

STEEL DECK CORROSION ASSOCIATED WITH PHENOLIC ROOF INSULATION: PROBLEM CAUSES, PREVENTION, DAMAGE ASSESSMENT AND CORRECTIVE ACTION

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In 1990/91, NRCA received an increased number of reports of severe deck corrosion, all of which utilized domestically produced phenolic roof insulation. NRCA commissioned several laboratory evaluations and began an in-situ corrosion research program in 1991.

The laboratory and in-situ work, as described herein, provides some valuable insights regarding the phenomenon of steel deck corrosion related to phenolic insulation.

This paper discusses steel decks, phenolic insulation developments and material properties, deck damage assessment, and corrective actions. Conclusions and recommendations for existing roofs, reroofing and new construction are presented.

KEYWORDS

Phenolic roof insulation, steel deck corrosion.

INTRODUCTION

In 1990 and early 1991, the National Roofing Contractors Association (NRCA) received an increased number of reports of severe steel deck corrosion. All of the jobs utilized domestically produced (i.e., manufactured in the U.S.) phenolic foam roof insulation. Because of the serious ramifications of severe deck corrosion, NRCA surveyed its contractor membership, commissioned several laboratory evaluations and began an in-situ corrosion research program. (*Note: Unless otherwise specifically noted, this paper discusses domestically produced phenolic insulation exclusively.*)

Domestic production of phenolic roof insulation ceased in early 1992. Reportedly, this decision by the manufacturer was unrelated to corrosion issues. Phenolic roof insulation is still produced in Canada and Europe.

Since there is no domestic source of phenolic insulation within the U.S. roofing industry, the concern regarding phenolic corrosion is primarily related to existing roof systems that have phenolic insulation adjacent to steel decks, and the potential problems that may occur if deck corrosion compromises the deck's structural integrity. For an overview of corrosion fundamentals, see Appendix 1.

This paper discusses steel decks (including protective finish options), phenolic insulation material properties related to corrosivity, laboratory and field evaluations, deck damage assessment and corrective actions, and presents conclusions and recommendations.

STEEL DECKS

NRCA's Project Pinpoint baseline data for 1983 to 1992 indicates that steel decks were utilized on 67 percent of non-residential new construction projects. In the U.S., steel roof decks are typically 1½ in. (38mm) or 3 in. (75mm) deep, with 1½ in. being the most common. One and one-half inch decks are available in three types, with the "wide-rib" (referred to as "Type B") being the most common. Decks are now available in 16 to 22 gauge (1.45 to 0.71mm). Twenty-two gauge decks are most commonly used. ASTM material standard A 611 covers the steel deck that is to be prime painted, and ASTM A 446 covers the steel deck that is galvanized.¹

In the U.S., most steel decks are prime painted. The prime paint is applied to the steel coil prior to the coil being formed into decking. According to Levine,² the dry film thickness of the prime paint may be as little as 0.2 mils (0.005mm) to 0.4 mils (0.01mm) on each side of the coil (edges are not painted). Voids and pinholes typically occur in the primer coat. He states that the primer is "primarily for eye-appeal and product appearance." He advises that "if greater corrosion resistance is required, multiple coats or galvanized should be applied."

The other common deck coating option in the U.S. is hot-dip galvanizing. ASTM A 525 specifies types of galvanized coatings and their designations. G-60 and G-90 (coating designations, as defined in ASTM A 525) are typically utilized for steel decks, with G-60 galvanizing being the most common. G-60 coatings provide a minimum of 0.60 ounces of zinc per square foot (183 g/m²), total coating weight for both sides of the steel sheet, when tested by the triple-spot test (as defined in ASTM A 525). G-90 coatings have 0.90 ounces per square foot (275 g/m²). Unless the galvanized deck is to be shop painted or sprayed with fireproofing, it is typically supplied in a mill protective coating that is intended to protect the galvanized steel from premature development of zinc oxide ("white rust").²

In Canada, steel decks are typically galvanized rather than painted. However, a thinner coating is normally used. The typical coating is a zinc-iron alloy, designated in accordance with ASTM A 525M (metric) as "ZF75." This coating provides a minimum of 0.25 ounces per square foot (75 g/m²), per the triple-spot test. The ZF coatings are produced as galvanized or wiped coat.

Other coating options include a combination of galvanizing and factory painting. Levine states that this "is the most effective corrosive protection in corrosive environ-

ments.”³ Decks can also be specified with a combination of factory-applied primer and one or more finish coats of various types of paint. Combinations of galvanizing and painting, or combinations of various paints are typically specified for facilities such as chemical plants, pulp and paper mills, swimming pools, etc., where the deck is subjected to a corrosive interior environment.

Decks can also be field painted (over the existing finish), but this is typically done on the bottom surface for aesthetics when the underside of the deck is exposed to view. Field painting the top of the deck is sometimes performed prior to reroofing, when additional protection is desired or the existing finish has deteriorated.

Another deck finish is aluminum zinc alloy (known by the proprietary name “Galvalume”). This type of coating is covered by ASTM A 792. Although aluminum zinc alloy steel is typically used for steel roofing panels, it is not commonly used for decking. Compared to G-90 galvanizing, aluminum zinc alloy is a relatively expensive coating.

Levine³ reported that adding copper to carbon steel would be beneficial for atmospheric (i.e., exposed to the ambient air) corrosion protection. However, he advised that more expensive copper-bearing steel would provide little or no benefit if the corrosion is caused by roof leakage or condensation.

PHENOLIC INSULATION

Domestically produced phenolic roof insulation (closed-cell) was introduced commercially in 1982.⁴ Canadian-produced phenolic roof insulation is discussed at the end of this section.

In a 1982 article,⁵ the issue of phenolic insulation and corrosion was briefly discussed. In the article, Dupuis was quoted as stating “acids used in the manufacturing process can combine with moisture after the product is installed.” He further stated that this can create an acidic solution and cause a corrosion problem around fasteners, but he stated “this is all conjecture.” In the same article, Stuart Smith was quoted as stating that he “knows of phenolic foams on the market that contain ‘free acids’.” And he stated that there was only a remote possibility of phenolic corroding a metal deck, but that “it can eat nails and aluminum facers right up.” A phenolic manufacturer’s representative in the article stated that “we’re studying it (corrosion) very carefully. We’re concerned enough to run some tests.”

There were several reports of problems involving phenolic insulation during the first few years after commercialization. However, these problems were primarily related to dimensional stability (board shrinkage) and board crushing or breakage, as described by Baxter.⁶ These problems were eventually largely resolved, in part by the introduction of different facers and by increasing the board density.^{7,8}

A 1985 document by Kifer (a phenolic manufacturer’s representative) discussed phenolic corrosion.⁹ He stated that closed-cell phenolic foam was “reasonably permeable to water vapor,” but it did not behave as a “sponge” because the passage of liquid water through the cell structure had virtually been eliminated. He also noted that there was a lesser degree of catalyst “leachability” from the closed-cell foam. In another paper later that year,¹⁰ he explained that because foam production was catalyzed with a blend of organic sulfonic acids, the acids “give corrosion

rates which decrease markedly as a function of time. The sulfonate salts produced by the initial surface reaction of available catalyst with common metals of construction appear to act as inhibitors to further interaction.” He further stated that “the single most important factor in causing end use corrosion is the presence of liquid water.” In Reference 9, he stated the following conclusions:

1. “Properly applied phenolic foam does not present a significant corrosion hazard to either metal decks or approved mechanical fasteners.
2. Any effects related to corrosion, as they occur in the field, are likely to be insignificant for all insulations tested; that is, none would be expected to affect the performance of the system.
3. Corrosive behavior of...closed-cell insulation is usually characterized by short-term passivation of active metal surfaces. Long-term corrosion rates are essentially the same as for comparable roofing insulations.”

In Reference 10, Kifer discussed pH. When “ground up in water, [phenolic insulation] will frequently give pH values of 2.5 to 3.0. However, the corrosive behavior of the resulting leachate is the property of importance, not the pH value itself.” He asserted that long-term corrosion rates of closed-cell phenolic “are comparable to those of other insulation materials, in spite of the potential for somewhat lower pH values.”

