PREMATURE METAL ROOF DECK CORROSION:

Difficult to Detect and Diagnose

By Mark H. Hopmann, PE and Kimberly Steiner

INTRODUCTION

Recent studies by various parties have examined premature corrosion of metal roof decks where fiberboard insulation was directly attached to the top surface of the metal deck and/or where ferrous mechanical fasteners were placed through the fiberboard to anchor it to the deck[1] (*Figures 1* and *2*). At present, fiberboard roof insulations are manufactured using both hardwoods and softwoods, although in the past, at least one facility produced cane-based (bagasse) products. The corrosion conditions associated with fiberboard roof insulation should not be confused with the phenolic insulation board corrosion problem identified in the 1980s. Often undetected by property owners, managers, and tenants, this new condition weakens the roof deck to the point that it presents safety concerns for rooftop equipment and workers. The corrosion can also decrease the capacity of the metal deck's connection to the structure, making the roof deck susceptible to damage from high-wind events. The National Roofing Contractors Association (NRCA) has reported cases in the southern, southeastern, and northeastern areas of the country; however, the extent of the problem across the nation is not yet known. No written requirements to manufacturers have been mandated, and ASTM C208, *Standard Specification for Cellulosic Fiber Insulating Board*, has not yet changed its language to address the issue of corrosion resulting from exposure of metal to the insulation.

In an article entitled "Roof Deck Quickly Corroded by Insulation," published

Figure 1 – Roofing membrane and insulation board removed to expose metal decking. Note corrosion occurs at both "peaks" and "valleys" of metal decking.

Figure 2 – Metal deck samples with corresponding section of fiberboard insulation.

Figure 3 – Small red rust spots (left arrow) and white rust (right arrow) developing on bottom side of roof deck.

Figure 4 – White rust starting on bottom side of roof deck looks like deposits from water droplets.

in the January 2011 issue of *Interface*,[2] the authors stated their opinion that the corrosive agent came from chloride-containing chemicals that were used by the manufacturer to kill mold and mildew in cane-based products prior to fabrication of the boards. (It is our understanding that the sole bagasse-based fiberboard insulation factory in the United States has been closed.) While that mechanism may explain some instances of corrosion associated with cane-based products, this article shows that other corrosive agents can come from the fiberboard material itself.

Other facilities are known to have been affected by this problem, but this article focuses on the field and laboratory evaluation of two facilities in Texas, both of which were affected by cane-based fiberboard insulations. This paper will list several hypotheses regarding the cause of the problem and will describe chemical analyses and the related findings behind them. Finally, recommendations for property owners, managers, and tenants are provided explaining how to perform initial checks and observations to determine if their facilities may be subject to this condition.

GENERAL DESCRIPTION OF FACILITIES AFFECTED

Although the range of construction dates exhibiting this problem is not fully known, the facilities addressed in this article were constructed between 2000 and 2005. Affected structures are typically industrial warehouses, often with conditioned office space in front and unconditioned spaces with large roll-up overhead doors in the rear. In these facilities, the bottom side of the roofs' metal decks may be exposed to view or covered by interior insulation and/or ceiling finishes, making their condition more difficult to assess. This type of structure can also present varying environmental conditions (temperature and humidity) within the spaces.

Roof deck corrosion at these facilities was typically discovered accidentally, within several years of original construction, when roof decks were exposed for modifications to rooftop equipment for new tenant requirements. Levels of corrosion were typically quite significant—much more than would be expected from a minor roof leak over many years of service life for this type of roof. Roof leaks at isolated locations had been reported and repaired but were not necessarily associated with the areas of significant corrosion observed.

EVALUATIONS AND STUDIES

As a safety measure, visual surveys (first from the entire underside of the roof deck) should be conducted, looking specifically for signs of metal decking distress. Simple probing and up-close inspections can be performed from manlifts to check for signs of corrosion and "soft spots" in the decks. These areas need to be marked on roof plans and then on the roof surfaces. Temporary support of the roof deck around these areas may be required before conducting condition surveys and testing on the top side of the roof. Because there does not need to be a significant amount of water present for this type of premature corrosion to occur, it is important to evaluate areas that are prone to roof leaks as well as those that are not.

