TECHNIQUES FOR PREDICTING THE SERVICE LIFE OF 55% AL-ZN ALLOY-COATED STEEL, LOW-SLOPE SSR SYSTEMS

ROB HADDOCK
METAL ROOF ADVISORY GROUP, LTD.
8655 Table Butte Rd., Colorado Springs, CO 80908
Phone: 719-495-8407 • E-mail: rob@rmhaddock.com

AND

RON DUTTON
RON DUTTON CONSULTING SERVICES LLC
862 Woodmont Rd., Annapolis, MD 21401
Phone: 443-569-2030 • E-mail: ron.dutton@verizon.net
Abstract

Consultants, building owners, and facility engineers eventually face this question: Is it better to replace or renew a roofing system? The presenters will offer a quantitative method to define the service lives of roof components of a 55% Al-Zn alloy-coated steel, low-slope, standing-seam roof system. Using protocols and analytical techniques, an objective answer can easily be formulated for this question.

Speakers

Rob Haddock – The Metal Roof Advisory Group, Colorado Springs, CO

Rob Haddock has been involved in construction contracting, forensic consulting, and education in the metal roofing industry for over 45 years. He has authored metal roofing industry standards and white papers. His work has been published in at least six languages, and he owns over 40 patents. He is an honorary lifetime member of the Metal Building Contractors and Erectors Association (MBCEA) and the Metal Construction Association (MCA), and is a Metal Construction Hall of Fame charter inductee, as well as a recipient of RCI’s Richard M. Horowitz Award.

Ron Dutton – Ron Dutton Consulting Services, Annapolis, MD

Ron Dutton has 40 years of experience with metallic-coated and prepainted steel products. He began his career with Bethlehem Steel Corporation, having worked for them and their successor companies in various disciplines, including research, marketing, new product development, and field forensic analysis. Dutton provides technical consulting services for the metal construction industry.
Techniques for Predicting the Service Life of 55% Al-Zn Alloy-Coated Steel, Low-Slope SSR Systems

ABSTRACT
The service life of roofing materials has been the subject of considerable discussion and analysis for decades. Much of this work has been qualitative or anecdotal. For steel roofing, recently published work has shown the validity of a novel technique that combines laboratory corrosion analysis of roof panels and physical property analysis of sealants, together with a physical roof inspection protocol, to predict the total roof service life of 55% Al-Zn alloy-coated steel, low-slope, standing seam roof (SSR) systems.

In this paper, the authors describe the use of this unique method to evaluate the performance of 14 such roof systems aged up to 35 years throughout the United States. Included in the analyses are the performances of all vital roof system components that bear on total roof system performance, including data assessing the long-term field performance of butyl polymer sealants. The practical and economic implications of “renewal” versus replacement are analyzed and discussed.

The results show roof panel service life to be strongly correlated with precipitation acidity (pH) and conservatively project a total roof service life in excess of 60 years for SSR systems constructed today using current best practices.

INTRODUCTION
Registered Roof Consultants (RRCs) are highly trained and experienced professionals who are called upon to perform many functions that have significant financial ramifications to the building owner. One of the clearest examples of this is forensic roof analysis.

The RRC is frequently tasked with evaluating the condition of a roof—in many cases where water intrusion has already occurred—and delivering an expert answer to the question of whether to repair or replace the roof. Clearly, a knowledge of expected roof service life is a key factor in answering such a question.

PROCEDURES

Site Selection
Five climate regions of various geographies in the continental U.S., exhibiting a spectrum of climates related to heat and humidity, were selected. They are designated as Hot-Dry, Hot-Humid, Cold-Dry, Cold-Humid, and Moderate-Acid, as seen in Figure 1.

Figure 1 – U.S. map showing general climate conditions of temperature and moisture.
Within each climate zone, buildings were selected with the following characteristics:

- Machine-folded, trapezoidal standing seam metal roof
- Roof slopes of ≤1:12 (4.5°)
- Unpainted 55% Al-Zn alloy-coated steel
- 20+ years of age
- Documented construction dates and details
- Representative construction practices of the time period
- Devoid of significant installation errors

A total of 14 buildings that met these criteria were inspected in 2012 and 2013 and evaluated according to the protocols summarized in this paper and reported in more detail elsewhere. These building locations are shown in Figure 2 on a map of the U.S. that shows precipitation pH. More detailed information on these locations is shown in Table 1. This pH variable is used to characterize the acidity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acidic, and higher values more alkaline. It will be shown later how significant this variable is in predicting panel service life.