Also in 1985, Dvorchak (a phenolic manufacturer’s representative) briefly discussed corrosion of steel decks and fasteners when in contact with insulation.¹¹ He mentioned reports of phenolic foam’s corrosiveness, especially when inorganic mineral acids such as hydrochloric, sulfuric and phosphoric are used as catalysts. But he stated “the corrosiveness of foam greatly diminishes with the use of organic catalysts [which his company used] such as oxalic, adipic, benzenesulfonic, p-toluenesulfonic, phenosulfonic and petro-based sulfonic, and catalysts.” He also advised that “further testing of all insulation materials is needed to more thoroughly evaluate corrosion potential and to determine whether corrosion represents a serious problem.”

A 1985 document by Blizzard¹² reported on a laboratory evaluation for a phenolic insulation manufacturer which compared the corrosive characteristics of some common insulation boards in contact with roof deck samples. The deck samples included prime painted steel, G-60 galvanized steel and bare carbon steel. The insulation board samples included expanded polystyrene (EPS), fiberglass, polyurethane and three phenolic samples. Specimens were conditioned at various temperature and humidity conditions and were exposed for periods of 20, 100 and 200 days. Distilled water was added to some specimens three times a week to “encourage the leaching process.” The report presented several findings, including the following:

- For the dry insulation test series, “the phenolic foams were more detrimental to the paint integrity (with this particular paint formulation) than any of the other combinations [of prime painted deck and other insulations utilized in the testing]. This paint peeling behavior is probably related to a particular chemical interaction with this type of paint at the facer/paint interface which may be pH sensitive.”

- For the wet insulation test series, "the phenolic foams were more likely to cause paint damage than most other test materials with initially wet insulation. The phenolic foams appear to be more compatible with the galvanized finish, along with most other insulations. Pitting, however, became a significant factor in several tests."
- For the continuously wet test series (in which water was periodically added), "with few exceptions, the phenolic foam samples were more damaging to the painted panels in this test series than the other insulations. Phenolic foams as a group had competitive corrosion rates on galvanized panels in the 200-day continuously wet test series."
- "Test data indicates significant deterioration of this particular organic deck coating (primer paint) with a change to initially wet or continuously wet test surfaces for all insulations tested."
- Pitting corrosion became more of a factor on both steel and galvanized surfaces in the long-term (200-day) tests with the wet and continuously wet exposure. It is important to note that the rate at which a pit can penetrate a metal surface is not necessarily or typically related to the general corrosion rate.... The most significant thing to note is that pitting can occur under a specific set of conditions which could reach serious proportions...."
- Galvanized steel appears to be the most desirable decking material for many insulations, and phenolic foam in particular."
- It would be helpful if a compatible corrosion inhibitor could be incorporated into the phenolic foam products to reduce short-term corrosion rates."

In 1985, a membrane manufacturer issued a technical note¹³ that stated "test results have indicated that some phenolic foam insulations can contribute significantly to corrosion of metals in certain environments." It further advised that "you should refrain from utilizing phenolic foam insulation" under their membrane system.

In 1989, ASTM material standard C 1126 for phenolic insulation was issued.¹⁴ Section 11.3 stated "phenolic foams may contain some compounds which may promote corrosion in the presence of liquid water.... When it is anticipated that the foam will be in direct contact with metal, the foam supplier shall provide the proper installation procedure."

In 1989, another domestic manufacturer purchased the phenolic manufacturing rights from the manufacturer that introduced the product in 1982. In 1990, the new manufacturer issued a bulletin on steel deck corrosion.¹⁵ In part it stated that prime painted decks are not designed for corrosion protection after roof installation. It also stated that phenolic insulation can "interact with the paint," thus "allowing a thin surface layer of corrosion to form on the steel. This process also accelerates in conditions of high temperature and high humidity...." It is not believed "that this reaction poses a threat to the structural integrity or performance of metal roof decks...."

In March 1991, the manufacturer introduced a "facer designed to prevent corrosion reactions" for their phenolic insulation.¹⁶

In March 1992, the manufacturer issued another bulletin on steel deck corrosion.¹⁶ It stated that observations "suggest that the corrosion phenomenon can occur under certain circumstances on galvanized as well as painted steel decks." ... "However, under extreme conditions, where the insulation is wet or damaged, we now believe there is a potential that the corrosion reaction could progress to a point which could weaken or penetrate an area in a metal deck." ... "Where evidence of wet or damaged phenolic insulation exists, or severe deck corrosion is observed, care should be exercised in operating equipment, moving heavy loads, and walking across a roof." ... "If you detect a leaking roof, severe deck corrosion, or, damaged or wet insulation associated with our phenolic foam, please call"

Also in March 1992, the company representing the phenolic foam that was manufactured prior to 1989 issued a product alert bulletin.¹⁷ It discussed the receipt of reports in the last year of steel deck corrosion under single-ply membranes. It stated that severe "deck corrosion can lead to an unsafe condition, which under extraordinary conditions could result in property damage or bodily injury" ... "If the following conditions exist, there is an increased chance of deck corrosion being present:

- Roof leaks have been experienced.
- When roof leaks were present, wet insulation was not removed.
- The insulation has been crushed"
- "The building is located in an area where there is a high average relative humidity."
- The interior relative humidity is in excess of 40 percent and the insulation is adjacent to the deck.

Lastly, it stated "if any of these conditions exist with a single-ply roof membrane, ballasted or unballasted, please contact"

Canadian Phenolics

One Canadian manufacturer began producing an open-cell phenolic roof insulation in the mid-1970s. Production ceased in 1991, reportedly for reasons unrelated to corrosion. Limited information on this product is presented later.

Another manufacturer began production of a product essentially identical to the U.S. phenolic in 1989. It is reported that this product now uses a corrosion inhibiting facer. Limited information on this product (prior to the introduction of the corrosion inhibiting facer) is presented later.

A third manufacturer began commercial production of a closed-cell phenolic in 1989. The manufacturer reported that "both the chemistry and manufacturing process are different from those used to produce other phenolic foams that are currently on the market."¹⁸ To differentiate this material from other phenolic insulations, it is now designated as a "resol" foam. As described in Reference 18, the manufacturer asserts that this product has a relatively low corrosivity potential. As will be discussed later, the results of NRCA's work is consistent with this claim. Table 1 presents the results of leachate analysis commissioned by NRCA, which shows this phenolic (sample "H") to have significantly higher pH, compared to U.S. phenolics. Figure 1 presents the results of moisture gain studies commissioned by NRCA, which shows that this phenolic (samples "H-1"

and "H-NF") has significantly different moisture gain properties, compared to U.S. phenolics. Also, in a limited field study conducted by NRCA (described later), this product, as well as the open-cell phenolic, did not show surface interaction (superficial corrosion) with the prime painted deck, whereas the domestically-produced phenolic and its Canadian counterpart did show surface interaction.

PROBLEM CAUSES

Steel deck corrosion associated with moist insulation (as a result of roof leakage, moisture entrapment during or prior to construction, or inadequate condensation control) is not new, nor is it only limited to certain types of insulations. If there is sufficient moisture at the deck/insulation interface, the deck will eventually corrode if it is prime painted. If the deck is galvanized, corrosion of the steel is also likely to occur, but if the galvanizing is G-60 or greater, it will take longer for this to happen.

However, for insulations other than domestically-produced phenolic insulation, it typically takes many years for the deck to be structurally compromised. The Steel Deck Institute (SDI) advises that corrosion was not an issue prior to the introduction of phenolic insulation.³ It may be understandable that this would be SDI's perception, for two reasons. First, it is probable that most building owners would not be greatly upset if they needed to replace some decking after 15, 20 or more years of service. Secondly, if there was a desire on the part of the owner or other parties to contact the deck manufacturer, in most cases, it would probably be difficult to determine who the manufacturer was.

For domestically-produced phenolic, the corrosion rate can be dramatically accelerated, compared to other rigid roof insulations. Severe deck corrosion has been reported to NRCA on jobs that were from approximately three to five years old.