Distress can appear as common small red rust stain spots but can also appear as white rust spots (which look like dried deposits from water droplets) or "wrinkled" surfaces (*Figures 3* and *4*). White corrosion

Figure 5 – Lines of white rust on top of metal deck at spot welds.

is often found at the spot-weld locations where the metal deck is connected to the open web bar joists. Because some specifications call for the coating of these spot welds and some contractors provide it as best practice, white rust can be mistaken for an applied coating (*Figure 5*). Material testing can determine if the white material is a coating or a form of corrosion.

HYPOTHESES CONSIDERED

When dealing with premature corrosion, it is critical to identify the source of the corrosive agent so that proper corrective action may be taken. Several sources of potential corrosive agents were considered, including:

- Presence of acid rain
- Presence of elevated levels of air pollution related to nearby elevated expressways
- Material installed in wet conditions, trapping water in the roofing system
- Moisture ingress through openings in the metal decking from interior spaces underneath the roofing system
- Excessive roof leaks
- Corrosive agents within the roofing system itself
- A combination of these factors

LABORATORY TESTING

Extensive laboratory testing was undertaken by Wiss Janney Elstner Associates Inc. (WJE) to determine the source of the corrosion.

Testing of the Corrosion Product

The first place to look for evidence of the corrosive agent(s) is within the corroded

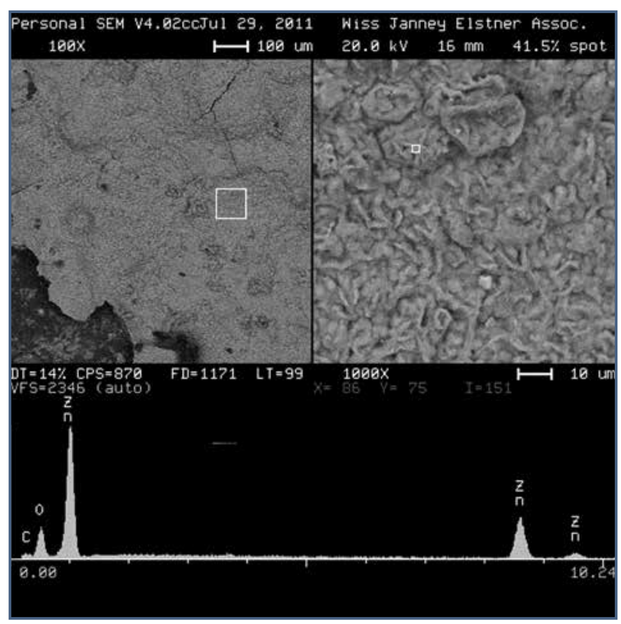

Figure 6 – SEM/EDS analysis of corroded galvanized steel roof deck. Note that the analysis found the presence of zinc, oxygen, and carbon only.

material itself, as many corrosion products retain a chemical signature of the corrosive agent. Corrosion product from the galvanized steel roofing was analyzed using three techniques. Scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM/EDS) identifies elemental composition (of elements heavier than boron) on a microscopic scale; Fourier transform infrared spectroscopy (FTIR) provides information about certain molecules, particularly organic (carbon-chain) molecules; and X-ray diffraction (XRD) identifies the crystalline (regularly ordered atomic arrangement) component.

SEM/EDS analysis of several corroded roof deck specimens from multiple locations indicated the presence of zinc, oxygen, carbon, and—where red corrosion product was present—iron (*Figure 6*). Typical corrosion accelerators—such as chlorine, indicating the presence of chloride; sulfur, indicating the presence of sulfate; or nitrogen, indicating the presence of nitrate—were generally not found. The elements observed (zinc, iron, oxygen, and carbon) would be present from typical moisture-induced corrosion or might indicate an organic component. FTIR analysis indicated the presence of a low-molecular-weight carboxylic-acid salt, such as an acetate or formate. In this case, a likely source of these chemical compounds is bagasse/sugar cane or other wood fibers used in the production of the fiberboard insulation. As discussed below, the source of the acetate and formate was the fiberboard insulation. XRD analysis of the corrosion products—particularly water extracts of the corrosion product where only water-soluble components were analyzed—indicated the presence of zinc acetate and sometimes zinc formate, along with other typical corrosion forms (zinc oxide, zinc carbonate hydroxide, iron oxide) in several samples of corrosion product.