**ROOF ANCILLARY PERFORMANCE**

The performance of ancillary components on the inspected roofs was observed by roofing professionals and compared to best practices as like roofs are constructed today. Best practices are summarized in the sections below.

**Best Practices: Soil Stack and Other Round Penetrations**

Best practice is to flash these types of roof penetrations using a special pipe flashing having black EPDM top (state-of-the-art would be black silicone rather than EPDM) with flexible aluminum base, sealed to the roof with butyl copolymer tape, as shown in Figure 3. These products have been used now for more than 30 years and have also become the standard practice for this type of roof. They are widely available from multiple sources and several brand names. The expected performance life of such a flashing is 25 years or more, at which time they are easily replaced at an installed cost of less than $150.

**Best Practices: Condensate Drainage**

Best practice today concerning condensate from air conditioning condensing units or effluent from swamp coolers is to plumb it through the roof using a pipe flashing boot (as described above), into a plumbing drain; or alternatively, direct it to the eave on the roof’s topside using PVC piping and discharge it to the ground, avoiding any contact with coated steel roof components.

An example of this type of arrangement is shown in Figure 4.

**Best Practices: HVAC (Typical Load-Bearing and Non-Load-Bearing Roof Curbs)**

Best practice today utilizes a welded, all-aluminum or stainless “floating” equipment curb similar to that pictured in Figure 5. The curb flanges are sealed with butyl polymer tape sandwiched between curb flange and the roof panel. Such an instal-

---

**Table 1 – Building locations and pertinent statistical information**

<table>
<thead>
<tr>
<th>Roof # and Location</th>
<th>Climate Region</th>
<th>Precipitation pH in 1999</th>
<th>Built</th>
<th>Age*</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Denver, CO</td>
<td>Cold-Dry</td>
<td>5.00</td>
<td>1977</td>
<td>33</td>
<td>½:12</td>
</tr>
<tr>
<td>2- Riverton, WY</td>
<td>Cold-Dry</td>
<td>5.05</td>
<td>1980</td>
<td>31</td>
<td>½:12</td>
</tr>
<tr>
<td>3- Riverton, WY</td>
<td>Cold-Dry</td>
<td>5.05</td>
<td>1977</td>
<td>34</td>
<td>¼:12</td>
</tr>
<tr>
<td>4- Ashland, OH</td>
<td>Moderate</td>
<td>4.36</td>
<td>1976</td>
<td>35</td>
<td>½:12</td>
</tr>
<tr>
<td>5- Ashland, OH</td>
<td>Moderate</td>
<td>4.36</td>
<td>1977</td>
<td>34</td>
<td>¼:12</td>
</tr>
<tr>
<td>6- Ashland, OH</td>
<td>Moderate</td>
<td>4.36</td>
<td>1979</td>
<td>32</td>
<td>¼:12</td>
</tr>
<tr>
<td>7- Athens, GA</td>
<td>Hot-Humid</td>
<td>4.64</td>
<td>1983</td>
<td>29</td>
<td>½:12</td>
</tr>
<tr>
<td>8- Irmo, SC</td>
<td>Hot-Humid</td>
<td>4.71</td>
<td>1992</td>
<td>20</td>
<td>¼:12</td>
</tr>
<tr>
<td>9- Elloree, SC</td>
<td>Hot-Humid</td>
<td>4.71</td>
<td>1983</td>
<td>29</td>
<td>¼:12</td>
</tr>
<tr>
<td>10- Phoenix, AZ</td>
<td>Hot-Dry</td>
<td>4.99</td>
<td>1989</td>
<td>23</td>
<td>¼:12</td>
</tr>
<tr>
<td>11- Albuquerque, NM</td>
<td>Hot-Dry</td>
<td>5.05</td>
<td>1983</td>
<td>29</td>
<td>1:12</td>
</tr>
<tr>
<td>12- Westford, MA</td>
<td>Cold-Humid</td>
<td>4.47</td>
<td>1983</td>
<td>30</td>
<td>¼:12</td>
</tr>
<tr>
<td>13- Westford, MA</td>
<td>Cold-Humid</td>
<td>4.47</td>
<td>1980</td>
<td>33</td>
<td>¼:12</td>
</tr>
<tr>
<td>14- Eugene, OR</td>
<td>Cold-Humid</td>
<td>5.37</td>
<td>1981</td>
<td>31</td>
<td>1:12</td>
</tr>
</tbody>
</table>

* Age in years at time of inspection
Best practice today’s best practice would have a service life of 65 years or more in most environments. In a mildly corrosive environment, such a curb may be expected to perform for 70 or 80 years—well beyond the service life of any HVAC unit, and likely beyond the service life of other, more crucial, roof system components. Such curbs are available from numerous sources within the metal roofing industry and can be replaced if necessary for $1,500 to $2,500 in today’s dollars (installed cost for the approximate size illustrated by Figure 5).