Based upon work performed by NRCA, as well as review of the references, there are two characteristics of domestically-produced phenolic insulation that appear to influence rapid corrosion of decks when the insulation becomes moist. The first is related to leachate from moist insulation. (Leachate is the solution that percolates from wet insulation. It contains soluble products dissolved from the insulation, and may contain other products that were in the water prior to it coming in contact with the insulation). As shown in Table 1 (and described later), domestically-produced phenolic leachate has a very low pH. While a low pH is not necessarily very corrosive, phenolic leachate has proven to be very aggressive. Factors other than leachate that influence corrosion are the rates of moisture ingress and oxygen diffusion that occur through the insulation.

(Note: pH is used to express acidity and alkalinity on a scale of 0 to 14, with 7 being neutral. Values less than 7 are increasingly acidic.)

The other significant characteristic of domestically-produced phenolic is related to its affinity for water. It is a hygroscopic material. Kifer⁹ was correct in stating that it is permeable to water vapor. (See Figure 1.) But, NRCA's studies found his statement about the passage of liquid water through the cell structure having been virtually eliminated to be incorrect. During NRCA field research, phenolic boards were found to fairly readily absorb water (i.e.,

when wetted, they greatly increased in weight), and they were slow to release it, compared to polyisocyanurate insulation.

The hygroscopic nature of domestically-produced phenolic probably plays a key role in surface interaction (superficial corrosion), which is commonly seen when phenolic boards are removed from prime painted decks. (Note: *Superficial corrosion is defined as a condition wherein the deck finish is still largely intact, but rust stains are present.*) Depending upon storage and transit conditions after manufacturing, and ambient conditions at the time of installation, the installed boards can have a relatively high moisture content by weight (see Table 2), yet still be perceived by the roofing mechanic as not being moist or wet. This small amount of moisture appears to be sufficient to develop some leachate, which then causes the superficial corrosion. During summer drying months, if there is no vapor retarder, the residual moisture content is typically reduced by downward drying. Unless moisture is added to the roof system by leakage or wintertime condensation, there appears to be insufficient moisture to continue the corrosion process. Also, as discussed in Reference 12, perhaps the layer of corrosion products is somewhat protective.

If the phenolic does absorb additional moisture, the corrosion process can continue. Loss of metal can occur somewhat uniformly across the deck (including the top and bottom flanges and the web). However, pitting corrosion also occurs on these surfaces. It appears that pitting is more pronounced at the shoulder of the deck (where the top flange meets the web). (See Figure 9.) As the corrosion becomes more advanced, the pits develop into small holes through the metal, which in turn can cause a separation of the flange from the web. (See Figure 1.) When this happens, the deck's structural integrity in the affected area is immensely compromised. Holes can also develop in the top flange. These can be quite small or up to a few inches (several mm) in diameter. (See Figures 2 and 3.) NRCA has received two reports of small pieces of corroded deck falling to the floor.

Under some circumstances (e.g., slow leakage), domestic phenolic's hygroscopicity may unfortunately serve to mask leakage. For example, one job that experienced severe corrosion was found to have two small membrane punctures. The severest corrosion occurred near the punctures, and decreased with distance from them. The building owner reported that interior leakage was not observed. The problem was discovered when a small portion of deck yielded when stepped on by a worker. About 8 squares (74 m²) of deck were corroded to varying degrees. About 5 squares (46 m²) were replaced, as directed by an engineer.

While a severely deteriorated deck may fail by collapsing from a uniformly distributed load (e.g., snow load), it may be more prone to a point load failure (e.g., a person walking on the roof).¹⁹

In many parts of North America, if there is roof leakage, acid rain could also be expected to play some role in steel deck corrosion, regardless of the type of roof insulation. Over the past several decades, the acidity of rainwater has increased.²⁰ In some locations, rainwater is now relatively acidic. Hence, although in the past it has likely taken several years (except in the case of phenolic insulation) for leakage to cause severe corrosion, acid rain may now accelerate the process.

REPORTS TO NRCA

In 1989, NRCA surveyed its contractor membership on problems with all types of insulation. Seventeen percent (29 jobs) of the 169 job reports indicated problems with phenolic insulation. The majority of these problems were crushing and shrinkage. None of the phenolic reports in the survey identified corrosion as a problem.

The first phenolic corrosion problem in the NRCA archives was reported in 1984. By early 1990, approximately six reports had been made to NRCA. A few more reports were received later in 1990 and early 1991. Some of these reported that the deck was structurally impaired.

Because of the increased incidence of corrosion reports, the NRCA contractor membership was surveyed in April 1991. Fourteen contractors responded by reporting 18 problem jobs. Seven of the 18 jobs had phenolic insulation adjacent to the deck. The other 11 jobs used four other different types of insulation. The reports of both phenolic and other types of insulation indicated that corrosion was experienced over galvanized as well as prime painted decks. It was unknown if the galvanized decks were G-60 or G-90. *(Note: Two other surveys on different subjects were sent concurrently with the corrosion survey. The number of returns on one of the surveys was relatively high. Accordingly, it is believed that the low return of the corrosion survey was reflective of the contractor experience at that time, rather than contractors not responding.)*

By June 1991, NRCA was aware of slightly more than 20 corrosion problems wherein phenolic was adjacent to the deck. The number of reports to NRCA has continued to increase, but the total number is still relatively low. The reports have involved a variety of low-slope and steep-slope systems. Roof coverings have included built-up, single-ply, tile and metal. Reference 17 implies the corrosion is limited to single-ply membranes, which is not the case. NRCA has received a larger number of reports involving ballasted EPDM membranes (the larger number appears to be related to puncture susceptibility), but clearly the corrosion problem is a direct function of moisture gain within the roof system rather than the type of roof covering.

The first definitive reporting of steel deck corrosion associated with phenolic insulation in the literature was made by Canon in 1991.²¹

NRCA RESEARCH

NRCA has commissioned laboratory research and has conducted field research as described below.

Leachate

A leachate study was performed on phenolic, perlite, polyisocyanurate, rigid fiberglass and wood fiberboard in 1991 and 1992. The phenolic samples included material from a job that experienced severe deck corrosion, as well as three phenolics that had not been incorporated into a roof. One of the phenolics had corrosion inhibiting facers, and one of the phenolics (resol) was manufactured in Canada.

The lab cut a specimen from each sample. For faced products, the specimen included the facers. Each specimen was broken into small pieces and placed in a beaker, which was filled with demineralized water. The beakers were stored at room temperature for one week. Free water (which contained water soluble extracted material) was

poured off from each beaker and analyzed by ion chromatography. Cations were detected by electrical conductivity. Anions were detected by electrical conductivity and ultraviolet (UV) absorption at 225 nm.

Table 1 gives the pH of the extracts and the concentrations of the cations and anions. The low pH of the extract from domestic phenolic samples "EP-2," "I-B" and "II-A-1" is believed to be caused by the large concentrations of toluene sulfonic acid and ethyl benzene sulfonic acid (anions), which were not neutralized by the cations to produce a neutral salt. It is believed that the composition of the cations (sodium, ammonium, potassium, magnesium and calcium) would not contribute to corrosivity. Regarding pH of the other samples, it should be realized that water absorbs carbon dioxide from the air—this alone can lower the pH to 4.5-5.

(Note: This was a limited study. It is unknown how representative these samples are of the products which they represent. However, the data appears to correlate with other reports and observations. If additional samples of similar products were similarly tested, there likely would be some variation in the findings, but it is believed that it would not be significant.)

Moisture Gain

A moisture gain study was performed on three phenolic and one polyisocyanurate samples in 1991 and 1992. One of the phenolics had corrosion inhibiting facers and one phenolic was manufactured in Canada. The samples measured approximately 12 in. x 12 in. (300mm x 300mm). They were placed in an oven for drying. After reaching a constant weight, they were placed in an environmental chamber maintained at 90°F (34°C) and 95 percent relative humidity. They were placed on racks so that all faces of each sample were exposed. The samples were periodically removed from the chamber and weighed. The testing was terminated after 28 days.