The absence of typical corrosion products (chloride, sulfate, or nitrate) and the presence of unusual corrosion products (acetate and formate) helped to rule out several potential hypotheses: 1) acid rain contains sulfurous acid, which would leave traces of sulfur in the corrosion product; 2) air pollution, which contains elevated levels of CO_2 and SO_x, would leave traces of high levels of carbonate and sulfate; and 3) elevated levels of moisture from the installation of wet materials or roof leaks (solely) or 4) moisture ingress from unconditioned spaces (solely) would have each led to the presence of oxide and hydroxide corrosion products, but no others. The data indicated that the source of corrosive species must be within the roofing materials, possibly in combination with another factor.

To confirm that the source of the corrosive species was within the roofing system itself, testing of materials sampled from the roofs under investigation was performed. The roofing system consisted of the galvanized steel deck and fiberboard insulation with an asphalt coating on its top side. The fiberboard insulation was subjected to two types of chemical analysis and exposure testing to observe the degree of corrosion of galvanized steel exposed to insulation specimens.

Testing of Components in Roof System

Anion analyses were conducted on water extracts of insulation samples using ion chromatography (IC) or chloride analy-

Anion	Anion concentration (mg ion/kg insulation) (7 samples tested for chloride, 3 sample tested for other anions)
Acetate	1422 - 15,938
Formate	Nd - 590
Chloride	160 - 2,020
Nitrite	Nd - 314
Sulfate	105 - 405

Nd = Not detected

Table 1 – Water-soluble anions extracted from insulation samples.

Carboxylic Acid	Concentration (7 samples tested)
Acetic Acid	Nd - 5974
Formic Acid	Nd - 26

Nd = Not detected

Table 2 – Vapor-phase carboxylic acids produced by insulation samples at elevated temperatures.

sis to determine the types and quantities of water-soluble anions (negatively charged ions) that may participate in corrosion reactions. The quantity of anions detected in the samples ranged significantly from specimen to specimen, even among those collected from the same building. Acetate, formate, chloride, and sulfate were typically detected in the insulation samples, all of which are associated with accelerated corrosion of zinc and steel (*Table 1*).

Vapors (particularly carboxylic acids) emitted by the insulation at elevated temperatures were analyzed. Insulation moistened with deionized water was heated to 160°F. Nitrogen gas was passed through and over the wet insulation, and water-soluble components were collected. Using IC, the water was then analyzed for anion content. The conjugate bases of acetic and formic acids—acetate and formate—were typically detected. The amount of the acids was calculated based on the quantities of conjugate base and the pH of the water solution. As with the anion analysis of the water extracts, the quantities of acetate and formate in the collected vapors varied from specimen to specimen, even those removed from the same building (*Table 2*).

Exposure Testing of Insulation Board

A final set of tests to evaluate the corrosivity of the insulation involved exposing noncorroded portions of the galvanized steel deck to the insulation under controlled conditions: 1) exposing the galvanized steel to moistened insulation in direct physical contact with the galvanized steel substrate, 2) exposing the galvanized steel to vapors produced by moistened insulation, and 3) exposing the galvanized steel to vapors produced by dried insulation. The purpose of these tests was to evaluate the relative effects of exposure to 1) the water-soluble ions in the insulation (moistened insulation by direct contact), 2) acetic and formic acid vapors produced by moistened insulation,