Best practice today’s best practice for a frame-mounted HVAC unit is for the frame to be mounted to the standing seams using nonpenetrating seam clamps as shown in Figure 6. Care should be taken to evenly distribute collateral loads into the roof, and that point loads do not exceed 200 pounds per ASTM E1514. Any necessary ducting through the roof for units such as these is done with welded, all-aluminum or stainless “floating” equipment curbs similar to that pictured in Figure 5.

**Best Practices: Mounting of Other Ancillaries**

Best practice for the mounting of ancillaries that need not penetrate the roof membrane, such as communications satellites, antennae, gas piping lightning protection, and the like is accom-
Such an installation is metallurgically compatible with the 55% Al-Zn alloy coating and permits free drainage on the surface of the roof, avoiding any situation that would trap moisture and thus lead to premature deterioration of the coating. These seam clamps are widely known and used within the industry. They have been commercially available at moderate cost since 1993. Such an interface would be expected to outlive the roof itself, based on the exceptional corrosion resistance of the 300-series stainless steel and aluminum materials used in these clamps. While gas piping and angle iron frame are beyond the scope of this report, prudence would suggest a rust-inhibitive paint coating to prevent formation and leaching of oxides onto the metal roofing.

**SSR PANELS – SAMPLE PROCUREMENT**

For most locations, the collection of coating specimens for laboratory analysis of corrosion was done by identifying a lap joint for disassembly and removal of material. Using a portable magnetic induction gauge to measure coating thicknesses over a wide range of roof panels, a representative loca-
tion was selected for sampling. Where a lap joint was not available, a ridge location was selected for material sampling.

Details of the sample procurement are reported elsewhere, but basically, samples are obtained that represent two conditions: 1) unexposed and 2) boldly exposed to the atmosphere. The photograph in Figure 8, depicting a laboratory mock-up of a standing seam end lap location, illustrates the relative locations for obtaining the unexposed and exposed samples. The sample locations are represented by the circular disks in Figure 8, although the actual samples taken from the roof were larger in size and rectangular in configuration.

Following the extraction of samples from each sample area, field patching was skillfully accomplished with new 55% Al-Zn alloy-coated material and sealed with butyl polymer tape. Figure 9 shows the sample area from an actual site after the sample extractions and field patching of the area were accomplished.

SSR PANELS – CORROSION ANALYSIS

The samples taken from the roofs were evaluated for corrosion by an independent laboratory (see Acknowledgments). A single specimen (denoted #1) was cut from the unexposed sample from each site visited. Two specimens (denoted #2 and #3) were cut from the exposed sample. Based on the corrosion measurements made on these specimens, the corrosion rate in grams per square meter per year (g/m²/yr) can be calculated by dividing the amount of corrosion loss on specimens 2 and 3, by the age of the roof, as shown in Equation 1. Details of this analytical technique may be found elsewhere.

\[ R = \frac{(S_1 - S_n)}{t} \]

where

- \( R \) = rate of corrosion, g/m²/yr
- \( S_1 \) = total coating mass of unexposed specimen 1, g/m²
- \( S_n \) = total coating mass of exposed specimen n, g/m²
- \( n = 2 \) or 3
- \( t \) = age of roof, years

These data were then used to calculate a projected panel service life for a 55% Al-Zn alloy-coated steel SSR panel installed today using best practices. The projected panel service life can be defined as the time required until total mass loss due to corrosion of the top coating surface has been achieved. Thus, for a 55% Al-Zn alloy-coated steel SSR constructed today, it was assumed that a nominal coating mass of 165 g/m² (AZ55) would be supplied, as this is representative of most current unpainted 55% Al-Zn alloy-coated steel SSR systems. A “worst-case scenario” was also assumed in that “not less than 40% of the single-spot test limit will be found on either surface” (ASTM A792/A792M-09a). The single-spot test limit for AZ55 is 150 g/m². Thus, further assuming that 40% of this single-spot test limit of 150 g/m² is on the top surface of the roof panels where corrosion occurs, then the most conservative projected panel service life would be calculated from Equation 2 as follows:

\[ L_p = \left( \frac{C_t}{R} \right) \]

where

- \( L_p \) = projected service life of roof panel, years
- \( C_t \) = coating mass on top surface, g/m²

(in this case, 40% of 150 equals 60 g/m²)

- \( R \) = rate of corrosion, g/m²/yr

It should be noted that these calculations are based on a straight-line relationship between year zero and the corrosion mass loss measured at the year representing the age of the roof. As such, it is a conservative estimate since the corrosion rate of 55% Al-Zn alloy-coated steel sheet is known to decrease with time.