Two samples ("H-1" and "H-NF") of a Canadian phenolic (resol) were included in the study. Both samples were taken from the same board. This product had a kraft paper facer adhered in asphalt to the foam. Since it was believed that the facer could play a significant role in limiting moisture gain, on one sample ("H-NF") the facer and asphalt were removed.

The results of this study are shown in Figure 14. The domestic phenolics "I-4A" and "II-1A" (with and without a corrosion inhibiting facer) essentially had the same moisture gain curve. After 28 days, they had a moisture content of approximately 20 percent (by weight). The moisture content of the polyisocyanurate sample ("IV-1A") was approximately 5 percent. The moisture content of the Canadian phenolic was approximately 6 percent with facers and 10 percent without facers.

Moisture Loss

Samples of phenolic and polyisocyanurate that were used in the NRCA field research project were taken for moisture content evaluation. Samples were taken in the spring of 1991 when the job was installed. Additional samples were taken in the fall of 1991 to determine the amount of downward drying in the summer. Samples were then taken the following spring to determine if they gained moisture dur-

ing the winter. Moisture content (by weight) was determined by oven drying. Results are shown in Table 2.

The phenolic "I" boards were approximately seven months old at the time of installation (see Table 1 for further product information). At the time of application, one sample had a moisture content of 32.1 percent—it did not feel damp. Another sample had a moisture content of 208 percent. This sample did feel damp in the field and was specifically taken for moisture content analysis.

The phenolic "II" boards had corrosion inhibiting facers (see Table 1 for further product information). They were approximately two weeks old at the time of installation. The polyisocyanurate "IV" boards were approximately one month old at the time of installation.

As can be seen on Table 2, all of the phenolic samples had a much higher moisture content at the time of application, compared to the polyisocyanurate. As expected, the boards lost moisture during the summer, but the moisture content of the phenolic samples was still much higher than that of the polyisocyanurate. The results of the fall 1991 evaluation show fairly large board-to-board variation of the moisture content within a given product. The spring 1992 tests suggests the boards gained a minor amount of moisture during the winter.

Field Research

In April 1991, NRCA began an in-situ corrosion research project in the Chicago, Ill. area. The building houses a roofing contractor's sheet metal shop and warehouse. It is heated, but not air conditioned. The roof system is a ballasted EPDM membrane over rigid insulation over 22 gage (0.71mm) 1½ in. (38mm) deep Type B (wide rib) steel deck. Four insulation products were utilized (their age at time of application was noted above):

- 2¼ in. (63mm) thick phenolic with fiberglass facers, designated as "I."
- 2 in. (60mm) thick phenolic with corrosion inhibiting fiberglass facers, designated as "II."
- 2¼ in. (70mm) thick polyisocyanurate with fiberglass facers, designated as "III." These boards were approximately two months old at the time of application.
- 2 in. (67mm) thick polyisocyanurate with organic/inorganic perforated facers, designated as "IV."

The majority of the deck was G-60 galvanized, however, an area of prime painted deck occurred under each of the four insulation products. Each area of prime deck measured approximately 6 ft. x 20 ft. (1.8 m x 6 m).

At one test area over each of the four insulations, the membrane was ballasted and a loaded ballast buggy made several passes over the ballast. The intent was to damage, but not pulverize the boards. This was done because several of the corrosion problem jobs also reported crushing problems. After crushing, the membrane was removed and the boards were examined. All four insulations had considerable damage of the upper portion of the foam, but there were no core fractures or damage on the underside of the boards.

The boards in the test area were wetted on both sides. The phenolic boards ("I" and "II") somewhat readily absorbed water that was poured on them (see Table 3 for the amount of applied water). The membrane was then

reinstalled and ballasted. Wet boards of all four insulations occurred over the galvanized and prime painted decks.

In late September 1991 (approximately five months after application), one 4 ft. x 8 ft. (1.2 m x 2.4 m) board was removed for observation at each of the four test sections. A synopsis of observations is presented in Table 3. For a full discussion of the field testing, see Appendix 2.

To determine if the corrosion process would stagnate or progress, the four boards were re-wetted and the membrane reinstalled.

In May 1992 (approximately one year after installation), three of the areas were re-opened. Because of the previous similarity between polyisocyanurate "III" and "IV," it was decided not to open "IV." (See Table 3.)

It was unclear if the lack of additional corrosion (as described in Table 3) was due to reduced winter temperatures (since corrosion is decelerated at lower temperatures), or due to a lesser amount of water being applied in the fall versus the spring, or if the corrosion products were offering protection against further corrosion. It was decided to re-wet the three areas and continue the study. (*Note: As noted at Table 3, approximately twice as much water was applied in April 1991 compared to September 1991.*)

In November 1992 (approximately 19 months after application), the three areas were re-opened. At each of the three insulations, an area of deck (including galvanized and prime painted) approximately 20 ft. x 9 ft. (6 m x 2.7 m) was exposed. The corrosion had progressed over the summer at phenolic I and II and polyisocyanurate III. (See Table 3 and Figures 4 to 13.) At this point, it appeared that if the boards remained wet, the corrosion would continue. Since the test area was over an occupied building, it was decided to terminate the test, rather than continue the test to failure.

Field Research

In 1988, the Midwest Roofing Contractors Association (MRCA) and NRCA conducted a joint in-situ research project on uplift and crushing resistance of polyisocyanurate and domestic phenolic roof insulation.⁷ The work occurred in Kansas City, Mo. The built-up membrane and insulations were applied over a prime painted steel deck. The deck was over an unenclosed storage area. Corrosion evaluation was not part of the work. However, superficial deck corrosion was observed under the phenolic insulation the following year when the roof covering was removed as part of a follow-up study.

The 1989 study, which was still limited to uplift and crushing evaluation, utilized three Canadian-produced phenolics and one domestic phenolic.⁸ The 1988 and 1989 studies used domestic phenolic from different manufacturers. In January 1992 (approximately 28 months after application), one test cut was made at each of the four phenolics. Under the domestic phenolic and its Canadian counterpart, the deck had superficial corrosion. The deck had not corroded under the other two phenolics (one of which was closed-cell, and the other was a resol foam). None of these phenolics that were applied in 1989 occurred where phenolic was installed for the 1988 project.

DAMAGE ASSESSMENT

If a steel deck has superficially corroded (i.e., the deck finish is still largely intact, but rust stains are present), structural degradation would be unlikely. Typically, the deck would not be in need of repainting. Conversely, if the deck has obvious signs of structural impairment (e.g., flange separated from the web or large holes through the deck), deck replacement is needed in the affected area. However, in assessing the structural condition of corroded decks, the difficult decks to assess are those that are between these two extreme cases.

At the present time, an accepted protocol for assessing corroded decks does not exist. There are no standards for field, laboratory or analytical evaluation of these problem jobs. Accordingly, structural integrity assessment is left to rely upon the good judgment and expertise of the person performing this task.

CORRECTIVE ACTION

If the deck has superficially corroded (i.e., the deck finish is still largely intact, but rust stains are present), typically the deck would not be in need of repainting. If the corrosion is more advanced, but the structural integrity is judged to be adequate, preparation of the surface and repainting with a suitable coating is recommended. Accepted protocols for deck preparation and painting do not exist.

If the deck or portions thereof has been judged to be structurally impaired, deck replacement in the affected area is needed to avoid compromising the safety of building occupants and people on the roof.

CONCLUSIONS

1. When moist, domestically-produced phenolic insulation (without corrosion inhibiting facers) can contribute to steel deck corrosion significantly more than other common types of rigid roof insulation (irrespective of the type of roof covering).

The NRCA in-situ corrosion research correlates with Blizzard's lab work¹² which indicated that the rate of corrosion is initially high, but decreases after a short time period. However, if this type of phenolic insulation remains moist, it appears that the corrosion does not become passive, but rather it continues. If the insulation remains moist for a long enough period (which may be as short as three years or less), it appears that prime painted 22 gage (0.71mm) steel deck can become structurally unsound.

With this type of phenolic insulation, galvanizing does not prevent the corrosion process. However, based on the NRCA in-situ corrosion research, G-60 galvanizing does retard the rate of corrosion. The additional "time-to-failure" that G-60 (or G-90) provides, compared to prime paint is unknown. But it appears that G-60 may offer perhaps another year or two, or more. With this additional time, there is an increased possibility that the problem will be discovered before the deck develops a hazardous condition.