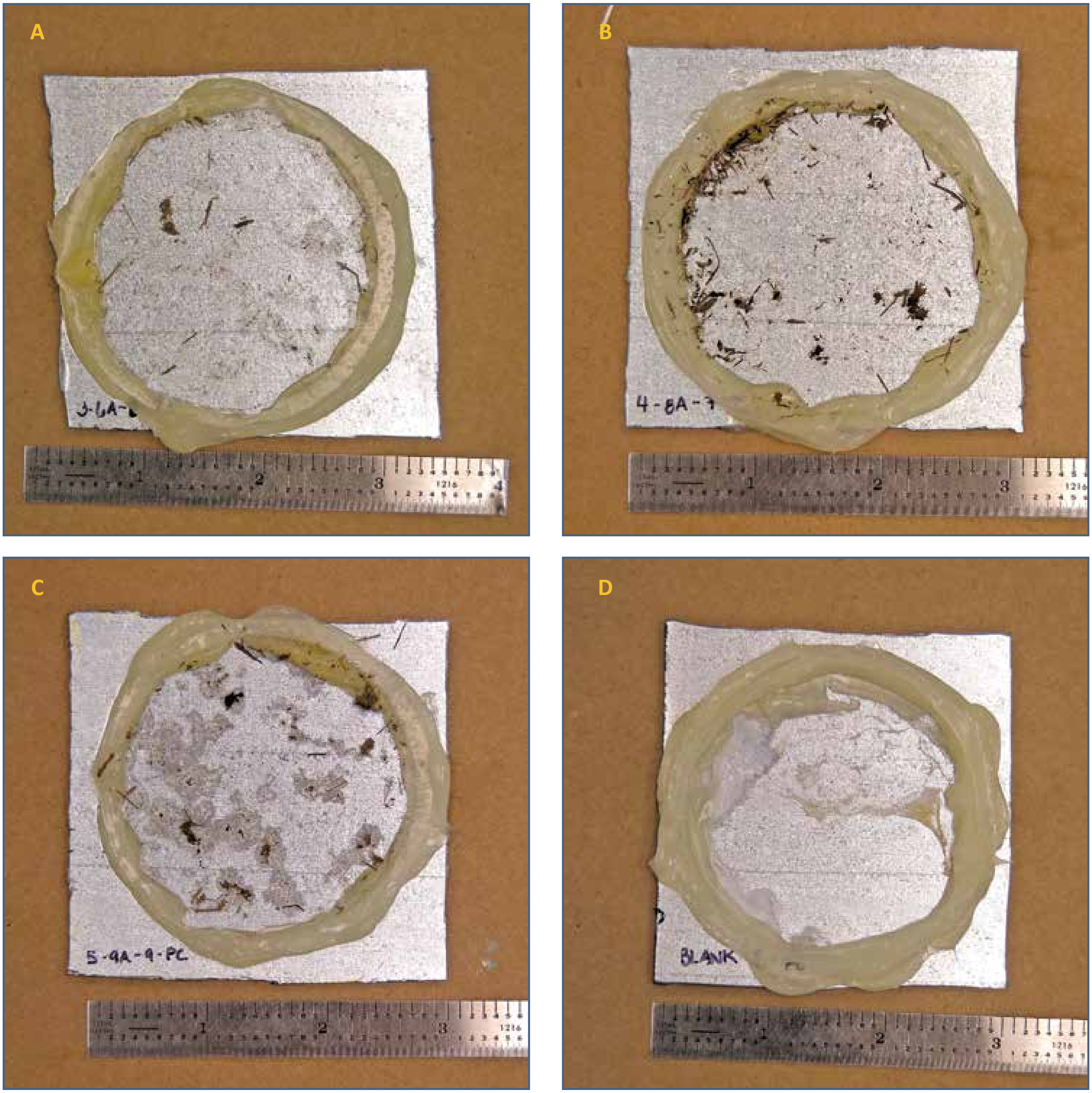

Figure 7 – Physical contact exposure test samples after eight days of exposure at 160°F to different moistened insulation samples. Levels of water-soluble anions detected on a separate portion of the insulation samples used for exposure tests were as follows: A) 16,000 mg acetate/kg insulation, <1 mg formate/kg insulation, 1,080 mg chloride/kg insulation, 314 mg nitrate/kg insulation, and 405 mg sulfate/kg insulation; B) 1,400 mg acetate/kg insulation, 420 mg formate/kg insulation, 160 mg chloride/kg insulation, <1 mg nitrate/kg insulation, and 105 mg sulfate/kg insulation; C) 5,800 mg acetate/kg insulation, 590 mg formate/kg insulation, 499 mg chloride/kg insulation, <1 mg nitrate/kg insulation, and 206 mg sulfate/kg insulation; and D) no insulation used for blank test.

and 3) vapors produced in the absence of moisture in the insulation. For all conditions, the controls were exposure to deionized water or laboratory air that was sealed into the exposure test system.