SEALANT – SAMPLE PROCUREMENT

For most locations, the collection of sealant samples for laboratory analysis was done by finding a representative end lap for disassembly and removal of material. Where an end lap was not available, a ridge, eave, or roof penetration location was selected for material sampling. After material removal, suitable replacement sealant was applied to the area to maintain the waterproof seal.

SEALANT – PROPERTY ANALYSIS

The visual properties of the sealants at all critical junctions were noted and documented photographically. In addition, material was collected and stored in airtight plastic bags for subsequent laboratory analysis. This analysis consisted of cohesive tensile strength (ASTM C907-03) and cone penetration at 72-78F (ASTM D217-10).

RENEWAL/REPLACEMENT ANALYSIS

The Renewal/Replacement Table contains a summary of the pertinent data upon which the renewal or replacement decision is made. The table lists all the relevant roofing components that impact total roof service life. Components that have or will expire would only be included in the table to the extent they are reflective of today’s best practices.

Example 1: A galvanized roof curb on a subject roof has expired at the time of inspection. Given that 0.080-in., all-welded aluminum curbs are today’s best practice and have expected service lives of 65+ years, the replacement of the subject roof curb should not be factored into the analysis because today’s best practice would be different than that of 30 years ago.

Example 2: A galvanized pipe flashing for a soil stack is expired at the time of inspection. Given that EPDM rubber pipe flashings are currently best practice and demonstrate a 25-year service life, replacement of this ancillary component should be factored for replacement in year 25 and again at year 50.

Thus, costs for renewal or replacement should be consistent with respect to best practices of today, and if multiple replacements are required during a 60-year term, they should be calculated accordingly using today’s dollar values. This 60-year time period is equal to the “assumed building service life” as described in LEED, version 4. That is, under Option 4, Whole Building Life-Cycle Assessment, the statement is made that the “service life of the baseline and proposed buildings must be the same and at least 60 years to fully account for maintenance and replacement”.

All these replacement costs for all components not defining the “end of roof service life” were aggregated for a given site. Replacement costs were calculated in a similar fashion to that reported previously, including both labor and material using fair value in today’s market. If and when these aggregated costs exceeded 20% of today’s costs for total roof replacement, the roof was deemed to be at end of life; albeit, the building owner may choose a different value to trigger a decision to renew rather than replace a roof.
Table 2 – Component renewal/replacement costs over 60+ year life of the roof system (Roof #1).

An example is shown in Table 2 for Roof #1 in Denver, Colorado. Each table row lists the component, along with its quantity, the year at which it should be replaced, and the material and labor costs associated with its replacement. The replacement year is estimated by a roofing professional whose assessment combines knowledge of the component material, the current life of the roof, observations of the current condition of the weathered component, and awareness of today’s best practices that would be used in similar construction today.

RESULTS

Roof Components

Closures are primarily used at the gutter line to seal between the roof panel and the back leg of the gutter profile, as seen in Figure 10. No failures were observed, though some nonmetal closures showed some early stages of degradation on older roofs where there was some exposure to UV.

In most cases, gutters were made from prepainted G-90 galvanized steel, and gutter hangar brackets were produced from unpainted G-90 galvanized steel, typical examples of which are shown in Figure 11. Current best practice for gutter hangar brackets is to use more corrosion-resistant 55% Al-Zn alloy-coated steel. Replacement

Figure 10 – Typical eave closure.

Figure 11 – Gutter hangar after 32 years in Ohio.
costs of gutters, hangar brackets, downspouts, and closures are included in the renewal/replacement table.

Screw fastener types and materials encountered included Series 300 stainless steel, Series 400 stainless steel, carbon steel with Series 300 stainless steel cap, and carbon steel with (unidentified) plating or coating, examples of which are shown in Figure 12. In all cases, the Series 300 materials showed no sign of corrosion, nor adverse effect on adjacent 55% Al-Zn alloy-coated sheet panels. In all cases, the 400 Series and plated carbon steel materials did show signs of corrosion to varying degrees and would require replacement at some point prior to end of life for panels and sealants. There was no evident adverse effect on adjacent 55% Al-Zn alloy-coated sheet panels. Such replacement is economically feasible, and the costs are computed within the renewal/replacement table.