(Note: Levine³ makes note of the importance of the zinc thickness (weight). Reduced thickness results in reduced corrosion resistance. It is likely that thinner galvanizing, such as ZF75 wiped coat (commonly used in Canada) would not offer signifi-

cantly greater corrosion protection with this type of phenolic than prime paint.)

Crushed versus uncrushed insulation does not appear to directly influence corrosion. One exception could be a case where crushing has moved the dew point near the critical deck/insulation interface, which when coupled with condensation, may result in development of leachate. Leaching exacerbation may be another exception.

If a vapor retarder with good integrity occurs between the phenolic insulation and the roof deck, the probability of deck corrosion associated with the phenolic is minimized. Even if the phenolic gets wet, the vapor retarder should be effective in preventing leachate contact with the deck. Also, the presence of a suitable vapor retarder should avoid leachate development associated with condensation from within the building.

2. As noted in Table 3, the corrosion inhibiting facer that was used in the NRCA research projects appears to significantly reduce deck corrosion if the insulation becomes wet. However, at board joints, its effectiveness appears to be minimal. (See Figures 11 and 12.)
3. Based on NRCA's limited assessment, the Canadian phenolic (resol) that reportedly uses a different chemistry and manufacturing process appears to be significantly less corrosive when wet, compared to domestically-produced phenolic that does not incorporate corrosion inhibiting facers.
4. Corrosion of fasteners in contact with moist phenolic was not assessed. However, based upon the limited number of reports to NRCA that included fasteners, it appears that if the fasteners passed FM 4470,²² and if there is no vapor retarder, deck problems would likely develop prior to fastener problems.
5. For those building owners that desire additional deck corrosion protection (regardless of the type of roof insulation), NRCA Bulletin 15-91 appears appropriate.^{23,24} However, for most buildings, mandating greater protection does not appear justified, but rather should continue to remain as an option.

Deck corrosion protection should not be viewed as a solution for insulation products that can emit leachate which greatly accelerates the corrosion rate.

RECOMMENDATIONS

1. Because of the potential for development of structurally impaired decks due to corrosion, it is recommended that building owners with domestic phenolic insulation (without corrosion inhibiting facers) over steel roof decks have semiannual roof inspections performed by a roofing professional to look for signs of leakage. (Note: This recommendation is applicable to all roofs, but is of particular importance for the insulation noted.)

It is recommended that building owners with domestic phenolic insulation (without corrosion inhibiting facers) also have semiannual inspections of the underside of the deck to look for signs of leakage and deck deterioration, if the deck can be readily observed. However, significant corrosion can exist without it being apparent from an under-deck observation.

For roofs that are capable of being surveyed by infrared thermography, it is recommended the building owner consider having the roof surveyed on a three-year interval. (*Note: Infrared thermography will unlikely indicate minor moisture gain due to condensation.*)

The building owner should control access to the roof. Personnel on the roof should be alerted to refrain from abusing the roof (e.g., dropping HVAC access panels or tools on the membrane).

If moist insulation is detected, it should be removed and the deck should be evaluated.

2. When reroofing, tear-off rather than recover is recommended when domestic phenolic (without corrosion inhibiting facers) occurs. This will allow visual observation of the entire top surface of the deck, which thereby minimizes the possibility of reroofing over deteriorated areas.
(*Note: During the reroofing work, care should be exercised if corroded deck is encountered. Worker or equipment fall-through is a potential problem if the corrosion is significant.*)
3. If other than superficial corrosion is discovered, it is recommended that the structural integrity of the deck be evaluated by an engineer. It is recommended that the roofing contractor obtain deck replacement and/or repair/repainting directions from the engineer. If the insulation is domestic phenolic, it is recommended the manufacturer be advised and consulted (see References 16 and 17).
4. For phenolic insulation with corrosion inhibiting facers, until enhancements are made to compensate for intensified corrosion at board joints, it is recommended that the deck have a G-60 (minimum) finish.
5. Regardless of the type of insulation, it is recommended that building designers specify galvanized finishes for steel decks in accordance with NRCA Bulletin 15-91.²³ (See Conclusion 5.)
This recommendation is correlated with the NRCA in-situ research and with Blizzard's lab work,¹² which concluded that galvanizing appeared to be the most desirable coating (compared to prime paint) for many insulations.
NRCA Bulletin 15-91 presents the option of using G-60 or G-90 galvanizing, or aluminum zinc alloy. Because of the cost differential, for most buildings, utilizing aluminum zinc alloy for decking is probably not cost-effective.
Incidentally, if a concrete or insulating concrete fill is placed over the deck, galvanized rather than aluminum zinc alloy should be used to avoid compatibility problems between the fill and the coating.
6. Regardless of the type of roof insulation, if the building has "highly corrosive or chemical atmospheres" on the interior of the building, or if unusually corrosive materials could leak into the roof system, special deck finishes may be prudent. In these situations, consult with the steel deck manufacturer.^{3,25}
7. It is recommended that work on an ASTM standard for assessing the corrosion potential of roof insulation products be continued. A standard could be of great impor-

tance and assist in evaluating new products or changes to existing products. Use of electrical impedance measurements may be applicable (see Appendix 3).

ACKNOWLEDGMENTS

Roofing contractors, designers and others who contributed samples, photographs and information on problem jobs deserve special thanks. Appreciation is also extended to Hans Rosenow Roofing Company for the use of their new facility and labor for the field work.

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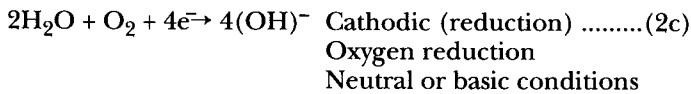
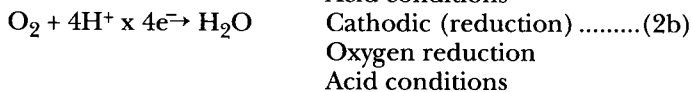
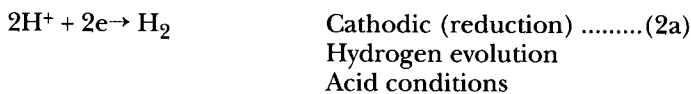
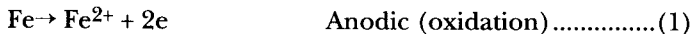
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APPENDICES

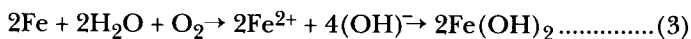
Appendix 1

Fundamentals of Corrosion

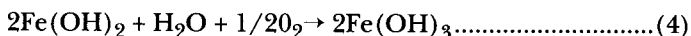
Corrosion is an electrochemical process that can be defined as the destruction or deterioration of a metal because of a reaction with its environment. For corrosion to occur, many factors are required. The basic requirements are the presence of moisture (water) and the ability for both oxidation (anodic) and reduction (cathodic) reactions to be sustained. If the metal is iron, then the most common reactions that combine to form the overall corrosion reaction are as follows:



For example, in water (near neutral) that is exposed to the atmosphere the overall reaction can be obtained by combining (1) and (2c):



Thus, the ferrous oxide is precipitated from solution. However, this compound is unstable in oxygen-containing solutions and is oxidized to the ferric hydroxide ("rust" forms).



It is important to note that the anodic and cathodic reactions are partial reactions—both must occur simultaneously and at the same rate on the metal surface. It is not important whether they are physically separated or occur at the same point; in some corrosion reactions the oxidation reaction occurs uniformly on the surface, while in others it is localized at specific areas. In the case of dissimilar metals joined together, the oxidation reaction will occur on the less noble metal and the cathodic reaction will occur on the more noble metal.

Factors Affecting Corrosion Rates of Metals

Within a given metal-electrolyte system, the corrosion rate will vary with a number of factors:

- **Temperature:** In general, higher temperatures result in higher corrosion rates. This is mainly because the rate of the electrochemical reactions are increased.