Although expected to lead to significant corrosion because of the levels of water-soluble chloride and sulfate in the insulation, exposure to moistened insulation in direct physical contact with the galvanized steel produced little to no corrosion compared to other exposure tests and a control of exposure to deionized water (*Figure 7*). This correlated well with the absence of detectable chlorine or sulfur in the corro-

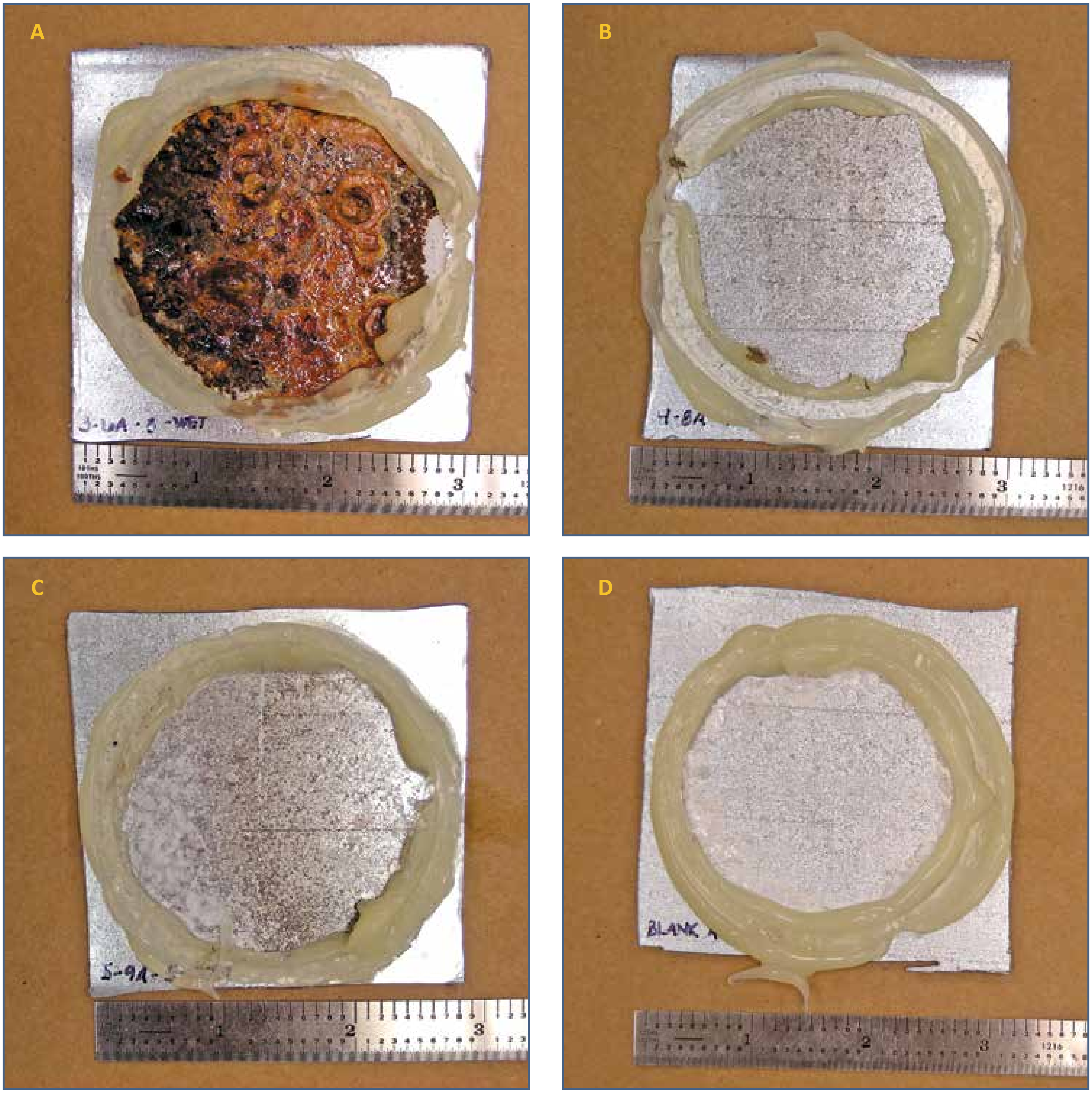

Figure 8 – Vapor phase exposure test samples after eight days of exposure at 160°F to different moistened insulation samples. Levels of volatile acetic and formic acids detected on a separate portion of the insulation samples used for exposure tests were as follows: A) 5,980 mg/kg insulation, B) <1 mg/kg insulation, C) 2,850 mg/kg insulation, and D) no insulation used for blank test.

sion product of the samples removed from service. If water-soluble chloride or sulfate were causing the premature corrosion, a chemical signature of chlorine- or sulfur-containing compounds would be expected in the corrosion product itself.

Exposures to vapor produced by moistened insulation generally produced the most corrosion of the galvanized steel, although the level of corrosion varied dramatically from sample to sample (*Figure 8*).