Sealing washers were in all cases black EPDM. Vacuum seal testing revealed positive seals in all cases, and only minor degradation was observed at the outermost exposed surfaces, even on the oldest specimens. Miscellaneous fasteners included cinch straps typically used at eaves or end laps. These aluminum components (alloy unknown) showed no signs of requiring replacement within the life of the system (Figures 12A and 12B). The same is true of 300 series stainless cinch straps as in Figure 12D (upper). Galvanized cinch straps consistently exhibited excessive corrosion (Figure 12C and 12D, lower). Galvanized cinch strap components are no longer used within the industry and do not reflect today’s best practice.

Round penetrations were primarily exhaust flues or soil stacks related to mechanicals. In many cases, these flashings had been replaced with more appropriate flexible rubber flashings that currently reflect best practice. In other cases, they had been coated and refurbished with liquid-applied coatings and external sealants. When these treatments had been executed, there were often detrimental effects to adjacent roof panels. Best practice today utilizes methods that have been well-known and utilized in the trade for more than 25 years, as shown in Figure 3.

A variety of load-bearing and non load-bearing curb and flashing types were found still in place for the mounting of rooftop HVAC equipment, many exhibiting the common practices of the 1980s. In many cases, these curb types were galvanized materials that had been treated with various topical sealants and coatings to restore weather integrity and prevent corrosion. Often units were mounted onto wood blocking, both pressure-treated and non pressure-treated, which in either case is detrimental to the roof material due to
leaching of corrosive ingredients from the wood or extended times of panel wetness in the absence of oxygen. Best practice for HVAC mounting is shown in Figure 6.

### Coated Steel Sheet

In analyzing the corrosion results, many climate characteristics, such as temperature, humidity, amount of rainfall, etc., were reviewed. The single key variable that correlated strongly with the amount of corrosion measured on the 55% Al-Zn alloy-coated steel panels was the acidity of the precipitation where the buildings were located. This precipitation acidity, or pH, has been measured across the U.S. for decades by the National Atmospheric Deposition Program. The precipitation pH values measured in 1999 are shown on the map in Figure 2, together with the building inspection locations. The 1999 data were selected since this year represents the approximate mid-point in age for many of the buildings.

The coating masses measured for each of the three specimens taken from each location and the corresponding calculated corrosion rates (from Equation 1) and projected panel service lives (from Equation 2) for each roof are shown in Table 3.

Using the calculated corrosion rates from Table 3, the average projected 55% Al-Zn alloy-coated steel service life is plotted in Figure 13 as a function of the precipitation pH associated with each building’s location. It is notable that panel service life:

<table>
<thead>
<tr>
<th>Roof # &amp; Location</th>
<th>Climate Region</th>
<th>Coating Mass of Unweathered Spec. 1, g/m²</th>
<th>Coating Mass of Weathered Spec. 2 &amp; 3, g/m²</th>
<th>Calculated Corrosion Rates, R, g/m²/yr.</th>
<th>Projected Panel Service Life, Years</th>
<th>Average Projected Panel Service Life, Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Denver, CO</td>
<td>Cold-Dry</td>
<td>200</td>
<td>188 189</td>
<td>0.36 0.33</td>
<td>167 182</td>
<td>175</td>
</tr>
<tr>
<td>2-Riverton, WY</td>
<td>Cold-Dry</td>
<td>190</td>
<td>178 179</td>
<td>0.39 0.35</td>
<td>154 171</td>
<td>163</td>
</tr>
<tr>
<td>3-Riverton, WY</td>
<td>Cold-Dry</td>
<td>203</td>
<td>193 189</td>
<td>0.29 0.41</td>
<td>207 146</td>
<td>177</td>
</tr>
<tr>
<td>4-Ashland, OH</td>
<td>Moderate</td>
<td>182</td>
<td>159 159</td>
<td>0.66 0.66</td>
<td>91 91</td>
<td>91</td>
</tr>
<tr>
<td>5-Ashland, OH</td>
<td>Moderate</td>
<td>200</td>
<td>182 176</td>
<td>0.53 0.71</td>
<td>113 85</td>
<td>99</td>
</tr>
<tr>
<td>6-Ashland, OH</td>
<td>Moderate</td>
<td>198</td>
<td>171 166</td>
<td>0.84 1.00</td>
<td>71 60</td>
<td>66</td>
</tr>
<tr>
<td>7-Athens, GA</td>
<td>Hot-Humid</td>
<td>198</td>
<td>181 179</td>
<td>0.59 0.66</td>
<td>102 91</td>
<td>97</td>
</tr>
<tr>
<td>8-Irmo, SC</td>
<td>Hot-Humid</td>
<td>181</td>
<td>168 167</td>
<td>0.65 0.70</td>
<td>92 86</td>
<td>89</td>
</tr>
<tr>
<td>9-Elloree, SC</td>
<td>Hot-Humid</td>
<td>180</td>
<td>166 169</td>
<td>0.48 0.38</td>
<td>125 158</td>
<td>142</td>
</tr>
<tr>
<td>10-Phoenix, AZ</td>
<td>Hot-Dry</td>
<td>204</td>
<td>194 197</td>
<td>0.43 0.30</td>
<td>140 200</td>
<td>170</td>
</tr>
<tr>
<td>11-Albuquerque, NM</td>
<td>Hot-Dry</td>
<td>200</td>
<td>n/a 191</td>
<td>n/a 0.31</td>
<td>n/a 194</td>
<td>194</td>
</tr>
<tr>
<td>12-Westford, MA</td>
<td>Cold-Humid</td>
<td>192</td>
<td>178 177</td>
<td>0.47 0.50</td>
<td>128 120</td>
<td>124</td>
</tr>
<tr>
<td>13-Westford, MA</td>
<td>Cold-Humid</td>
<td>213</td>
<td>189 188</td>
<td>0.73 0.76</td>
<td>82 79</td>
<td>81</td>
</tr>
<tr>
<td>14-Eugene, OR</td>
<td>Cold-Humid</td>
<td>185</td>
<td>180 180</td>
<td>0.16 0.16</td>
<td>375 375</td>
<td>375</td>
</tr>
</tbody>
</table>