- **Oxygen:** In the case of iron in an aqueous environment, the presence of oxygen (or other oxidizer) will also increase the rate of corrosion.
- **Composition of the environment:** Factors such as hydrogen ion content (pH), and the presence of other contaminants such as chlorides, sulfur species, etc., can also affect the corrosion rate of metals. In general, iron will corrode faster in acidic solutions, while the presence of chlorides can accelerate the localized corrosion attack.

These factors form the basis of the thermodynamic (or equilibrium) information about a metal-electrolyte system. This thermodynamic information can be used to determine a tendency to corrode; what this information cannot predict is how fast the corrosion reactions will occur (the kinetics of the process). Corroding systems are not at equilibrium. However, since corrosion is an electrochemical process, the rate of corrosion can be monitored by measuring the magnitude of the current passing through the system. This rate of corrosion will be a function of additional factors such as type of corrosion products formed and the type of corrosion that occurs.

If the corrosion product is a uniform oxide film that acts as a barrier that impedes diffusion of species to the metal surface, then the rate of corrosion will be reduced. If the corrosion products are soluble species, then the corrosion reactions will continue to proceed; in some cases the by-products remaining in solution after the corrosion products have been dissolved are then available to participate in the corrosion reaction again, thus acting as further accelerants in an autocatalytic fashion.

The type of corrosion, i.e., whether it is uniform attack or localized attack such as pitting or crevice corrosion, intergranular corrosion or selective dissolution can also determine the ultimate rate of attack.

Appendix 2

Detailed Observations, NRCA In-situ Corrosion Research

Available upon request from NRCA.

Appendix 3

Use of Electrochemical Impedance Measurements

Available upon request from NRCA.

Sample	pH	Cations					Anions				
		Sodium	Ammonium	Potassium	Magnesium	Calcium	Chloride	Sulfate	Toluene Sulfonic Acid	Ethyl Benzene Sulfonic Acid	Phosphate
Phenolic "EP-2"	2.10	65	435	1,620	310	790	35	TRACE	44,200	7,000	(-)
Phenolic "I-B"	1.75	35	210	1,480	30	40	85	TRACE	58,000	12,700	(-)
Phenolic "II-A-1"	2.40	25	70	590	90	4,800	110	TRACE	35,100	8,200	(-)
Phenolic (resol) "H"	4.85	75	5	<1	15	125	150	TRACE	750	160	(-)
Perlite "E"	5.65	680	20	40	290	385	315	1,910	(-)	(-)	(-)
Polyisocyanurate "IV-C"	6.25	370	30	130	30	170	115	430	TRACE	170	(-)
Rigid Fiberglass "G"	6.70	350	130	10	20	155	65	1,890	(-)	1,260	(-)
Wood Fiberboard "F"	3.70	170	10	680	(-)	(-)	25	440	(-)	(-)	310

* In mg/kg as received.

Note:

1. Phenolic "EP-2" was from a job that experienced severe deck deterioration. The insulation was manufactured in 1986. It had fiberglass facers and was 1½ in. (35mm) thick.
2. Phenolic "I-B" was used in the NRCA in-situ corrosion research project (this sample was not incorporated into the roof). The insulation was manufactured in 1990. It had fiberglass facers and was 2½ in. (63mm) thick.
3. Phenolic "II-A-1" was used in the NRCA in-situ corrosion research project (this sample was not incorporated into the roof). The insulation was manufactured in 1991. It had fiberglass facers with a corrosion inhibiting agent. It was 2¾ in. (60mm) thick.
4. Phenolic (resol) "H" was manufactured in 1991 in Canada. It had kraft paper facers adhered in asphalt. It was 1½ in. (32mm) thick.
5. Perlite "E" was 1½ in. (38mm) thick.
6. Polyisocyanurate "IV-C" was used in the NRCA in-situ corrosion research project (this sample was not incorporated into the roof). The insulation was manufactured in 1991. It had an organic/inorganic facer. It was 2¾ in. (67mm) thick.
7. Rigid fiberglass "G" had an asphalt/kraft paper facer on one side. it was ¾ in. (16mm) thick.
8. Wood fiberboard "F" had an asphaltic coating on one side. It was ½ in. (13mm) thick.
9. Except for sample EP-2, all samples were procured from a contractor's yard or a distributor's warehouse. Only sample EP-2 came from a roof.
10. (-) denotes below detection limit.
11. Laboratory work was performed by Puricons, Inc.

Table 1 Analysis of leachate from roof insulation samples.*

	01/22/91	09/27/91	05/11/92
Phenolic I-0 I-4A I-4C I-5A I-5C I-6A	208.0% 32.1	6.1% 7.2	6.7% 7.0
Phenolic II-1A II-4A II-4C II-5A II-5C II-7A II-20A	10.7 10.8 9.9 9.7	 6.0 7.8	7.2
Polyisocyanurate IV-1A IV-4A IV-20A	2.3	1.6	1.9

* By weight percent.

Note:

1. Samples were taken from the NRCA in-situ corrosion research project. The dates indicate the day the samples were taken from the roof.
2. The "I," "II" and "IV" samples correspond to the "I," "II" and "IV" samples in Table 1, although they were taken from different boards (of the same lot).
3. Key to sample identification (e.g., I-4A):
 - I = Specific insulation (same manufacturer, product and lot), as identified in Table 1.
 - 4 = Chronological number that was assigned to installed boards.
 - A = Chronological letter that was assigned to samples taken from the same board.

For example, I-4A and I-4C are samples taken from the same board. I-4A and I-5A are adjacent boards.
4. The samples taken on 4/22/91 were approximately 3 ft. x 4 ft. (900mm x 1,200mm). The samples taken on the other days were approximately 3 ft. x 3 ft. (900mm x 900mm). Soon after they were taken from the roof, they were wrapped in plastic bags and sent to the lab. All samples were trimmed to 24 in. x 24 in. (600mm x 600mm) for testing.
5. Chicago Testing Laboratory analyzed sample "I-0." The remainder of the work was performed by Holometrix, Inc.

Table 2 Moisture contents* of insulation samples.

	9/27/91 (5 months)	5/11/92 (12 months)	11/23/92 (19 months)
Phenolic "I"	Underside of EPDM and top board wet. Bottom of board dry. Board stuck to deck (considerable amount of corroded primed deck remained adhered to the board. Entire surface of primed deck was corroded. The layer of corrosion products was quite thick. Pitting occurred at the deck shoulder. Galvanized deck had white rust and a few areas of red rust, but the corrosion was superficial.	A little moisture on underside of EPDM. Both sides of board damp. Appeared that corrosion on primed and galvanized had progressed very little over winter. Pitting at deck shoulder more advanced with Phenolic "I" vs "II"	A little moisture on underside of EPDM. Top of all 5 boards damp. Bottom of boards dry. Prime: Pits more advanced at the board that was rewetted twice vs the board rewetted once. At 30x, some pits much deeper than others. Galvanized: At board joints, pits were more advanced. Pitting was less significant than at the primed area. Minimal corrosion at boards that were not wetted (prime & galvanized). No significant difference in corrosion under crushed vs. uncrushed boards.
Phenolic "II" (corrosion inhibiting facers)	Underside of EPDM and top board wet. Bottom of board was dry. Portions of top flange of primed deck had superficial corrosion. Galvanized deck had white and red rust, but not as extensive as at Phenolic "I" Corrosion was exacerbated at board joints.	A little moisture on underside of EPDM. Top of board damp. Bottom wet. Appeared that corrosion on primed and galvanized had progressed very little over winter.	Underside of EPDM wet. Top of 2 boards damp. Prime: at 30x some pits much deeper than others. Pitting not as advanced as at Phenolic I. Large portions of several flanges somewhat corroded. At board joints, more advanced corrosion—pitting similar to Phenolic I. Galvanized: At board joints, more advanced corrosion. Pitting is not as advanced as primed area. Minimal corrosion at boards that were not wetted (primed & galvanized).
Polyiso-cyanurate "III"	Underside of EPDM and both sides of board dry. Some superficial corrosion of primed deck, but not as extensive as Phenolic II. Some white rust at galvanized deck.	One small wet area on underside of EPDM. Appeared that corrosion on primed and galvanized had progressed very little over winter.	Underside of EPDM and both sides of boards dry. Prime: Pits developed, but not as deep or wide as at Phenolic "I" or "II". Minimal corrosion on flanges. Galvanized: No red rust. Minimal corrosion at boards that were not wetted (primed & galvanized).
Polyiso-cyanurate "IV"	Essentially the same as Polyiso-cyanurate "III"	—	—

Note:

1. The dates indicate the date the observations were made.
2. Wetting of insulation boards
 - 4/22/91: 2 boards of each insulation were sprayed with water.
 - 4/23/91: The boards were resprayed. After crushing, approximately 1.75 gallons (6.6L) of water was poured on each board.
 - 9/27/91: 1 board of each insulation that was previously wetted, received approximately 1 gallon (3.8L) of water. The gallon was applied to the top and bottom, with the majority being applied to the top.
 - 5/11/92: The boards that were wetted on 9/27/91, received approximately 3.75 gallons (14.2L) of water. The water was applied several times over a 1 - 2 hour period, to both the top and bottom, with the majority being applied to the top.