Exposure to vapor produced by dried insulation resulted in no corrosion product (*Figure 9*). The results of the exposure testing of the oven-dried insulation, compared to that of the moistened insulation, indicated the role of moisture in the corrosion reaction. Moisture is essential for any corrosion reaction to occur, and the laboratory tests indicated that moistened insulation leads to corrosion at a greater rate than oven-dried insulation.

LITERATURE SEARCH

A literature search was undertaken to determine if fiberboard insulation has been associated with corrosion. Numerous sources discuss the emission of acetic acid vapors from hemicellulose-containing products, including wood- and cane-based materials. Fiberboard insulation, specifically cane-based fiberboard produced by a single manufacturer, has been used in storage containers of nuclear material. Reports published by the Department of Energy indicated corrosion in some of these containers due to emission of acetic acid vapors from the insulation and water-soluble chloride in the cane-based insulation.[3,4,5,6,7,8,9] Other literature describes the emission of carboxylic acid vapors from wood.[10,11] The quantity of vapor emitted depends on the species of wood and whether the wood material has been exposed to elevated temperature and humidity for extended time periods, in which case the quantities of acetic and formic acids were typically substantially increased.[11] In addition, specifically for a bagasse product, variations during the processing of the sugar cane into bagasse affect

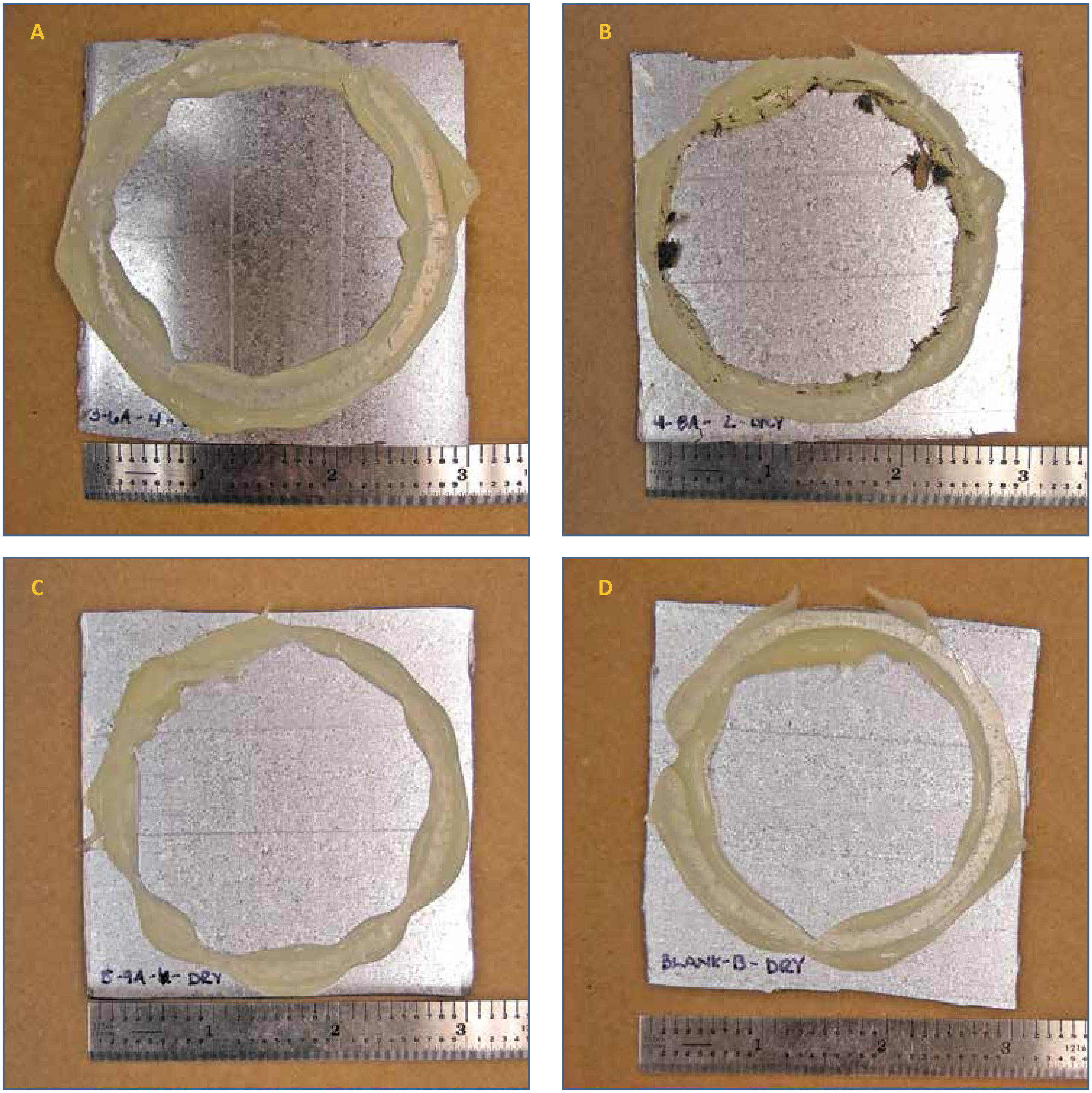

Figure 9 – Vapor phase exposure test sample after eight days' exposure at 160°F to oven-dried insulation. The sample in 9D was exposed to laboratory air only. The other samples were exposed to different insulation samples.

quantities of carboxylic acids emitted from the material.[12,13,14] The production of corrosive vapors from wood-based materials is also well-studied within the museum and conservation industries, which involve storing artifacts in wood-based cabinets where they can be susceptible to corrosion from vapors.[15] No literature was found describing corrosion related to wood-based fiberboard insulation used in the roofing industry.

CONCLUSIONS

The range of laboratory tests performed indicated that a primary source of corrosion was vapors (particularly carboxylic acids) emitted from the cane-based fiberboard insulation itself, particularly if the insulation was in a somewhat moistened condition. The source of the moisture was not determined, but the insulation was not noticeably wet when sampled, and areas of severe corrosion were not related to roof leaks. Neither high levels of water moisture nor direct physical contact of the tested fiberboard insulation with the metal decking was necessary to cause this type of corrosion. Even in the absence of corrosive vapors, the insulation contains water-soluble chloride, nitrate, and sulfate, which can lead to corrosion of galvanized steel. The other potential sources of corrosion previously listed were ruled out.