Table 3 – Total coating masses, corrosion rates, and projected panel service lives.

Figure 13 – Strong correlation between average projected service life for 55% Al-Zn alloy-coated steel SSR panels and precipitation pH.
life is defined as the time required for total coating mass consumption to occur due to corrosion of the top coating surface. Thus, it is a conservative definition because it does not include the additional years required for the then-exposed steel substrate to corrode to a point of jeopardy to weather integrity.

As seen in Figure 13, there is a very good correlation between the precipitation pH and the average projected 55% Al-Zn alloy-coated steel panel service life, a finding that helps to explain the wide range of service life values calculated from the corrosion rates determined in this study. Such a relationship is consistent with the expectation that more aggressive environments (lower pH) are more corrosive to materials of construction exposed to those atmospheric conditions. The reference line in 60 years in Figure 13 is significant in that it equals the “assumed building service life” as noted earlier.

Thus the data from this project are conclusive in the following: that a 55% Al-Zn alloy-coated steel SSR system, compliant with best practices when installed today in a wide range of environments, would not require replacement during the building’s entire service life. This is a significant advantage compared to other roof systems that require one or more full replacements within this 60-year period. Based on the results of the current study, a 60-year service life for 55% Al-Zn, alloy-coated steel sheet SSR systems was recently incorporated into the Impact Estimator for Buildings by the Athena Sustainable Materials Institute. Of course, periodic roof inspections and maintenance associated with roof ancillaries and environmental fallout are advised to maximize roof system life.

While this level of projected service life is impressive, it is still a conservative projection due to the significant improvement in climate experienced in the U.S. over the past 30 years as a result of industry’s compliance with government regulatory air quality requirements. As a result of these climatic improvements, the service lives determined in this study. Such a relationship helps to explain the wide range of service life values calculated from the corrosion rates reported in 1999, when pH levels were more corrosive. Thus, if those roofs were installed today, where the precipitation pH levels have improved, the projected panel service lives would be even greater. The tabulated data for precipitation pH across the lower 48 U.S. states are available for 2014 and show that the 252 reporting stations have values ranging from 4.79 to 6.50. The nine stations grouped into the lowest grouping have pH levels of 4.79 to 4.90 and are located in Pennsylvania, Ohio, West Virginia, and New York. That range of pH is depicted on Figure 14 and indicates that average projected panel life for 55% Al-Zn alloy-coated steel SSR systems, if constructed today in those low-pH locations, would likely exceed 100 years. This data point is shown in Table 2 and indicates that 55% Al-Zn alloy-coated steel panel service life is not a limiting factor in defining total SSR system service life.

To fully assess panel performance, observations of panel edges and profile bends were also made. These areas typically exhibit the first signs of corrosion, as they are areas where a raw steel edge is exposed or where there may be a condition of tensile strain on the panel profile bend radius. Field inspections revealed excellent to very good performance in these two areas. The close-up photograph in Figure 15 shows a representative condition of a sheared, panel lap edge on the roof in Athens, GA. The sheared edge is free of red rust, indicating excellent long-term edge protection after 29 years. This performance is consistent with prior work that reported only superficial stain and no rust deposits on exposure panels after 30 years of exposure in rural, industrial, and moderate marine environments.