Table 3 Synopsis of observations, NRCA in-situ corrosion research project.



Figure 1 Corrosion-induced separation of top flange from the shoulder (flange/web intersection). Phenolic sample "EP-2" (Table 1) came from this job.

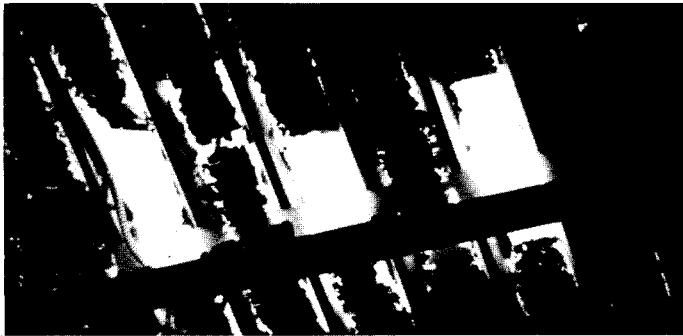


Figure 2 Looking up at a corroded deck after the phenolic insulation and roof membrane were removed. Note the separation of the top flange from the web at several areas. Also, the entire top flange is missing at three locations.

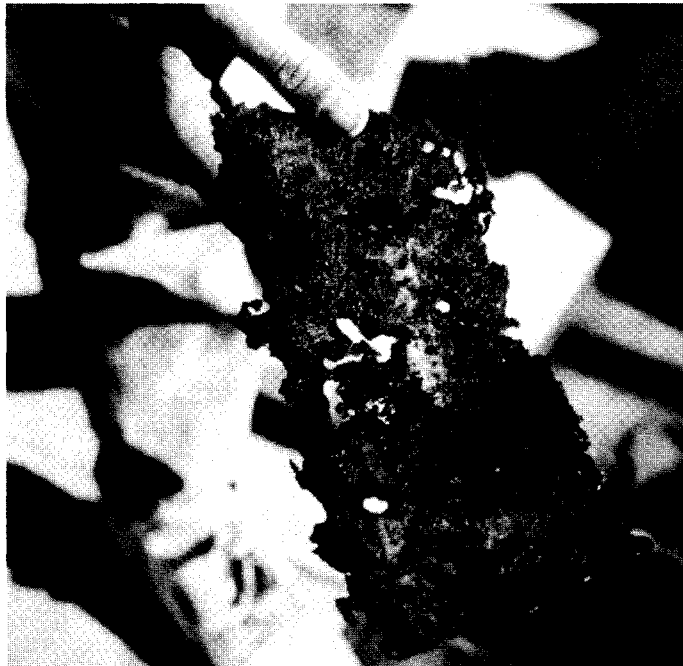


Figure 3 Top flange from job shown in Figure 3. Flange was separated from the web by corrosion. Note the holes through the flange.

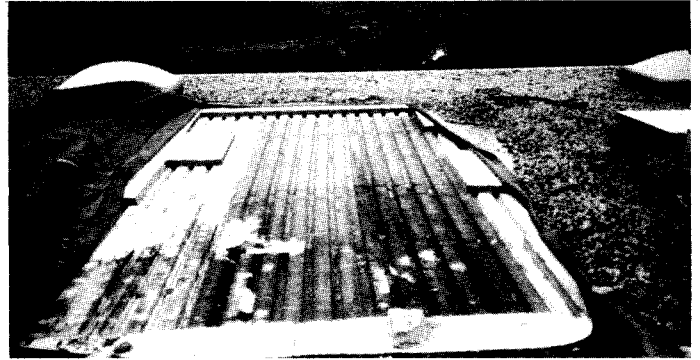


Figure 4 NRCA in-situ corrosion research (Figures 4 to 13). Figure 4 to 6 were taken in November 1992, approximately 19 months after application. Figure 4 shows the area where phenolic "I" insulation was installed. Galvanized deck occurs on the left, and prime painted on the right. The wet boards occurred in the foreground. See Figure 7 for close-up.

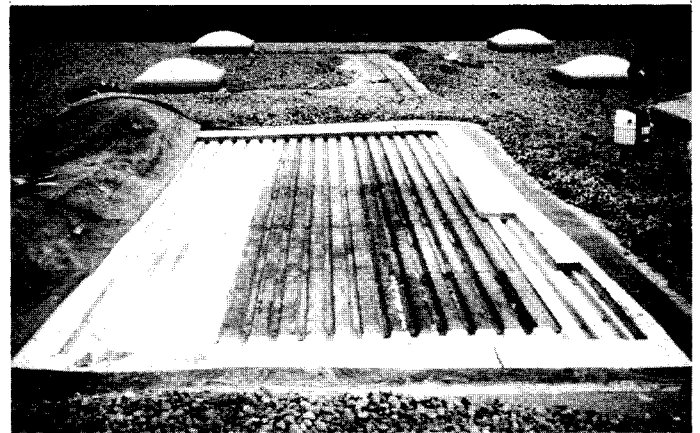


Figure 5 Phenolic "II" (with corrosion inhibiting facers).

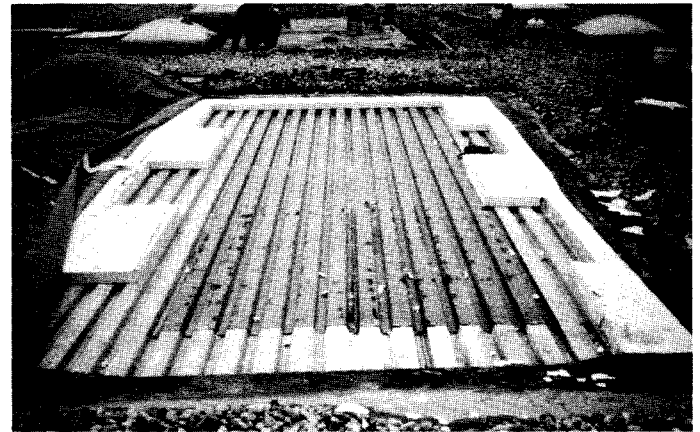


Figure 6 Polyisocyanurate "III."



Figure 7 Close-up view of Figure 4 (phenolic "I", but in opposite direction). The galvanized deck is on the right—the dark areas are red rust (see Figure 10). Notice the enhanced corrosion that occurred at insulation side and end joints (see arrow). The prime painted deck is on the left—the entire surface is very corroded. The light colored areas on the left area are where the facer stuck to the deck.