Our literature review indicates material containing hemicellulose, including wood- and cane-based products, has the potential to emit acetic and formic acids upon exposure to elevated temperatures and moisture.[3,4,5,10,11] Previous roofing industry publications have linked this problem specifically to bagasse (sugar cane-based) insulation. However, as the published literature referenced above suggests, wood-based roofing fiberboard insulations, to our knowledge, have not yet been tested to be able to definitively state if they do or do not produce similar corrosive environments. The amount of carboxylic acid emission has been shown to be affected by the processing of both cane- and wood-based materials.[11,12,13,14]

It is also possible that manufacturing processes led to conditions in which the fiberboard is more likely to break down and emit acetic and formic acids than fiberboard of a similar composition but processed differently. In addition to concerns about vapor emission, the presence of water-soluble chloride, nitrate, and sulfate in the insulation are also expected to lead to corrosion, although minimal evidence was observed that these ions were involved in the corrosion reactions examined within this investigation. The quantities of water-soluble anions and carboxylic acids emitted varied substantially from specimen to specimen, and the specific mechanism of corrosion may also be variable.

RECOMMENDATIONS

Difficulty in detecting and diagnosing premature corrosion presents a safety concern. Steps should be taken by facility owners and managers to identify its presence, and designers and contractors should be aware of the potential problem.

For Owners and Property Managers:

- Identify the type of roof materials used on your facilities. If fiberboard insulation materials have been used, the method of attachment to the metal deck and the manufacturer should be identified. This can possibly be done by reviewing the specifications and/or the approved submittals for the facility. It can also be done by contacting the architect of record and/or roofing and general contractors for the building. If the fiberboard insulation material was applied directly to the deck or if metal screws were used to attach the fiberboard insulation to the metal roofing deck material, condition surveys of the roofs should be performed as described below.
- Make general observations of the bottom side of the roof deck to determine if there are visible signs of decking distress as described earlier in this article. If such conditions are identified, the next step should be to perform simple probe tests (or metal thickness testing) to see how significant the corrosion of the metal deck is. All distressed areas should be documented on roof plans. The roof condition survey should also include locating all roofing penetrations (such as rooftop units, vent stacks, etc.), previous roof repairs, and/or leaks so that correlations between leak and corrosion areas can be made, if present.