Panel profile radii may undergo a degree of tensile strain if the panel is not properly roll-formed. These improperly roll-formed radii can exhibit crazing of the metallic coating, which can lead to premature corrosion in more aggressive environments. Currently, however, steel manufacturers, working with roof panel manufacturers and trade organizations, have developed roll forming best practice guidelines that virtually eliminate such occurrences today.

The photograph in Figure 16 shows a representative condition of the major rib profile radius of the SSR panel. Only minor crazing and light superficial staining are observable. The performance along the top...
radius of the standing seam is also excellent, as shown in a representative seam in Figure 17.

**Sealants**

From a qualitative perspective, the butyl sealants used in the construction of these roofs were observed to be consistently tacky to the touch with good elastic webbing characteristics and adhesion to adjacent surfaces. A representative example of this performance is seen in Figure 18, which shows the disassembly of a 33-year-old end lap.

From a quantitative perspective, long-term aging characteristics of butyl-based sealants are not well documented. In fact, the authors could find no durability data for this type of sealant used in metal roofing systems. Thus, an attempt was made to provide basic information that might prove useful in determining the service life of butyl-based sealants. To that end, sealant samples were obtained from the 14 roof systems in this study for further analysis.

Cohesive tensile strength and cone penetration values were chosen as the physical properties that were thought to be most relevant and measurable, given the quantity of sealant that could be removed from each roof. If this had been a controlled experiment initiated at the times the roofs were installed, it would then have been a simple procedure to measure the change in these properties over time, compared to the properties exhibited by the original materials. However, as the original sealant material was not available for analysis, fresh, unweathered sealant material was used to provide an approximation of the properties of the original material.

Results of the laboratory analysis of cohesive tensile strength and cone penetration values revealed excellent performance on three roofs after up to 35 years. However, there was not enough sample material to conduct these tests for the other 11 roofs in the original 14-roof study. Therefore, an additional seven roofs in one climate region were identified and used to “harvest” additional sealant samples for testing. These seven roofs were located in the New England states of Massachusetts and New Hampshire and ranged in age from five to 35 years.

The premise for evaluating sealant material that had been in service for up to 35 years was to determine whether key properties that could affect service life had changed over that time period. The results demonstrate that even samples that had been in service for up to 35 years did not have a significant change in these physical properties.

Cohesive tensile strength can be thought of as a measure of the ability of a sealant to resist depolymerization and to effectively seal the joint. The cohesive tensile strength of the butyl sealant samples obtained in this study is plotted in Figure 19 as a function of the age of the roof. In addition, fresh, unweathered sealant material was tested to provide an approximation of the properties of the original material. The inadequate performance value was assumed to be at one-fourth of the minimum specification limit of 17 psi, or at 4.25 psi, and is plotted as such. At this low level of cohesive tensile

**Figure 19** – Cohesive tensile strength of butyl sealant vs. roof age. Sealant samples from New England roofs, except as noted. Circle symbols indicate samples exhibited some degree of depolymerization.

**Figure 20** – Cone penetration values of butyl sealant vs. roof age. Sealant samples from New England roofs except as noted. Circle symbols indicate samples exhibited some degree of depolymerization.
strength, it was surmised that the sealant would have undergone significant decomposition or depolymerization, with the result being that the sealant would behave more like a low-viscosity liquid that would easily flow out of the joint, thus rendering the joint unacceptable.

The plot in Figure 19 shows that, even for those sealant samples exhibiting some degree of depolymerization (as determined in cone penetration testing, discussed later), the cohesive tensile strength continued to maintain consistent levels above the minimum specification and well above the inadequate performance level. Based on the data in Figure 19, there is no evidence of deterioration of this property through 35 years of service on these roofs.

The cone penetration data are plotted vs. roof age in Figure 20. Higher cone penetration values indicate the sealant exhibits an increased tendency to flow. The maximum specification at 120a is a value selected for testing conducted at 72 to 78°F (22.2 to 25.6°C) for qualifying butyl sealants for initial use. All but one of the data points are under this maximum value. The sealant samples from the 26-, 30- and 35-year roofs, noted with circle symbols, showed evidence in laboratory analysis of some degree of depolymerization. This condition was noted in the cone penetration testing done at 120°F (49°C), in which the materials exhibited a level of softness that prevented valid test results from being obtained. Notwithstanding these laboratory observations, the behavior of these sealants in the actual roof systems was judged to be entirely adequate and without issue, providing a weathertight seal.