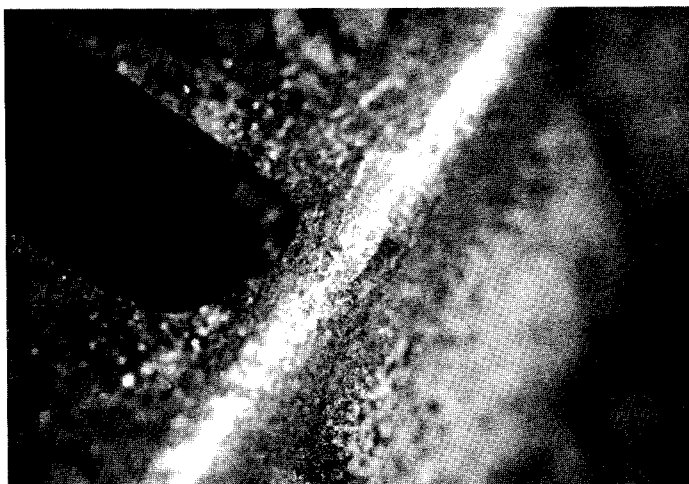


Figure 8 Phenolic "I" in May 1992 (approximately one year after application). The loose scale was removed from the primed deck at the shoulder—several large pits occur at this area (near the end of the ink pen).

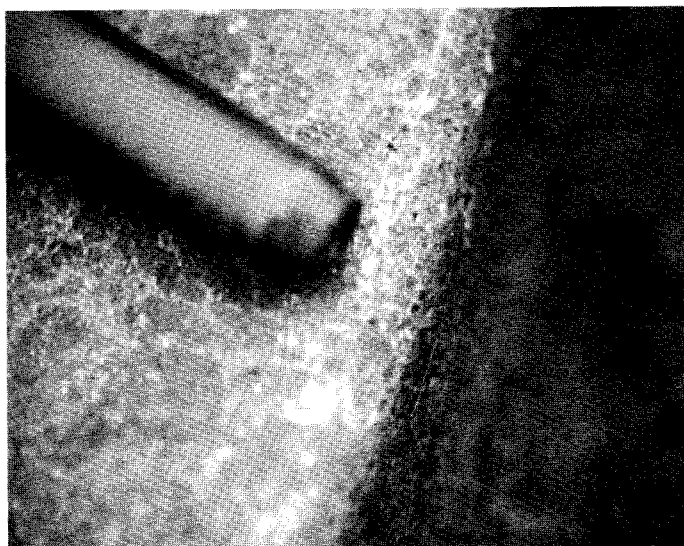


Figure 9 Phenolic "I" in November 1992, approximately 19 months after application. The loose scale was removed from the top flange and shoulder of the primed deck by sanding. Many large diameter pits and a few deep pits (dark areas) occur. Compared to Figure 8 (seven months earlier), the pits have enlarged and interconnected, and become deeper.



Figure 10 Phenolic "I" in November 1992. The loose scale was removed at the shoulder of the galvanized deck by sanding. This occurred at the insulation end joint shown in Figure 7. The shoulder is pitted, but not nearly as greatly as at the primed deck (Figure 9).

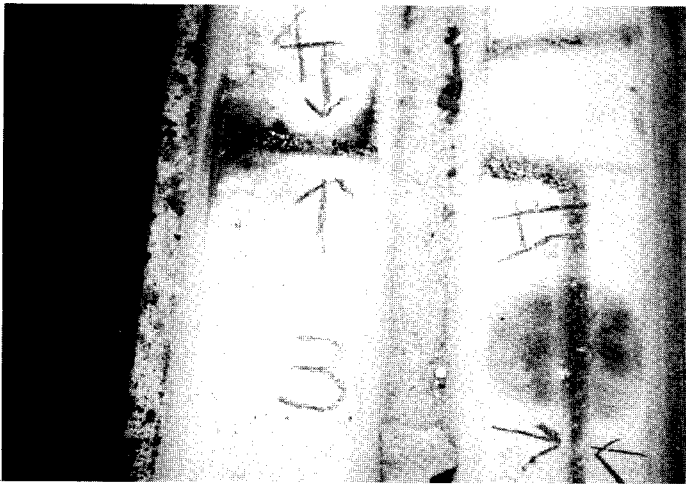


Figure 11 Phenolic "II" (corrosion inhibiting facers) in November 1992. Galvanized deck is on the right—the dark line occurs at insulation side and end joints. The dark area is the prime painted deck—see Figure 12.

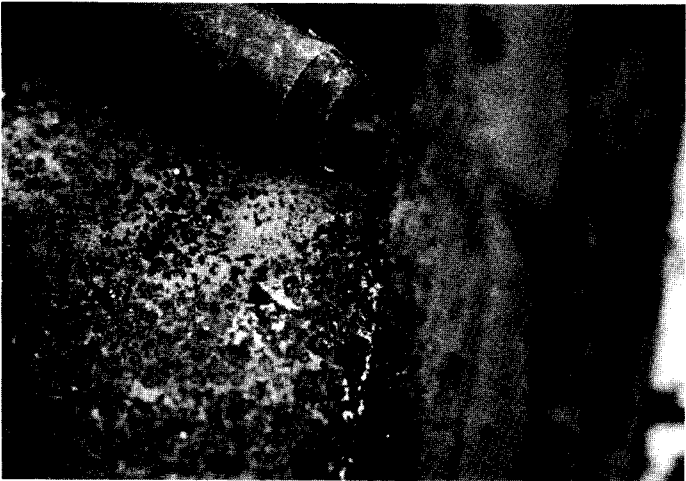


Figure 12 Phenolic "II" at the prime deck/insulation joint location shown in Figure 11. The shoulder area was sanded. Pitting at the insulation joint area was similar to that observed under phenolic "I"—see Figure 9.

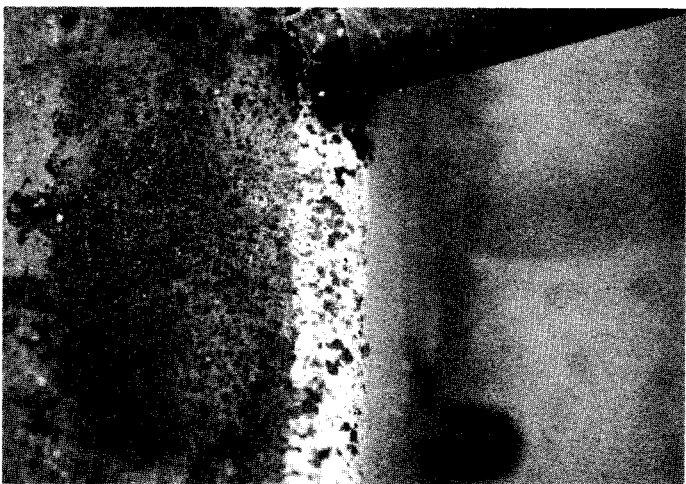


Figure 13 Polyisocyanurate "III" in November 1992. The primed deck was sanded at the shoulder area. In this very early stage of steel corrosion, the large quantity of pitting is apparent. Also in this early stage, the joining together of two or more pits to form one large pit can be seen.

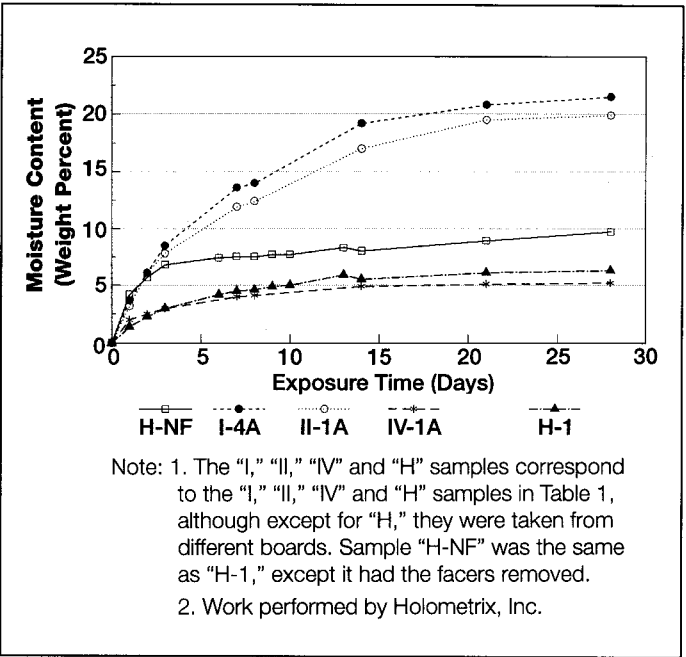


Figure 14 Moisture gain of roof insulation samples.