- Have the roof investigated by an RRC or an architect or engineer knowledgeable of this particular type of roofing problem if the characteristics of the roof align with those of premature roof corrosion described in this paper. The extent to which the roof needs to be repaired depends greatly on the extent of the corrosion, both in area of the roof and in thickness of corrosion in the metal deck. To address this condition properly, the entire roof system (including the metal deck) may have to be removed and replaced. If the corrosion is minor, the metal deck may be able to be cleaned and coated, and then a new roofing system placed on the repaired metal deck. Care must be taken to use a new roof system that does not overload the existing roofing support members and allows detailing of penetrations and edge conditions, similar to the original roof details.

For the Roofing Design and Construction Industries:

- Create and maintain a database of information on roofs with significantly corroded metal decking where fiberboard has been used.
- Perform testing specifically on wood-based products used in the roofing industry to determine if they can cause significant corrosion in materials of roof deck systems. Test various manufacturers' fiberboard insulations to determine if they contain carboxylic acid or other corrosive chemicals such as water-soluble chloride.
- Define sampling and testing methods for determining the actual cause of corrosion. This could result in the adoption of an ASTM test method requiring manufacturers to conduct testing and publish the results in their product literature.
- Have professional roofing and design organizations address the issue in their publications and standards.
- Do not use fiberboard insulation in direct contact with metal decking or ferrous anchors (with no anti-corrosive coating) unless it is shown that the fiberboard does not contain chemicals that could cause corrosion with metal decking and fasteners. Details (such as separation materials) can be used to keep the metal deck from being exposed to the fiberboard.

FOOTNOTES

1. The conditions being discussed in this article have been described in NRCA's publication *Professional Roofing* (March 2012 issue), in an article entitled "A Concern with Fiberboard Insulation: Corrosion of Metal Components Poses Safety and Performance Issues" by Mark S. Graham. In that article, manufacturers who have been identified as having this problem with their fiberboard insulation products are listed. The problem was also announced in a Steel Deck Institute (SDI) position statement in May of 2012. NRCA's Technical Operations Committee has met with representatives of the North American Fiberboard Association (NAFA) and fiberboard manufacturers to begin to better understand this corrosion issue.
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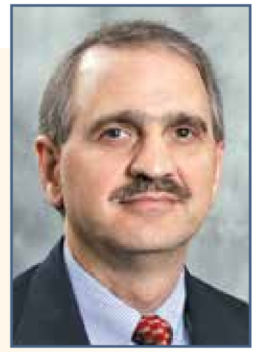

Kimberly Steiner

Kimberly Steiner is a chemist specializing in failure analysis of construction materials. She has expertise in many different types of laboratory analyses as well as field observation. Prior to joining WJE, she was a research scientist specializing in ceramic materials and coatings for Applied Thin Films, Inc. and Northwestern University.

Oklahoma Prohibits Sole-Source Specs on Public Construction

Oklahoma Governor Mary Fallin (R) recently signed Oklahoma Senate Bill 630 into law, which prohibits sole-source specifications on all public construction projects in the state. The legislation, authored by Sen. Clark Jolley (R-OK, District 41) and Rep. Jason Murphey (R-OK, District 31), passed the Oklahoma Senate and House 43-0 and 85-1, respectively. SB630 is designed to stop unfair bidding practices that can significantly inflate the cost of public construction projects.

Recent news reports found that the lack of competition in some Oklahoma school districts had resulted in costs that were up to 60% higher than if a competitive bid process had been followed. The new law will ensure competitive pricing and the protection of Oklahoma taxpayers' dollars in several different ways:

- For public construction projects, at least three equivalent items from more than one manufacturer and more than one supplier or representative must be included in the bidding specifications.
- Any sole-source bid proposal cannot set a geographical boundary from which the material must be obtained.
- Any bid submission on a public project that substitutes an item with one that is alike in quality and design or that meets the required specifications must be considered and shall not be prohibited.
- Any competitive bid submitted under the Public Competitive Bidding Act of 1974 to a school district, county, or municipality for furnishing of goods or services must be accompanied by a sworn noncollusion statement that states, among other items, that neither the bidder nor anyone subject to the bidder's direction or control has been a party to any efforts or offers with state agency or political subdivision officials or others to create a sole-brand acquisition or a sole-source acquisition in contradiction to the new law.

— Coalition for Procurement Reform