The cone penetration data plotted in Figure 20 show no clear trend and exhibit significant scatter. One roof sample from a 26-year-old roof tested above a cone penetration value of 120, whereas all other sealant samples, including those from five roofs aged 29 to 35 years, continued to test below this value. What is unclear is how much greater than 120a a cone penetration value must be in order to indicate the sealant is unable to provide a weathertight seal in the field. What is clear is that all roofs up to 35 years of age continue to perform well in this regard. Thus, the authors see no reason to suspect butyl sealant failure prior to another 30 years of service, or after a total service life of about 60 to 65 years. A 60-year value was therefore factored into Table 2, indicat-
ment, is shown in Table 4 for the 14 buildings represented in this study. For all roof systems, located in a wide range of climate regions, the total cost for renewal is well below the 20% of replacement value prescribed in the inspection protocol as signifying end of service life. Specifics of these costs are detailed in individual site reports available from the authors. It is worth noting that gutter and downspout replacement costs represent from one-third to two-thirds of the total renewal costs. In no case were the 55% Al-Zn alloy-coated panels on the roofs installed 20 to 35 years ago considered at risk for renewal prior to a 60-year time frame.

SUMMARY

Using a novel analytical protocol that is based on laboratory analyses and field inspections, 14 low-slope, unpainted 55% Al-Zn alloy-coated steel SSR systems in service for up to 35 years in a wide range of climates in the U.S. were evaluated, resulting in the following conclusions:

- A relatively simple renewal/replacement table can be constructed to evaluate the merits of rehabilitating roof components vs. replacing the total roof to achieve a 60-year roof service life.
- Based on the performance of all roof components as established in this study, the expected service life of a similar roof constructed today in a wide range of environments using best practices can be expected to be in excess of 60 years, a value that equals the assumed building service life as described in LEED, version 4, and which is based on butyl sealant service life.
- Butyl sealant life was established as the deciding factor in defining end-of-life for these roof systems. The butyl sealants evaluated in this study have shown no significant deterioration in cohesive tensile strength or cone penetration values, nor have there been any indications of joint weathertightness issues after up to 35 years of performance at laps and joints. The sealants are therefore projected to achieve a service life of 60 years.
- 55% Al-Zn alloy-coated steel panels were found to have weathered uniformly (cosmetically) with corrosion rates that conservatively project flat-panel service life to exceed 100 years for roofs installed today in the lowest-precipitation pH locations in the U.S. using today’s best practices. For sheared edges and panel profile bends, the absence of significant red rust after up to 35 years indicates exceptional corrosion resistance in areas susceptible to exhibiting the first signs of corrosion.
- On many of the sites, ancillary roof components have begun to rust and exhibit inferior service lives that could negatively impact the service life of panels with which they are in contact. In most cases, these corroding components are not consistent with current best practice, but can easily and economically be replaced.
- The cost of renewal of these ancillary components totaled significantly less than 20% of what a total roof replacement would have cost at end of service life, according to the evaluation protocols. Therefore, ancillary service lives do not dictate roof service life, which is more directly a function of the butyl sealant at laps and joints.
- The 300 series stainless steel fasteners, cinch plates, and other related hardware were aging well, showing little sign of corrosion and no adverse effects on the 55% Al-Zn alloy coating. These metal components are expected to have a life consistent with or exceeding that of the metal panels. The same is true of integral aluminum components and ancillaries. Hence, these materials demonstrated excellent compatibility with 55% Al-Zn alloy-coated steel sheet. The 400 series stainless steel fasteners were exhibiting varying degrees of corrosion, depending upon site location, and will require replacement prior to end of roof service life.
- Although a 55% Al-Zn alloy-coated SSR system is relatively maintenance-free, a roof inspection program should be conducted on a regular basis to detect and eliminate problems before they lead to localized, premature corrosion that could decrease the service lives reported in this study. On sites where deciduous leaves, pine straw, dirt, and other fallout accumulate, periodic cleaning, at least every two years, is prudent. In wet climates, where roofs are prone to algae growth, cleaning at even five-year intervals will help maximize the service life of the roof.

REFERENCES

4. J.L. Hoff. “Historical Warranty Repair Cost as a Measure of Long-Term Roof System Performance.” Proceedings of


FOOTNOTE

1. GALVALUME® and Zincalume® are internationally registered trademarks of BIEC International, Inc. or one of its licensed producers.