Effect of acid treatment (10% H_2SO_4) on a rust spot: a) a rust spot in the as-received condition, b) the same spot after acid dipping for 5 min., c) acid dipping for 10 min., and d) acid dipping for 15 min. [Room temperature]

elongated rust stains (e.g., Fig. 2) showed that these are only superficial. The very presence of such rust stains, which are caused by corrosion of loose bolt lying idle on the roof, however, suggests the unawareness/ carelessness of the concerned installation/ maintenance personnel about the danger of improper cleaning of the roof panel.

Effect of steel debris on panel corrosion

The main effect of steel particle staining on painted panels is aesthetic. It is usually not detrimental to the overall corrosion performance. Typically, paint separates the debris from the metallic coating. It forms red rust until completely rusted away. The natural weathering action will deplete the red stain on top of the paint.

Only rarely, steel particles will penetrate the paint and contact the protective metallic coating. The red rust is inert, but steel particles in contact with the coating will accelerate Zn corrosion, leading to premature coating depletion and paint peeling. On bare metal coating, steel debris will cause accelerated corrosion in a small area[11]. The zinc in the coating sacrifices itself to prevent oxidation of both the steel debris and any exposed areas of the base steel. This leads to premature coating failure and a shorter panel life. Any cleaning that does not remove the steel particles will not help the coating.

Preventing steel debris stain – Clean-up

Stain prevention is much easier and less expensive than repairing the stain caused by the steel debris. In severe cases, such staining can lead to replacement of the whole panels. Thus stain prevention is very important. There are several steps to preventing steel debris staining. The best method is to avoid formation of iron fines in the first place. When this is not possible, the exposed surface should be protected from debris generated during cutting, drilling or welding. Additionally, the panels need to be protected against tracking and finally all debris should be cleaned off the panels.

Careful sweeping is necessary as the job progresses to remove loose particles and particles not well embedded in the paint. Great care should be taken to avoid any action that is likely to remove the paint or metal when attempting to detach embedded debris. Any damage to these coatings will lead to a reduced life of the material. A bristle (nonmetallic wire) brush should be used to dislodge steel debris[11]. Wire brushing can change the panel's appearance and might remove some of the metallic coating. If corrosion from the debris severely damages the metallic coating, affected areas may require painting to obtain the desired protection. Using any kind of steel wool will break up and create newly steel debris. Any steel particles that remain after cleaning will cause further stain. Larger iron pieces, such as nails and screws, should be removed manually, not be washed off as part of the final clean-up. For critical applications or bare metal, routine inspection is necessary. Rain or condensation will cause the remaining steel particles to rust, highlighting affected areas. On bare roofs, steel particles not removed can become a serious corrosion problem. Paint blistering in the immediate vicinity of a stain indicates penetration by the steel debris. This penetration is rare, but the corrosion causing the blistering will continue if not repaired.

CONCLUSIONS

In order to find out the causes of premature corrosion of steel roof panels of a prefabricated factory building, the steel panels were physically investigated. Laboratory tests were performed on both the affected and unaffected panels. The conclusions may be summarized as follows:

The rust spots formed on roof panels are superficial and are caused by the outside source. Nature of the rust spots suggests that steel swarf is the likely cause of such damage. The paint and the aluminium-zinc coating have not been penetrated by rust. Proper cleaning of roof panels after installation is required and the possibility of contamination from nails, screws and such other steel particles lying idle onto the roof as well as nearby steel buildings under construction should be removed. Although the rust spots of the roof panel are superficial and have not yet caused damage to the paint, steps should be taken to clean the panels in order to get rid of these by adopting appropriate techniques and repaint the roof as necessary. Mild abrasive cleaning will remove the stain and most of the particles, but any remaining steel particles will cause the stain to return. A soft bristle brush should be used to dislodge steel debris. Using any kind of steel wool will break up and create newly steel debris.

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